Modelling Coastal Vulnerability

Design and evaluation of a vulnerability model for tropical storms and floods

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Preface

The Andhra Pradesh Cyclone Hazard Mitigation Project commenced in August 1999 as part of a World Bank loan to the Government of Andhra Pradesh, India. This project became unique in several ways. A Real Time Operational Early Warning System for cyclone related storm surges was developed. The wind hazard and rainfall that accompany such storms were addressed. The reduction in the long term vulnerability through integrated coastal zone management also received attention. Indeed, an Expert Decision Support System (EDSS) for ICZM for the analysis of the various policy options that could reduce vulnerability in the long term was developed.

In September 2006 I began this PhD research at the Faculty for Technology, Policy and Management of Delft University of Technology with co-financing from my employer Deltares. By then the EDSS – ICZM was already completed by an interdisciplinary team which I had the privilege of leading. The experience of developing and finalising the model inspired me to undertake this PhD research focussing on both the design process and the evaluation of the model. By reflecting critically on the model design and its applicability, this research generates new knowledge on the integration of vulnerability aspects in long term sustainable development. Hence, the model in this research is the object of enquiry, not its result. Therefore the thesis consists of three parts: Part 1 describes the experience, Part 2 is a literature study and Part 3 consists of the evaluation of the model. This structure reflects the somewhat unconventional character of the research set-up as reported in this thesis.

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Rs: Indian rupee. 1 Rs ≅ 0.02 euro (2002)

VND: Vietnamese Dong. 1 VND ≅ 0.00005 euro (2006)

Summary

Recent tragic events such as Hurricane Katrina (2005), the Asian Tsunami (2004) and the tropical cyclone that struck Burma (Myanmar) in 2008 have highlighted coasts as being hazardous places to live. This research thesis focuses on vulnerability in low lying coastal and deltaic environments and on ways of reducing the impact of natural hazards on society. More precisely, the research explored the vulnerability of coastal societies to tropical cyclonic storms and floods.

Past disasters have triggered many governments to embark on disaster management such as flood control, early warning systems and evacuation planning, with the ultimate aim of protecting their inhabitants from the vagaries of nature. But the awareness is growing that besides disaster preparedness and response, societies need to be made more resilient in overcoming the impacts of natural hazards. This requires knowledge on how development can reduce but also aggravate the vulnerability of society. Development planners face difficult decisions as the implications of on-going development on vulnerability are difficult to assess. Indeed, the multi-dimensional character of vulnerability reduction represents a planning situation for which no standard solution is available. Vulnerability touches upon many disciplines, including the technical, environmental and social sciences, and therefore can only be understood in a truly interdisciplinary fashion. This explains the difficulty in formulating a widely accepted theory on vulnerability that can be used in planning situations. It is within this context that this research thesis should be understood.

The many definitions and descriptions of vulnerability have three elements in common: exposure, sensitivity and resilience. Based on these elements, I formulated a working definition of vulnerability to a hazard as an attribute of a person or social system determined by a combination of the exposure, sensitivity and short term resilience of that person or social system. I include only *short term* resilience – that is the coping capacity of a person or social system – as part of the definition. This leaves long term adaptative capacity of a person or social system outside the definition of vulnerability. This makes the definition useful in a planning context: an assessment of vulnerability at any given moment in time can then be used to determine the need for adaptation measures to reduce vulnerability in the future.

Literature on disaster management practice reveals a scarcity of *knowledge* and *models* that take the holistic and integrated approach needed to grasp the interdisciplinary nature of vulnerability. Models that explore vulnerability under various planned and unplanned conditions hardly exist, even though these could be viewed as a logical next step in damage and casualties modelling. Because coastal planning is about the distribution of scarce resources and space, the differential aspect of vulnerability

should be accounted for in these models. Who should be given financial incentives? Which sector requires government support? Where should urban development be situated? All these questions require insight in who the most vulnerable people are, where the most vulnerable areas are and which activities are most sensitive.

A model that tried to address these questions was originally developed as part of an assignment for the Government of Andhra Pradesh, India. Within the *Andhra Pradesh Cyclone Hazard Mitigation Project* an Expert Decision Support System (EDSS) was designed and implemented linking coastal vulnerability to integrated coastal zone management (ICZM). This model development provided unique material and experience for my research. The interpretation and critical inquiry of model has led to new knowledge on the design of such a model as well as on the use of its results in reducing vulnerability through planning.

The fundamental idea underpinning the EDSS is that in order to determine the impact of a cyclonic disaster on coastal society, first the structure and functioning of this society needs to be modelled under 'normal' conditions. Only by understanding the dependencies between the use of land, its resources, socio-economy and environmental conditions, is it possible to simulate the impacts of a disruption of these dependencies by a cyclone. Hence the model captures the annual economic and environmental conditions of a coastal area with and without a cyclone. Vulnerability is then calculated as the difference in assets and income in the area for both years.

By linking the socio-economic character of the coastal zone to the land use and all related activities that generate income, the model is sensitive to both planned (crop selection) and unplanned (cyclone disaster) land-use changes. It uses a spatial resolution of administrative units (e.g. districts or municipalities) and calculates the estimated annual incomes for different income groups (households) based on their private and income generating assets. The model shows the differential economic effect as a function of rural or urban household income and according to a range of impact scenarios and environmental conditions.

The EDSS has a modular architecture and a graphical user interface that allows the boundary conditions of the model to be changed through scenario definition, a selection of strategic measures or a combination of both. Exposure to hazard is determined for both storm surge and damaging wind speeds, each originating from separate (off-line) mathematical models. Distinctions in sensitivity (damage curves) have been made for movable and immovable private and income generating assets. In this way impact calculations on household wealth as well as income are enabled. Resilience is calculated as the extent to which households are able to restore their income position and to replace their lost assets (recovery factors on income and assets) in one year.

The model was applied in two different deltas: the Godavari Delta in Andhra Pradesh and the Red River Delta in Vietnam. Both applications provided insight in how vulnerability changes as a function of physical and socioeconomic conditions. Perhaps the greatest achievement of the model application for the Godavari Delta is the confirmation that reducing vulnerability to cyclonic storms requires a broader set of measures than is usually taken into account by disaster managers. The model illustrates not only the need for flood protection and early warning, but also the need for measures that reduce the sensitivity and increase the resilience of households. For example by diversifying cropping patterns and broadening the economic basis. Flood protection, early warning and evacuation measures do reduce the number of deaths, but cannot prevent wind damage, which still accounts for approximately half of the total damage. This insight is made possible both by including wind hazard as an inextricable part of the cyclone hazard and by linking damage to household livelihoods.

The Andhra Pradesh application indicates that the poor suffer disproportionally from a cyclonic disaster and that a small improvement in the income situation would dramatically reduce their vulnerability. The poor also have the lowest recovery factors in Vietnam, but the differences with the higher income categories are less dramatic than in India. Hence, in situations where a significant portion of the population living in hazardous places is around or below the poverty line, the only short term measure for reducing vulnerability is the provision of relief funds. Also improvement of credit and insurance facilities for the poor as well as medium income groups (micro-credit, micro-insurance) could directly enhance the resilience capacity in two ways: firstly, by reducing the negative effect of interest on income and secondly, by helping in starting up the production again.

Both model applications for India and Vietnam showed that economic growth, although increasing the damage due to more invested capital, can result in some decrease of vulnerability. At the same time the model shows that economic growth alone (without taking into account redistribution effects) hardly reduces the vulnerability of the poorest sections of the population. Therefore, in the long term the best measures are those that effectively reduce the number of poor people.

Being rooted in a practical, project situation, the design of the model was not a purely academic exercise. What then can be said about the general applicability and quality of this model example? For this evaluation, I refer to theoretical notions of integrated modelling and policy analysis. Design of a model for policy analysis is determined by both practical, epistemological and subjective/normative factors. By systematically analysing the choices in the design it was possible to identify these factors. From this analysis, conclusions could be drawn on the usefulness of the model and lessons derived on the future of vulnerability modelling.

The policy analysis style, its objectives and formal directives of the client in the Andhra Pradesh project favoured a rational planning model paradigm: policy strategies and scenarios were analysed and the strategy that best meets the policy preferences and criteria was identified. This is often what a government client wants. But the absence of stakeholder involvement in the policy analysis and model design could eventually hamper the formulation of policy recommendations and their effective implementation. The model only produces an output, not an outcome. Eventually there is a difference between analysing, deciding and doing, between modelling, policy making and implementation. Nevertheless, for policy making, the EDSS model can provide suitable support, in the sense that it explores the effect of different strategies under various plausible futures.

A comparison of the model with theoretical concepts of vulnerability, supplemented by a review from an external Expert Panel, enabled the identification of strengths and weaknesses of the model, including an assessment of its general applicability. The usefulness of this model as a contribution to the wider scientific, disaster expert and coastal management community lies in *three innovations* the implementation of which has been proven to be feasible:

- The modelling of the *entire impact chain* of hazards to consequences, including exposure, sensitivity and resilience;

- A high level of *integration between hazards and the human-environment system*, enabling explorative analyses of 'typical' disaster management measures as well as land use planning and environmental management measures;
- Its ability to *quantify differential vulnerability* at household level, enabling the analysis of measures targeted at critically vulnerable groups.

Since the model uses a simple economic model as a basis for calculations, it is not capable of determining which scenarios or measures are effective for stimulating economic growth. And as the model is developed for economies that are dominated by agricultural, livestock and fisheries production, it cannot be applied without modifications to modern, highly urbanised and industrial deltas or service-oriented open economies. Also the damage calculations are relatively straightforward, leaving aside many potential backward and forward linkages in the economy that could result in a higher indirect loss, but also in a lower loss due to compensation effects.

Lessons that can be drawn for future modelling activities relate to choices in relations and boundaries, choices in scale and resolution and the choice of a representative storm or flood event.

Literature distinguishes between relations *in place*, *cross scale* and *beyond place*. This can be helpful in choosing which relations should be considered as internal to the model and which could be used as external and/or boundary conditions. Since vulnerability is a place-based phenomenon, a good guideline to start with is to focus on internalizing the *in place* relations into the model and assume all *cross scale* relations as boundary variables. The specific context of the area then determines whether or not this initial representation holds. For instance, in a very open economy, resilience could be more dependent on the cross scale interaction with the wider region than with the human conditions within the locality where the flooding occurs. This could lead to the choice to internalize this cross scale relation in the model.

Scale choices do not necessarily derive from the conceptual model. There is no ideal scale and aggregation level for vulnerability modelling. This depends largely on the purpose of the model and the type of decision context. But whatever choice is made, one should always be aware of the fact that aggregation can obscure essential impacts of vulnerability and mitigation measures at lower aggregation levels. For vulnerability to natural hazards, the lowest possible aggregation level is recommended. The main reason lies in the rather localized impact of a tropical cyclone. Disasters affect people, their enterprises and households first, then the local and regional economy and not the other way around.

In contrast to a risk calculation – which should include all possible events on a range of probabilities – a vulnerability calculation, in the definition used throughout this thesis, requires a *choice* of a certain event. It is clear that this choice influences the outcome of the calculation and should depend on the purpose of the vulnerability calculation. For instance, using a recent disaster is particularly useful for calibration purposes of the vulnerability model. A worst case scenario is useful if one is interested in the need for preparedness measures. The event that causes the maximum annual damage is a typical choice for macro-economic and regional planning purposes.

Since vulnerability modelling is in its infancy, it is too early to formulate a 'best way' of how to do it. Interdisciplinarity is a prerequisite, but its methodological basis is weak and largely based on heuristics. Therefore an open minded, diverse and unconventional attitude is required. This research provides hints and suggestions, rather than recipes or guidelines. The research has produced a contribution to the knowledge of modelling vulnerability: on the differential character of vulnerability being essential for linking it to planning issues, on choice of storm event being dependent on the planning question, on a place-based approach of vulnerability favouring a lowest possible scale level of analysis and on finding vulnerability metrics that most closely relate to real world counterparts. The developed model and its applications for coastal Andhra Pradesh and Vietnam act as proof that modelling coastal vulnerability is possible and useful for the mainstreaming of disaster management into sustainable coastal development.

Samenvatting

Recente natuurrampen zoals orkaan Katrina (2005), de tsunami in Azië (2004) en de tropische cycloon die in 2008 over Birma raasde hebben weer eens aangetoond dat kusten gevaarlijke woonplaatsen kunnen zijn. Dit proefschrift gaat over de kwetsbaarheid van laaggelegen kusten en delta's en over manieren om het gevolg van natuurlijke gevaren voor de samenleving te verkleinen. Het onderzoek is daarbij vooral gericht op de kwetsbaarheid van kustsamenlevingen voor tropische stormen en overstromingen.

Rampen in het verleden hebben veel overheden doen besluiten om aandacht te besteden aan het voorkomen en bestrijden van rampen, bijvoorbeeld door hoogwaterbescherming, waarschuwingssystemen en evacuatieplanning, met als uiteindelijk doel om de bevolking te beschermen tegen de grillen van de natuur. Er is echter een groeiend besef dat behalve het goed voorbereid zijn op een ramp de samenleving ook veerkrachtiger zou moeten worden om de gevolgen van een natuurramp snel te boven te komen. Hiervoor is kennis nodig over hoe ontwikkeling kan leiden tot een verkleining maar ook tot een vergroting van de kwetsbaarheid. Ontwikkelingsdeskundigen staan vaak voor moeilijke keuzen omdat de effecten van ontwikkeling op kwetsbaarheid moeilijk zijn vast te stellen. Het veelzijdige karakter van kwetsbaarheid sluit een standaard oplossing die gebruikt kan worden in de planvorming uit. Kwetsbaarheid raakt aan vele disciplines, zowel vanuit de technische en milieukundige als sociale wetenschappen en vereist derhalve een interdisciplinaire aanpak. Dit verklaart waarom het zo moeilijk is om een breed gedragen theorie over kwetsbaarheid te formuleren en te gebruiken in de planvorming. Tegen deze achtergrond is dit proefschrift geschreven.

In de vele definities en beschrijvingen van het begrip kwetsbaarheid komen telkens drie onderdelen terug: blootstelling, gevoeligheid en veerkracht. Gebaseerd op deze drie elementen heb ik kwetsbaarheid voor een gevaar gedefinieerd als een eigenschap van een persoon of sociaal systeem die bepaald wordt door een combinatie van blootstelling, gevoeligheid en korte-termijn veerkracht van die persoon of sociaal systeem. Ik maak een onderscheid tussen de veerkracht op korte termijn (het opgewassen zijn tegen de gevolgen) en het aanpassingsvermogen op lange termijn van een persoon of sociaal systeem. Door dit aanpassingsvermogen niet in de definitie van kwetsbaarheid op te nemen wordt deze geschikt voor gebruik in de planvorming: bepaling van de kwetsbaarheid op ieder moment in de tijd kan dan gebruikt worden om de noodzaak voor aanpassingen vast te stellen die de kwetsbaarheid in de toekomst kunnen verkleinen.

Uit literatuuronderzoek naar de praktijk van rampenbestrijding blijkt een tekort aan *kennis* en *modellen* met een holistische en geïntegreerde aanpak, die nodig is om tegemoet te komen aan het interdisciplinaire karakter van kwetsbaarheid. Er bestaan tot op heden nagenoeg geen modellen die kwetsbaarheid onder zowel geplande als onvoorziene situaties kunnen onderzoeken. Terwijl zulks toch gezien kan worden als een logische vervolgstap op de bestaande schade- en slachtoffermodellen. Omdat de essentie van planning neer komt op het verdelen van schaarse middelen en ruimte is belangrijk bij de modellering het differentiële karakter van kwetsbaarheid mee te nemen. Wie dienen financiële tegemoetkomingen te ontvangen? Welke sector zou overheidssteun moeten krijgen? Waar moeten stadsuitbreidingen gepland worden? Dergelijke vragen vereisen inzicht in wie het meest kwetsbaar zijn, waar de meest kwetsbare gebieden liggen en welke activiteiten het meest gevoelig zijn.

Een model dat wel aan deze vragen aandacht besteedt is ontwikkeld in opdracht van de overheid van de deelstaat Andhra Pradesh, India. Als onderdeel van het *Andhra Pradesh Cyclone Hazard Mitigation Project* is een Expert Beleidsondersteunend Systeem (Expert Decision Support – EDSS) ontworpen en geïmplementeerd, waarin kwetsbaarheid van de kust is gekoppeld aan geïntegreerd kustbeheer (ICZM). Deze modelontwikkeling leverde uniek materiaal en ervaring voor mijn onderzoek. De interpretatie en kritische analyse van dit model heeft geleid tot nieuwe kennis over modelontwerp en over het gebruik van modeluitkomsten bij het plannen van maatregelen die de kwetsbaarheid zouden kunnen verkleinen.

De achterliggende gedachte achter het EDSS is dat voor het bepalen van het effect van een tropische storm op een kustsamenleving allereerst de structuur en het functioneren van deze samenleving onder 'normale' omstandigheden moet worden gemodelleerd. Slechts door de afhankelijkheden tussen landgebruik, hulpbronnen, socio-economie en milieucondities te begrijpen is het mogelijk de effecten van een verstoring ten gevolge van een storm te simuleren. Het model beschrijft derhalve de jaarlijkse economie en milieuomstandigheden van een kustgebied met en zonder een storm. Kwetsbaarheid in het gebied wordt vervolgens berekend als het verschil tussen (kapitaal)goederen en inkomen voor beide jaren.

Omdat de socio-economische structuur van de kust is gekoppeld aan het landgebruik en gerelateerde activiteiten die inkomen genereren is het model gevoelig voor zowel geplande (gewaskeuze) als ongeplande (stormramp) veranderingen in het landgebruik. Het model berekent voor administratieve eenheden (bijv. districten of gemeenten) op basis van privé-goederen en kapitaalgoederen de jaarinkomens voor verschillende inkomensgroepen (huishoudens). De modeluitkomst laat verschillen zien tussen huishoudens op het platteland en die in de stad van hun economische positie als functie van scenario's en milieucondities.

Het EDSS heeft een modulaire architectuur en een gebruikers interface die het mogelijk maakt de randvoorwaarden van het model te wijzigen door het definiëren van scenario's, het kiezen van strategische maatregelen of een combinatie hiervan. Zowel voor de blootstelling aan stormvloed als aan hoge windsnelheden wordt gebruik gemaakt van aparte (off-line) mathematische modellen. Voor de berekening van het effect van de storm op huishoudelijk bezit en inkomen wordt gebruik gemaakt van verschillende schadefuncties voor zowel roerende als onroerende privé- en kapitaalgoederen. Veerkracht wordt berekend als de mate waarin binnen een tijdsbestek van een jaar de huishoudens in staat zijn hun inkomenspositie te herstellen en hun verloren bezittingen te vervangen (herstelfactoren op inkomen en vermogen).

Het model is toegepast op twee verschillende delta's: de Godavari Delta in Andhra Pradesh en de Rode Rivier Delta in Vietnam. Beide toepassingen leverden inzicht in kwetsbaarheid als functie van fysieke en socio-economische condities. Een van de belangrijkste verdiensten van de modeltoepassing voor de Godavari Delta is de bevestiging dat het reduceren van de kwetsbaarheid voor tropische cyclonen een omvangrijkere set maatregelen vergt dan gewoonlijk door rampenbestrijders wordt gebruikt. Het model illustreert niet alleen de noodzaak voor overstromingsbescherming en waarschuwingssystemen, maar ook voor maatregelen die de gevoeligheid van huishoudens verminderen en hun veerkracht vergroten. Dit kan bijvoorbeeld door een grotere diversiteit aan gewassen en door de economische basis te verbreden. Bescherming tegen overstromingen, waarschuwingssystemen en evacuatie verlagen weliswaar het potentieel aantal slachtoffers, maar deze maatregelen kunnen niet de windschade voorkomen die ongeveer de helft van de totale schade uitmaakt. Dit inzicht wordt mogelijk gemaakt doordat de windschade als een onlosmakelijk deel van de cycloon in het model is meegenomen en door schade te koppelen aan het levensonderhoud van huishoudens

De modeltoepassing in Andhra Pradesh laat zien dat de armen meer dan proportioneel lijden onder een cycloonramp en dat een kleine verbetering in hun inkomenspositie hun kwetsbaarheid sterk doet verminderen. Ook in Vietnam hebben de armen de grootste moeite zich te herstellen, maar de verschillen met de hogere inkomenscategorieën zijn minder extreem dan in India. Hieruit kan worden opgemaakt dat wanneer een groot deel van de kwetsbare bevolking rond of onder de armoedegrens leeft het bieden van schadeloosstellingen de enige maatregel is die op korte termijn effect sorteert. Tevens kan een verbetering van de krediet- en verzekeringsfaciliteiten voor zowel de armen als de modale inkomensgroepen (microkrediet, micro-verzekering) de veerkracht verhogen. Namelijk allereerst doordat dit de rentelast verlaagt en ten tweede doordat hierdoor de productie sneller opgestart kan worden.

De modeltoepassingen voor zowel India als Vietnam laten zien dat economische groei kan resulteren in een afname van de kwetsbaarheid, zelfs als deze groei leidt tot meer schade meer geïnvesteerd kapitaal. Tegelijkertijd laat het model zien dat economische groei alleen (zonder rekening te houden met herverdelingseffecten) de kwetsbaarheid van de armsten nauwelijks verlaagt. Derhalve leveren maatregelen die het aantal armen effectief doet verminderen op termijn de beste resultaten.

Het modelontwerp was geen zuiver academische aangelegenheid, maar een onderdeel van een concreet beleidsondersteunend project. Wat betekent dat voor de generieke toepasbaarheid en kwaliteit van dit model? Voor deze evaluatie ben ik te rade gegaan bij theorieën over integrale modellering en beleidsanalyse. Het ontwerp van een beleidsanalytisch model wordt immers bepaald door zowel praktische als epistemologische en normatieve factoren. Door systematisch de keuzen in het ontwerpproces te analyseren was het mogelijk deze factoren te identificeren. Uit deze analyse zijn enkele conclusies voortgekomen omtrent de geschiktheid van het model. Ook zijn hieruit lessen getrokken voor de toekomst van kwetsbaarheidsmodellering.

Zowel de beleidsstijl als de doelstellingen en formele directieven van de klant van het Andhra Pradesh project hebben geleid tot een rationeel planningsparadigma: er werden beleidsstrategieën en scenario's geanalyseerd en er werd geïdentificeerd welke strategie het meest past bij de beleidsvoorkeur. Dit is vaak wat een overheid als klant wil. Maar het ontbreken van betrokkenheid van stakeholders in de beleidsanalyse en bij het ontwerpen van het model kan het formuleren en implementeren van beleidsaanbevelingen bemoeilijken. Het model levert alleen uitvoer, niet een oplossing. Uiteindelijk zijn er verschillen tussen analyse, keuze en doen, tussen modelleren, beleidsontwikkeling en implementatie. Toch kan het EDSS model voor beleidsontwikkeling ondersteuning leveren, omdat het de effecten van verschillende strategieën kan onderzoeken onder een reeks van denkbare toekomsten.

De sterkten en zwakten van het model zijn geïdentificeerd door het model te vergelijken met theoretische concepten van kwetsbaarheid en door het model te laten beoordelen door een extern panel van experts. De bijdrage van het model aan de bredere wetenschappelijke, rampendeskundigen- en kustbeheerdersgemeenschap ligt in *drie innovaties*, die bleken te werken:

- Het modelleren van de *gehele effectketen* van dreiging naar gevolg, met inbegrip van blootstelling, gevoeligheid en veerkracht;
- *Integratie tussen de dreiging en het mens-milieusysteem*, dat het mogelijk maakt om analyses te maken van zowel ‘typische’ rampenbestrijdingsmaatregelen als van de planning van landgebruik en milieumaatregelen.
- De mogelijkheid om *differentiële kwetsbaarheid* te kwantificeren op het niveau van huishoudens, waardoor maatregelen die gericht zijn op kwetsbare groepen kunnen worden onderzocht.

Omdat het model een simpele economische module gebruikt als basis voor de berekeningen is het niet mogelijk om vast te stellen welke maatregelen effectief zijn voor het stimuleren van economische groei. Ook moet bedacht worden dat het model niet zonder aanpassingen toegepast kan worden op moderne, sterk verstedelijkte delta’s of op diensten georiënteerde open economieën. Het is immers ontwikkeld voor economieën die worden gedomineerd door landbouw, veeteelt en visserij. Ook zijn de schadeberekeningen nogal rechttoe rechtaan en ontberen ze terugkoppelingen in de economie die zouden kunnen leiden tot hogere indirecte schade, maar evenzogoed in een lager verlies door compensatie-effecten.

De lessen voor toekomstige modelactiviteiten hebben betrekking op de keuze van de te modelleren relaties en randvoorwaarden, op de keuze in schaal en resolutie en de keuze van een representatieve storm of overstroming.

De literatuur maakt een onderscheid tussen drie typen relaties: *locatiegebonden*, *schaal-overschrijdend* en *buiten de locatie*. Zulk onderscheid kan nuttig zijn om vast te stellen voor welke relaties interne variabelen in het model dienen te worden opgenomen en voor welke externe parameters of randvoorwaarden voldoende zijn. Omdat kwetsbaarheid een plaatsgebonden fenomeen is, kan het beste begonnen worden met het incorporeren van de locatiegebonden relaties in het model en alle schaal-overschrijdende relaties als randvoorwaarden op te nemen. De specifieke context van het gebied bepaalt vervolgens of deze initiële representatie vol gehouden kan worden of niet. In een erg open economie kan veerkracht bijvoorbeeld meer afhankelijk zijn van relaties met de wijdere omgeving dan van de omstandigheden binnen de locatie waar de overstroming plaats vindt. Dan is het te verdedigen deze schaal-overschrijdende relaties in het model op te nemen.

De juiste schaal is niet zonder meer af te leiden van het conceptuele model. Er bestaat geen ideale schaal of aggregatieniveau voor kwetsbaarheidsmodellering. Dit hangt namelijk vooral af van het doel van het model en de beleidsvraag. Maar welke keuze men ook maakt, men moet zich altijd realiseren dat aggregatie er toe kan leiden dat essentiële aspecten van kwetsbaarheid en mitigerende maatregelen onzichtbaar kunnen worden op lagere aggregatieniveaus. Als het gaat om kwetsbaarheid voor natuurrampen dan is een zo laag mogelijk aggregatieniveau aan te bevelen. De belangrijkste reden hiervoor is het overwegend lokale effect van een tropische cycloon. Rampen treffen vooraleerst mensen, hun ondernemingen en boerderijen, en pas dan de lokale en regionale economie; niet andersom.

In tegenstelling tot een risicoberekening – die alle mogelijke gebeurtenissen met verschillende waarschijnlijkheid dient te omvatten – moet voor kwetsbaarheidsbepaling, conform de in dit proefschrift gehanteerde definitie, een keuze voor een bepaalde gebeurtenis gemaakt worden. Uiteraard beïnvloedt deze keuze de uitkomst van de berekening en deze dient daarom af te hangen van het doel van de kwetsbaarheidsberekening. Zo kan een recente ramp worden gebruikt om het model te kalibreren. Daarentegen is de keuze voor een ergst denkbare ramp nuttig als men geïnteresseerd is in de wenselijkheid van voorbereidende maatregelen. En de gebeurtenis die leidt tot de hoogste gemiddelde jaarlijkse schade is goed bruikbaar voor macro-economische en regionale planningsdoeleinden.

Kwetsbaarheidsmodellering staat nog in de kinderschoenen. Daarom is het te vroeg om een 'beste manier' aan te bevelen. Inderdisciplinariteit is een voorwaarde voor de modelontwikkeling, maar de methodologische basis is zwak en vooral gebaseerd op ervaringen. Daarom is een open, veelzijdige en onconventionele houding nodig. Dit onderzoek geeft tips en suggesties, geen recepten of richtlijnen. Het onderzoek heeft bijgedragen aan de kennis voor kwetsbaarheidsmodellering als het gaat om: het differentiële karakter van kwetsbaarheid die essentieel is om het te kunnen koppelen aan planningsvraagstukken, de keuze van de stormgebeurtenis die afhankelijk is van de planningsvraag, de plaatsgebonden benadering van kwetsbaarheid die tot een zo gedetailleerd mogelijk schaalniveau noopt en de zoektocht naar een maat voor kwetsbaarheid die zo dicht mogelijk de werkelijkheid benadert. Het model dat ontwikkeld en toegepast is voor Andhra Pradesh en Vietnam dient als bewijs dat het modelleren van kwetsbaarheid van de kust mogelijk is en kan helpen rampenbeheersing regulier in duurzame kustontwikkeling op te nemen.

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1 Introduction

This chapter describes the rationale for the research and its objectives and research questions. It also formulates the research approach and structure of the thesis.

1.1 Coastal hazards, damage and human suffering

Recent tragic events such as Hurricane Katrina (2005), the Asian Tsunami (2004) and the tropical cyclone that struck Burma (Myanmar) in 2008 have highlighted coasts as being hazardous places to live. Many low lying coasts experience natural disasters owing to their exposure to the dynamics of the environment, while at the same time attract human occupation because of the richness of their natural resources, such as fertile soils, fish stocks and navigation facilities. This paradoxical situation is likely to be exacerbated owing to climate change in combination with population growth, exposing more and more people to these natural hazards.

But how severe is the problem, and what are the causes? This research thesis focuses on the problem of tropical cyclones as a major hazard in low lying coastal environments and on ways of reducing their impact on society. Worldwide more than 100 million people are found to be exposed on average every year to tropical cyclone hazards. Countries with substantial populations located on coastal plains and deltas with a relatively high vulnerability to cyclones include India, Bangladesh, Honduras, Nicaragua, the Philippines and Vietnam (Pelling et al. 2004).

Disasters are increasing. Nevertheless, studies do not suggest any significant worldwide increase in the frequency or intensity of cyclones (Knutson et al. 2008). A recent study on the damages caused by hurricanes in the United States revealed that Hurricane Katrina is not outside the range of normalized estimates for past storms. The trend in higher damages that is observed along the US coast is predominantly attributable to societal factors, such as an increase in coastal populations and associated higher economic investments (Pielke Jr. et al. 2008). A similar picture is found for the coast of Andhra Pradesh, India: the observed increase in damages due to tropical cyclones in the past 30 years is ascribable mainly to economic and demographic and not meteorological factors (Raghavan & Rajesh 2003).

Whereas the damage from cyclones shows an increasing trend, the loss of life seems to reduce somewhat over the years, although there are large differences between countries. For instance, in Andhra Pradesh a marked reduction in casualties occurred between two cyclones of similar intensity and landfall (1970 and 1990), that could be attributed to improvements in early warning and contingency planning (Raghavan & Rajesh 2003). A similar improvement in warning and preparedness (e.g. cyclone shelters) is observable in Bangladesh. However, the Burma cyclone in 2008 with over 100,000 lives lost showed that not all countries have as yet embarked on efficient contingency planning with regard to cyclones.

What can be done? Hazards will continue to play a role in societies. Traditional engineering options, such as strong embankments and dikes, are not always effective or economically feasible. Other measures include spatial planning, early warning and evacuation, improved housing and community preparedness. Within the domain of disaster management there is an increasing awareness that solutions should be sought in a combination of measures to protect against a hazard and reduce vulnerability. But how can the 'optimal' combination be found? Quite an extensive body of knowledge is available with respect to the effectiveness of protection measures. This is in striking contrast to what is known about measures that effectively reduce the vulnerability of coastal communities. In order to answer these questions, insight is needed regarding a coastal community's current vulnerability and the level of reduction through measures so that the effectiveness of potential measures can be compared. This requires, inter alia, defining precisely what we mean by vulnerability and other disaster terminology, such as risk and hazard (see Box 1).

Box 1Terminology

There is much confusion and ambiguity regarding the terminology used in disaster literature and practice. Risk, hazard and vulnerability are often used without proper definition, leading to overlapping meanings. A chapter of this thesis is devoted to defining our main topic of research: vulnerability. Meanwhile, in this chapter it suffices to state that I use the most common definition that relates these three concepts: ***Risk = Hazard x Vulnerability***. In this definition ***Hazard*** is defined as a physical event, phenomenon or human activity with the potential to result in harm. A hazard does not necessarily lead to harm (Gouldby & Samuels 2005). Part of the hazard is the probability or frequency of occurrence. Included in ***Vulnerability*** is the direct consequence of a hazard when it occurs (such as damage) plus the way an individual, society or system can cope with these consequences. **Risk** can be expressed as the (annual) expected impact (e.g. an average annual damage). This implies that although a risk could be very small (due to the infrequent occurrence of the hazard event), in contrast, the vulnerability could be very high. Hence, it can make a difference if coastal managers use risk as their basis for planning or if they use vulnerability.

This thesis focuses on the assessment and modelling of vulnerability, both in a real situation and as an ex ante analysis of disaster mitigation measures. Before I identify the need for new assessment tools in section 1.3, I will first introduce the disaster management context for which these tools are needed.

1.2 Coastal vulnerability and disaster management

As a response to the worldwide increase in natural disasters both the international community and national governments have initiated various disaster reduction programmes and policy goals over the past two decades. At the global level the Hyogo Framework for action acts as focal point for present day disaster reduction policy.

1.2.1 Disaster management: global initiatives

Following the International Decade of Natural Disaster Reduction (IDNDR 1990-1999), the United Nations initiated the International Strategy for Disaster Reduction through an Inter-Agency Secretariat for ISDR (as the focal point) headquartered in Geneva and with four regional offices, and a Global Platform for Disaster Risk Reduction (formerly known as the Inter-Agency Task Force on Disaster Reduction) to develop a disaster reduction policy. A major contribution to this disaster reduction policy is the Hyogo Framework for Action 2005-2015, which was adopted at the

World Conference on Disaster Reduction in January 2005 in Kobe, Hyogo, Japan (see Box 2). As the expected outcome speaks of a significant reduction in disaster losses by 2015, this can be considered a very ambitious target, because it effectively implies reversing the increasing trend in annual disaster damages, that can be observed for more than 2 decades (Munich RE 2002).

The United Nations through the IDNDR and its successor provided and continues to provide technical knowledge, support for institution building and coordination of actions. These are necessary elements, but not sufficient to really reduce losses. As Wisner (2001) words it: 'This period [i.e. the International Decade for Natural Disaster Reduction – *author insert*] was one of accelerated and intensive international exchange of scientific information. More than enough knowledge was generated, refined, debated, systematized, and disseminated to have prevented the loss of life in the landslide in Las Colinas, El Salvador. That knowledge could have dramatically reduced the number of lives claimed in Gujarat, and it certainly could have protected priority infrastructure such as schools and hospitals. […] The missing ingredient is the kind of moral imperative that can mobilize local political will' (Wisner 2001). Even more explicit in his comment on the International Decade is Burton, who considered that the effort 'largely failed', mainly because of the weaknesses of the UN system and the lack of commitment by many national governments. Also an overly optimistic expectation with respect to the advancements of scientific understanding contributed to its mediocre performance (Burton 2001).

Box 2 The Hyogo Framework for action 2005-2015

Governments around the world united at the World Conference on Disaster Reduction (2005) to adopt the Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters. It is a global blueprint for disaster risk reduction efforts during the next decade. Its goal is to substantially reduce disaster losses by 2015 – in lives, and in the social, economic and environmental assets of communities and countries. It has three strategic goals:

- the more effective integration of disaster risk considerations into sustainable development policies, planning and programming at all levels, with special emphasis on disaster prevention, mitigation, preparedness and vulnerability reduction;
- the development and strengthening of institutions, mechanisms and capacities at all levels, in particular at the community level, that can systematically contribute to building resilience to hazards;
- the systematic incorporation of risk reduction approaches into the design and implementation of emergency preparedness, response and recovery programmes in the reconstruction of affected communities.

Priorities for action have been formulated to guide states, organisations and other actors at all levels in designing their approach to disaster reduction:

1. *Make disaster risk reduction a priority:* ensure that disaster risk reduction is a national and a local priority with a strong institutional basis for implementation.
2. *Know the risks and take action*: identify, assess, and monitor disaster risks – and enhance early warning.
3. *Build understanding and awareness*: use knowledge, innovation and education to build a culture of safety and resilience at all levels.

Whatever judgement one gives to these global initiatives, it is evident and generally accepted (also by the ISDR), that priority responsibility for disaster reduction lies at the national and sub-national levels. The Hyogo Framework can only assist the efforts of nations and communities to become more resilient to and cope better with the hazards that threaten their development (UNISDR 2005a).

1.2.2 Disaster management in practice broadens its scope

The Hyogo Framework is an important point of reference with regard to the overall approach and philosophy of disaster management. Indeed, few would disagree with its intentions and objectives. With respect to its implementation however, much remains to be done. The political will of governments from individual countries is no doubt of key importance, as Wisner (2001) mentioned, but there is more to it than that. Leaving aside situations of wilful mismanagement for political strategic purposes, most governments have the intention of minimising the consequences of a disaster. The extent to which they succeed depend on many factors, such as the financial and economic resources available, the history of disasters and cultural and religious traditions determining risk perceptions and acceptance. Hence we see a wide divergence in disaster management attention between countries.

Many countries have their own disaster management department or agency in order to streamline and coordinate disaster emergency relief, recovery and rehabilitation activities. They mostly began as or are response oriented organisations. Increasingly these agencies are concerned with disaster preparedness and risk reduction activities. But while doing so, they need to cooperate with line departments working in different fields such as housing, water management and regional planning. In many countries, however, there is a lack of sufficient national and intersectoral coordination impeding the wider implementation of national strategies (UNISDR 2005b).

Also the international NGO's that work on a national and regional/local level, such as the Red Cross, Oxfam and Islamic Relief, are increasingly focusing on disaster prevention. As they work at the grassroots level, they have become interested in the social vulnerability concept. Van Eekelen, scientific officer of Islamic Relief, observed in his organisation a shift in focus with regard to disaster response: 'We used to have an emergency unit. We still have that unit, but now we also have a Disaster Preparedness and Response Unit. We used to go to a country in response to a disaster, and then stay there. Now, we increasingly hope to go to countries that are disaster-*prone,* but without any particular disaster triggering our move. And instead of focussing on disaster response, we would implement socio-economic and human development programmes, and have disaster preparedness measures *as part of* those programmes. When we still do disaster response work, we do so with a view to reducing risk and vulnerability. When we do other work – Islamic micro credit, for example – we would look more closely than before at its effect on disaster preparedness and livelihood resilience' (Eekelen 2006).

Hence, there is a growing belief among the disaster management community that there is a need to broaden the scope of disaster management. So, in addition to protection measures, vulnerability reduction becomes a key objective.

1.2.3 Vulnerability reduction as an ill-structured problem

Past disasters have triggered many governments to embark on disaster management such as flood control, early warning systems and evacuation planning, with the ultimate aim of protecting their inhabitants against the vagaries of nature (UNISDR 2005b). But in addition to these predominantly hazard-induced protection measures, governments, NGO's and the scientific community acknowledge the need to make societies more resilient to be able to overcome the impacts of natural hazards. The awareness is growing that besides disaster preparedness and response many other aspects of development can also reduce or aggravate the vulnerability of society. Development planners face complicated decisions as it appears that the implications of development on vulnerability are difficult to assess. Some questions that need to be answered relate to the many dimensions of vulnerability, such as:

- Time: will vulnerability change over time?
- Space: is vulnerability place-based and why?
- Distribution: who suffers most from disasters?
- Cost efficiency: which vulnerability reduction measure is cheapest and at the same time effective?
- Intangibles: should the loss of lives be given an economic value or not?
- Uncertainty: can we assess current vulnerability based on the past? Can we predict future changes?

This multi-dimensional character of vulnerability reduction is typical of a planning situation and makes it an ill-structured problem (Dunn 1981) for which no standard solution is available. There are many decision-makers and other stakeholders involved, there are many potential solutions to the problem and there is no consensus on the values and interests at stake. The problem of disaster management includes political will, organisational and institutional arrangements (from national to community level), finances, technology, planning and development. Interpreting vulnerability reduction (as the main aim of disaster management) as a purely rational approach to the problem ignores the different rationalities to risk perception, social inequalities that explain vulnerability and institutional problems that hamper efficient management.

The complex and value laden character of the problem explains the difficulty in formulating a widely accepted theory on vulnerability that can be used in planning situations. Vulnerability touches upon many disciplines, including the technical, environmental and social sciences, and therefore can only be understood in a truly interdisciplinary fashion. It is within this context that this thesis should be read. It is written out of a belief that only an interdisciplinary scientific effort can contribute to the successful inclusion of vulnerability assessment in development planning. Before I formulate this contribution as research objective, I will first address the need for new knowledge, approaches and tools.

1.3 The need for new knowledge and tools

The development of tools to measure vulnerability is a prerequisite for effective preparedness strategies and sustainable recovery. This requirement was formulated and agreed upon by professionals and received strong political endorsement at the World Conference for Disaster Reduction in Kobe 2005 (Birkmann & Wisner 2006). It was taken up in the Hyogo Framework for Action as a need for a vulnerability indicator system with concepts and practical methods that are robust and ready to be used while sound enough to withstand critical scientific scrutiny (introduction of Janos Bogardi in Birkmann (2006).

And what is the current state-of-the-art? Considering natural hazards, the past decades show an increase in models that predict a possible event and its potential damage. Especially with regard to flooding, these models have been improved considerably over the last few years. Two international conferences on flood risk management, held in 2008 (Simonovic & Bourget 2008; Samuels et al. 2009a) produced 365 papers in total, of which 197 papers (or 54%) described a modelling approach for predicting the occurrence of floods and / or the extent of flooding. Many tools have been developed that can simulate the extent of inundations given particular hydrodynamic boundary conditions. The impacts of such inundations are mostly described in terms of casualties, direct damages to properties, infrastructure and other assets (Jonkman et al. 2008; Kok et al. 2006; Messner et al. 2006). However, most of these models say little about how people and communities cope with the damages and losses. Indirect effects on the economy are outside the scope of most of the analysts who are executing flood vulnerability and damage analyses. One of the notable exceptions is the thesis of Bockarjova, on the modelling of the economic impacts of a flood disaster (Bockarjova 2007). Her contribution is based on the notion of imbalances caused by disruptions in the interconnected network, which forms the economy.

From the same sample of the two conferences, only 28 papers or 8% addressed the social aspect of vulnerability. This is a rather low score, considering the fact that the importance of vulnerability is under discussion for more than two decades already. It shows that the social aspect of vulnerability is still largely in its embryonic phase when it comes to its quantification and inclusion in flood risk models (McGahey & Sayers 2008)

More interesting is how exactly these papers deal with this vulnerability. Half of these papers are of a descriptive nature, describing social vulnerability as differences in exposure, perception and how vulnerability has worked out in real flooding conditions and the recovery process. Four papers only stress the importance of taking different forms of vulnerability into account, without mentioning how this should be accomplished. Six papers have included social vulnerability in a GIS by assigning hotspots on the map or through more complex vulnerability indices. Three papers include differential vulnerabilities in loss of life models. And only one paper described the modelling of vulnerability: Brémond et al. (2008) presented a model to asses flood vulnerability at farm level in France.

Table 1 The way vulnerability is addressed in the 28 Oxford and Toronto papers

describing difference in exposure	3
describing difference in warning perception and risk perception	4
describing the need to address social vulnerability by government agencies	2
describing the differential impact of flooding, resilience and community participation	5
social vulnerability is only mentioned, but not worked out	4
social vulnerability as hotspots on maps and as index in GIS	6
social vulnerability as part of loss of life models	3
vulnerability modelled at farm level	1
total number of papers:	28

In summary, we can conclude that:
- the current state of flood vulnerability modelling is limited to the hazard and the direct impacts (damages, loss of life). Resilience and coping aspects are generally not included;
- where social or socioeconomic aspects of vulnerability are taken into account, it is mostly in a descriptive way or by portraying vulnerability using indicators.

Hence, there is a scarcity of *knowledge* and *models* that take a more holistic and integrated approach needed to grasp the interdisciplinary nature of vulnerability. This is not surprising as the complexity and diverse data required make it difficult to develop a model that predicts changes in vulnerability (Dercon 2001). Furthermore, the fragmentation of disaster studies into sub-fields and specializations does not make things easier, as it hampers cross-disciplinary theory development (Bockarjova 2007). This is all the more pitiful because we are interested not in vulnerability *per se*, but in relation to socioeconomic development and planning. As mentioned in section 1.2.3 knowledge on disasters and vulnerability need better be integrated in development planning and management. Allocation of scarce resources and subsequent income distribution effects are key elements of planning. In this respect is it is essential to look at the differential nature of vulnerability.

1.4 The differential nature of vulnerability

By now, a large body of evidence exists that shows the differential nature of vulnerability, implying that two social entities exposed to the same hazard are unlikely to share the same vulnerability, because of their difference in character (Blaikie et al. 1994; Winchester 1992; Cannon 2000; Anderson & Woodrow 1998). What is often called the social dimension in vulnerability – or in short social vulnerability – relates to differences in gender, age, social position, income and many other potential factors that determine the ability to cope with adverse impacts (Cutter et al. 2003; Tapsell et al. 2002; Fordham & Ketteridge 1995). Therefore, it is imperative that approaches and models for vulnerability assessment should address this differential nature of vulnerability in one way or another.

Notwithstanding the necessity, it has nevertheless proven difficult to include the differential nature of vulnerability into an assessment model that simulates vulnerability as a function of changing boundary conditions and policy strategies. One of the reasons is the scale effect: what emerges as a difference at one scale, can become blurred through aggregation at another scale level. Another reason is the absence of a generally accepted metric to measure (differential) vulnerability. When we want to describe how a social entity, be it an individual, household, community or country, is able to cope with the adverse impacts of a coastal hazard (in our case a tropical storm), it is clear that this depends on specific characteristics of this entity. We can call them vulnerability features that together determine the vulnerability profile of the entity. Because of the heterogeneity of social entities, this vulnerability profile will also be heterogeneous. Should one combine the different factors that determine a vulnerability profile into one index and which algorithm should then be used? These and other relevant existing dilemmas will be addressed in this thesis.

1.5 Research objective

Based on the observation that it has proven quite difficult to provide an adequate assessment of the status and future development of vulnerability of coastal communities, the focus of this research is on providing knowledge and tools to make such an assessment. Accordingly, the relations between vulnerability and coastal development are studied as are the design conditions, opportunities and limitations of vulnerability modelling. This leads to the following objective of this research:

> *To advance the state-of-art in modelling vulnerability of coastal zones to cyclonic storms and floods in such a way that this will enhance integration between disaster management and coastal planning.*

There are many and varied concepts of vulnerability and consequently many definitions and modelling approaches. At this introductory stage it is important to stress that the vulnerability concept is used in its widest sense ranging from physical exposure to socioeconomic resilience.

The research has led to two distinct products: *knowledge* on the differential nature of vulnerability in relation to coastal planning and a *model*[1] on vulnerability. This model links vulnerability to many themes relevant to coastal planning. The model was developed as part of an assignment for the Government of Andhra Pradesh, India. This undertaking provided unique material and experience that has been used as the basis of this research. As the model development was rooted in a real world situation, it has been possible to evaluate its practical feasibility as well as its usefulness within a specific policy analysis context.

Evidently, we are not only interested in the usefulness of the model in one specific situation, i.e. Andhra Pradesh, but also in its wider applicability. Therefore the model has also been applied in a different context: the Red River Delta in Vietnam. For the same reason it is also important to assess the dependency of the model design on the design context. In other words: would the same (or a similar) model have been developed if conditions were quite different from the existing ones? This is important for defining the boundaries of model applicability. And it will also help to formulate adaptations to the model design for application in other circumstances.

1.6 Research questions

To achieve its objective, the research is structured by a number of research questions. These questions should generate new knowledge, based not only on the design of the model itself, but also on the usefulness of this model for future vulnerability assessments.

Research Question 1: What are the characteristics of vulnerability and how can these be conceptualised?

This question is answered by conducting a literature study on vulnerability, exploring its definitions and theories. A working definition of vulnerability and a conceptual model resulted.

The second question relates to the design of a model for vulnerability in relation to the theoretical background of vulnerability to natural hazards.

Research Question 2: How can we model vulnerability?

Modelling vulnerability requires a metric, data and empirical and/or causal knowledge that allows us to infer how vulnerability is likely to change under changing conditions. Due to the complex multidisciplinary nature of vulnerability, an integrated modelling approach seems justified, bringing with it its own set of opportunities and limitations. To deal with complexity requires choosing the appropriate level of aggregation in time and space, simplification where possible and integration where necessary. From the literature, different approaches and methods for measuring vulnerability are described and evaluated for their potential use in modelling vulnerability. The

[1] Unless explicitly stated otherwise, when I use the word 'model' as a noun I refer to a computerised model system as a tool.

experiences of the actual design of a model in the Andhra Pradesh study form the main input in answering this question.

The third question focuses on the quality of the designed model and can only be answered by putting the model into its context:

Research Question 3: How useful (valid) is our model?

This question is about model evaluation and should reveal the strengths and weaknesses of the model that was developed for Andhra Pradesh. This insight contributes to assessing the validity of the model, which is defined as useful for its intended purpose (Parker et al. 2002). Determining the usefulness of a complex interdisciplinary model is complex in itself. Therefore a list of validation criteria will be formulated, using recent theory and experience in Integrated Assessment Modelling and Policy Analysis.

Research Question 4: What can we learn from the model applications?

The model has been applied to two geographically different regions: the Godavari Delta, Andhra Pradesh, India and the Red River Delta, Vietnam. These applications give insight in the options for vulnerability reduction for these concrete examples, but are also of more general value regarding coastal planning in densely populated coastal areas.

The context in which the model is designed plays a crucial role in the design choices made. Examples of context factors that determine the design include time and budget constraints, data availability and team composition. Insight in these factors provides an idea about the generic value of the developed model. This will generate knowledge that helps us to design or adapt a model for a different situation. This brings us to the last question:

Research Question 5: (a) Which factors played a crucial role in the design of the model? and (b) Has this influenced the general applicability of the model?

1.7 The research strategy

This research arose from the researcher's experiences in consultancy, advisory and training assignments within the field of ICZM and vulnerability assessments. One of the most extensive assignments was the development of a Decision Support System (model) on ICZM linked with vulnerability reduction in Andhra Pradesh, India. Both the model design itself and the application was used as research material for this thesis. This enabled the inclusion of the context in which the model was designed, which allowed the distillation of new knowledge from these experience.

For a better understanding of my research approach it is necessary to clarify the role of the model design in this approach. In fact, the model was not designed and developed as part of this research itself, but as part of the Andhra Pradesh Cyclone Hazard Mitigation Project (the 'Andhra Pradesh Project' for short), in which I was a participant. This means that the model is not a product of a purely academic research exercise, but is rooted in a Client – Consultant relationship. Evaluating the model, its design process and application makes a valuable contribution to the progress of vulnerability assessments in general, specifically *because* its conception was not a purely academic exercise, but one which is firmly rooted in a practical, real world situation. This reflection contributes to an epistemology of practice (Schön 1983) on the design of models. Modelling has become a widely used method to support all kinds of assessments and decision processes, executed by professionals working mainly outside the academic world. Assuming that these professionals apply scientifically valid methods and approaches, they will nevertheless be confronted with a range of context-dependent factors, including budget constraints, a normative problem setting and ever changing client demands. By explicitly including this context in the research it becomes possible to use this experience in future (applied) research and development.

The research strategy therefore has an *evaluation* character: it draws on existing empirical evidence and theory on vulnerability and disaster management (Blaikie et al. 1994; Adger et al. 2005; Alcantara-Ayala 2002; Parker 2000; Cannon et al. 2003; Twigg 2001b; Winchester 1992; Birkmann 2006) to evaluate the design of a model for measuring vulnerability and its role in reducing vulnerability.

For reasons of methodological clarity it is important to take a closer look at the role of the model design. Design here is identified as 'devise courses of action aimed at changing existing situations into preferred ones' (Friedman 2003). In our case, it is the design of a model for vulnerability. But design alone does not necessarily lead to new knowledge. As Friedman (2003) writes: 'It is not experience, but our interpretation and understanding of experience that leads to knowledge. Knowledge emerges from critical inquiry. Systematic or scientific knowledge arises from the theories that allow us to question and learn from the world around us.' Critical reflection on the model design in this research has the purpose of generating new knowledge from experience, to aid in developing an understanding of the complexity of vulnerability.

In order to add an impartial and independent dimension to the reflection on the validity and practical usefulness of the model I have used an independent Expert Panel. During a half day workshop the Panel members were given an introductory presentation and were able to work with the model themselves. The remainder of the workshop was used for an evaluation, including discussions and filling in a SWOT (Strengths, Weaknesses, Opportunities and Threats) matrix.

As will be explained in the next section, I have chosen three different research perspectives that helped me in conducting this critical inquiry.

1.7.1 Three research perspectives

Making and evaluating a model on vulnerability requires a broader scope than the model itself. The model is but an artefact or tool that serves a certain purpose. And although we should study its architecture and internal consistency, we need to look beyond the model and also include its relation with its context. Only then are we able to evaluate its role and value. Particularly the research questions 3 ('How useful is the model?') and 5a ('Which factors played a crucial role in the design of the model?') demand this wider research scope. I have therefore developed three distinct perspectives of inquiry (Yin 1994). These three perspectives have been derived from a simplified representation of model development, being a sequence of steps from a problem formulated as part of a policy analysis, via a conceptual model to a computerised model and its application (Slinger et al. 2008b). Using this representation (Figure 1), I distinguish three perspectives of 'looking back':

- The *Model* perspective, looking back from the computer model to its conceptual counterpart;

- The *Application* perspective, looking back from the application to the problem we started with;
- The *Context* perspective, providing feedback from the entire model design to the policy analysis context.

1.7.2 The Model perspective

The Model perspective examines the design of the model. The perspective describes how the model has been designed, based on an interpretation of its objectives that was provided by the decision-making context. It includes both the method of vulnerability quantification and the implementation into a computer-based decision support system as undertaken in the Andhra Pradesh project. This perspective tackles the problem of integration at the level of artefacts (cf. Hinkel, 2008).

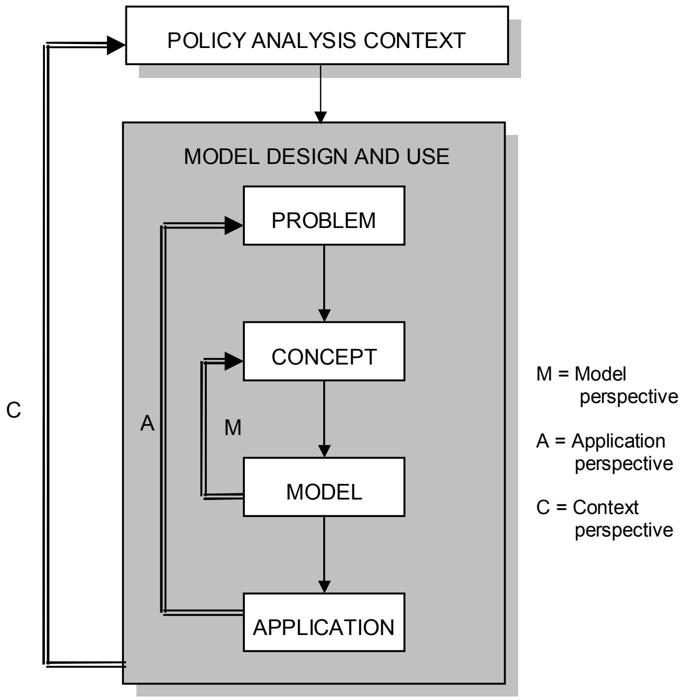

Figure 1 Relationships between the three research perspectives of the thesis

(modified after Slinger et al., 2008b) Model design and application are depicted as a simplified linear process from problem, via a conceptual model to a computational model and an application. Of course in reality this process is not linear, but is executed in an iterative fashion, but these iterations are omitted for the sake of clarity. This model design and application took place in the wider context of a policy analysis, which is schematised in the upper box. The arrow from the policy analysis context and the grey 'model design and application box' indicates the (myriad) influences the context has on the model design. The Model Perspective is indicated as an arrow from the small 'model' box back to the 'concept' box. It denotes the inquiry into the problem of how to build a practical, working computational model from an theoretical concept of vulnerability. Likewise, the Application Perspective is shown as an arrow from the 'application' box to the 'problem' box, illustrating the question how the model results are contributing to solving the problem. And finally, the Context Perspective is illustrated as the arrow from the entire grey 'model design and use' box to the 'policy analysis context' box. Here, the way the model design and use is influenced by the context is questioned.

The Model perspective will use the theories of quantitative analysis and integrated modelling to arrive at design criteria against which the tool can be evaluated. It also examines the choices that have been made with respect to the quantification of vulnerability and coastal planning. Furthermore, the issue of model validation will be raised, in view of its usefulness in the planning context.

It relates to the Applications perspective in two ways: the application enables the model to be used as an analytical instrument after having been calibrated with data from a specific geographic location. In turn, the experience with using the model in an application can (and often will) reveal shortcomings in the model, which could result in a redesign or adaptation of the instrument.

1.7.3 The Applications perspective

Applying the model requires loading the model with data, calibrating the model and using it for analysing alternative planning strategies under uncertain future conditions (scenarios). Through these activities the feasibility of the model can be tested e.g. in terms of data availability and accuracy, parameter assessment and interpretation of the results. As the model is designed to support the advice on vulnerability reduction measures, we can also learn from it at this level: what do the analysis results tell us about the preferred course of action to reduce the vulnerability of coastal communities to cyclone hazards? And how generic are these recommendations for other regions or countries?

1.7.4 The Context perspective

Within the Context perspective, I will analyse the situation in which the model was designed. The importance of this perspective is that it provides insight in the reasons for choices that have been made in the model design. Choices about the aim of the model, about what is considered essential and policy relevant and what not. This context can be labelled the 'policy analysis context' as viewed in Figure 1. It cannot be predefined more precisely, but should be approached through progressive contextualisation, in which there is no other a priori research unit than the issue to be explained (De Groot 1992).We can at most indicate which contexts *could be* of relevance.

Clearly, the policy decision arena influences the choice of the policy analysis framework and its instruments. There are four elements that influence this choice: the problem area, the policy process, policy style and evaluation norm (Monnikhof 2006). With respect to the problem area, we will encounter the concepts of disaster, vulnerability and integrated coastal zone management (ICZM). Within this problem area the objectives of the tool development are formulated.

The policy process and style refer to the procedures and institutional arrangements in which the decision making takes place. A policy style can differ per society and distinctions are often made between an active and reactive policy style, and a more consensus oriented versus hierarchical policy style (Monnikhof 2006). The actual policy process largely determines which role the policy analyst has. We will see later that the model development in this case is heavily influenced by the rational style of policy analysis (Mayer et al. 2004).

Although the Context perspective does examine the decision making process, I do not intend to search for explanations as to why the process is as it is. Instead, it is used as a reference or context without which the evaluation of the model development cannot be undertaken.

The Context perspective also addresses the social activity of the research team that executed the study, built the tool and applied it. The experience from the Andhra Pradesh project allows a reflection against practice. It is the position Schön (1983) calls the *Reflective Practitioner*. It is reflection on the knowing-in-practice, on how to deal with unique, uncertain and conflicting situations of practice. With 'research team' I include also the counterpart staff of the client, subcontracted researchers and others that have at any point participated in the study.

In contrast to Klein & Hinkel (2008) who state that any lessons learnt from the social dynamics in a collaborative research team are highly project-specific and that it therefore is non-academic to generalise them, I take the position that we can learn from this perspective. Model design requires a combination of knowledge and skills. Integrated Models, as we will see in chapter 4, specifically require team skills and arrangements, because of their interdisciplinary character (Nicholson et al. 2002). Hence, understanding and evaluating the model must include an investigation of the practical conditions under which the model has been designed. This includes the team composition and the influence of preferences and habits or even biases the team members have on each other and on the model design.

A summary of each of these perspectives is given in Table 2.

Table 2 Three research perspectives of the thesis

Research Perspective	Description	Research questions
Model	The theoretical and methodological aspects of quantifying vulnerability and the translation into a computer based model	1. What are the characteristics of vulnerability and how can these be conceptualised? 2. How can we model vulnerability? 3. How useful (valid) is our model?
Application	Use of the model as a planning aid	4. What can we learn from the model applications?
Context	Reflection on the model design process	5. Which factors played a crucial role in the design of the model? And how has this influenced the general applicability of the model?

1.8 Structure of the thesis

The remainder of this thesis consists of eight chapters, grouped into three parts. Figure 2 presents the research steps arranged as subsequent chapters of this thesis.

In Part 1 of the thesis, I will first describe the design and application of the model within the Andhra Pradesh project (Chapter 2) so as to provide the reader with a taste of the design experience I had. I will then move on to develop an evaluation framework on the basis of a literature study (Part 2, Chapters 3 to 5). This sequence underlines the fact that the Andhra Pradesh project cannot be viewed as a case-study study as commonly accepted in social research (Yin, 1994), but should be viewed as an historic event in which the researcher was involved and gained experience (Box 3). The project provided the context for the model design. In Part 3 the results of the evaluation of the model are presented and discussed (Chapters 6, 7 and 8). In Chapter 9, the research questions formulated in the beginning are answered and discussed.

Box 3 The difference between cases, case studies and experience

A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident (Yin 1994). By this definition we can denote the model design as the 'phenomenon' and the Andhra Pradesh project as the 'real-life context'. However, the Andhra Pradesh project in this research cannot be regarded as a case-study in the strict sense. Except for 'action research', in a case study inquiry, the investigator has no or little control over the phenomenon. Furthermore, a case study is usually executed as part of a sequence of research activities that start with the development of theoretical propositions to guide data collection and analysis of the case study (Yin 1994; Adger 1999a). With respect to the Andhra Pradesh project, I did have substantial influence over the phenomenon, and the collection of data and analysis (for the evaluation, not for the model) only started after the project has finished. This makes the use of the Andhra Pradesh project methodologically different from most case study research. Therefore I will not label the project as a 'case', but as an '*Experience'*, which expresses the fact that it is a historic event in which the researcher was involved and gained experience. This also avoids potential confusion with the use of the word 'case' in the modelling context, where it denotes a combination of a scenario and a measure.

Chapter 2 (*'Design and application of an Expert Decision Support System (EDSS) for coastal Andhra Pradesh'*) consists of a narrative describing the Andhra Pradesh Project as the setting for the design of the model and functions as the 'raw' field observations from the three research perspectives, i.e. the Model, Application and Context Perspectives. Elements included in this narrative are: project assignment, problem description, the paradigms used and practical problems encountered during the project leading to essential choices in the design of the model. Also a concise description of the model itself is given. The application of the model to the Godavari Delta in coastal Andhra is also presented, including model calibration and the main analysis results.

A literature study has been executed within three different knowledge domains, i.e. on vulnerability, integrated modelling and policy analysis. Results of this study are presented in the subsequent chapters 3, 4 and 5:

In **Chapter 3** (*'Defining Vulnerability'*) a review is given of contemporary vulnerability concepts, definitions and theories (research question 1). Also common methods for vulnerability assessment are described and evaluated and the added value of a model approach is discussed. Based on this inventory and critical examination, a framework for vulnerability is chosen for a vulnerability assessment on a regional scale, that will be used to evaluate the model in Chapter 6.

Chapter 4 ('*Choices in Integrated Modelling'*) starts with a description of Integrated Assessment and discusses the role of models in these assessments (gives input to research question 2). Specific attention is paid to integration aspects which can give rise to particular choices in integrated modelling. Also the issue of model validation is addressed, leading to a list of evaluation criteria for Integrated Assessment Models that will be used in Chapter 6 (research question 3).

Chapter 5 (*'Policy Analysis: linking context with content'*) presents an historic perspective of policy analysis (PA) approaches with the aim to better understand the role of PA in the Andhra Pradesh project. We need this understanding to answer research question 5 (Which factors played a crucial role in the design of the model?).

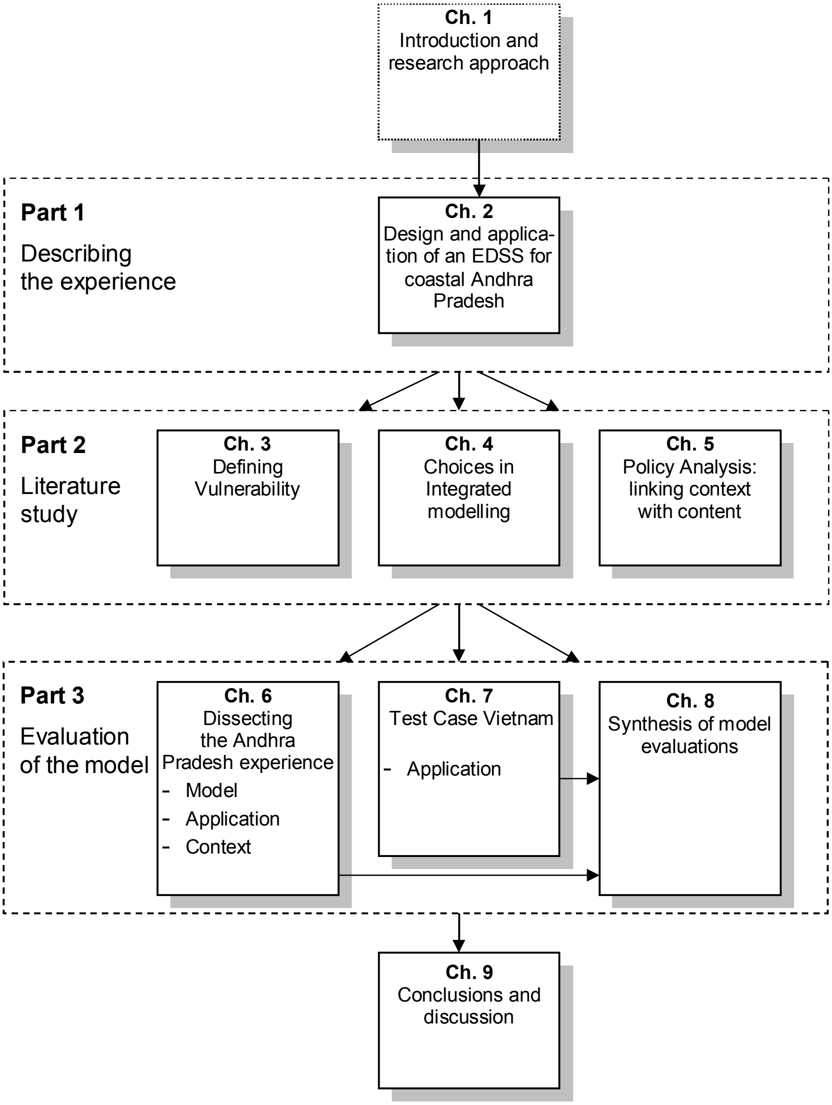

Figure 2 Set up of the thesis

In **Chapter 6** (*'Dissecting the Andhra Pradesh Case'*) the model approach is critically reviewed against the existing body of knowledge on policy analysis (for the process and context influencing the model design), on vulnerability (being part of the contents of the model) and integrated assessment modelling (as the methodological aspects of the model design). It is a kind of forensic examination that places the model (the subject of inquiry) in the context of the activities that happened during its genesis. The examination uses the theories from the literature study (Chapters 3 to 5) to understand and where possible to explain how the model design was influenced by the activities and events of the project (research question 5). An example is the way in which the dynamics of interdisciplinary work were of decisive influence in the design of the model. The result of this forensic examination is to be able to assess the dependency of the model design on its context.

The evaluation criteria for Integrated Modelling derived in Chapter 4 are used in Chapter 6, in order to evaluate the model from a 'good modelling practice' point of view. This provides an answer to research question 3.

Finally, the application results for the Godavari Delta are described and analysed to see if these results give new insights in vulnerability reduction measures (research question 4).

Chapter 7 ('*Test case Red River Delta, Vietnam*') is devoted to testing the model in a similar coastal environment in a different country, i.e. Vietnam. This test case provides insight in the practical applicability of the model in a different context. The model application and results are compared with those of the first model application in India, which provides additional insight on the general applicability of the model (research question 5).

Chapter 8 ('*Synthesis of model evaluations*') synthesises the experiences of designing and working with the model, the dissection of the model, the test case and the review by the Expert Panel, following the three research perspectives. It includes an overview of strengths and weaknesses and draws conclusions from the model results that are relevant for planning and disaster management.

Chapter 9 ('*Conclusions and recommendations*') draws conclusions of the research by extracting the generic lessons from the experience, thus contributing to the knowledge of vulnerability modelling. Propositions and guidelines for future modelling activities are formulated. A critical reflection on the research approach is also included.

Part 1
Describing the experience

2 Design and application of an Expert Decision Support System (EDSS) for coastal Andhra Pradesh

This chapter documents the design of the EDSS for Andhra Pradesh, as part of the Cyclone Hazard Management Project, which was executed between 1999 and 2006. After a description of the its inception, the model design will be presented. Hereafter an application is described for the Godavari Delta. In the last section the results of the calibration and analysis for the Godavari delta are discussed.

2.1 Describing the process: the Andhra Pradesh Cyclone Hazard Mitigation Project (APCHMP)

2.1.1 The assignment

As part of a World Bank loan to the Government of Andhra Pradesh, a study started in 1999 on the mitigation of the cyclone hazard along the coast of Andhra Pradesh. This study was executed by a consortium of consultancy firms led by Delft Hydraulics and included both the development of a real time early warning system and an Integrated Coastal Zone Management (ICZM) study to analyse the long term planning opportunities for hazard reduction. The Coastal Zone Management study was given the following objective: *to envisage optimum utilisation of coastal resources, minimisation of impacts due to natural disasters and improvements in equitable quality of life levels while ensuring environmental protection and ecology* (Description of Services, page 29, GoAP 1999).

With respect to the Coastal Zone Management study the Description of Services (DoS) stipulated a complete inventory of the environmental compartments 'Water', 'Land', 'Biology', 'Air' and 'Noise' as well as the socio-economic environment. The assimilative and supportive capacities of these compartments needed to be estimated and an 'Evaluation of Alternative development scenarios and delineation of preferred scenario' was prescribed. Also a 'Delineation of institutional mechanisms and capacity building' was required. This should lead to an output formulated as '*Preparation of a resource management plan, disaster prevention and impact minimization plan after examining various scenarios relating to integrated coastal zone management*'.

Another deliverable of the ICZM study was the development of an '*Expert Decision Support System (EDSS) for the river basins, deltas and other vulnerable areas along the coast taking into consideration the aspects of Study 'A' and 'B' for optimum utilisation of coastal resources with minimum impact due to natural disaster*' (Description of Services, page 34, GoAP 1999). The aim of the EDSS was to support the decision making with regard to measures and policies that can be taken by the AP Government to improve equitable quality of life levels, to safeguard the environment and to reduce vulnerability of the population in coastal area of Andhra Pradesh. Study 'B' refers to the study relating to rainfall, wind, storm surge modelling including coastal zone management, which was called the Andhra Pradesh Cyclone Hazard Mitigation Project (APCHMP). Study 'A' refers to another study forming part of the AP Hazard Mitigation & Emergency Cyclone Recovery Project which dealt with watershed and delta management including modelling floods from riverine origin. This study was conducted by a consortium led by Babtie International and executed parallel in time with Study 'B'.

Delft Hydraulics accepted the assignment for providing consultancy services for Study 'B' and started work in August 1999. The consortium consisted of an international team of experts from Delft Hydraulics (NL), DHV Consultants (NL), HR Wallingford (UK), the UK Met Office, Centre for Ecology and Hydrology (UK), Flood Hazard Research Centre of Middlesex University (UK), Argos (NL) and a team of Indian experts from Consulting Engineering Services (India) Ltd, JPS Associates (P) Ltd and the Indian Institute of Technology Madras. Total input to the ICZM study from international and Indian experts was originally planned to be around 22 and 53 person-months, respectively. The study was planned to be finished within a period of 2 years.

2.1.2 The study approach

The initial study approach closely followed the Framework for Analysis as used by Delft Hydraulics for policy analysis studies (Pennekamp & Wesseling 1993) This framework consists of several phases (see also Figure 3):

1. *Diagnosis / problem analysis phase*: in this phase an initial analysis is performed on the basis of which the problems and objectives for development are determined. This information is then used as input for the formulation of the study approach. The outcome of this phase is reported in the Inception Report and Interim Reports.
2. *Development / system design phase:* In this phase the complete computational framework for the policy analysis is set up. The set up includes testing, calibration and a first rough analysis. It also engages in the screening of measures.
3. *Evaluation / selection phase:* The system as been developed in the previous phase is used to analyse the most promising measures in terms of effectiveness and side effects. For the analysis these measures are combined into strategies or policies. Cost-benefit evaluations are also part of this phase.
4. *Planning phase:* In this phase the results of the previous phases are used in order to write the ICZM Plan. The most promising measures will be presented in a consistent and coherent way. This is especially important with respect to the multiple objectives of ICZM: care should be taken that measures in one sector of the society do not impair the development in other sectors. Due to the fact that the decisions on development cannot be taken by the Consultant, the planning products will have the status of proposals/recommendations only.

From the onset an interdisciplinary approach was taken. The study team consisted of experts from both the natural and social sciences who undertook field visits, contributed to workshops and collaborated on desk studies together. This greatly improved our understanding of the complex problems and feasibility of potential solutions. For example, we had lively and serious discussions regarding the rapid development of aquaculture in the coastal zone. Environmental concerns, culture techniques, economics and social impacts were exchanged and led to a balanced and scientifically sound assessment of current practices and recommendations for enhancing a sustainable and socially justified development. Likewise other coastal problems were studied, which resulted in an extensive knowledge base on these issues, documented in 14 Technical

Reports and 11 Supporting Documents. Each of the reports was written from a specific sector (e.g. 'fisheries') or aspect (e.g. 'Village institutions') perspective. Table 3 shows an overview of the Technical Reports.

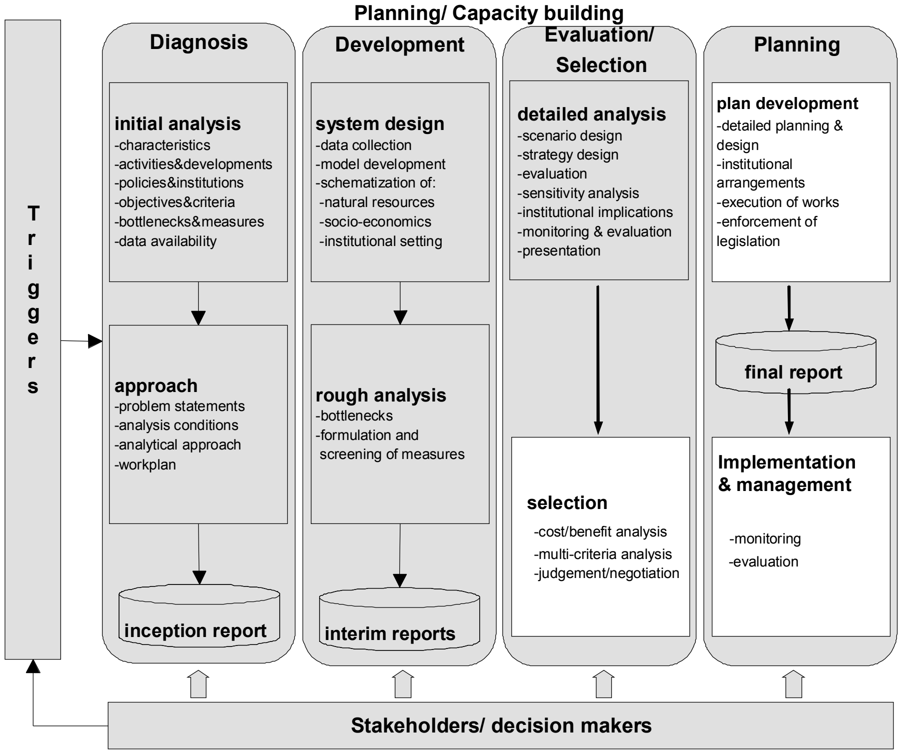

Figure 3 Framework of Analysis used in the ICZM study

Table 3 List of Technical Reports (TR) of the ICZM study as part of the APCHMP

No	Title
TR1	Problems and opportunities for sustainable coastal development in Andhra Pradesh: a synthesis
TR2	DSS on Vulnerability for the Andhra Pradesh coast
TR3	The socio-economy of the Andhra Pradesh coastal areas and cyclone vulnerability
TR4	The Shoreline management of Andhra Pradesh
TR5	Forestry and nature conservation in coastal Andhra Pradesh
TR6	Fisheries and aquaculture in coastal Andhra Pradesh
TR7	Land Use, Agriculture, Tourism and Industries in coastal Andhra Pradesh
TR8	Water resources and water quality in coastal Andhra Pradesh
TR9	Air and noise quality in coastal Andhra Pradesh
TR10	Solid waste management in coastal Andhra Pradesh
TR11	Cyclone disasters, early warning, communication and disaster mitigation in coastal Andhra Pradesh
TR12	Institutional arrangements for ICZM in Andhra Pradesh
TR13	Village level institutions: capacity building at village and mandal level in coastal Andhra Pradesh

Besides describing the present situation within a sector, many of these reports also addressed cross-cutting issues, such as ‘cyclone hazard mitigation’ or ‘integrated water resources management’. Also a synthesis report (TR1) was prepared that summarized the problems and opportunities for sustainable coastal development in Andhra Pradesh.

However useful this wealth of information may have been, it did not directly provide guidance for the future sustainable development of the coastal zone vis-à-vis vulnerability. For this the use of GIS data and the EDSS would be essential.

The delivery of GIS data from Study A was considered a prerequisite for the whole study. In the Inception Report it was formulated as follows: ‘*Study B is relying for the majority of the spatially oriented data on the GIS maps which are to be provided by Study A. It is therefore of the utmost importance to make sound agreements between both studies on the terms on which this information becomes available.’* Due to a number of reasons a great delay in the provision of GIS data was encountered. August 2000, one year after the start of the project no GIS data were provided and a tentative estimation of the first delivery mentioned February 2001. More delays were experienced which jeopardised the development of the EDSS and a successful finalisation of the whole project, until a way out was found after agreement between the Client (the Government of Andhra Pradesh) and the Consultant on the ‘Revised Action Plan’ of January 2003. In this plan the contours of the EDSS were sketched taking into account the limited availability of GIS based data.

2.1.3 Towards integration

The limited availability of detailed thematic GIS layers shifted our attention to the question: what can we do with the data we do have? This proved to be a successful strategy. In fact, a huge database was available from the decadal Government Census, of which the latest was from the year 2001. And once the mandal (the administrative unit of an area roughly in the order of 10,000 ha) was chosen as the appropriate ***spatial unit for modelling***, the limited availability of GIS layers did not hamper the DSS design any longer. Much data was readily available at the mandal level and for other data, aggregation or interpolation was applied to fill the database for the EDSS. Once the appropriate spatial unit for the tool was chosen and the basic set up of the calculations was formulated, the previously collected data could logically be arranged and made useful. At once, all the pieces of the jigsaw puzzle fell into place.

Besides the data issue, the development of the EDSS also required an approach for the formulation of scenarios and strategies in relation to disaster mitigation. Here the results of the studies by the different experts, especially in the field of land use, water management and socio-economy, led to some interesting and cross-cutting conclusions. For instance, the land use experts came to the conclusion that ‘*from the land use point of view, the focal issue in ICZM, both in terms of development and in terms of cyclone impact mitigation, should be* ***integrated water management*** *at all levels.*’ (Mulder 2001). The overall conclusion of the land use studies was that most land use issues are related to water: equitable distribution of irrigation and drinking water, flooding hazard and lack of drainage, water quality and water pollution, cross-sectoral competition for water, upland watershed development, ground water development and depletion, degradation of natural wetlands. Amounts and quality of water are setting the limits for development.

In the course of the project – and as a result of the interdisciplinary approach – the interpretation of disaster management shifted from a mainly technical and engineering scope to the concept of vulnerability. Because the other major component of the project was the development of a real time early warning system for cyclone hazards, including wind and storm surge, this focused much attention within the project on technical issues, at least initially. Each of the members was specialised in his or her own field of expertise, such as storm surge modelling, land use, fisheries, forestry, institutional development, solid waste management etc. (see Table 4). In the course of the project, people started thinking about the relation between their knowledge domain and disasters. Discussions between experts made them aware of the complexity of the issue and that mitigating measures from within their own perspective needed cross-checking with others. For instance, the idea of green shelter belts of *Casuarina* trees, which was initially considered a useful mitigating measure against cyclone hazard by some, was critically examined by the forestry expert, who concluded that '*there is absolutely no doubt about the positive effects of shelter-belts under "normal" conditions with respect to reducing wind velocity. However, their protective function during cyclones, with wind speeds above 120-150 km/hr, must be questioned indeed. With increasing wind speeds, the protective function of shelter-belts decreases. […] trees present a serious danger hazard during a cyclone'*. (Mohapatra & Bech 2001). In another example the project team learned to understand that an effective early warning and evacuation system is not only a matter of high-tech computer forecasts and transmission of warnings, but also requires an insight in how people and communities react to these warnings.

Table 4 Team composition of the APCHM Project

number of persons contracted*	discipline / function
12	Project management and support staff
10	Storm surge modellers/ experts
9	Software & GIS specialists
5	Wind forecasting and hazard experts
5	Sociologists/economists/geographers
4	Rainfall/meteorologists
4	Water resources experts
3	Instrumentalists
3	Land use experts
3	Training specialists
2	ICZM experts
2	Forestry and biodiversity experts
1	Air pollution expert
1	Solid waste expert
1	Fisheries expert
1	Disaster management expert
1	Remote sensing expert
67	*Total*

* excluding counterpart staff from the Government of AP

The role of the sociologist and geographer[2] was of great influence in the development of an approach to disaster mitigation and reduction of vulnerability. As for myself, as the ICZM expert and co-ordinator of the ICZM study, I did not have any specific knowledge of the socioeconomic aspects of vulnerability. But during the process, I learned to appreciate how complex the issue of vulnerability is, not in the least because of the differential impact a disaster can have on the society. And once the ***differential nature of vulnerability*** was understood, this proved to be a strong guiding principle for linking economic development options with the aim of reducing vulnerability. At that moment it became one step clearer how the EDSS needed to be designed.

2.2 Design of the EDSS

2.2.1 The design process

The actual design of the EDSS was not a straightforward step by step process following the framework of analysis from Figure 3. Instead, it consisted of a combination of luminous ideas, discussions, trials and errors. For instance, the very first idea of a model that linked vulnerability with the economic situation of a household was based on a simple spreadsheet, where losses due to a cyclone were hypothetically assigned to different household income levels. This concept was later incorporated into the larger EDSS by including realistic damage equations for different assets and a more complete economic model that related the damages in a realistic way to the annual income of the different households.

Much discussion was needed to clarify the scope of the EDSS: initially the focus was on the vulnerability to flooding with an explicit linkage to land use. Later the scope widened to include elements of resource use to be able to use the model to support the drafting of a resource management plan. In a later stage also the damage calculation in the model was extended to include wind damage in addition to flood damage.

Ideally, the EDSS would have been developed in Phase 2 of the framework, called ‘Development/system design’, somewhere halfway in the project lifetime. This would have enabled a proper use of the EDSS as analysis instrument in the subsequent Evaluation Phase. It would have allowed intensive interaction with all experts within the project. But due to problems in data availability and other delays, the actual design of the EDSS only started after most of the project members already went home or turned to other projects (in fact, the EDSS design started in 2003, whereas most of the project activities ended in 2001). Therefore, the EDSS design was taken up by only four team members[3]: the land use expert, an integrated modelling expert (who was hired specially for the EDSS design), an IT specialist and myself. This design team worked for several months intensively together and had regular meetings with the counterpart staff of the client. Afterwards, it can be concluded that this work in a small group was quite efficient, and probably was necessary for its success. Designing a model with more people would have most likely been very much time consuming and extremely difficult. The downside of the model being out of phase with the rest of

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[2] Sociologist Dr. Winchester and geographer prof. dr. Penning-Rowsell provided the team with expertise in the field of social vulnerability.
[3] The team consisted of Paul Mulder (land use expert), Gerrit Baarse (integrated modelling expert), Chris Sprengers (software design expert) and Marcel Marchand (ICZM expert)

the project was that once the model was ready to use, there were no other team members who could provide feedback. It also limited the possibilities of extensive interaction with external stakeholders, e.g. through workshops, as the project infrastructure was sized down considerably once the model was ready for use.

2.2.2 Main features of the EDSS

The very basic idea of the EDSS was that in order to determine the impact of a cyclonic disaster on the coastal society, first the structure and functioning of this society needed to be grasped under ‘normal’ conditions. Only by understanding the dependencies between the use of land, its resources, socio-economy and environmental conditions it would be possible to simulate the impacts of a disruption in these dependencies by a cyclone. Hence the model captures the economic and environmental conditions of a coastal area in a time step of one year without a cyclone and again after this area was struck by a representative cyclonic storm. Vulnerability is then calculated as the difference in assets and income in the area at the end of both years.

Therefore the model links the socio-economic character of the coastal zone to the land uses and all related activities that generate income thus being sensitive to both planned (crop selection) and unplanned (cyclone disaster) land-use changes. Calculations can be made for annual production, income, resource use and waste generation for any area in any time horizon.

The model has a spatial resolution of the administrative unit of a *mandal* – a geographical area of c. 10,000 ha - and can calculate the estimated annual incomes for groups based on private and income generating assets. The model will show the differential economic effect of combinations of occupations, household size and family size, according to a range of impact scenarios and environmental conditions. It can calculate the socio-economic and environmental effects of cyclones, storm surges and floods, and the rates of recovery from these events for households in each income category by comparing the asset status of households in different income categories one year after a cyclone or storm surge with their pre-event asset status.

For the representation of the coastal system the following interrelated components were discerned: land use, socio-economy, resource demand, waste generation and environmental quality. Due to the relative dominance of land-related economic activities the primary economic sector (agriculture, forestry and fisheries) was worked out in most detail. For instance, the model distinguishes a large varieties of crops, but also different livestock components and two types of aquaculture. The secondary economic sector (industries) is represented by a limited number of industries that only differ in scale (number of employees and volume of non-labour inputs). The tertiary sector (commercial enterprises and services) is represented as a multiplier over the output of the first two sectors only.

The DSS needed to be useful in analysing the possible effects of government policy initiatives such as: changes in land use, introduction of new types of employment, distribution of relief funds, introduction of flood-resistant crops, further investment in the cyclone shelter and housing programmes, further expanding the road network, and so on. Therefore the DSS has a graphical user-interface (Figure 5) that enables to change the boundary conditions of the model either through scenario definition or selection of strategies. It also handles the output of the model in various degrees of detail, including a summary of results in terms of impacts and criteria. The functionality of the

DSS enables the user to define a specific case, which is a combination of one scenario and one strategy, to run the modules and then to analyse the results (see Figure 4). While working with different cases, the system builds up a library of results that can be compared and enable new cases to be defined. The results can also be exported for post-processing (e.g. in Excel and Word).

Another design principle was the condition that all model components should have a similar relatively simple level of mathematical complexity. Complex numerical models (such as a 3D storm surge model and wind hazard model) would slow down performance of the whole DSS unacceptably, which therefore have been kept off-line. Instead, a library of model results from these models were made available for use in the DSS.

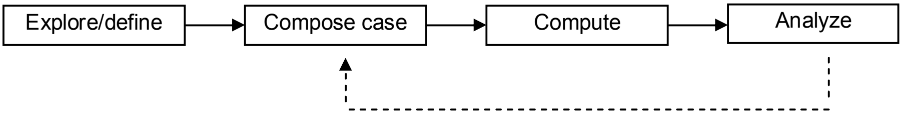

Figure 4 Steps in the use of the EDSS

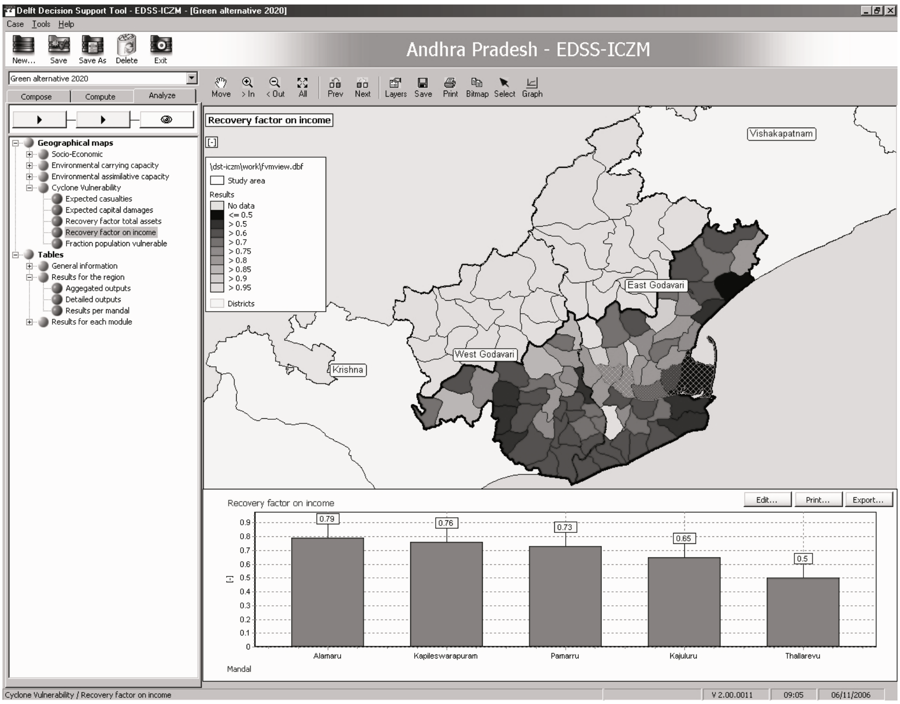

Figure 5 Screen lay out of the EDSS (Analyse mode)

2.2.3 Functional design of the EDSS

The aim of the EDSS is to assist the decision making with regard to measures and policies that can be taken by the AP Government to improve equitable quality of life levels, to safeguard the environment and to reduce vulnerability of the population in coastal Andhra Pradesh. Therefore the output of the EDSS should be given in terms of criteria for the following objectives: social, economic, environment and vulnerability. We have chosen a set of criteria and indicators that would be both feasible to calculate and meaningful for indicating impacts of scenarios and measures on the above objectives (Table 5).

Table 5 Overview of criteria and indicators used in the EDSS

Category	Criterion	Indicator
Social	Equality	Gini Coefficient
	Employment	Employment rate
	Health risk	Water sanitation index
		Atmospheric pollution risk index
Economic	Income	Per capita income
		Total income
Environmental	Carrying capacity	Water deficits
		Energy deficits
	Assimilative capacity	Water quality indices
		Atmospheric pollution density index
Cyclone vulnerability	Risk	Expected casualties
		Expected capital damages
	Resilience	Recovery factors
		Number of people financially vulnerable

The basic structure of the design (Figure 6) involves a set of interrelated modules that make the calculations based on user defined input in the form of scenarios and measures, leading to an output that is presented in the form of indicators for the criteria. Each of the six interrelated modules represent different aspects of the coastal economy and its environment:

1. Land Use Module (LUM): Describes present and future land use and related activities (crops, labour demand, wage rates, gross revenues);
2. Socio-Economic Assessment Module (SAM): Calculates incomes and income distribution in specific areas taking into account the employment rate and regional income;
3. Resource Demand and Waste Generation Module (RWM): Calculates the use of water and energy resource, transportation needs and pollution loads;
4. Environmental Assessment Module (EAM): Calculates the environmental impact of resource depletion;
5. Cyclone Probability and Severity Module (CPM): Calculates the geophysical aspects of storm surge flooding and wind hazard. Probability depends on the hydraulic conditions and cyclone frequencies and the physical characteristics of the geophysical units (elevation, degree of protection). This module reflects the severity of a storm expressed in casualty rates and damage factors, inferred from the hydraulics characteristics of the flooding (floodwater level) and from the wind characteristics;
6. Cyclone Vulnerability Module (CVM): Combines information from LUM, SAM and CPM to estimate vulnerability of people by calculating expected casualties and damages and using this for calculating the recovery factors.

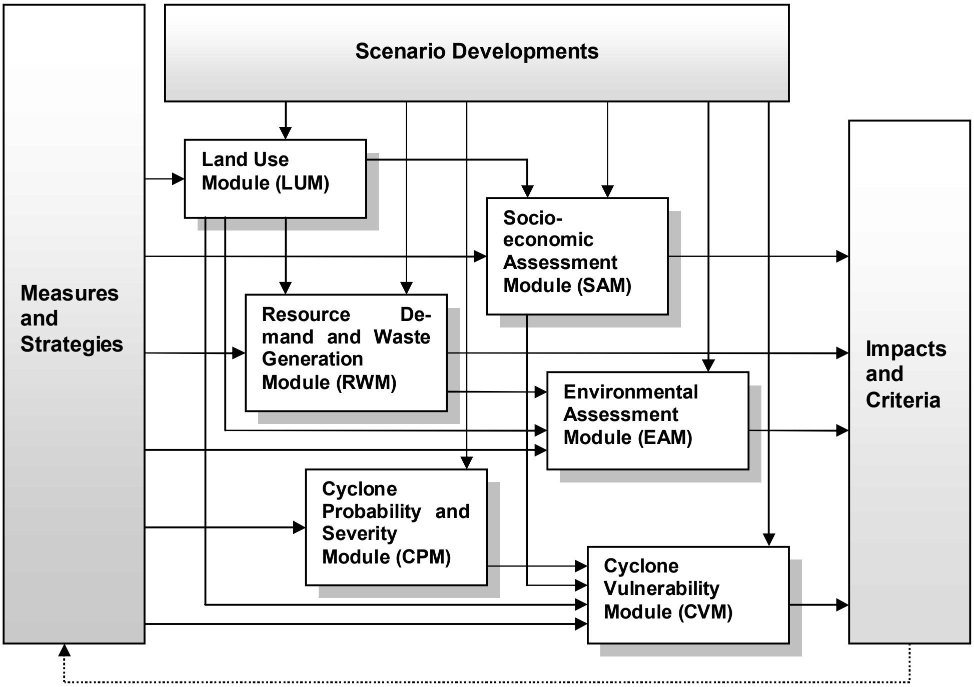

Figure 6 Over-all structure of the EDSS

Describing the design of the EDSS is like describing a fractal pattern: at a high level of observation one sees a coarse structure, but when zooming in more detailed patterns are revealed. Opening the module boxes of Figure 6 reveals new boxes, each of them containing formulas with parameters and variables. The parameters contain values behind which a wealth of data and knowledge is hidden. And it is typical for integrated models that knowledge of many disciplines and sub-disciplines are involved. In other words: there is not a single 'core' of the model, but it consists of a multitude of 'cores'. Hence, the question is at which level of detail the model should be described in order to explain its working and enable evaluation. The answer is that there is not *one* ideal level of detail, but that understanding complex models require describing them on different levels and in different detail (Thissen 1978). In this chapter I will remain at a fairly high abstraction level, indicating only the main principles of calculations within each module and a concise description of the model application. Model documentation is included in the EDSS and can also be found in Baarse & Marchand 2006, Marchand et al. 2008 and (Sprengers 2006). Later, in Chapter 6, I will go in more detail when the model is evaluated against the theory.

The basis for the computations is formed by the population, its economic activities, the soil and water resources and the environmental characteristics of each mandal. In the Land Use Module the areas of each cropping type (such as rice, bananas, aquaculture) are multiplied with the crop specific yields, values, labour requirements and non-labour inputs. Also livestock numbers are multiplied with yields, values, labour and non-labour requirements for the different animal types. These gross inputs and outputs are used in the Socio-economic Assessment Module to calculate the total income per mandal from the primary economic sector. Crop areas and livestock numbers are also used directly in the Cyclone Vulnerability Module to calculate potential damages, based on the different damage functions for each crop and animal type and the specific liability to flooding and wind hazard of each mandal.

Changes in the land use, such as revised cropping patterns and livestock intensities can be modelled by modifying the input in LUM through scenario or measure selection. With respect to the physical constraints and development potential of the land and water resources, the concept of ‘Resource Development Units’ (RDU) is introduced (Mulder 2001). These are units with more or less uniform physiography, soils and water availability and, hence, development potential and constraints. For each of these RDU’s a number of rules/algorithms are defined to which conversion from landuse classes or level of intensification is allowed or possible. Each mandal falls under one or more RDU classes (expressed as a percentage per class). For instance, a mandal can consist of 80% of RDU ‘Middle/Upper Delta Canal Irrigated’ and for 20% of RDU ‘Alluvial Upland’.

The secondary or industry sector is included in the Socio-economic Assessment Module (SAM) in terms of gross output value, labour and non-labour inputs, based on mandal statistical data of existing industries. The value of the tertiary sector, including commercial services, trade and transport is represented as a multiplier over the gross income from the other two economic sectors.

The primary function of the SAM is to create a basis for the assessment of *income* and its *distribution* that is consistent with (and driven by) the land use and industrial activity per mandal. The profit per economic sector is based on the gross income minus the labour and non-labour costs. This profit accrues to the suppliers of the income generating assets. Labour costs are calculated from applying a wage rate for skilled and unskilled labour. For agriculture, the costs of non-labour inputs follow from the requirements per hectare per crop type, such as fertilizers and pesticides, as computed in the LUM. For the other sectors, non-labour costs are defined per unit of generated gross income.

The labour supply is calculated by applying an available labour fraction per rural and urban income class. Employment rate and number of unemployed follow from the comparison of total labour supply and total labour requirement, which are computed for the activities in each sector.

For the calculations of the income by income class four different income categories are discerned: poor, medium-low, medium high and rich. Also a distinction between rural and urban income classes has been made as there are significant differences between the two. For each of the income classes the asset values are split into: income generating assets (e.g. land and livestock), non-fixed capital (capital on the bank) and private assets with a distinction between immovables (e.g. houses) and movables (e.g. bicycles) in order to differentiate the susceptibility to flood and wind damage (see Figure 7 below) .

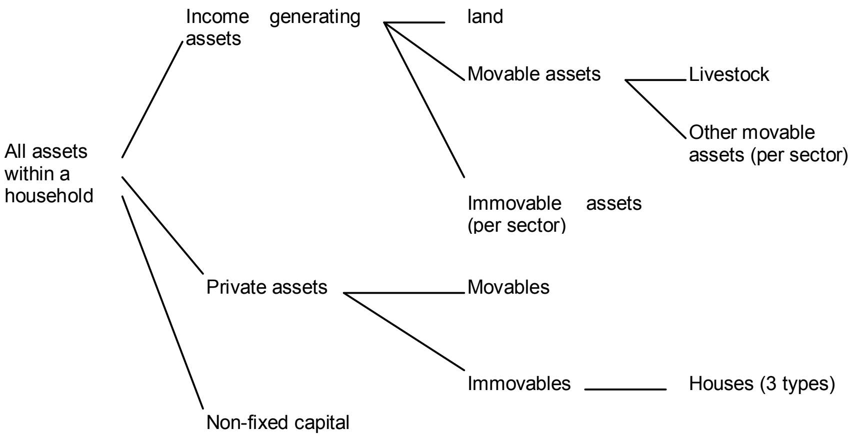

Figure 7 Distinction of different assets per household

The rural and urban income per household and by income class is generated from three sources, i.e. :

- from labour, based on the number of employed persons per household and wages by labour class (skilled or unskilled)
- from income generating assets: the distribution of sector profits by the ratio of income generation assets owned by the income class
- from non-fixed capital: the annual return on capital owned by the income class

The total income for the mandal is the summation of these income sources multiplied by the total number of households. Per capita income is the total income divided by the population number. Based on the income distribution across rural and urban income classes a Gini-coefficient is computed to express the degree of inequality between the income classes.

The Resource Demand and Waste generation Module (RWM) is a resource accounting model that calculates the use of water and energy resources, the transportation needs and pollution loads to the environmental compartments, based on the types and volumes of the human activities in the region (mandal). Typical measures that can be included in the model relate to the possibilities to change the volumes and locations of activities and technological measures to reduce specific demands and emissions (for example related to water and energy conservation, changes in production processes and waste treatment).

The demand of resources and the extent of waste loads are used in the Environmental Assessment Module (EAM) to estimate the impacts in terms of resource depletion and the state of the natural environment. Water and energy balances are made by confronting demands with known existing availability of these resources. A distinction is made between total resource availability in the region and the specific mandal availability and/or capacities to distribute the resource (for instance through the public water supply network or the electricity grid). The transportation balance is expressed in a ratio of a weighted total road transportation demand and road capacity, taking into account the various road types.

For the water-related compartments (soil/groundwater, surface water and coastal water) a computation is made of an annual change in the concentration of the relevant pollution types, taking into account the loads (output from the RWM) and annual degradation rates. The volumes and fluxes from one compartment to the other reflect a very rough description of the basic hydrological/hydraulic characteristics of the mandals. For the atmospheric compartment, the severity of the problems is expressed by computing a local atmospheric pollution density per mandal (annual pollution loads per m^2). The amount of solid waste to be dumped is expressed in an annually required area of dumping sites (taking into account the total annual volume to be dumped and an average dumping height).

The Cyclone Probability and severity Module (CPM) distinguishes both flood and wind hazard. The EDSS uses the output of the cyclone storm surge model (SSM) that was developed within the APCHM Project (Vatvani et al. 2002) to assess the flood hazard for each mandal. Based on a number of model simulations a 'representative' storm is derived that is used for the calculation of casualties, damages and vulnerability. For each mandal the output of the storm model simulations is aggregated into an average percentage of the mandal that is flooded with a representative inundation depth. For estimating the wind hazard we use the output from the Wind Hazard Model (WHM), which has been developed by IIT-Chennai within the APCHM Project (IIT-Chennai 2002). This model simulates the wind speeds of a cyclone per grid cell and uses several correction factors (for gust, terrain and duration) to produce a *damaging wind speed*. By using a number of simulations with the WHM for different cyclone events a representative storm condition can be constructed similar to the flood hazard.

The Cyclone Vulnerability Module (CVM) combines information from LUM, SAM and CPM and estimates vulnerability of people by calculating (expected) casualties and damages and using this for calculating the recovery factors. Because the asset values are disaggregated in those that are movable or not susceptible to loss (e.g. land) and those that are immovable (e.g. houses), a relatively accurate estimation is possible with respect to damage. For all assets except land and non-fixed capital, damage functions have been drafted that allows estimation of the potential damage as a function of inundation depth and wind speed. Care has been taken that no double counting takes place: what has been damaged by flood cannot be damaged by wind.

In the detailed calculations an evacuation rate is applied for capital assets which can be moved so as to reflect the reduction in damage by evacuation of (part of) these assets. Differences in susceptibility of crops and livestock are reflected in crops and livestock-type dependent, (relative) damage factors. Damages which would occur under the representative cyclone are summed and multiplied with the probability of the representative cyclone.

Recovery factors express the rate of recovery of losses after a period of one year following the representative storm taking place. Recovery factors are calculated for assets and income for each of the rural and urban income classes. These recovery factors follow from the comparison of available income generating assets, income and private assets before and one year after the storm, taking into account the effects of damages and the potential for asset recovery following from outside help (grants), available non-fixed capital, loans and savings (Figure 8).

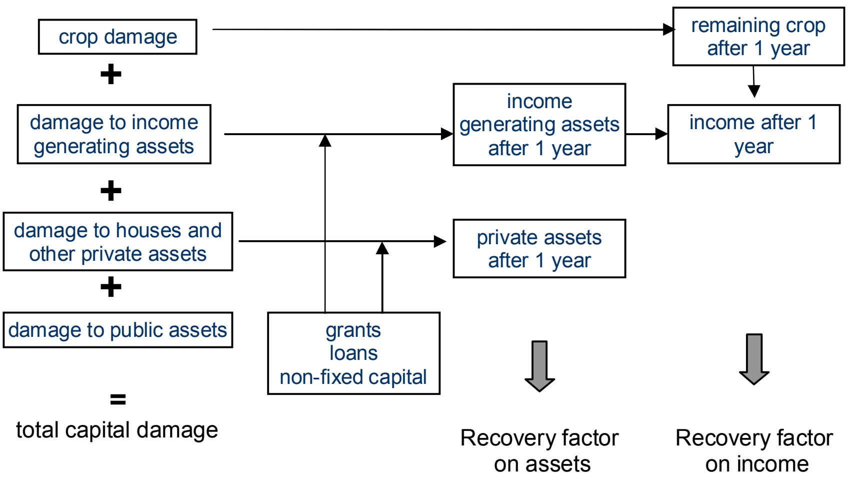

Figure 8 Overview of calculations for assessing recovery

Some of the computational steps are basically a repetition of computations in SAM but with modifications to account for the damages after the storm. For instance the remaining potential for agriculture income is equal to the total annual crop yield minus the crop damage. The actual yield realised depends on the available agriculture income generating assets (tools, equipment, barns, buildings) with the exclusion of land. Land itself will not be damaged. The yield realised therefore depends on the availability of the other agriculture income generating assets. The income to commerce/services after storm is taken as the minimum of two types of computations: (1) multiplier applied to the reduced incomes from agriculture and other production; and (2) the fraction expressing reduced availability of income generating assets in the commerce and services sector applied to the income in this sector before the storm.

2.3 Application of the EDSS for the Godavari Delta

2.3.1 Brief introduction to the Godavari Delta

Geography and climate

The Godavari Delta is the second largest delta in India and has a coastline of 150 km. The delta apex is located roughly at 16°58’N and 81°46’E, where the city of Rajahmundry can be found (Figure 9). The delta encompasses an area of 9,260 km^2 and includes a population of approx. 7 million people (2001). With a population density of over 500 people per square km, the region can be characterised as intensively utilised. Nearly every hectare of area is used in one way or another and there are very few areas that still have a relatively natural character. The economy is dominated by agricultural production although there are a number of urbanised centres with a diverse industry.

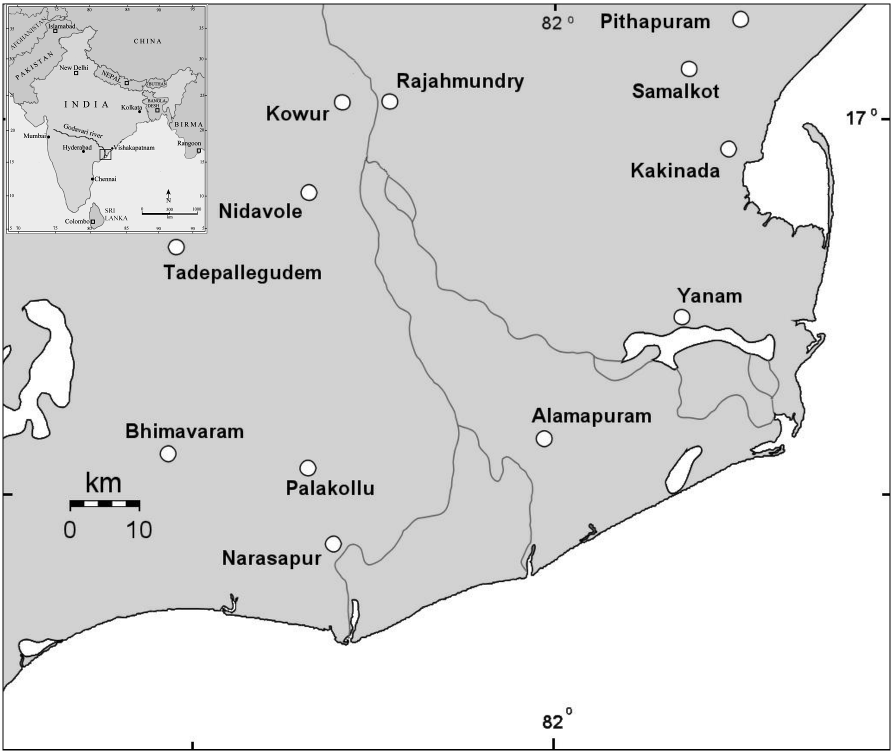

Figure 9 Map of the Godavari Delta

Generally, the climatic conditions can be characterised by a hot and dry summer period (February till June), the Southwest Monsoon season (from mid June to the end of September) and the winter season with the Northeast Monsoon (September-February). The relative humidity is generally high throughout the year in the coastal region and ranges between 60 to 80%. Annual rainfall is in the order of 1,000 to 1,100 mm. A very significant feature of the climatic pattern of the coastal areas is the proneness to cyclones and depressions, which develop in the Bay of Bengal.

Administratively, the Delta falls into two districts: East and West Godavari. The study area for which the DSS has been prepared includes a total of 75 *mandals* (administrative units one level below the district). Figure 10 shows the location of the mandals.

Land use

In the delta irrigated agriculture is the dominant land use. Paddy fields are lined with coconut and Borassus palms. Other forms of land use include coconut/banana plantations, sugar cane and aquaculture. The area under irrigation is known for its intensive agricultural development, complex water management issues and the relatively high income levels of their inhabitants. A constraint is that suitable land is abundantly available but is almost cropped to its full extent. Agricultural land covers more than 60% of the total available land in these areas; in about half the area it is even more than 80%. Available irrigation water currently sets the limit for agricultural production.

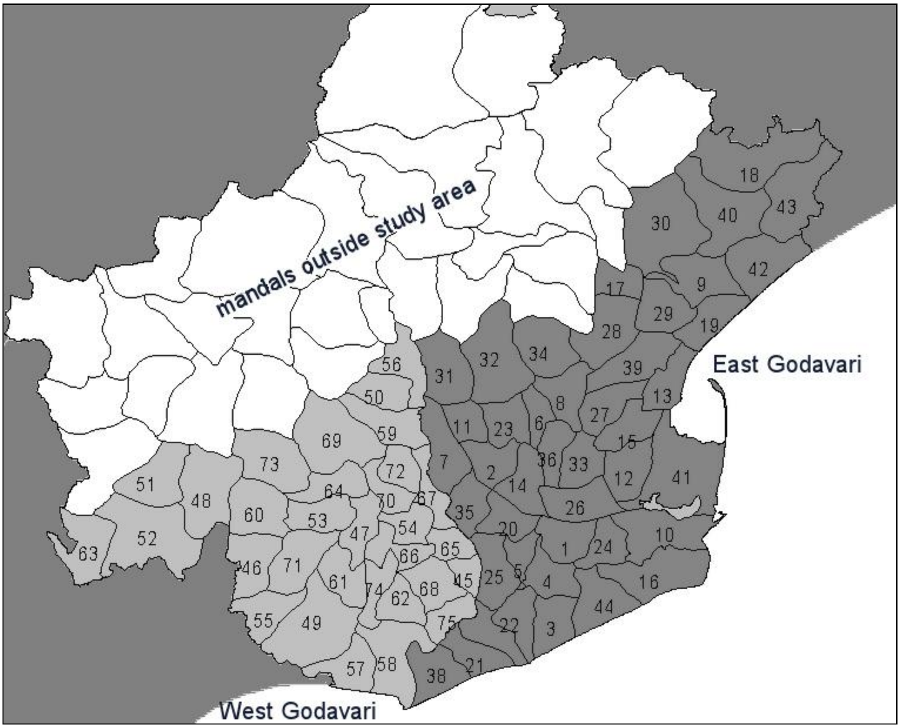

Figure 10 Map of the Godavari delta and location of mandals

East Godavari:1.Ainavilli; 2.Alamaru; 3.Allavaram; 4.Amalapuram; 5.Ambajipeta; 6.Anaparthy; 7.Atreyapuram; 8.Biccavolu; 9.Gollaprolu;10.I.Polavaram; 11.Kadiam; 12.Kajuluru; 13.Kakinada; 14.Kapileswarapuram; 15.Karapa; 16.Katrenikona; 17.Kirlampudi; 18.Kotananduru; 19.Kothapalle; 20.Kothapeta; 21.Malikipuram; 22.Mamidikuduru; 23.Mandapeta; 24.Mummidivaram; 25.P.Gannavaram; 26.Pamarru; 27.Pedapudi; 28.Peddapuram; 29.Pithapuram; 30.Prathipadu; 31.Rajahmundry ; 32.Rajanagaram; 33.Ramachandrapuram; 34.Rangampeta; 35.Ravulapalem; 36.Rayavaram; 37.Razole; 38.Sakhinetipalle; 39.Samalkota; 40.Sankhavaram; 41.Thallarevu; 42.Thondangi; 43.Tuni; 44.Uppalaguptam. **West Godavari:** 45.Achanta; 46.Akividu; 47.Attili; 48.Bhimadole; 49.Bhimavaram; 50.Chagallu; 51.Denduluru; 52.Eluru; 53.Ganapavaram; 54.Iragavaram; 55.Kalla; 56.Kovvur; 57.Mogalthuni; 58.Narasapuram; 59.Nidadavole; 60.Nidamarru; 61.Palacoderu; 62.Palacole; 63.Pedapadu; 64.Pentapadu; 65.Penugonda; 66.Penumantra; 67.Peravali; 68.Poduru; 69.Tadepalligudem; 70.Tanuku; 71.Undi; 72.Undrajavaram; 73.Unguturu; 74.Veeravasaram; 75.Yelamanchili

In contrast, the delta fringes and coastal plain has a quite different complexity because of the interaction with the marine environment. The result is a strip of land with varying width and a variety of terrain units: tidal flats and creek systems, lakes, lagoons, sand dunes, mangroves, sand bars. The common factor is the low lying position and thus hampered drainage, and the mainly saline or brackish surface – and ground water conditions.

A number of rather contrasting and partly conflicting land use types have established here: grazing, aquaculture, salt production, fishery, mangroves, and nature areas. Mangroves have almost completely been reduced by overexploitation although a substantial stand of about 23,000 ha still exists in the protected Coringa Forest south of Kakinada (Mohapatra & Bech 2001). Grazing land, having had its place in the upper and lower delta parts, has largely been replaced there by cropland while “being pushed" further into the more marginal areas (tidal flats and mangroves). Salt production has developed very gradually.

Aquaculture has most strongly developed during the latest decades, in different forms. Started as intensive brackish water shrimp farms with significantly negative environmental impact and meanwhile being banned, it has now become somewhat differentiated. Semi-intensive brackish water aquaculture appears a profitable activity in an otherwise non-productive area, but its establishment in a fresh water environment should still be prohibited. Fresh water aquaculture (fish ponds) has become increasingly competitive with irrigated cropland.

Water resources

Water of good quality is a limited resource in the Delta. Any further development can only occur with improved management of the available water resource. Important water resources are provided by the barrage constructed across the Godavari river. Groundwater in upland areas is fresh potable, while in coastal tracts it is often brackish. A major constraint in water management is the uneven availability of water throughout the year. There is dependence on the monsoon which brings overabundance of rainfall in certain months, while during non-monsoon season demand for irrigation, drinking and industrial water is high. Particularly for drinking water, the issue is very acute in command area coastal tracts during April-June, due to closure of canals (Villars et al. 2001).

Not only the *quantity* of water resources but also the preservation of water *quality* is an important concern, as many economic activities (such as industry, agriculture and brackish aquaculture) create negative impacts to the available water resources. Currently, integrated water management of surface and groundwater resources for multiple needs is lacking, and there is little interaction or co-operation between the many different agencies involved in water management (Villars et al. 2001).

Air pollution

Air pollution is of specific concern in the urban and industrial areas of the region. Large urbanised centres such as Rajahmundry and Eluru experience relatively high concentrations of pollutants mainly from traffic sources, which also poses problems to the noise environment (Padmanabhamurty 2001).

Energy resources

There is a large variety in energy sources used for different types of activities. Many households are still dependent on fuelwood, charcoal or cow dung for cooking, which poses a direct threat to the local and regional forest and tree reserves. Many economic activities are dependent on electrical power supply and are vulnerable to regular power failures. There are large gas reserves found in the Delta region, especially offshore, that are currently largely untapped. These reserves will become an important source of energy with relevance to the region as well as the State as a whole in the near future.

Biological resources and biodiversity

An important biological resource in the region is the fish stock, both from marine and freshwater origin. The current marine fishery shows signs of over-exploitation, particularly in the near-shore fishing grounds. Aquaculture is booming and considered to be a potential sustainable alternative to capture fishing provided that strict regulations are adhered to (this issue is further dealt with under land use management).

Areas of high biodiversity in the Delta are restricted to the remaining mangrove stands (notably the Coringa Forest Reserve near Kakinada) and the Kolleru Lake Protected Area. Furthermore the string of numerous tanks and reservoirs have some biodiversity relevance as feeding and nesting habitat for birds. Generally speaking the existing protected areas in the coastal zone are under extreme threat. They suffer from encroachment and unsustainable resource exploitation by local population. Management is inadequate to cope with the very high human pressure, and degradation of the resource base is on-going as can be witnessed in Kolleru Lake. Recently, conservation efforts with active participation of the local population have started in Coringa mangrove WS, which seem to achieve promising results (Mohapatra & Bech 2001).

Socio-economy

In the coastal mandals the principal occupation is agricultural cultivation. Approximately 5% of the population are “cultivators” (people whose main occupation is to cultivate their own land or hire people to do so) and approximately 20% are agricultural labourers (people whose main occupation is to work for others) whereas approximately 11% of the population are engaged in other occupations, including small/medium and large scale industries, commercial services and government services. Nearly 60% of the population consists of ‘non-workers’. Figure 11 presents an overview of the main occupations within the study area.

The rural economy is dominated by agricultural activities and agro-related industries, transport and commercial services. There are a number of urbanised areas where medium to large scale industries are concentrated. The largest urban centres are Rajahmundri (around 400,000 inhabitants), Kakinada (370,000) and Eluru (215,000).

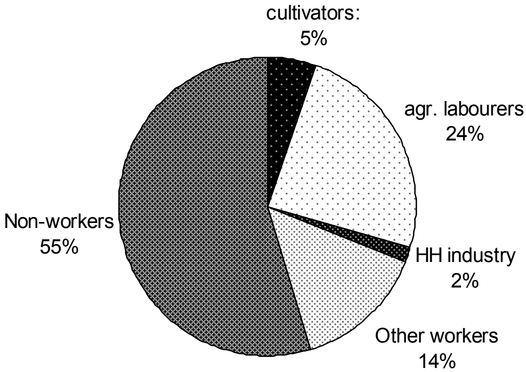

Figure 11 Distribution of the population according to occupation (cat. *Other workers* includes industry and commercial services) (source: Population Census, 2001)

Income distribution

There are large differences in income per household in the study area, which vary roughly between 20,000 and 400,000 Rs per annum. Table 6 shows the survey results of a selection of households in a number of study mandals in East and West Godavari. Based on this survey it can be observed that there is a marked difference in income distribution between the study mandals of the two districts (source: Pragna Consultants, 2003).

More than 60% the total population in the two districts is literate (Census 2001 data). For the literate, only a small percentage has followed higher education (between 10 to 25% in the rural and urban areas, respectively).

Table 6 Income distribution in surveyed households in study mandals of E. and W. Godavari

	Poor	Medium Low	Medium High	High
East Godavari				
lowest:	15,538	32,224	70,167	130,000
highest	95,917	343,484	757,370	1,008,750
Average	**45,084**	**129,930**	**285,634**	**446,056**
West Godavari				
lowest:	7,655	14,900	77,143	200,000
highest	45,499	65,400	250,000	622,000
Average	**17,829**	**34,246**	**136,875**	**337,258**

(source: survey Pragna Consultants, 2003)

Based on the census data[4] on roof and wall material a picture can be made of the housing types. Huts (10 to 20% of all houses) are made of grass, leaves etc. walls and can consist of all kinds of roof material, but mostly natural material like wood and reeds. 'Katcha' houses are defined as houses with mud, wood or unburnt brick walls or burn brick walls and grass, tiles or iron roofs (approx. 60 to 70 %). 'Pucca' houses are made of burnt brick, cement or other durable wall materials and durable roof material. The distribution of these house types provides an insight in the socio-economic situation and is also an important input to the possible damage to houses during a cyclone (Winchester 2001).

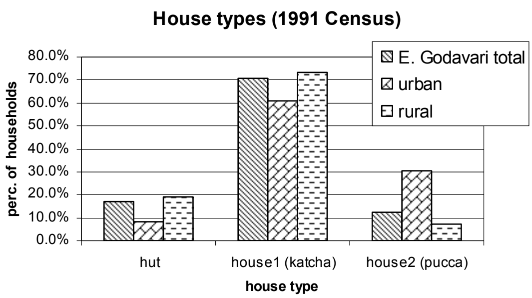

Figure 12 Percentage of different house types in E. Godavari

2.3.2 Input data

2.3.2.1 Land use data (LUM)

The EDSS uses land use data from the District Handbook of Statistics[5] for East Godavari and West Godavari, but with some modifications and remote sensing data from the National Remote Sensing Agency (NRSA). Mandal wise areas of crops sown and

[4] Unfortunately the Census 2001 does not contain data on house types. Hence the data of Census 1991 are used instead.

[5] Note: unless otherwise stated, the District Handbooks of Statistics that have been used are for East Godavari and West Godavari Districts for the year 2001.

cropping intensity (number of crops per year) are available on an annual basis from the Agricultural Department. Crop parameters such as yield, labour and non-labour inputs are estimates from annual crop budgets prepared by the Agricultural University Hyderabad and from literature (FAO Sourcebook). Mandal wise data on livestock numbers are taken from the District Handbook of Statistics. The data from the livestock performance are taken from animal husbandry budgets of the ISPA project (pers. comm. H. Op 't Veld), with a correction factor for the less performing husbandry level in most of the rural areas. Aquaculture performance is based mostly on expert judgements of the fisheries expert in the project (Singh 2001).

2.3.2.2 Socio-economic data (SAM)

Calculations of sector income and revenues related to land based activities (agriculture, aquaculture, livestock rearing) derive from intermediate variables and input from the LUM. The SAM adds up gross income, labour demand as well as labour and non-labour costs from each of the crops, livestock types and aquaculture crops grown in each of the mandals. For the industrial data the District Handbook on Statistics has been used, which provides for each mandal the number of small, medium and large factories and their number of workers. Parameters for gross output value and non-labour input is inferred from a summary of economic data for 14,000 factories in Andhra Pradesh. Based on the economic statistics of the Andhra Pradesh State for the year 1999-2000 a multiplier of 0.8 for the tertiary sector has been deduced.

A survey among all mandals in the Godavari study area provided insight in the monthly wages in different sectors and enterprises (Pragna Consultants 2003). It showed that skilled labour has wages that on average are twice as high than unskilled labour and that urban wages are usually higher than rural wages. Wages in the agricultural sector are usually lowest and are in the order of 40 Rs. per day. Because the EDSS only uses two wage values, one for unskilled and one for skilled labourers, the average wage should reflect the respective dominance of unskilled (agricultural) labour in the rural area and skilled labour in the urban area. Hence we take for the unskilled labour the rural average for agricultural labourers and for the skilled labour the urban average.

Rural and urban population data is provided in the District Handbooks of Statistics (2001). An average household size of 4.3 is used for all mandals, because no mandal-wise data are available. In order to assess the available labour supply and employment rate we need to know the labour rate per household for every income category and differentiated for rural and urban communities and for unskilled and skilled labour.

For the labour rate – i.e. the percentage of people per household that is available for labour data has been used for 2001 (Table 1.8 of District Handbook). A summary of this data is given in Table 7. This gives a labour rate of 36% for rural and 31.9 % for urban population.

Table 7 Summary statistics of labour in East Godavari (both rural and urban) for 2001

categories	Total population	total workers	cultivators	percentage workers (excl cultivators)
Rural mandals	4,004,344	1,658,570	21,5051	36.0%
Urban mandals:				
Kakinada	421,718	133,611	2,477	
Rajahmuhdry	446,560	147,585	1,961	
total urban:	868,278	281,246	4,438	31.9%

Source: District Handbook of Statistics – East Godavari (2001). Table 1.8

Unfortunately the 2001 Census does not provide detailed data on skills or education level. Therefore we have relied on the 1991 Census data that does provide this. These data show that approx. 90% and 75% of the rural and urban population, respectively, has a 'low education' level (i.e. up to primary school). We have interpreted this low education level as 'unskilled'. The data does not provide a split of education level over the income categories. We have assumed that generally poor people will have a lower education level than richer families. Hence, in the rural area the work force consists mainly of relatively poor, low educated (agricultural) workers, whereas in the urban areas the workforce consists of more higher educated people.

Reliable statistical data on income levels are hard to find. Therefore we use the land distribution data from Andhra Pradesh (Table 8) as a proxy for the percentages of the total population belonging to one of the four income categories in the rural area. For the urban population we have assumed that the percentage of medium high and rich people is higher than in the rural area.

Table 8 Percentage distribution of households and area operated by size class of operational holdings

	India		Andhra Pradesh	
	percent of households	percent of operated area	percent of households	percent of operated area
landless (0- .002 ha)	21.8	-	37.5	-
marginal (.002 – 1 ha)	48.3	15.5	36.9	17.5
small (1-2 ha)	14.2	18.6	13.3	23.0
semi-medium (2-4 ha)	9.7	24.2	8.4	26.5
medium (4-10 ha)	4.9	26.5	3.4	23.6
large (> 10 ha)	1.1	15.2	0.5	9.5

Source: 48th NSS land and livestock holdings survey, 1991-1992 (National Sample Survey Organisation. Department of Statistics. Government of India, 1997). (Turner 2004)

The distribution of assets among the four income classes is based on a more detailed distribution of assets based on 10 income classes. For these class deciles both annual income (equivalents) and asset values are inferred from the social survey (see Winchester 2001). Furthermore the assets are qualified into four major groups:

- Essentials
- Fixed income generating assets
- Moveable income generating assets
- Luxury assets

In Table 9 a description of the asset distribution is given over the income classes. For the EDSS model the following class deciles are grouped together:

poor = lowest + very low 1 + very low 2
medium = low 1 + low 2 +medium low 1 + medium low 2
medium high = medium + medium high
rich = high

Unit prices have been used to estimate the value of each asset category. The basis of estimation is the rural households. For the urban equivalents attention is given to the fact that land and livestock ownership is far lower and housing is usually better than in the rural areas.

Table 9 Asset distribution amongst 10 income classes in Andhra Pradesh

	Essential	Income generating assets		Luxury
Socio-economic classification by income equivalent		***Fixed*** *House type, land, others (e.g water pump), varying amounts of loan capital (unfixed asset)*	***Moveable*** *Livestock animals, chickens, livelihood equipment, carts, fishing nets, threshers, tractors, surplus food to sell, stock*	*Electrical goods, air conditioning, bicycle, moped, scooter, car, telephone*
Lowest (10%)	Cooking utensils	Hut	Nil	Nil
Very low 1 (10%)	" " (cot)	Hut	Chickens	Share in bicycle
Very Low 2 (10%)	" " (cot)	1 pole house, lease-hold shared cultivation	Share in livestock animal	Bicycle
Low 1 (10%)	Cooking utensils, cot, furniture	1 or 2 pole house, ½ - acre freehold	Livestock animal, share in equipment, share in cart	Bicycle
Low 2 (10%)	Cooking utensils, cots, furniture	1 or 2 pole house, ½ - 1.0 acres	Livestock animal, share in equipment, share in cart	Electrical goods, bicycle, moped
Medium low 1 (10%)	Cooking utensils cots, furniture	2 pole house, 1.0 – 2.0 acres freehold, loan capital	Livestock animals, equipment, share in cart	Electrical goods, bicycle, moped, scooter
Medium low 2 (10%)	Cooking utensils cots, furniture	2 pole house, 2.0 – 3.0 acres freehold, loan capital	Livestock animals, equipment, cart	Electrical goods, bicycle, moped, scooter
Medium (10%)	Cooking utensils, cots, bed furniture	2-truss house, 3.0 – 5.0 acres freehold, loan capital	Livestock animals, equipment, carts, surplus food to sell	Electrical goods, bicycle, moped, scooter, telephone
Medium high (10%)	Cooking utensils beds, furniture	2-4 truss house, 5.0 – 10.0 acres freehold, water pump, loan capital	Livestock animals, equipment, carts, share in tractor surplus food to sell, stock	Electrical goods, air conditioning, bicycles, mopeds, scooter(s)
High (10%)	Kitchen equipment, cooking utensils, beds, furniture	4 truss / *pucca*, 10 acres freehold, water pump(s), loan capital	Livestock animals, equipment, carts, thresher, tractor(s) surplus food to sell, stock	Electrical goods, air conditioning, bicycles, mopeds, scooters, telephone
Highest (benchmark)	Kitchen equipment, cooking utensils, air conditioning, beds, furniture	4 truss / pucca, 10 –25 acres freehold, water pumps, capital to lend	Livestock animals, equipment, carts, threshers, tractors surplus food to sell, stock	Electrical goods, air conditioning, telephones, bicycles, mopeds, scooters, cars

Source: Winchester 2001.

2.3.2.3 Data on resources and waste (RWM)

Water

Domestic water consumption is highly related to the general economic standard. In industrialised countries the consumption is in the order of 100 to 150 litres. In developing countries it is lower on average, but also depending on the income position and housing situation of the household. In India public water supply (PWS) design capacity is 40 litres per capita per day, which is used in the model for the medium income households**.** For the poorer and richer households the input values have been tuned somewhat lower and higher, respectively. Sources for drinking water are either PWS, groundwater or surface water. The District Handbooks provide statistical data of drinking facilities in villages, through which the percentages of use over the different sources have been estimated.

The water requirement of a crop depends on the type of crop, the length of the growing season, growth stages and climatic factors. These requirements can be met from sources such as irrigation water, rainfall, soil and groundwater contribution. The EDSS distinguishes a wet and dry season in order to estimate the dependency on irrigation throughout the year. The fraction of irrigation from groundwater resources has been calculated for each mandal based on the statistical data from the District Handbooks that give the net area irrigated by tube wells and filter points as well as the total irrigated area. Much information on water use by crops, aquaculture and livestock has also been made available through the Delta Water Management Study (Babtie International 2003). With respect to the water requirements of the secondary and tertiary sector no information is available, but it is probably very small compared to the irrigation requirements of the cropped area.

Energy

Energy requirements for households are typically very dependent on the relative wealth. For example, average household electricity consumption in the Netherlands is 3,500 kWh, whereas an additional 2,000 m^3 of natural gas is used. The bulk of the natural gas consumption in the Netherlands is used for heating of houses. In India energy consumption is mainly attributable to cooking requirements and electricity for household appliances and cooling (aircos). A large portion of this is provided by fuelwood. The annual average per capita demand for fuelwood in India amounts to 1 m^3. For the Godavari region energy for cooking in the rural areas largely comes from wood and charcoal. In 1991 this amounted to 86% for the rural areas and around 50% for urban households. Other energy sources include LPG, biogas and electricity. Wealthy people tend to prefer LPG as electricity is not much used due to its high costs. In the model a split of fractions is made over the various sources and income classes. It is hereby assumed that richer people will have a higher portion of their energy requirement coming from LPG and electricity than the poorer households.

The average energy consumption of the agricultural sector in India is comparatively small (around 5% of the total energy consumption). Mechanisation is at a relatively low level and typically include basic machines such as tractors and water pumps. Much work is still done by hand. An exception is the energy requirement for aquaculture, which is higher compared to agricultural crops which is mainly due to the intensive use of water pumps and aerations.

The use of energy in the industrial and commercial services sectors is expressed as energy units per produced value, also termed as energy intensity. The energy intensity for the whole of India is around 0.015 toe/1000Rs, and ranges from 0.003 toe for agriculture to 0.03 toe for the industrial sector[6]. Using the conversion from toe to kWh, this equals 385 kWh and 110 kWh per 1000 Rs. of gross sector produce of industry and commercial/services, respectively.

Transportation demands

Mobility data for different income classes has been estimated through expert judgements, assuming that poorer people do not travel large distances and mainly use public transport and two-wheelers. Transport requirements for the different economic sectors are crude estimations, because statistical data is lacking. For the agricultural sec-

[6] A toe is a tonne of oil equivalent and measures the energy contained in a metric ton (1000 kg) of crude oil and is equal to 10^7 kilocalories, 41.868 gigajoules, or 11,628 kilowatt-hours (kWh)

tor the following computation has been made. Consider the bulk of agricultural products to be rice. 100,000 tons of rice at a value of 5 Rs./kg resembles a value of 500 million Rs. In other words, per 1000 Rs of agricultural value this equals 0.20 tons. Suppose an average distance of transport is 10 km, the transport requirement for agriculture would be 10 km x 0.2 tons = 2.0 Ton-km per 1000 Rs. It is assumed that transport requirements for industry and commerce/services are higher and are estimated at 10 Ton-km per 1000 Rs. Transport requirements of goods for rural and urban population are set to 1 Ton-km per person.

Solid wastes

Data from the AP Pollution Board provide insight in the amount of garbage produced per capita per day in the main towns and cities in the Godavari Delta. In the rural areas probably much of the solid waste from households is used as compostable matter in agriculture. In the urban areas recycling of solid waste is probably less effective and most of it is transported and dumped in low-lying areas (Acharya 2001). Solid waste from aquaculture is a special case. Between crops, the ponds are completely emptied and the bottom sediments (sludge) is removed. This can yield up to 300 m^3 of solid waste per hectare per year (pers.comm. Baderinath 2001). This sludge contains a lot of organic matter and leftover nutrients, and possibly molybdenum used to increase productivity. The sludge can also contaminate soil and groundwater (Villars et al. 2001).

Information regarding the generation of solid waste from the industrial and commercial sector is scattered. The industries in coastal Andhra Pradesh generate various types of industrial solid wastes and hazardous wastes. In West Godavari alone some 158 tonnes of hazardous waste is generated each month (Acharya 2001).

Water pollutants

Currently the model only calculates the nitrogen load to the environment. Average emission for humans is 14 g N per capita per day (5,1 kg/year). There is very little treatment of domestic wastewater in coastal area of Andhra Pradesh. Visakhapatnam Municipal Corporation is constructing a 25 million litres per day sewage treatment plant. Vijayawada City has a treatment plant that is functional for 25% of the population. A new treatment plant to cover 60% of the population is planned. For the remainder of the population, domestic wastewater is discharged locally to surface water or infiltrates to groundwater.

In agricultural systems the main factor determining the pollution of nitrogen is the application of fertiliser. Ideally the fertiliser should be taken up by the plants completely, because all excess fertiliser gift that is not utilised is an economic loss to the farmer. Worldwide the nitrogen use efficiency is around 33%, which means that 67 % is wasted. Most of this loss goes to the atmosphere and losses to the soil and water range between 1 and 13%, but can exceed 40% (Raun & Johnson 1999). We have taken an average of 15% of crop fertiliser use that is lost to the soil and groundwater. Pollution from aquaculture ponds differ from the crop type. Freshwater fish ponds tend to have relatively low pollution levels. For brackish water shrimp more pollution problems are apparent, depending on the intensity of the culture. The resulting emission of nitrogen into the effluent is not known, and is tentatively estimated at 10 kg/ha. Treatment facilities are usually absent.

Emission coefficients of nitrogen into the soil and groundwater for livestock are estimated, using the human emissions as a reference. Larger body weight of animals such as cattle and buffaloes will give larger emissions, while poultry has a much smaller body weight and thus smaller emissions.

Accurate data on emissions and treatment facilities of industries and the tertiary sector are lacking. Parameter values are best guesses. The treatment efficiency for wastewater treatment plants is unknown. An efficiency rate of 0.2 is assumed.

Air pollutants
The major pollutant of concern in cities in India, based on ambient concentrations recorded to date and known health effects is suspended particulate matter (SPM) (TERI 2001). Of these the respirable parts RSPM(< 10 μm) are the most dangerous for health and typically make up 30% of total SPM. Therefore the EDSS calculates emissions for this polluting component. Sampling of urban centres in coastal Andhra Pradesh in 2001 revealed that in 70% of the locations SPM and RSPM levels were exceeding the standards (Padmanabhamurty 2001). Major contributors to SPM are the transport and commercial sectors. However, when focusing on RSPM a potentially high source is the burning of household waste and wood. Emission factors for transport (different vehicle types), fossil fuels and wood have been used from literature (TERI 2001).

2.3.2.4 Environmental data (EAM)

Water supply
Domestic water is supplied by three different sources: surface water, groundwater and piped water supply schemes. The Public Water Supply (PWS) in Andhra Pradesh is undertaken by the Rural Water Supply Department of the Panchayat Ray organisation, that provides statistical information regarding the coverage of PWS for each mandal. For 2002 around 25% of the habitations in the Godavari had access to PWS.

The two main sources of surface water in the Godavari delta are local rainfall and river discharges. Although the total annual river volume is large enough to fully meet the irrigation requirements, its discharge is unevenly distributed and there is insufficient storage capacity. Hence, on average a total volume of 85,400 million m^3 of Godavari water is not utilised annually and this surplus flows to the sea. Study A has calculated that for the wet and dry season a river volume of 7,840 and 6,160 million m^3 is available, respectively (Babtie International 2003). Local rainfall is not included in the total available volume of surface water. Indirectly it does play a role, as it adds to the recharge of tanks in the wet season. But this effect is not quantified.

With respect to the irrigation water supply, much data and information was available from the Delta model that was developed by Study A (Babtie International 2003). This model calculates crop water demands over periods of two weeks throughout the year, depending on water supplies through canals and rainfall, water consumption and water losses, for each Water Users Association (WUA) in the AP delta areas (one mandal may have one or several WUA). The number of periods during which deficiencies were experienced, vary from one WUA to another but are highest at the tail ends of the irrigation system. For the purpose of the EDSS, canal length per mandal was calculated and each mandal was given a ranking for irrigation water deficiency, according to the average number of shortage periods experienced by WUAs in this mandal.

Groundwater in the Godavari Delta command area is recharged via rainfall and seepage from the river, irrigation canals and drains traversing through the delta. The annual groundwater recharge is assessed to be 1238 million m^3, compared to an annual draft of 381 million m^3, leaving a surplus of 858 million m^3 un-exploited groundwater (Babtie International 2003). Mandal wise data on utilizable groundwater is available from the Groundwater Department (GoAP 1999). At least 16 mandals have no fresh groundwater reserves because the water is saline.

Energy supply

For the supply of fuelwood, use has been made of figures for sustainable harvesting of forests, communal lands and tree plantations (Mohapatra & Bech 2001). The electricity capacity of a mandal depends on the extend and capacity of the local electricity grid and on the total regionally installed electricity capacity. Mandal wise data of the total connected load and total installed capacity and power generation is available in the District Handbook of Statistics.

Transportation capacity

The District Handbooks of Statistics provide numbers of different persons transport types, which show that transport is dominated by motor cycles, scooters and mopeds (300,000 for East Godavari) and that cars and jeeps play a minor role only (around 8,000 cars in East Godavari). For the transport of goods, the statistics show a dominance of tractors and small vans. Data on road length (various types) are provided at mandal level from the GIS layers in the AP State Disaster Management Society. Weight factors have been used to distinguish the demand that different vehicle types put on the roads (for instance two-wheelers occupy less space than a bus or a large truck). Also weight factors are used for the different capacities the road types have.

Quality of the environmental compartments

For estimating the quality of the surface and groundwater a quantification of volumes of soil, groundwater and surface water is required at mandal level. Also an estimation of fluxes from the soil/groundwater compartment to the surface water compartment and from the surface water compartment to the coastal waters is needed. For the volume of soil/groundwater a simplified schematisation has been used, that assumes a uniform soil layer of 3 metre depth consisting for 30% of pore water. Similarly, for the surface water volume it was assumed that on 10% of each mandal area is surface water with an average depth of 4m. However, the EDSS allows for mandal specific adjustments of these variables. A residence time of 200 days is estimated for the groundwater compartment and 108 days for the surface water compartment.

The EDSS models nitrate as the principal component of water pollution. Its degradation is dependent on the denitrification process, which occurs primarily under anaerobic conditions. The highest denitrification rates can be found in environments with alternating water tables, such as wetlands. The values for the rates used in the model are rough assumptions.

Critical values for water quality can be taken from official quality standards. The Central Pollution Control Board has classified the inland surface waters into 5 categories - A to E on the basis of the best possible use of the water. The classification has been made in such a manner that the water quality requirement becomes progressively lower from class A to class E. For surface waters with the specific use to be treated for public water supply and for bathing Ghats, there is Standard IS:2296-1974 which prescribes the water quality tolerance limits. With respect to nitrates the tolerance limit is 11.3 mg N per litre maximum (Villars et al. 2001), which is the same as used by the EU-Nitrate guideline. We have adopted in the EDSS for surface water a critical concentration of 5 mg/l and assumed a lower threshold for groundwater (3 mg/l) in view of the fact that groundwater is often used for drinking water. For coastal waters a critical level of 2 mg/l has been taken, although the actual impact of nitrate on the marine ecosystems is dependent on the N:P ratio rather than the absolute concentration.

For the air quality no specific input parameters are needed other than the total area of a mandal, because only a simple atmospheric pollution density is calculated (the load of RSPM per m^2).

2.3.2.5 Data on flood probability and severity (part of CPM)

Because the modelling of flooding and wind are different from each other, I will discuss the data requirement for each of them separately.

In order to calculate the flood risk both the probability is needed and the severity. The flood risk is given by the flood probability times the consequences. Hence this is a theoretical expression indicating both the chance of a certain flooding and its impact. In the Godavari Delta there is a wide range of potential storms, each with a different severity and landfall position. In other words, there is not one risk, but there are many. There is a large chance of storm depressions of low severity and there is a small chance of severe cyclonic storms. In order to encapsulate all possible events, a large number of potential situations should be calculated, which is not feasible. Therefore a choice has been made to make use of the November 1996 cyclone, of which the dramatic impact is well known. This makes calibration of the model possible. In order to derive a representative picture of the possible impact should this storm have made landfall at all possible points along the Delta, six simulations have been simulated with the Storm Surge Model, using the Nov. 1996 cyclone as basis. For each storm the actual storm track has been shifted so that the entire Godavari Delta was covered (see Figure 13). The first storm simulation (EG1) used a track having landfall at the southern most point of the district. With the help of this track the other tracks having land fall at a distance of every 20/ 30 km were generated and the runs are repeated, while making minor adjustments at the landfall point wherever necessary. The other tracks have been generated by incrementing the latitude by 0.2 or 0.3.

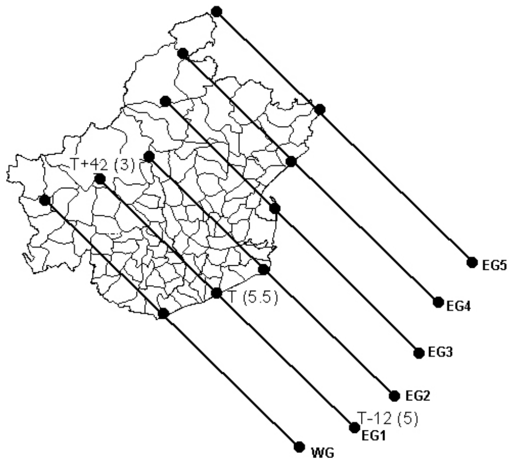

Figure 13 Principle of replacing the cyclone tracks using the Kakinada 1996 cyclone (EG2) as basis **(T -12 means 12 hours before landfall, values in brackets indicates cyclone strength).**

The output of each run of the Storm Surge Model consists of maximum inundation level for each calculation grid. Eventually the output per grid cell and per storm simulation has been aggregated into two variables per mandal: average percentage inundation *AreaP* and *FloodClass*. *AreaP* is the average of the areas that are inundated for each storm run. The *FloodClass* parameter is based on inundation depths intervals ranging from < 5m to > 2m with intervals of 0.5 m and is a weighted average of the inundation depth per storm. This implies that an inundation with a certain depth has more weight when the inundation area is larger.

For the flood probability the estimation of the chance of occurrence of the 1996 Kakinada cyclone has been used as proxy, i.e. once in 50 years. Because the inundation for each of the 6 storms is aggregated to one percentage, it is adequate to use 1/50 for the chance of this aggregated flood impact.

2.3.2.6 Data on flooding vulnerability (part of CVM)

For the computation of the damages and casualties the model requires input on the evacuation rate of people and movable assets, the susceptibility of assets to damage and casualty rate as a function of inundation depth.

The evacuation rate for people has been estimated using the following variables:
- Warning efficiency
- Evacuation efficiency
- Existence of cyclone shelters

The success of an evacuation depends on many factors. First of all people have to be warned and ordered to evacuate. This determines the percentage of people that actually receive the message. Even if this percentage 100 %, not all people will be able or willing to get out of the area. There can be many reasons for this, such as the unwillingness to leave their belongings or the physical inability to leave. This is expressed in the evacuation efficiency factor. For all those people who for one reason or another have not left the area, their last option is to find a cyclone shelter. The evacuation rate can be specified for each mandal.

The evacuation rate of movable assets highly depends on the accessibility of the road system during a cyclonic storm. Non-metalled roads quickly become inaccessible because of the heavy rainfall. Many coastal villages only have one or two village roads leading to another village more inland and are often only dirt roads. Therefore the percentage of metalled roads in a mandal has been used as a proxy for the quality of infrastructure on which the evacuation depends. But even if 100% of the roads are in perfect condition and metalled, people will of course not be able to move all their movable assets to a safer place. Therefore, a maximum evacuation rate of 0.5 has been used. Since there is no information that indicates a difference between the evacuation of urban movable assets, livestock, income generating assets and movable public assets from rural movable assets, the evacuation rates are considered identical. However, the EDSS input file structure does allow for mandal specific differentiation between these evacuation rates.

Casualty rates depend on a large number of factors. In the case of the EDSS the only parameter that can be used is inundation depth, expressed as Flood Severity Class. A simple non-linear relation has been assumed with a maximum rate of 10% for depths above 2m (see Figure 14).

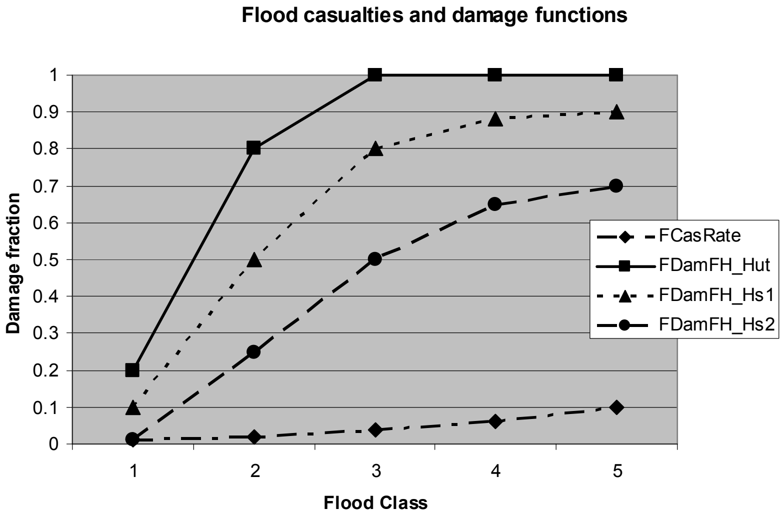

Figure 14 Flood casualties and damage functions

Damage from flooding depends on both inundation depth and water velocity. In fact, complete destruction of houses is likely when velocities exceed a critical value. Walls made of brick have a critical velocity around 1 to 2 m/s, whereas for RCC walls the critical value is around 6 to 8 m/s (Vrisou van Eck & Kok 2001). Because the CPM does not include water velocity data, the damage function cannot include this parameter. However, it can be assumed that higher flood depths also imply higher flow velocities. Therefore, the damage will rapidly rise with higher flood depths. A significant difference in flood susceptibility is assumed between thatched mud walled huts and houses from brick or concrete walls (house1, house2) (Figure 14). For the flood damage to other immovable assets (public buildings etc.) the same damage factor has been used as for house type 2. Flood damage factors for movable public assets and private assets other than houses, as well as for livestock, aquaculture and agricultural crops have been estimated roughly. Empirical data from the November 1996 cyclone has been used for calibrating the damage functions (see also section 2.4).

2.3.2.7 Data on wind hazard (part of CPM)

The Wind Hazard Model (IIT-Chennai 2002) uses 18 wind severity classes – ranging from 0-4 m/s (class 1) up to > 85 m/s for class 18 – for the calculation of damages of a specific cyclone. Figure 15 shows the spatial distribution of the wind severity of the November 1996 cyclone, for which the model has been calibrated. For the *representative* cyclone, however, another approach has to be used. In terms of probability, the Nov. 1996 storm could have made landfall at any point along the Godavari Delta. For the flood probability module, this has been modelled by running the storm field along 6 different tracks (see Figure 13) and averaging the mandal-wise inundation percentage and inundation depth. For wind this is not really possible, because there is no percentage of area affected by wind. Instead, the actual wind field of the November 1996 storm has been translated in percentages per wind class for 3 zones. These Wind Hazard Zones are roughly defined as follows (see Figure 16):

- Wind Hazard Zone 1: all mandals located along the coast

- Wind Hazard Zone 2: roughly three rows of mandals located behind the coastal mandals
- Wind Hazard Zone 3: mandals located further inland

When comparing the wind severity distribution of the Nov. 1996 cyclone, as illustrated in Figure 15, it can be seen that in Zone 1 closest to the coast all mandals experience a wind severity of at least 7 and the highest severity is 13. The area-wise distribution of the wind severity classes as pictured in Figure 15 has been used as a proxi for the probability. The probability of occurrence for all wind severity classes has thus been estimated for each of the three zones (see Table 10).

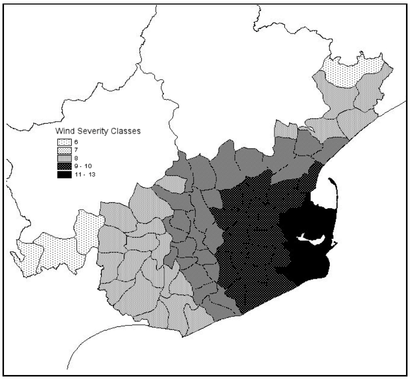

Figure 15 Wind Severity Classes for the Nov. 1996 Cyclone

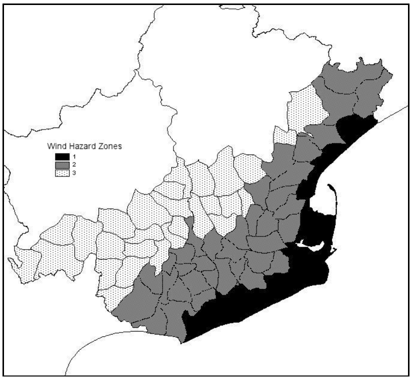

Figure 16 Wind Hazard Zones

Table 10 Estimated probability of occurrence of wind severity classes (WSC) per zone

Zone 1		Zone 2		Zone 3	
WSC	%	WSC	%	WSC	%
7	16	7	40	6	20
8	25	8	40	7	40
9	25	9	20	8	40
10	10				
11	8				
12	8				
13	8				

2.4 Calibration of the DSS

2.4.1 Calibration of the Socio-economic Assessment Module (SAM)

Andhra Pradesh is one of the agriculturally rich and food grains surplus states of India and it makes its surplus rice available for consumption in other states. The main crops of the state are paddy, millets, sugarcane and tobacco. Pulses of all kinds are also widely sown in the state. About 70% of the workforce in the state is dependent on agriculture and more than a third of the state's gross domestic product is derived from agriculture. The industries in the large scale sector consist of sugar mills, spinning and textile mills, electrical, paper and cement manufacturing units. In the small scale sector there are pesticides and insecticides production, engineering workshops, automobile units and repairs, chemical industries, utensils manufacturing, wooden furniture, electrical items, cotton ginning and edible oil etc.

This broad picture of the macro-economy of Andhra Pradesh is considered equally relevant for the description of the Godavari Delta. It has therefore been assumed that statistical data at state level can be compared with data from our study area using a factor 11, because the population ratio between AP and the study area is also a factor of 11 (approx. 77 million versus 7 million). The output values for calibration are: i)value and ratio of gross sector products; ii) per capita income; iii) Gini coefficient; iv) employment rates and v) poverty levels. The calibration parameters are: i) labour days per year; ii) commercial sector non-labour requirements; iii) commercial sector labour requirements and iv) industrial sector non-labour requirements.

Value and ratio of gross domestic products

Using the State statistical data as a proxy, the study area GDP for 2001 would have been in the order of 12,648 Crores[7] Rs. (see Table 11). In comparison, the GDP for East and West Godavari for the same period was 9,722 and 8,337 Crores Rs, respectively. Because the study area is somewhat smaller than East and West Godavari together, we have to use a correction factor based on population ratio:

Total study area population / (total population E.+W. G.) = 7.094 / 8.697 = 0.816

Total GDP E.+ W. Godavari = 18,059 Crores Rs.

Study Area equivalent: 18,059 x 0.816 = 14,736 Crores Rs.

Per capita income

As can be seen in Table 11 the per capita income compares reasonably well with the official statistics.

Gini coefficient

The Gini coefficient calculated by the model is somewhat higher than the all India average. Specific data for Andhra Pradesh is not available for comparison.

Employment rate

As can be seen in Table 11 the employment rate compares reasonably well with the official statistics. The number of people working in the secondary sector is calculated to be 61,700 for unskilled employees and 46, 343 for skilled, in total roughly 100,000 employees. This compares reasonably well with the statistics (see Table 13).In the commercial and services sector these numbers are 1,140,589 and 256,635 for unskilled and skilled employees, respectively.

Poverty level

Calculated income per rural poor households (Basecase 2001) is 26,171Rs. This applies for 36% of the rural population in the model. The official estimates from the Government of India show low rural poverty in Andhra Pradesh (15.9%). Other estimates of rural poverty incidence suggest a significant higher head count ratio in rural Andhra Pradesh. In a study on prices and poverty in India, Deaton (1999) estimates unit prices for different states for the year 1987-88 and 1993-94. Deaton estimates suggest that the rural poverty line for Andhra Pradesh is more or less similar to all India. According to his estimates, rural poverty ratio for Andhra Pradesh ranges from 29 to 33% in 1993-94. (Mahendra Dev & Padmanabha Rao 2002).

[7] 1 Crore is 10,000,000

Table 11 Key macro-economic data compared with EDSS results (Basecase2001)

Parameter	statistical data for 2001	EDSS Results
Gross sector product ratio:		
Primary:Secondary:Tertiary	33:22:45	31:24:44
GDP of AP per sector:	in Rs. Crores	in Rs. Crores
Primary (agriculture)	46,461 (4,223)*	4,120
Secondary (Other Production)	29,871 (2,715)	3,089
Tertiary (Commercial/Services)	62,805 (5,709)	5,768
Total GDP:	139,137 (12,648)	12,977
Total NDP:	125,877 (11,443)	10,253
Per capita income	16,562 Rs.	14,453 Rs.
Gini Coefficient	Rural average: 0.29 Urban average: 0.35 (all India)**	0.39
Employment rate	88% ***	95 %

* in brackets the study area equivalent is given by dividing the state values by 11
** (Jha, 2000)
***Ramaswami and Wadha, 2006

Table 12 Characteristics of sector production(EDSS Basecase 2001) (Rs. Crores)

Sector	Gross Income	Labour Costs	Non labour Costs	Net Profit	Margin
Agriculture	4,120	1,107	1,263	1,750	42%
Other Production	3,089	299	1,236	1,554	50%
Commercial/Services	5,768	2,690	923	2,155	37%
Total	12,977	4,096	3,422	5,459	42%

Table 13 Employment in industry (male and female)(2000-2001)

Industry type	number of workers
Small scale industry (East Godavari):	9,851
Large and medum scale industries (East Godavari):	12,538
Working factories registrered under the factories act (E. Godavari):	41,880
Id. West Godavari:	23,531
Total	87,800

The official poverty line in Rs. per capita per month for rural Andhra Pradesh for the year1999-2000 is 262 Rs. Using 4.5 people per household this comes to an annual househould income of 14,148 Rs. The revised poverty line from Deaton, 2002(cited in (Lanjouw et al. 2003)) is 3,708 Rs per capita per year, which equals a household income of 16,686. Both figures are lower than the income of the poorest 36% of the population in the model. Considering the uncertainty of percentage of people living under the poverty line, the difference between reality and model is acceptable.

2.4.2 Calibration of the Environmental Assessment Module (EAM)

Resource balances and deficits

Calibration of the environmental assessment module with regard to the resources was geared towards obtaining a balance between current demands and supply in the basecase situation. In principle the current situation should not show significant deficiencies except for those resources that are overexploited. Unfortunately, observational data on resource use per mandal is lacking, so that the calibration remains largely a theoretical exercise.

The basecase shows mixed results with respect to the resource balances and deficits (Table 14). Public water supply, surface water supply in the dry season and electricity are in balance with demands. Significant deficits are apparent in dry season with respect to the surface water (minus 20%). Mandals with water deficits are typically located at the tail end of the irrigation system, which pattern seems to fit local experiences with difficulties in getting fresh water (Figure 17).

Particularly high is the deficit in groundwater: minus 40.9%. This is mainly due to the fact that in mandals where the groundwater is saline (according to the GWD of Andhra Pradesh) the amount of utilisable groundwater is set to zero in the model. However, other statistical data indicate areas that are irrigated by tube wells. Therefore a large number of mandals along the coast face a shortage (see Figure 18). It may be that in mandals where groundwater is saline some irrigation could still be possible, but this is certainly not a sustainable situation. Salinity will become a larger problem in the future, which means that in these coastal mandals solutions need to be found to become independent of groundwater.

Table 14 Resources and deficits results (Basecase2001)

Resource	deficit (%)
Public Water Supply	-2.3
Surface water (wet season)	-2.8
Surface water (dry season)	-20.4
Surface water total	-13.3
Groundwater	-40.9
Electricity	-1.8
Fuelwood	-77.2

Some mandals located in the upstream part of the delta also have serious groundwater shortages. This is not because of a salinity problem, but because the calculated groundwater demands exceed the utilisable resource, and therefore the safe yield. For instance, the GW demand of Tadepalligudem is calculated as 146 MCM, whereas the safe yield is said to be only 45,5 MCM. There could be errors in the data input, but statistical data suggest at least 10,000 hectares of crops which are irrigated by tube wells (Table 5.5 District Handbook West Godavari).

The basecase also shows a serious fuelwood shortage of 77%. An explanation of this huge deficit could be that most of the fuelwood used for cooking in the rural areas is imported from outside the delta area. Only two mandals have no shortages (Rajanagaram and Prathipadu), while Thallarevu has a shortage of only 8%. This correlates positively with the amount of forests and plantations in these mandals: Rajanagaram has the highest hectares of plantations (over 9,000 ha), Prathipadu has the highest extent of upland forest (over 8,900 ha) and Thallarevu has the largest mangrove forest in its boundaries (over 8,900 ha).

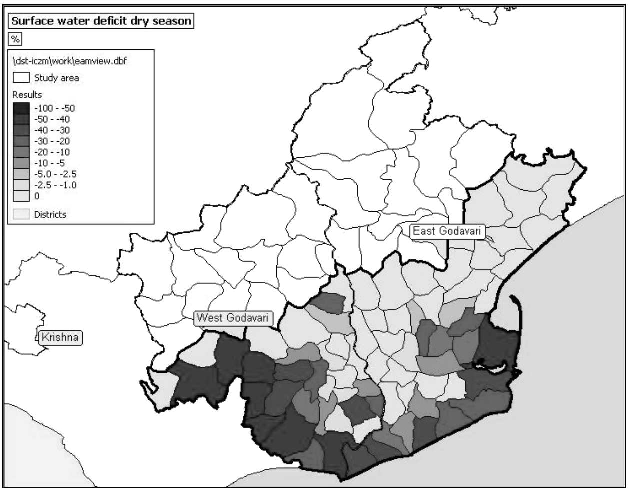

Figure 17 Dry season surface water deficits for the Godavari Delta (Basecase 2001)

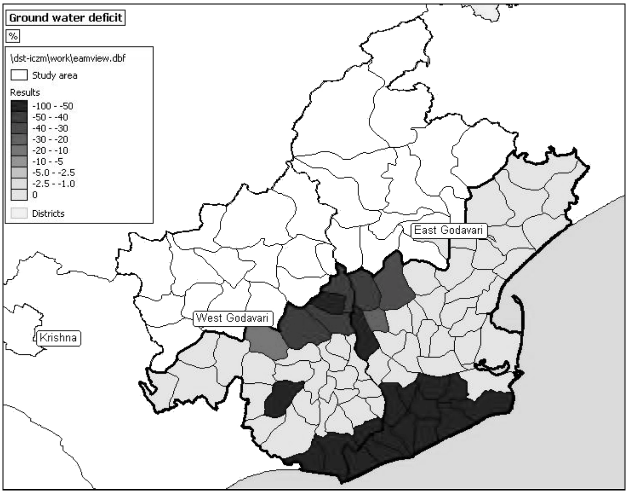

Figure 18 Ground-water deficit for the Godavari Delta (Basecase 2001)

The ratio of equivalent vehicle-km/hour and equivalent road-km reflects an annual average measure for the intensity/capacity ratio of the entire mandal road network The average road intensity/capacity ratio for the Delta is around 50, but varies significantly between mandals, the highest being Kakinada with an IC ratio of 988. Rural mandals have a ratio in the order of 10 to 20. An IC ratio denotes the number of vehicles per lane per hour. In developed countries an average capacity is 2000 vehicles per hour, above this number serious congestion can be expected. As the IC ratio calculated in the EDSS is an annual average, it could well be possible that at certain periods (e.g. at rush hour) the actual intensity is much higher. No observational data ara available to compare against the model outcome, but the general picture seems not unrealistic.

Quality of the environment

Accurate data on the present quality of the environmental compartments water, air and soil are lacking. Therefore, the calibration has been focused on the production of a baseline environmental situation that in broad lines complies to the general understanding, which is that the Godavari Delta has a reasonably healthy environment, but with significant signs of increasing stress. Critical issues include water pollution with agrochemicals, air pollution around hot spots in urban centres and ineffective solid waste management.

With respect to water quality, the calculations for total nitrogen show overall concentrations slightly above the chosen critical levels (Table 15). The maps for surface and groundwater (Figure 19 and Figure 20) show the variation in classes. Clearly visible are the hot spots for surface water pollution in urban centres such as Kakinada and Rajamundry. For groundwater the majority of the problem areas are situated in the centre of the delta, where the agricultural activities are highest.

Table 15 Quality of the environmental compartments (Basecase 2001)

Environmental parameter	Critical concentration	Basecase model results
equilibrium concentration of surface water for total Nitrogen	5 mg/l	8.7 mg/l
equilibrium concentration of groundwater for total Nitrogen	3 mg/l	5.1 mg/l
equilibrium concentration of coastal water for total Nitrogen	2 mg/l	3.6 mg/l
atmospheric pollution density for RSPM	--	21.3 kg/ha
total area of solid waste dumpsites	--	514 ha

For the atmospheric pollution, model results cannot be compared with critical levels, because no concentrations are calculated. The geographical variation in pollution density shows a clear correlation with the urban centres of the Godavari Delta (Figure 21). Also for the area of dump sites no critical levels are at hand. Here the map shows a high concentration of solid waste in the mandals with aquaculture, as well as in the two heaviest urbanised mandals Kakinada and Rajahmundry (Figure 22).

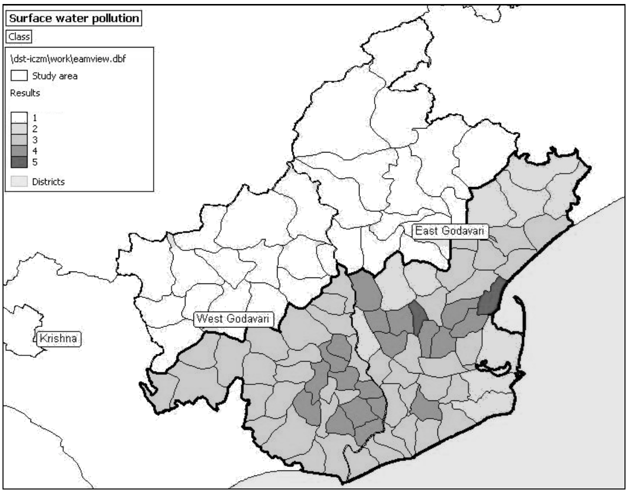

Figure 19 Surface water pollution classes for the Godavari Delta (Basecase 2001)

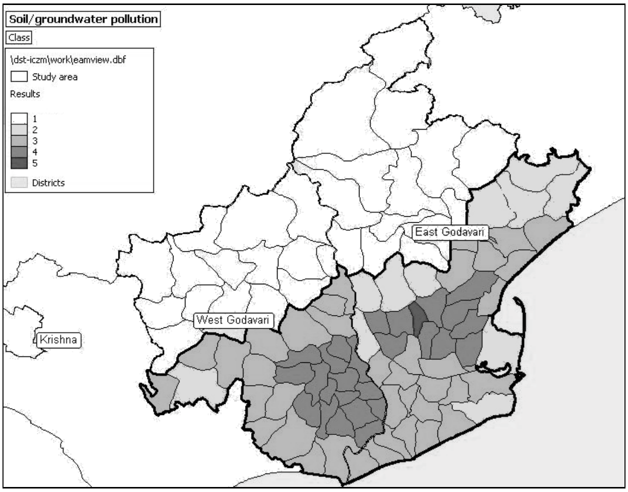

Figure 20 Groundwater pollution classes for the Godavari Delta (Basecase 2001)

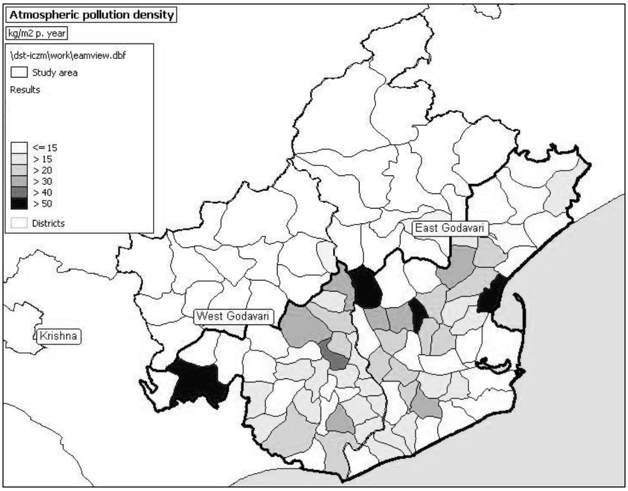

Figure 21 Amospheric pollution density (kg/m2 per year) for the Godavari Delta (Basecase 2001)

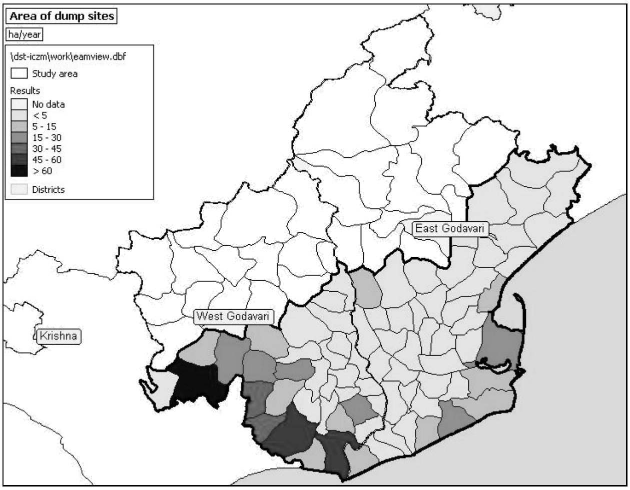

Figure 22 Area of dumpsites (ha) for the Godavari Delta (Basecase 2001)

2.4.3 Calibration of the Cyclone Vulnerability Module (CVM)

Casualties and damages

The Cyclone Vulnerability Module has been calibrated with data from the November 1996 cyclone (‘*cyclone 07B*’). The cyclone landed in November 1996 near Kakinada and resulted in a tragic loss of over 1000 lives, 44 billion Rs (around 880 million US$) of crop losses and 6 billion Rs (120 million US$) of damage in the housing sector. This damage equals around one third of the Gross Domestic Product of the Delta. As the recurrence period of this severe cyclone is around 50 years, this represents an annual economic risk of around 1 billion Rs, i.e. 0.5% of the annual GDP for the Delta.

We used the registered casualties and damages that were recorded per mandal for East Godavari by the Office of the District Collector in Kakinada and for West Godavari by the Office of the District Collector in Eluru. As calibration parameters we used the casualties and damage factors. A summary of casualties and damages is presented in Table 16.

The map of Figure 23 shows the madal-wise distribution of confirmed deaths. On the map of Figure 24 the distribution of casualties as calculated by the model is given. The model calculates over 1,698 casualties, which is higher than the official death toll of 1,076 (although there were also 1,683 people missing). There are also some substantial differences in the spatial pattern. For instance, the model calculates lower number of deaths than actually happened in the coastal mandals. One explanation could be that the effectiveness of evacuation and the shelters has been estimated too high in the model. For instance, in Katrenikona the 16 cyclone shelters together with an effective early warning and evacuation would lead to only 8 calculated deaths, whereas in reality 80 people have died. For a number of mandals lying more inland the model has produced too high estimates of casualties. But eventually these discrepancies between the model and reality do not need to worry us too much. An accurate simulation of local death tolls is virtually impossible, because there is always a large factor of bad luck involved.

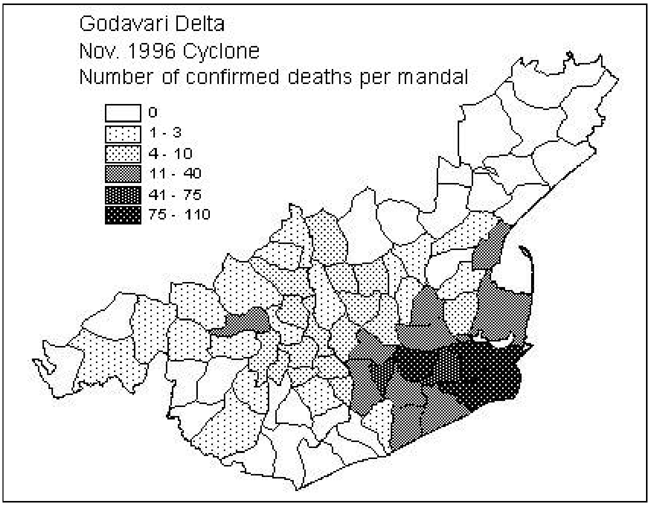

Figure 23 Mandal wise distribution of deaths from Nov. 1996 Cyclone (only study area shown)

(Source: Offices of the District Collectors in Kakinada and Eluru).

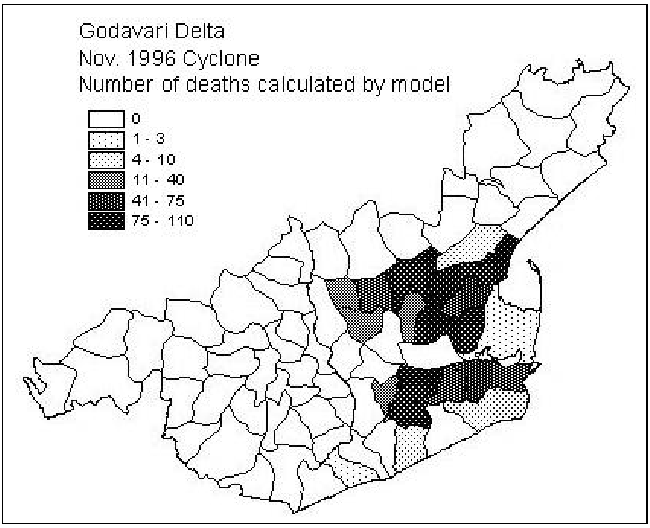

Figure 24 Mandal wise distribution of deaths calculated by the model for the Nov. 1996 Cyclone (only study area shown)

Table 16 Summary of casualties and damages of the November 1996 cyclone

item	East Godavari	West Godavari	total
Confirmed deaths	978	98	1,076*
Houses partially damaged	184,698	117,607	302,305
Houses fully damaged	258,389	49,711	308,100
Cattle losses	11,848	2,838	14,686
Other animal losses	5,455	1,781	7,236
Paddy crops affected (ha)			346,810
Coconut affected (ha)			30,000
Horticultural crops affected (ha)			81,253
Other crops affected (ha)			52,553
Total crop area affected (ha)	253,335	237,785	491,120

*: besides 1683 people were missing.
Sources: Offices of District Collectors in Kakinada and Eluru; (O'Hare 2001)

The capital value of damages is given in Table 17. From these data is becomes clear that the majority of damages occurred in the agricultural and housing sectors. Damages to public infrastructure was relatively small, of which on its turn the electricity sector suffered most (Andhra Pradesh Electricity Board: 1,000 million Rs damage).

Table 17 Estimated damage values (in Rs. million)

item	subtotal	total	percentage
Rice crop losses	3,360		
Coconut crop losses	30,000		
other crop losses	10,920		
total agricultural sector		44,280	82.6%
Housing		6,420	12.0%
Animal husbandry		137	0.3%
Municipal Admn & Urban		900	1.7%
APSEB		1,000	1.9%
Panchayat & Rural Devp		392	0.7%
Fisheries		267	0.5%
Roads & Buildings		75	0.1%
Irrigation		73	0.1%
Others		52	0.1%
TOTAL damage		**53,596**	

Sources: Offices of District Collectors in Kakinada and Eluru;
(O'Hare 2001),(Shanmugasundaram et al. 2000)

The loss sustained as a result of the damage of around five million coconut trees was initially put by the government sources at Rs 30,000 million although this figure is now seen to be a gross exaggeration (O'Hare 2001). Using the crop parameters of the Agricultural University Hyderabad the direct crop loss of losing 5 million trees is at maximum 5 million x 100 coconuts x Rs.2 = 1,000 million Rs. Taking into account the fact that it takes 4 years before new trees bear fruit, the total damage could be not more than 4,000 million Rs.

East Godavari had in total 115,989 ha of paddy damaged of which 112,000 in the 44 study mandals. This is an equivalent of 59% of the total paddy area of 2001. Assuming that the cropping area between 1996 and 2001 is only marginally different, a damage percentage has been calculated per mandal. Using the damaging wind speeds from the Wind Hazard Model and the Specific Risk Coefficients for paddy given by the WHM Report a damage percentage can be calculated for each mandal. In total this gave a damage of 45%. For a better fit of the model to the observations, the damage factors for each wind speed class has been raised (i.e. all factors were shifted one wind class). Now a modelled damage percentage has been calculated of 60%. Figure 25 shows the almost linear relationship between wind speed and crop damage. The EDSS model works with discrete wind classes, so the representation of the crop damage for paddy also shows discrete values.

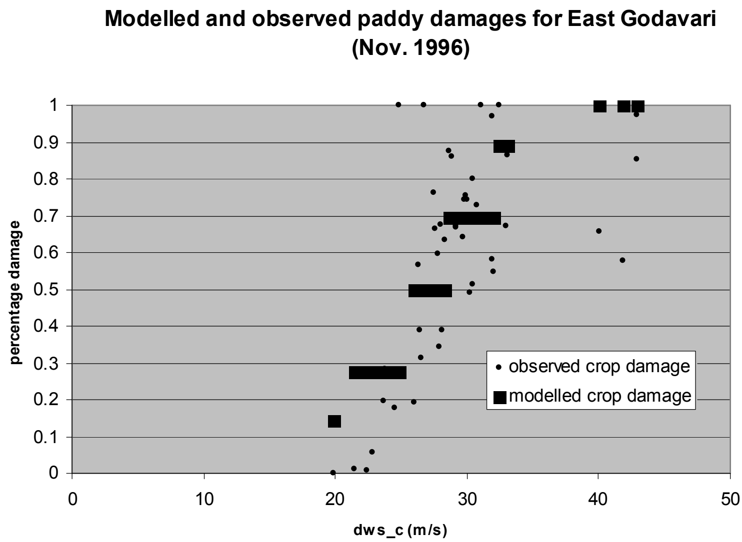

Figure 25 Modelled and observed paddy damages per mandal for Nov. 1996 cyclone, East Godavari

Similarly to the correction of wind damage factors for rice also the damage factors for the other crops have been shifted one class. Also the flood damage factors for crops, houses and infrastructure (see also Figure 14) have been adjusted to better resemble the actual damages. The resulting modelled damage values compare quite well with the estimations of the actual damage, except for the category 'other remaining damage' (Table 18).

Table 18 Comparison of modelled and observed capital damages

Capital value item	Estimations real damage** (million Rs)	EDSS results (million Rs)
Total damages	**23,597**	**26,129**
Crop damage	**15,280**	**13,677**
of which:		
rice	3,360	2,572
coconut	*1,000**	1,214
other crops	10,920	9,891
House damage	**6,420**	**6,377**
Other remaining cap. damage	**2,896**	**6,033**

* coconut damage assumed 1,000 million (see text for explanation)
** same sources as Table 16

Differences between observed and modelled damages are not only caused by the used damage factors, but also because estimation of total values present in the study area have a certain inaccuracy. For instance, the category 'other remaining capital damage' includes a number of assets the total value of which is very difficult to estimate (e.g. the public assets, such as road infrastructure).

Vulnerability and recovery

The model calculates the recovery of the assets values and incomes of households one year after the cyclone strikes. The model shows that for a severe cyclone such as 07B in one year the average recovery of asset value could be more than 95% of their pre cyclone levels for the better-off households (Figure 26). However the average recovery for the lowest income groups in the rural areas could be as low as 50% of their pre cyclone levels demonstrating the differential nature of vulnerability and the greater vulnerability of the low income groups. These findings from model runs supports our key definition of vulnerability – the differential ability or inability to cope with or recover from a cyclone strike (disaster).

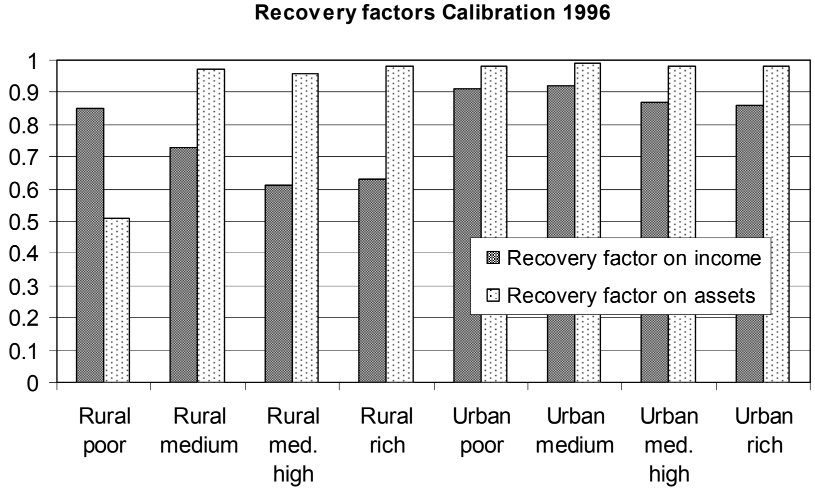

Figure 26 Recovery factors for different income classes (calibration run)

The recovery factors are difficult to calibrate, because there are no quantitative data on the recovery after Cyclone 07B. Instead, we can use the study of O' Hare, which gives a description of the suffering of the people in the aftermath of the cyclone (O'Hare 2001). Based on qualitative interviews with several farming families, O'Hare found that a small number of farmers in the delta were bankrupted by the severe agricultural losses they suffered from cyclone 7B. However, the great majority were able to rely on savings and other resources to tide them over to the next harvest. Considerably more affected were the rural poor, especially landless agricultural labourers reliant on a meagre daily wage. The most vulnerable group in this sector were migrant, scheduled (low) caste women from the state of Orissa who performed most of the agricultural work in the rice fields of East and West Godavari. Although some of these women could rely on handouts of food from considerate landlords, most had to subsist by other means by begging or by selling what possessions (mostly jewellery) they had. Others entered domestic service in the towns and villages where they could find such work, while others migrated temporarily either to neighbouring agricultural districts in southern Andhra or even back to their home village. This picture seems to be reflected in the results of the EDSS: in terms of income the poorer classes seem to recover relatively good because they are flexible and do not rely on income generating assets (which they do not have). Conversely, the richer income classes rely more on their income generating assets, which if (partially) lost, will result in a drop in their income. Also the large crop losses influence the income of the owners more than of the agricultural labourers.

2.5 Scenario and strategy analysis with the EDSS

The model has examined a number of land use development scenarios incorporating differences in land use, water use, and population growth trends for the next 20 years in the Godavari delta (Marchand & Mulder 2007) with the focus on the relationships between agricultural practice and employment potential and between development and environmental destruction. These scenarios were: (i)"Autonomous Development" (ii)"Rice Bowl" (ii)"Maximum Land Development and Diversification", and (iv) "Environmentally Sound Land Development" (Table 19).

The model runs suggest (Table 20) that the Maximum Land Development and Diversification scenario is best for employment. It is also less damaging to the environment (surface water deficit, pollution and destruction of the mangrove forests) than all the other scenarios except the "Environmentally Sound Land Development" scenario.

Table 19 Development scenarios (Delft Hydraulics 2003)

	Baseline (2001)	**Autonomous Development (2020)**	**Rice Bowl (2020)**	**Maximum Land Development and Diversification (2020)**	**Environmentally sound land Development (2020)**
Land Use	Current land use	Estimated annual trends	Priority to rice	Priority given to Aquaculture (+ 46%) and Horticulture (+ 60%)	Reduction of aquaculture (-33%) priority to horticulture (+ 118%), reforestation and sylvo pastures
Population growth	N.A	Assumed 1.4 % annual growth	Assumed 1.4 % annual growth	Assumed 1.4 % annual growth	Assumed 1.4 % annual growth
Irrigation system	Current situation (70% of design cap.)	No major investments (70% of design cap.)	Major investments to increase irrigation capacity (85% of design cap.)	No major investments (70% of design cap.)	No major investments (i.e. 70% of design cap.)
Ground water development	Current situation	No increase in ground water use	Increase in ground water use in 15 *mandals*	No increase in ground water use	No increase in ground water use

Furthermore the runs suggest that by 2020, traditional *paddi* agriculture in the Godavari delta, even with greater investment in irrigation and efficiency (the Rice Bowl Scenario) will be unable to generate enough employment for the population which will then have increased from 7 million (2001) to 9 million (1.4% p.a). The Maximum Land Development and Diversification scenario indicates that the greatest employment potential lies in improving livestock and poultry rearing, mixed cropping, and most importantly, in agricultural diversification. Agricultural diversification is likely to be most profitably directed into horticulture, sylvo-pasturalism and alternative aquaculture crops.

If these activities can be controlled (disease prevention and reduction of soil erosion) then it should be possible to have high financial yields from low value land (Krishna 1994). Many of these new activities would not require extra investment in irrigation and those resources could go to providing greater capacity in the power sector, better roads to markets, and more extension services, credit facilities and education in order to encourage farmers to change their practices. The new activities would also reduce environmental degradation (for instance, the Maximum Land Development and Diversification, and Environmentally Sound Land Development scenarios are better at reducing the surface water deficit and the pollution index than the Autonomous Development scenario (Table 20).

Table 20: EDSS results for Godavari Delta

	Baseline (2001)	Autonomous Development (2020)	Rice Bowl (2020)	Maximum Land Development and Diversification (2020)	Environmentally sound land Development (2020)
Population	7,193,754	9,368,644	9,368,644	9,368,644	9,368,644
Per capita annual income	14,253 Rs	11,642 Rs	11.362 Rs	12,848 Rs	11,034 Rs
Unskilled employment rate	94%	71%	76%	75%	65%
Skilled employment rate	92%	75%	74%	82%	70%
Net agricultural profit (million Rs) (% change)	17,502 (0%)	21,920 (+25%)	18,617 (+6%)	27,857 (+59%)	21,316 (+22%)
Damage to crops (million Rs)	13,745	15,840	13,784	18,412	14,990
Surface water deficit	-13.3	-10.6	-13.8	-5.0	-4.9
Percentage of mandals with water quality problems	85%	89%	90%	93%	90%
Mangrove area (ha)	15.621	13.314	15.621	16.404	17.632
Fraction people vulnerable to financial losses	0.34	0.37	0.33	0.36	0.35

The correlation between different land use scenarios an vulnerability is indistinct. For instance, it is not proven that the Maximum Land Development and Diversification scenario reduces physical and social vulnerability, or whether the Environmentally Sound Land Development scenario significantly reduces financial losses of the poorest in the event of cyclones and or floods. The model runs do show, however, that the Rice Bowl Scenario (a monoculture), or the Maximum Land Development and Diversification scenario focusing on aquaculture (another monoculture) are also risky and that crop choice and diversification are crucial. They also highlight two crucial issues that need to be resolved in the coastal areas: (i) the reversal of environmental degradation, and, (ii) the opportunities for more equitable growth with the introduction of new land uses.

Results from the model runs show that there seem to be no viable alternatives for economic development to benefit the majority of the population other than large scale diversification in the agricultural sector as a result of the projected population growth and subsequent increasing labour pool. Diversification is particularly relevant in the delta areas where the resources of land and water are more sustainable over the long term, but, even in these areas, the model runs cannot show definitely whether the sector can absorb the large increase in the labour supply. Both the use of resources and labour require careful planning and management and the diversification programmes need to go hand in hand with environmental protection policies that control water pollution and guarantee the continuation of designated "protected areas" such as the replanted mangrove stands (Environmentally Sound Land Development scenario).

Model runs also permitted several strategic measures directly aimed at vulnerability reduction to be analysed. These showed that an obvious measure of 'maximum flood protection' against storm surges would have assets damage to assets, but would hardly reduce the crop damage, mainly caused by high winds. Maximum flood protection would have a significant impact on the number of casualties, because most are flood victims. Likewise, evacuation improvement would significantly reduce casualties. Several measures can be taken to reduce the gap between actual and maximum evacuation rates, such as improvements in the road system, warning improvements and the provision of more cyclone shelters. Improved evacuation, simulated by the model, would cause a drop in expected casualties from 34 to 14 per year. However, because the majority of the assets are immovable, the damage remains almost as high as without evacuation improvement. Therefore, relief funds given as grants to households that have suffered losses remain of utmost importance to reduce vulnerability in terms of assets and income, providing the differential nature of those losses is taken into account. In the model several levels of grants can be implemented as measures. A 'medium grant', defined as the provision of relief funds that compensate for 70% of losses incurred by poor households and 50% compensation for medium income households would cost on average 2 billion Rs and would reduce the number of people vulnerable to financial loss by 60% (Figure 27).

Loans as a financial coping mechanism do not have a significant effect on vulnerability, as Figure 27 also shows. They do not help in recovering total asset value, since the new assets that are bought with it are counterbalanced with a debt. For the Godavari Delta this also does not lead to a significant increase in the production after the storm, mainly because the damages to income generating assets are relatively small for the delta as a whole.

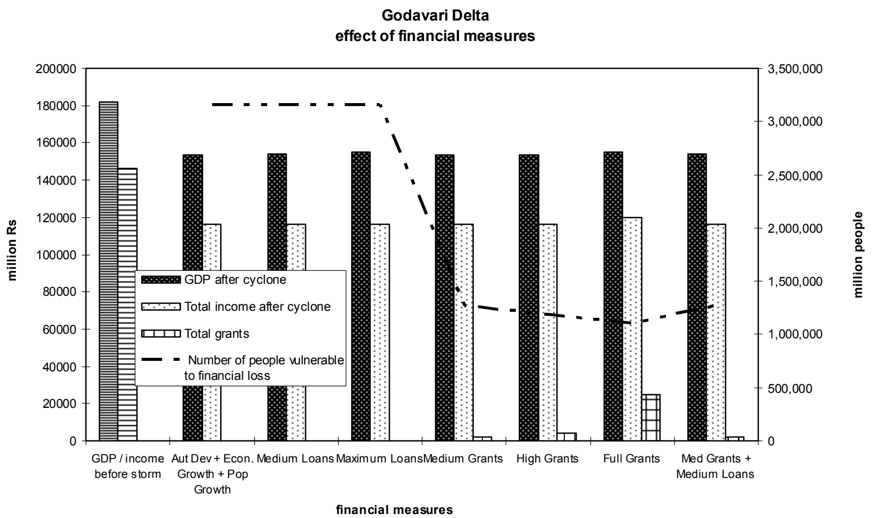

Figure 27 Effect of financial measures on vulnerability

Part 2
Literature study

3 Defining vulnerability

In this chapter a review is provided of contemporary vulnerability concepts, definitions and theories leading to a working definition for the research. Common methods for vulnerability assessment and measurement are described and evaluated. Based on this inventory and critical examination, a framework for vulnerability is selected that will be used to evaluate the EDSS.

3.1 Definitions

The word vulnerability is used in ordinary language and in everyday situations. Everybody understands what vulnerability means, especially when the context is clear. For instance in the following sentences:

'A vulnerability has been discovered in Internet Explorer, which can be exploited by malicious people to disclose potentially sensitive information'[8]

'Vulnerability is a matter of positioning.'[9]

'Children are usually more vulnerable to diseases than adults.'

'The Whale Shark has the status of vulnerable on the Red List of threatened species'[10]

From these examples we learn that vulnerability can refer to a computer program (e.g. Internet Explorer), a soldier's exposure to harm, a child's susceptibility to disease or an animal's survival. The word is used to describe a property of an object and usually has a negative connotation. Vulnerable is not good, because there is a risk of something bad happening with the object. Often used synonyms of 'vulnerable' are: weak, defenceless, helpless, susceptible, liable etc. We also know that it is not always possible to avoid being vulnerable. It can even have a positive effect: for instance, because children are vulnerable to child diseases it helps those that survive to build up resistance against malicious bacteria and viruses. Children that grow up in a highly protected environment can face health problems when they are older. Sometimes people deliberately put themselves in a vulnerable situation, as the benefits of doing so can outweigh the potential risk. This is another important aspect of the term: there is the *potential* for harm (Dow 1992), but it is uncertain if it will materialise.

From these ordinary, everyday uses of the term vulnerability I extract the following conclusions: i) vulnerability derives its true meaning from the context: i.e. the object in question and the type of harm; ii) vulnerability refers to something bad that can but not necessarily will happen.

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[8] http://secunia.com/advisories/22477/

[9] From: Sun Tze –Art of War. http://www.mailsbroadcast.com/the.artofwar.htm

[10] IUCN Red List of Threatened Species: 'A taxon is vulnerable when the best available evidence indicates that it meets any of the criteria A to E for Vulnerable and it is therefore considered to be facing a high risk of extinction in the wild'. IUCN (2001). *IUCN Red List Categories and Criteria: Version 3.1.* IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge, UK. ii + 30 pp.

When using the concept in a science or policy context these descriptions do not suffice, however. A more precise definition is required because vulnerability refers to a condition that forms a starting point for either further research and/or for decisions to change this condition. Or, as Green and Penning-Rowsell put it: 'The reason we seek to define vulnerability is in order to help us decide what to do to reduce that vulnerability. The value of a definition of vulnerability is consequently the degree to which it gives new and useful insights into the nature of the problem at hand.' (Green & Penning-Rowsell 2007).

In its widest sense vulnerability refers to all characteristics of a system, which could include individuals, households or larger entities, that have the potential to be harmed (Dow 1992). These systems could also refer to natural entities, such as ecosystems, landscapes or a species, as we have seen above. In order to delineate the topic of vulnerability I prepared a simple mind map[11]. As the map shows (Figure 28), vulnerability can be used in almost every context, for instance in the medical world, but also in the humanities and natural sciences. In this research the vulnerability concept will be used only for *entities of human society that live in the coastal zone and are impacted by natural disasters such as floods, high winds and storm surges.* Note that other possible events or sources of vulnerability may be relevant to consider as well. When entities face multiple risks their total vulnerability could be more than the sum of each separate vulnerability. But our principal focus is the vulnerability to a natural hazard in the coastal zone.

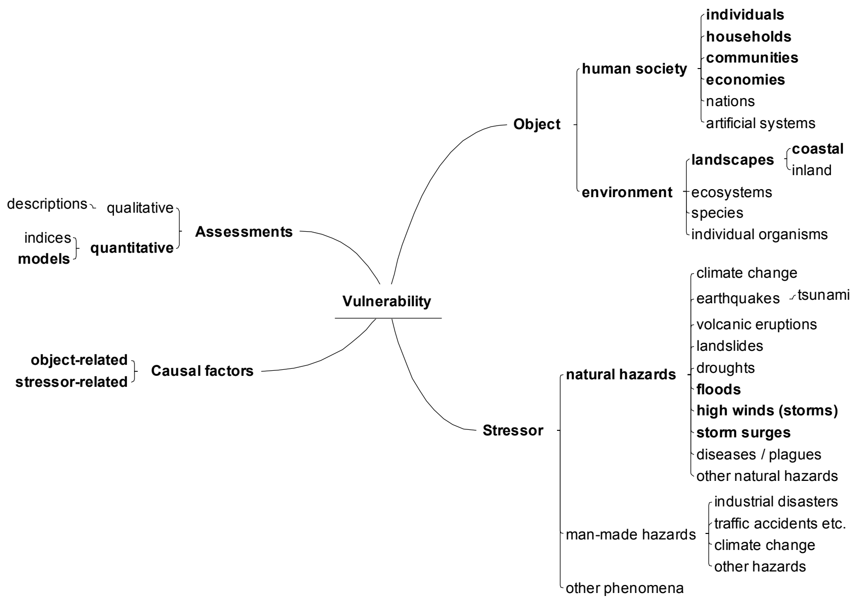


Figure 28 Mind map of vulnerability (attributes in bold are included in the research)

11 A mind map is a diagram used to represent words, ideas, tasks, or other items linked to and arranged radially around a central key word or idea. Mind maps are used to generate, visualize, structure, and classify ideas, and as an aid in study, organization, problem solving, decision making, and writing (Wikipedia, accessed 16 March 2008).

Defining vulnerability is not a trivial matter, not only due to the many dimensions it contains, but also because choosing a definition reveals the worldview of the person who proposes that definition (Green & Penning-Rowsell 2007). Table 21 presents a selection of vulnerability definitions found in recent disaster management literature.

Common in most of these definitions are three elements: the external factor, the object that is considered vulnerable and the reaction of that system to the external factor.

Table 21 A selection of vulnerability definitions (in chronological order of publication)

'Vulnerability is the degree of loss to a given element or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude' (UNDRO, 1982)
'Vulnerability is the capacity to get wounded' (Kates, 1985, cited in Dow, 1992)
'Vulnerability is exposure to contingencies and stress, and difficulty in coping with them' (Chambers, 1989, p.1)
'Vulnerability is a function of the combination of exposure, resistance and resilience' (Dow 1992)
'Vulnerability is [here] defined as being determined by the characteristics of a person or group in terms of their limited capacity to anticipate, cope with, resist and recover from the impact of a natural hazard' (Blaikie et al., 1994)
'Social vulnerability is the exposure of groups or individuals to stress as a result of social and environmental change, where stress refers to unexpected changes and disruption to livelihoods' (Adger 1999a)
'Vulnerability is the extent to which a person, group or socio-economic structure is likely to be affected by a hazard (related to their capacity to anticipate it, cope with it, resist it and recover from its impact)' (Twigg 2001a)
'Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes' (Glossary of IPCC Third Assessment Report; (McCarthy et al. 2001)
'Vulnerability is a measure of the exposure of a person, group, community or agency to a hazard and indicates the type and severity of damage that is possible' (Buckle et al. 2001)
'Vulnerability is the capacity to be wounded from a perturbation or stress' (Kasperson & Kasperson 2001)
'Vulnerability is defined as the conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards'. UN/ISDR. Geneva 2004.
'Vulnerability is the characteristic of a system that describes it potential to be harmed. This can be considered a combination of susceptibility and value' (Gouldby & Samuels 2005)
'Social vulnerability is defined as the susceptibility of social groups to the impacts of hazards, as well as their resiliency, or ability to adequately recover from them. This susceptibility is not only a function of the demographic characteristics of the population (age, gender, wealth etc.), but also more complex constructs such as health care provision, social capital, and access to lifelines (e.g. emergency response personnel, goods, services)' (Cutter & Emrich 2006)
'Vulnerability is the predisposition of societies to be affected and the incapacity to cope with disasters' (Villagran De Leon 2006)
'Vulnerability = Impacts minus effects of adaptation (V = I – A)' (McFadden et al. 2007)
'A system f in state x is vulnerable to an exogenous input e with respect to $\prec$ if and only if $f(x,e) \prec x$' (Hinkel 2008)

However, the exact wordings and extent to which these elements are described differ (Table 22). And this differentiation indicates the importance that the authors put on each of these elements, often based on their own view of the causes of vulnerability. This ranges from a purely exposure driven vulnerability, which defines the exposure to a hazard as the main cause of vulnerability, towards social vulnerability, where resilience and coping strategies are major determinants of vulnerability. For instance the definition from the UNDRO in 1982 relates a certain degree of loss only to the occurrence of a natural phenomenon, whereas later authors bring in the social factors as being equally or more important (e.g. Chambers 1989; Dow 1992; Blaikie 1994, Twigg 2001; Cutter & Emrich 2006). Bohle (2001) joins both sides into his conceptual framework and calls them the external and internal sides of vulnerability.

Indeed, when the receptors are perceived only or mainly as victims then the social causes of vulnerability may be evaded (Cannon 2000). Technical and apolitical solutions are then seen as most appropriate. Evidently, the social vulnerability literature places the solutions towards the other end of the spectrum. As Cannon puts it: ‘The focus should be on its political economy determinants and their effects in differentiating people (into groups that are differentially exposed to risk) and not simply structures that happen to be in places where a particular hazard is likely to strike’ (Cannon 2000).

Table 22 Wordings used in the definitions (Table 21) for the three basic elements of vulnerability

external factor	object	reaction of the object
(natural) hazard (6)	elements at risk	degree of loss
natural phenomenon	person or group	wounded (2)
contingencies	groups or individuals	manageability
stress	person, group, socio-economic structure	difficulty in coping
perturbation	person, group, community, agency	resistance and resilience
exposure	community	anticipate, cope with, resist and recover from the impact(2)
	system	disruption of livelihoods
	social groups	type and severity of damage
	societies	impact (2)
		harm (a combination of susceptibility and value)
		susceptibility, […] as well as their resiliency or ability to adequately recover
		affected
		incapacity to cope
		impacts minus effects of adaptation

The drawback to the rather reductionist approach to the concept of vulnerability in Table 22 is that it fails to capture the interactions between the core elements. For instance, ‘exposure’ denotes not only the external factor, but also the object on which it has an influence. Similarly, the word ‘susceptibility’ does not only refer to the reaction of the object, but also to the object itself and the external factor. In fact, the true meaning of vulnerability only expresses itself in the combination, or interaction between the external factor, the object and its reaction to the external factor. For a better insight in this ‘holistic’ viewpoint, we should include the context in which the definitions are used and their embedding in a theoretical framework. Hence, before choosing a working definition of vulnerability, first I will look for theories on vulnerability. Thereafter a working definition will be given. I restrict myself in this theoretical overview to the disaster management field, and do not include the relation between vulnerability and climate change, although some interaction is acknowledged (see Box 4).

Box 4 Vulnerability and climate change

Much of recent literature dealing with vulnerability stems from the climate change research community (Abramovitz et al. 2002; Adger 1999a; Bohle et al. 1994; Brooks et al. 2005; Ionescu et al. 2009; Kasperson & Kasperson 2001).Therefore, a word of caution is needed, as vulnerability in the context of coastal hazards differs from that of climate change (although these two are related). When we talk of coastal hazards turning into disasters we usually consider an event that occurs at a certain location in a matter of hours or days. The aftermath shows casualties, damages and a disruption of life and economic activity, from which people and communities struggle to recover or cope with over a period of months to years. With vulnerability to climate change the temporal and spatial scales are significantly larger. Consequently, not the events are central to climate change vulnerability, but the change in averages that matter. Rising temperatures, CO_2 and sea levels pose a challenge to the current socioeconomic fabric and instead of '*recovering from'* the key aspect is '*adapt to'*. Of course, within the climate change domain also extreme events play a significant role, as storm frequencies or hurricane intensities could increase. But also in this respect the question of climatic vulnerability is rather how to adapt to increasing storm frequencies than how to recover from a single storm. Interestingly, here these two vulnerability discussions meet, as it is clear that if a society is less vulnerable to a single storm it can more easily adapt to a higher frequency. Alternatively, vulnerability analyses to hazards should include the longer term climate change issue so that their recommendations also hold on the longer term.

Because my research deals with the impact of natural hazards on coastal communities, I will focus primarily on vulnerability to events. Climate change issues are included insofar this changes the boundary conditions in a vulnerability assessment.

3.2 Theories on vulnerability

Vulnerability assessments are increasingly being used as a step towards disaster mitigation and management. Clearly these assessments are necessary in order to determine the need for action and they can be regarded as a diagnosis step in a policy analytical framework (see Chapter 5 on Policy Analysis). But what forms the basis for these assessments? Where do we start? Is there a framework, a protocol available? And where does this come from? It is evident that we need to review theories on vulnerability if we want clear answers to these questions. So let us look at possible causes of vulnerability and what explanations and theories literature provides.

3.2.1 Causes of vulnerability

Vulnerability caused by exposure

The strongest argument for identifying exposure as a major factor in vulnerability is the fact that if one reduces or eliminates exposure to a hazard, the vulnerability to that hazard also reduces. Even poor and disadvantaged people are not vulnerable to flooding if they are not exposed to floods. The preoccupation with the hazard itself as the major determinant of vulnerability has a long standing tradition amongst physical scientists, geologists, geographers and others that study natural phenomena such as earthquakes, floods, wind storms and droughts. Knowledge regarding the incidence and severity of the various hazards, return periods and geographical limits of vulnerability to the hazards can evidently contribute to disaster management (Arthurton 1998; Bryant 2005).

Although few will disagree on the relevance of knowledge regarding natural hazards, all the more dispute arises over the responses to these hazards. The focus on the hazard as a natural phenomenon has led to a technical, or hard science approach to vulnerability reduction, i.e. reducing the hazard itself or protecting societies against the hazard by engineering measures, spatial planning and early warning systems. It will be no coincidence that this approach has made significant progress with the increasing potential of mankind to manipulate its environment. A typical example of such technical approach is the history of flood management in the Netherlands, for which the nation became famous and that contributed to its identity (Veen 1948; Veen 1953). Just over a decade ago a similar technical approach to flooding hazards was propagated in Bangladesh, although much debate emerged about the appropriateness of this solution (see Box 5). A rather extreme consequence of vulnerability mitigation by reducing exposure is to relocate entire communities to safer places. For example, after the Alaska earthquake of 1964, federal officials ascertained that the coastal city of Valdez would be at chronic risk from future tsunamis, as well as from earthquakes. The community was forced to relocate, because federal disaster officials refused to contribute any disaster assistance funds to rebuilding structures on land known to be at continuing high risk (Rubin et al. 1985).

Box 5 The Flood Action Plan for Bangladesh

A classic example of exposure reduction is the Flood Action Plan for Bangladesh in the '90s of the last century. After the disastrous floods in 1987 and 1988 major aid donors offered technical assistance to the government of Bangladesh with the objective of finding a lasting solution to the country's chronic flood problem. The Bangladesh government as well as some donors (e.g. the French) had insisted during the negotiation of the plan that the country's rivers must be embanked and that the embankments should be built close to the river banks so as to protect as much of the population as possible. The plan was highly disputed from the onset both from the inside and outside Bangladesh by NGO's, scientists and several donor agencies. And despite an investment in the order of probably US$ 200 million, ten years after the 1987 and 1988 disasters, the government and the people of Bangladesh appeared to be in no better position as a result of the FAP to withstand a recurrence of such a major flood (Brammer 2000; Adger 1999a). Debates are still going on whether to 'live with floods' and be at the mercy of nature or to execute more 'flood control projects' and protect all lands from flooding. Nevertheless, more options are explored than in the past, including flood warning, spatial planning, public education and the maintenance of embankments (Nishat 2003). This example indicates that a pure 'technical fix' has its limitations

The General Assembly of the United Nations declared the 1990's as the International Decade of Natural Disaster Reduction (IDNDR). Its basic objective was to decrease the loss of life, property destruction and social and economic disruption caused by natural disasters. The IDNDR was criticized for its overemphasis on technology and hazard management (Blaikie et al. 1994). While the IDNDR followed a strictly techno-centric and scientific approach in the beginning, the Yokohama conference in 1994 put socio-economic aspects as component of effective disaster prevention into perspective. It was recognised that social factors, such as cultural tradition, religious values, economic standing, and trust in political accountability are essential in the determination of societal vulnerability (Wikipedia, accessed 13 April 2007).

An interesting historic snapshot of the world views on development in flood prone areas was given by an International Symposium called 'Polders of the World' which was held in the Netherlands from 4 to 10 October 1982. An analysis of the more than 150 papers published in the proceedings, enabled insight in the then prevalent way of thinking on development as these papers were a direct expression of the attitudes of polder designers and polder promoters, unintentionally revealing their normative background. (Marchand & De Groot 1986).

Although the symposium did not address the flooding issue sensu stricto, it did show the preoccupation at that time with a technical solution to protect low lying, flood-prone areas and reclaim wetlands for the sake of development. Simultaneously it showed the criticisms to this approach. Technology was being attacked both from a sociological and ecological viewpoint as it became clear that there were limits to adjusting the physical environment for the benefit of society. Human ecology emerged as a new paradigm for human adaptation to floods and other natural hazards (Parker 2000) and also showed that modernization through technological advances could even increase vulnerability of societies (Farvar & Milton 1972).

Vulnerability caused by modernisation.
Farvar & Milton were among the people that called attention to the negative environmental consequences of 'careless' technological development. Development projects that aimed at economic growth through large scale investments in water resources infrastructure, such as irrigation schemes and large dams, often had not only a poor economic performance, but could actually have many adverse effects on the local environment and communities (Farvar & Milton 1972). By their sheer scale alone as well as the rationale behind them they could easily upset traditional livelihood patterns as many local people could not adapt to the changes in both the environment and socio-economic conditions. Vulnerability towards natural hazards was actually being increased because of three factors:

1. traditional coping strategies for calamities such as droughts and floods were demolished as these development projects aimed at maximisation of productivity rather than minimisation of risk;
2. development projects that involve deforestation, hill roads, reservoirs and land reclamations could increase the risk of flooding through increased run-off, dam breaks and reduction of natural buffer areas, respectively;
3. ill-planned (re-)settlement in flood prone areas increase the number of people being exposed to a flood hazard (Burton et al. 1993).

Sometimes these kinds of modern projects with immediate negative effects on local communities are referred to as 'development aggression' and are considered by local people as human-made disasters from which it is much more difficult to recover than from natural disasters as the latter do not necessarily undermine the basis of people's means of survival (Heijmans 2001).

There is considerable evidence that the number of casualties and extent of damage from flood disasters have increased significantly over the past decades not because of an increase in the frequency of extreme events, but largely due to the increase of the number of people and investments at risk (Burton et al. 1993; Tansel 1995; Pielke Jr. et al. 2008; Raghavan & Rajesh 2003). For instance, there is no evidence that floods in the Ganges, Brahmaputra and Megna river basins have intensified over the past decades. So reports of increased flood damage must be attributed to other factors, such as better damage assessment techniques and the expansion of settlements in flood prone areas (Monirul Qader Mirza et al. 2001). The growth of megacities, many of which are located along flood and hurricane prone coastal areas and deltas is another example of this phenomenon (Kron 2005; Anonymus 2004).

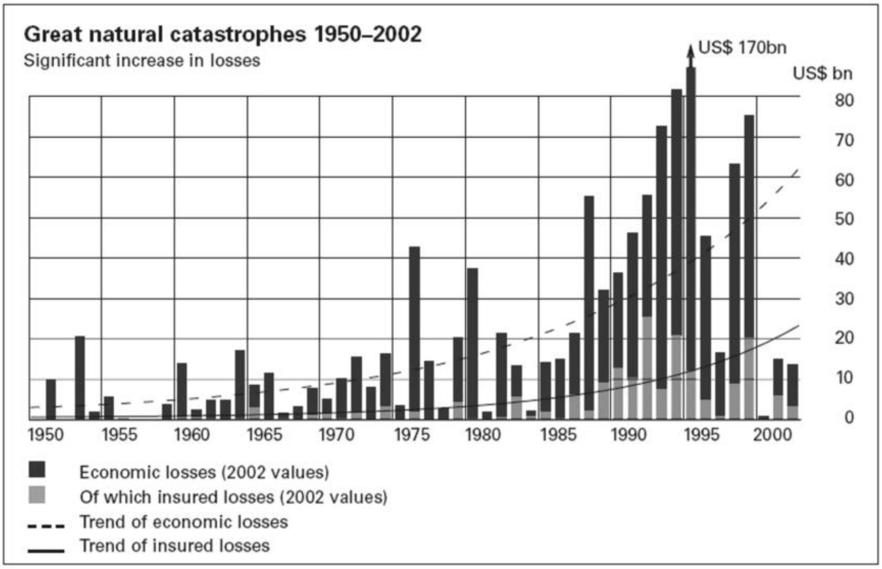


Figure 29 Increase in worldwide losses due to natural catastrophes
Source: Munich Re (2003) NatCatSERVICE – a guide to the Munich Re database for natural catastrophes

Although this trend in damages is increasing, it does not automatically imply that vulnerability is also increasing. The graph in Figure 29 also shows a trend line of insured losses. Although this trend probably worries the re-insurance industry, one can also look at it in a more positive way: insurance makes economies and households less vulnerable to damage. This leads us to another side of vulnerability: the distribution of risk within the society.

Vulnerability caused by marginalisation
Population growth, large scale migration to urban areas and neoliberal economic policies are all factors that contribute to the emergence of marginalised communities, particularly in developing countries. Often these groups of people live in hazardous environments, such as on steep slopes or in floodplains (Mustafa 2003). These groups interact with the environment in ways that increase their vulnerability to hazards while often causing physical degradation to the environment that in turn increases the risk of hazards or severity of impacts (Wisner 1993). Marginalisation as a process provides an explanation of the trend observed earlier that there is an increase of losses caused by natural disasters in underdeveloped countries despite the fact that the probability of the natural hazards has not increased (Baird et al. 1975, cited in Burton et al. 1993). In fact the social process of marginalisation and disasters reinforce each other in a positive feedback, resulting in a vicious circle from where few people can escape.

This explanation is grounded in social theory and puts disasters in an explicit socio-political context. For instance, Wisner (1993) concluded: ‘The modern state distributes risk unevenly among its citizens’.

Vulnerability caused by poverty
In general poor people tend to be more vulnerable to natural hazards than rich people. This can be attributed to different mechanisms, such as that poor people are living in more unsafe conditions, their houses are weaker, they have less capital resources to fall back on, they cannot afford insurances etc. Already back in 1976 an earthquake in

Guatemala was nicknamed as a ‘classquake’, because low-income, indigenous people were hardest hit (Wisner 2000).

The actual mechanism in place very much depends on the type of natural hazard and the socio-cultural conditions and it is therefore dangerous to generalise. For instance, poor people living for generations in a hazardous environment are usually better prepared for natural vagaries than those that have migrated recently to a place unfamiliar to them. Their absolute income level could be identical, whereas their vulnerability is not. Hence, poverty as a proxy for vulnerability (Adger 1999a), has its limitations. Income levels are only part of the story that explains vulnerability. This implies that it is often too simple to state that poverty reduction automatically reduces vulnerability. Sometimes, anti-poverty programs even have resulted in vulnerability increases. Therefore, vulnerability and poverty are not synonymous, although they are often closely related (Blaikie et al. 1994).

Vulnerability caused by age, class and gender
Several authors have stressed the fact that ultimately it is individuals that are able or not able to cope with an event. Vulnerability is balanced by people’s capabilities and resilience (Cannon 2000) and depend on such basic characteristics as age, class and gender. Elderly people find themselves often disproportionately unable to bring themselves to safety because of physical limitations. Women have often the additional task of saving their children and caring for them, reducing the chances of their own survival. Social mechanisms that favour certain classes to the detriment of others under normal conditions often are exacerbated during times of crises, when resources are under high pressure. All these factors have been extensively described in the literature (for instance Cannon 2000; Cutter & Emrich 2006; Cutter et al. 2006; Dow 1992; Enarson & Fordham 2001; Tapsell et al. 2002) and can be summarised into what can be called the demographic aspect of vulnerability.

3.2.2 Theories

One cannot say that any of the aforementioned perspectives on the causes of vulnerability is right or wrong. They do increase our understanding that vulnerability is caused by a complex of factors and demonstrate that appreciation of this fact has increased over the past decades.

Theories have developed that highlight the deeper causes and underlying factors behind vulnerability. Some have a strong explanatory character, while others merely provide a framework, a line of reasoning that leaves room for contextual detail. From a historical viewpoint, one can observe a shift in thinking about disasters. In ancient times disasters were often seen as acts of God, not in the least because of the limited knowledge of geological, hydrological or meteorological processes that caused the earth to tremble, the winds to rage or the rivers to overflow. Little by little our knowledge of these processes grew, and the ‘Acts of God’ came to be regarded as ‘Forces of Nature’. These disasters were seen as isolated natural phenomena with passive victims who unfortunately happened to be in the wrong place at the wrong time. With an increasing toll in terms of casualties and economic losses in the second half of the last century the simple unidirectional idea of a hazard leading to a disaster was no longer acceptable. Ecologists stressed the impact of humans on the physical fragility and disasters became ‘Acts of Men’. Later, sociologists became involved and highlighted the inequalities in suffering between people and societies. Finally, it became evident that disasters are recurrent events in which vulnerability forms an intrinsic component of society as it interacts with the environment and the wider political economy.

However rich the literature seems in dealing with vulnerability, researchers stress that we are still at the beginning of what may be called vulnerability research (Villagran De Leon 2006). Limited information exists as to how vulnerability can be actively reduced to promote sustainable development (McFadden et al. 2007). Some are of the opinion that vulnerability is too complicated to be captured by models and frameworks (Twigg & Bhatt 1998) while others are more optimistic, but warn that one must always be aware that there are many answers to the question of vulnerability (Thywissen 2006). While keeping this warning in mind, a number of emerging theories and models that address the vulnerability to natural disasters are described below.

Risk-Hazard models

In a rather archetypical reduced form, the Risk-Hazard model (Burton et al. 1993) seeks to understand the impact of a hazard as a function of exposure to the hazard event and the dose-response (sensitivity) of the entity exposed. The basis of this model lies in the human ecological quintessence that society and its environment are in a constant and complex interaction. Nature, technology and society interact to generate vulnerability and resilience to hazard. Thus there are no uniquely natural, social or technological hazards (Burton et al. 1993).

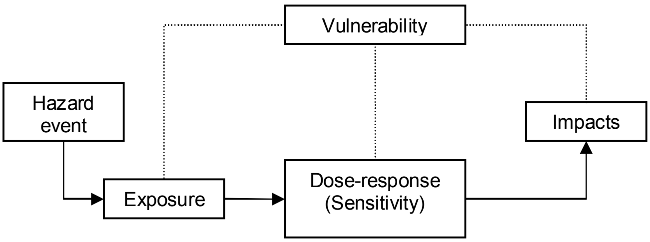


Figure 30 Risk-Hazard framework

Chain sequence begins with hazard; concept of vulnerability commonly implicit as noted by dotted lines. Source: (Turner et al. 2003).

Figure 30 pictures the Risk-Hazard framework with the arrows denoting a causal relationship: impacts occur as a consequence of a hazard event, exposure and sensitivity[12]. The dotted lines to vulnerability indicate that the actual vulnerability is a function of exposure, sensitivity and impacts, but it remains vague how. Remarkably weakly elaborated in this model are the consequences of a disaster. The social component of vulnerability is not explicitly analyzed. We see this reflected in the work of Burton et al. (1993) who only pay attention to measures such as: relief and rehabilitation, insurance, warnings, building design, and land use changes/relocation.

As we will see later, this rather basic framework has evolved into a much more comprehensive version, in which the vulnerability ‘box’ is elaborated (see page 95). But in order to fully appreciate this evolution, I first will discuss other well known approaches and frameworks.

[12] NB. The diagrams used in this section illustrate a way of thinking about vulnerability that I not necessarily endorse. They originate from different authors and show diversity and a lack of coherence in the field of vulnerability.

Conceptual Model of Vulnerability

Based on a longitudinal study on the recovery of households, Winchester (1992) developed a conceptual model of vulnerability focusing on individual households and their characteristics and the key relationships between these characteristics and the context in which the households lived. This relationship largely determines the vulnerability of households to all internally or externally generated shocks. Figure 31 shows the main elements of this model.

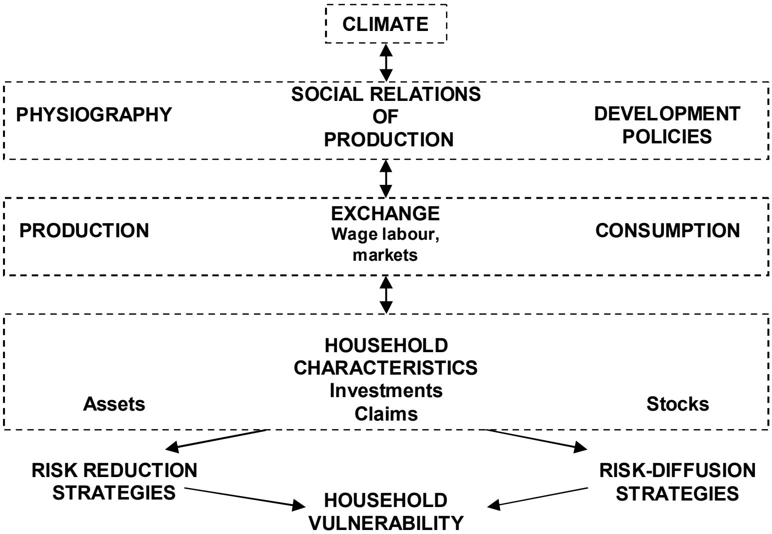


Figure 31 A conceptual model of vulnerability (Winchester, 1992)
The original version of this figure did not contain boxes and arrows because – according to Winchester – 'It is not meant to be a sequential model but an interactive one with variable time frames'. I have included them in my interpretation with permission of the original author to express the interdependencies between the household vulnerability and wider socioeconomic conditions.

At the top of the model we find the external relationships and processes of climate, physiography, the social relations of production and development policies. Below these are the relationships between production, exchange and consumption. All these relations affect the asset and stock levels of households, as well as the level of investments and claims. These in turn determine the risk-reduction and risk-diffusion strategies a household may be able to use.

By following a sample of 42 households over a period of 10 years after the devastating cyclone that struck the Krishna Delta (Andhra Pradesh) in November 1977, Winchester was able to apply and test his model. He found that the 'Number of workers in a household', 'Health' and 'Land assets' were the three variables that had the greatest influence in accounting for the difference in vulnerability (measured as recovery over the 10 year period). Households that had most difficulty in recovering were characterised by low numbers of workers and high levels of illness. Surprisingly, 'Location' was among the variables that had no explanatory value to recovery success. These findings led to the concept of differential vulnerability, which state that people or households with equal exposure are not necessarily equally vulnerable. As described in Chapter 2, this concept became a strong guiding principle for the EDSS model developed in the Andhra Pradesh Project, of which Winchester was a team member.

Capacities and Vulnerabilities Analysis

C & V Analysis is an approach developed by Anderson & Woodrow (1998) of the International Relief/Development Project of Harvard's Graduate School of Education, based on 30 "success" stories around the world on how NGOs provided disaster assistance so that it promoted, rather than undermined, long-term development. The tool has broader application and is used to help donors and recipients ensure that project planning and implementation support long-term development. It has been used extensively by the Red Cross and other NGOs, particularly for disaster response and preparedness, and in such sectors as primary health care, housing, agriculture and the environment. The basic thesis is that any development initiative is sustainable only if it builds on local capacities and tackles deeply-rooted vulnerabilities (Morgan & Taschereau 1996). Anderson & Woodrow define development as '*the process by which vulnerabilities are reduced and capacities increased*'.

The C&V analysis looks at three interrelated areas and estimates the capacities and vulnerabilities of a community for each of these areas. These areas are (Anderson & Woodrow 1998):

- *Physical/material*, which includes climate, environment, health, skills and labour, infrastructure, housing, finance and technologies;
- *Social/organizational*, including the formal political structures and informal systems through which people get things done;
- *Motivational/attitudinal*, dealing with factors that describe how people in society view themselves and their ability to affect their environment. Strength or weakness in this realm can make a significant difference in a society's ability to rebuild or improve its material base or its social institutions.

C & V analysis can help to ascertain the nature and level of risks that communities face; where the risk originates; what and who will be affected; what resources are available to reduce risks; and what conditions need to be strengthened (Morgan & Taschereau 1996). The interesting aspect of this analysis framework is that it relates sustainable, long term development with hazards and risks. It is not focused on one type of hazard, but brings the entire spectrum of potential and actual factors that could hamper development into view. The explanatory capacity of this framework, however, is limited as far as the causes of vulnerability are concerned. In fact, it consists merely of an empty matrix with on the vertical axis the three areas physical/ social/ motivational and on the horizontal axis 'vulnerabilities' and 'capacities' (Table 23). What has to be filled in remains purely contextual of the situation, location and country in question. It does not propose a set of generic causal relations which link vulnerability to the different 'areas' and which could be uses for modelling. However, we will keep in mind the distinction of the three areas, which show a resemblance with the layer model of Williamson (1998).

Table 23 The Capacity and Vulnerability Analysis Matrix

'areas'	vulnerabilities	capacities
physical/material		
social/organizational		
motivational/attitudinal		

Pressure and release/Access Models

Based on experiences from a wide range of countries and hazard types, Blaikie et al. (1994) developed a 'Disaster pressure and release model', with the idea that an explanation of disaster requires tracing a progression i.e. connecting the impact of a hazard on people through a series of levels of social factors that generate vulnerability. In the model the immediate (or proximate) cause of vulnerability is termed 'unsafe conditions', while the underlying or fundamental causes are called 'dynamic pressures' and 'root causes'. Figure 32 presents the general lay-out of the model, which can be adapted to the specific local conditions and hazard types.

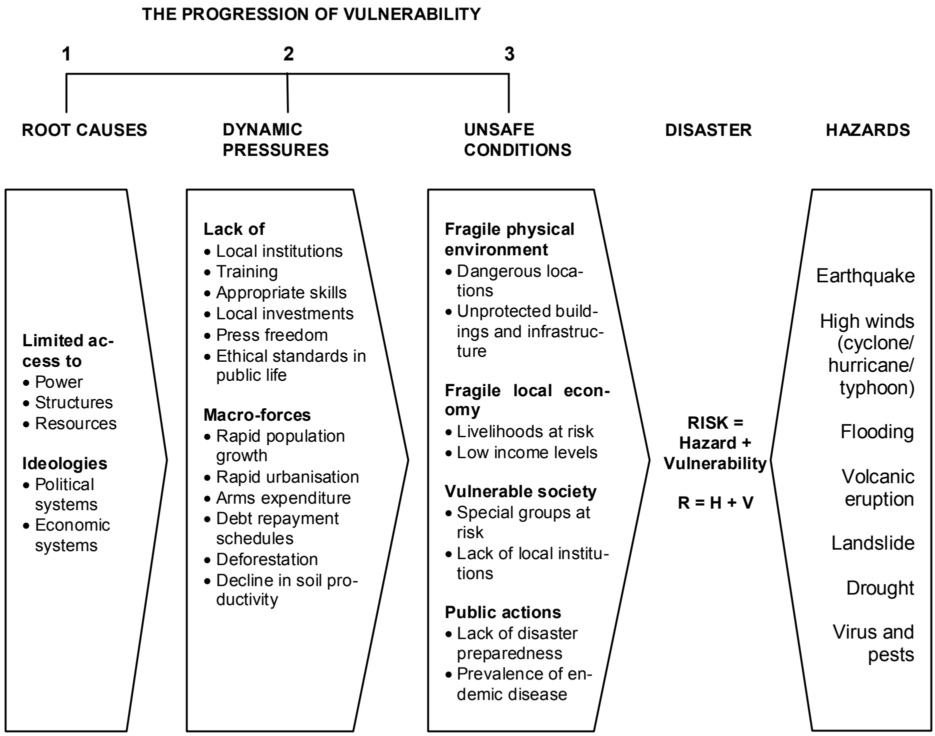


Figure 32 The Pressure and Release Model proposed by Blaikie et al., 1994.

By distinguishing between the causal levels, the model provides clarity in the discussions that we have seen in section 3.2.1. For instance, 'population growth' or 'deforestation' are the dynamic pressures that generate unsafe conditions in which the vulnerability of a population is expressed in time and space in conjunction with a hazard. These dynamic pressures in their turn are from root causes that reflect the distribution of power in a society (Blaikie et al. 1994).

Because of the limitations to the model – its static nature and the exaggeration of the separation of the hazard from the social process – the authors also introduced a second model they called the 'Access Model'. It explains the mechanisms through which the root causes and dynamic pressures result in unsafe conditions. The model is derived from rural economic analyses that identified the way access to resources changed over time for various economic and social groups. It is influenced by the work of Chambers (1983), Sen (1981) and Winchester (1992), amongst others. The authors labelled the model as ‘an explanatory and organizational device’ (Blaikie et al. 1994). and is largely based on factors that influence a household that needs to maintain a livelihood. Some households structure their income opportunities in such a way as to avert the risk of threatening events, such as drought or flood. They also employ survival strategies and coping mechanisms once that event has occurred. The model does not provide a ‘blueprint’ for dynamically modelling vulnerability. However, the focus on households, coping mechanisms and livelihood is an important potential guidance for modelling vulnerability.

The Hazards-of-Place Model

By integrating potential exposures and societal resilience with a specific focus on particular places or regions, Cutter and others developed the Hazards-of-Place model (Cutter et al. 2003). In this framework, risk interacts with mitigation to produce the hazard potential. The hazard potential is subsequently either moderated or enhanced through a geographic filter, such as site and situation of the place, as well as the social fabric of the place. The social and biophysical vulnerabilities interact to produce the overall place vulnerability (Cutter et al. 2003). In Figure 33 this model is illustrated. It positions the various elements of vulnerability, with the arrows connecting them denoting a certain (implicit) relation or influence. Researchers such as Rygel (2005), Yarnal (1994), Clark (1998) and Messner & Meyer (2005) have employed this approach. Messner & Meyer (2005) claim that this model integrates two ‘schools of thought’ on vulnerability – i.e. on biophysical causes and on social causes – and is gaining in significance in the scientific community .

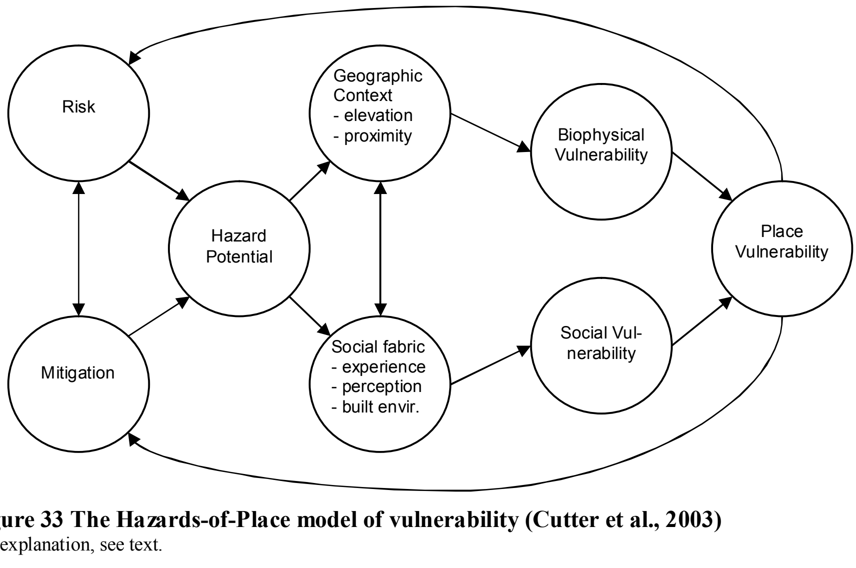


Figure 33 The Hazards-of-Place model of vulnerability (Cutter et al., 2003)
For explanation, see text.

Although the model emphasizes the spatial heterogeneity of vulnerability, it lacks the explanatory depth of the Pressure and Release Model of Blaikie et al. (1994). Furthermore, it does not explain how for instance ‘Geographic Context’ and ‘Social Fabric’ are related and which mechanisms are responsible for the suggested feedback from ‘Place Vulnerability’ to ‘Risk’ and ‘Mitigation’. Problems also arise with the use of 'Risk' in the diagram. The diagram suggest that 'Risk' leads to, or influences the Hazard Potential. In my view this does not conform with the widely adopted definition of Risk = Hazard x Vulnerability. The strength of the model is putting vulnerability in the context of place. I will show later that this place based view of vulnerability has an important role in modelling vulnerability.

Internal-external model (exposure/coping):
Based on the work of Chambers (1989), Bohle (2001) extended the general distinction between the 'external' and 'internal' side of vulnerability, where the external perspective refers mainly to the structural dimensions of vulnerability and risk, while the 'internal' dimension of vulnerability focuses on coping and action to overcome or at least mitigate the negative effects of economic and ecological change (see Figure 34).

Indicated in the figure, this model links vulnerability to a number of existing theories, such as:

- *Human ecology* (Burton et al., amongst others), which explains the relation between human populations and the exploitation of their environment;
- *Entitlement theory*, which relates vulnerability to the incapacity to obtain or manage assets via legitimate economic means ((Lewis 1982; Sen 1983);
- *Action theory*, explaining the means and ways used by the people to act, either by free will or as a result of societal, governmental, or economic constraints (Villagran De Leon 2006); and
- *Access to Assets*, which is considered to be a fundamental factor in the capacity to cope with risks and shocks. The more assets people control, the less vulnerable they are because such assets increase their capacities to cope with risks and disasters. Within the wide range of asset categories, the so-called 'social assets' play a most important role for the most vulnerable populations who, as a rule, control very few economic, political, infrastructural, ecological and personal assets (Bohle 2001).

The model also refers to 'Political Economy Approaches' and 'Conflict and Crisis theory', which put the socio-economic relations as described by the other theories in the actual disaster situation. Bohle (2001) describes the Conflict and Crisis Theory as dealing with 'access to control over resources, assets and coping capacities, which are, as a rule, highly contested in an arena of risk and criticality' and with the capacities to successfully manage crisis situations and solve conflicts. This explicit attention to the crisis situation of a disaster is an important component that is lacking in the aforementioned theories.

The model has been largely based on case studies regarding food security and famine, which limits its use for natural disasters. Although a famine is sometimes triggered by a natural phenomenon, such as a drought or flood, often the root causes lie in market imperfections and poverty (Sen, 1983). With this in mind, it is easy to understand why 'Entitlement theory' is positioned at the 'Exposure' side of the figure: it is because a lack of sufficient entitlements that people get hungry. When using this model for our purpose of vulnerability to floods and storms, the use of the Entitlement theory to explain why people are exposed to floods and storms makes less sense. It is also unclear whether 'Exposure' in the sense used by Bohle also fits for situations regarding natural hazards. For instance, people can get exposed to a hazard, while not being affected by it in case they have made sufficient precautions. In the Bohle model, 'Exposure' already implies a certain harm, to which people have to cope with. The double structure of the model leaves susceptibility implicit. The next framework puts exposure, susceptibility and coping ability in an equal position, which fits better for situations dealing with natural hazards.

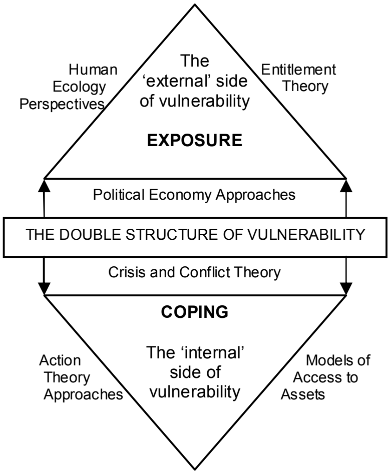


Figure 34 A Conceptual Model for Vulnerability Analysis (Source: Bohle, 2001)

Expanded Vulnerability Framework

Partly from a critique on the Pressure and Release Model, which was considered insufficiently comprehensive for the broader concerns of sustainability science, Turner et al. (2003) proposed an expanded vulnerability analysis. The basic architecture of the framework consists of: i) linkages to the broader human and biophysical (environmental) conditions and processes operating on the coupled system in question; ii) perturbations and stressors/stress that emerge from these conditions and processes; and iii) the coupled human-environment system of concern in which vulnerability resides, including exposure and responses (Figure 35). Vulnerability as such is broken down into three components: exposure, sensitivity and resilience. The authors explicitly mention that the framework is not explanatory, but is meant to provide a template suitable for 'reduced-form' analysis yet inclusive of the larger systemic character of the problem (Turner et al. 2003).

Although the framework abounds in arrows that link components with each other, one direct link is strikingly lacking: the arrow from 'Adjustment & adaptation' to 'Characteristics & components of exposure'. For instance building a flood protection dike as an adaptation measure directly reduces the exposure to floods. Nevertheless, the diagram succeeds in showing the complexity of vulnerability without becoming indecipherable. It therefore has been used as a basis for the conceptual model, presented in the next section, against which I will evaluate the Andhra Pradesh EDSS in Chapter 6.

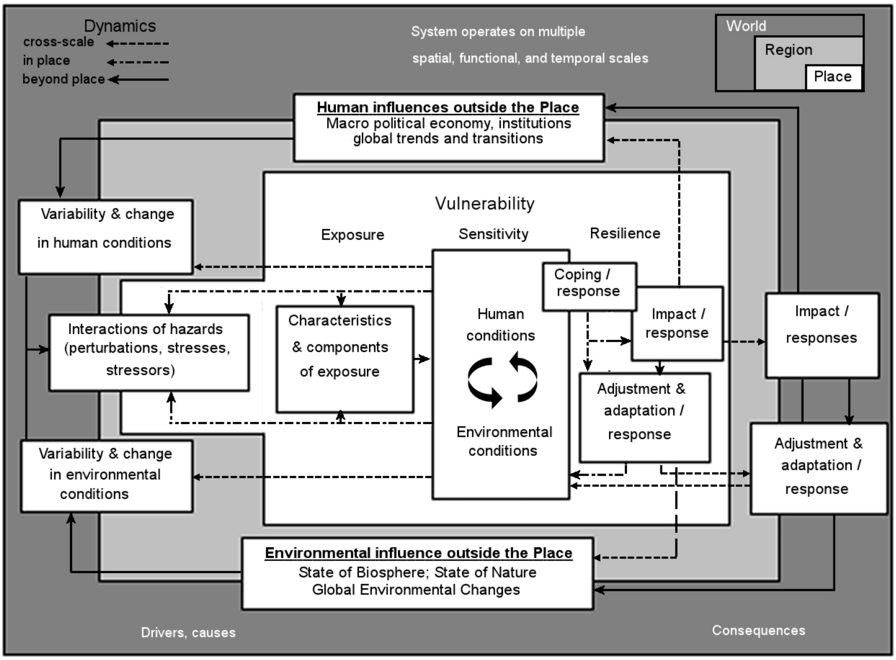


Figure 35 Expanded Vulnerability Framework according to Turner et al. (2003)

3.3 Making vulnerability operational – a conceptual model

On the basis of the concepts and theories on vulnerability that have been described, I distil common elements that need to be taken into account in measuring vulnerability. These elements are *hazard*, *exposure*, *sensitivity* and *resilience*. Relations between these elements, as well as the influences from outside the location where the hazard is physically felt, are provided in the conceptual model I drafted in Figure 36; this is based on the Expanded Vulnerability Framework of Turner *et al.* (2003). Others are also using the 'Turner' Framework. Scott used it in her paper to unravel the relations between environment and chronic poverty (Scott 2006) and Damm (2008) chose this framework to develop a vulnerability map for Germany after a review of different models and concepts.

Compared to the original framework (see Figure 35) the components of Exposure and Sensitivity, Coping, Impact and Adaptations have been detailed. With respect to Coping, the different coping strategies of Chambers & Conway (1991) have been included. Furthermore, a more logical order has been given to Impacts. In my view, impacts, such as deaths, illness and damages originate from exposure and sensitivity. Resilience is the capacity to cope with these impacts, which depends on the human conditions as well as local adaptations. This capacity also determines the impact on the longer time scale, hence the arrow back from Coping to Impact, and eventually to the macro-economic consequences, indicated by the arrow to 'Above local Impacts'. And the missing link – as indicated in the previous section – has been added between 'Local Adaptations' to 'Exposure'. Furthermore, the Local Adaptations have been placed outside the vulnerability box, in order to account for the temporal scale: vulnerability at any given time precedes a future vulnerability after which local adaptations may have occurred. In the next sections the key elements of the conceptual model will be described in more detail.

3.3.1 Hazard

First of all we need to look at '*hazard'*. The hazard is the external phenomenon which occurs in nearly every theory or framework, or is implicitly included as part of exposure. Most authors do not include the hazard itself as an integral part of vulnerability. For instance, in the frequently used definition of Risk = Hazard x Vulnerability, hazard is placed outside vulnerability. Turner et al. (2003) also places 'hazard' outside the vulnerability 'box' in their framework, but do include it in the expanded part of a vulnerability analysis ('multiple interacting perturbations and stressors /stresses'). In the Hazards-of-Place model (Cutter et al. 2003) the hazard is filtered through a geographic (place) and social filter to produce vulnerability. Bohle (2001) does not mention hazard in his conceptual model, but puts the link through exposure to the human ecology perspective. There is another reason not to include hazard with vulnerability: an essential aspect of hazard is probability. Many natural hazards are rather unpredictable and from historical evidence can be assigned a certain frequency of occurrence. Vulnerability, however, is an attribute and does not have a probability. Vulnerability is a dimensionless quantity (Villagran De Leon 2006). It denotes a certain condition *given* a certain exposure to a hazard. Vulnerability is zero if exposure is zero, which can occur either because there is no hazard or if the people are completely protected from it. Therefore, it is more logical to separate the two, as is in line with the earlier mentioned definition of risk, being a function of both hazard and vulnerability.

In practice this distinction between hazard and vulnerability, and more specifically the exposure part of it, is not always easy to make. Take for instance the protection against a flood. If people are protected by higher grounds, for instance by constructing mounds on which the houses are built, we have reduced the exposure and thus vulnerability. Nothing has changed with regard to the hazard: the flood frequency remains the same. If on the other hand the communities are protected with a dyke, which seems not a fundamental difference with constructing mounds, we have to include the probability that the dyke can breach. If we label flood protection by a dyke as part of exposure reduction, we have introduced probability in vulnerability, which by definition is not allowed. The solution therefore is to consider flood protection as a means to reduce the hazard. The consequence is that flood protection does not alter the vulnerability, but does reduce the risk. For instance in a highly protected country such as the Netherlands, this logic implies that although the flood risk is very low, its community is still significantly vulnerable[13].

[13] Interestingly, this insight has only recently emerged in the flood risk management community of the Netherlands. After the greatly increased flood safety since the Deltaworks finished, the issue disappeared from the political agenda almost completely. It was only after Hurricane Katrina created a disaster in New Orleans, that people started to realise that the Netherlands also have a high vulnerability. This resulted in considering the potential consequences when the worst scenario could materialise, i.e. a major flooding of the highly populated western part of the country.

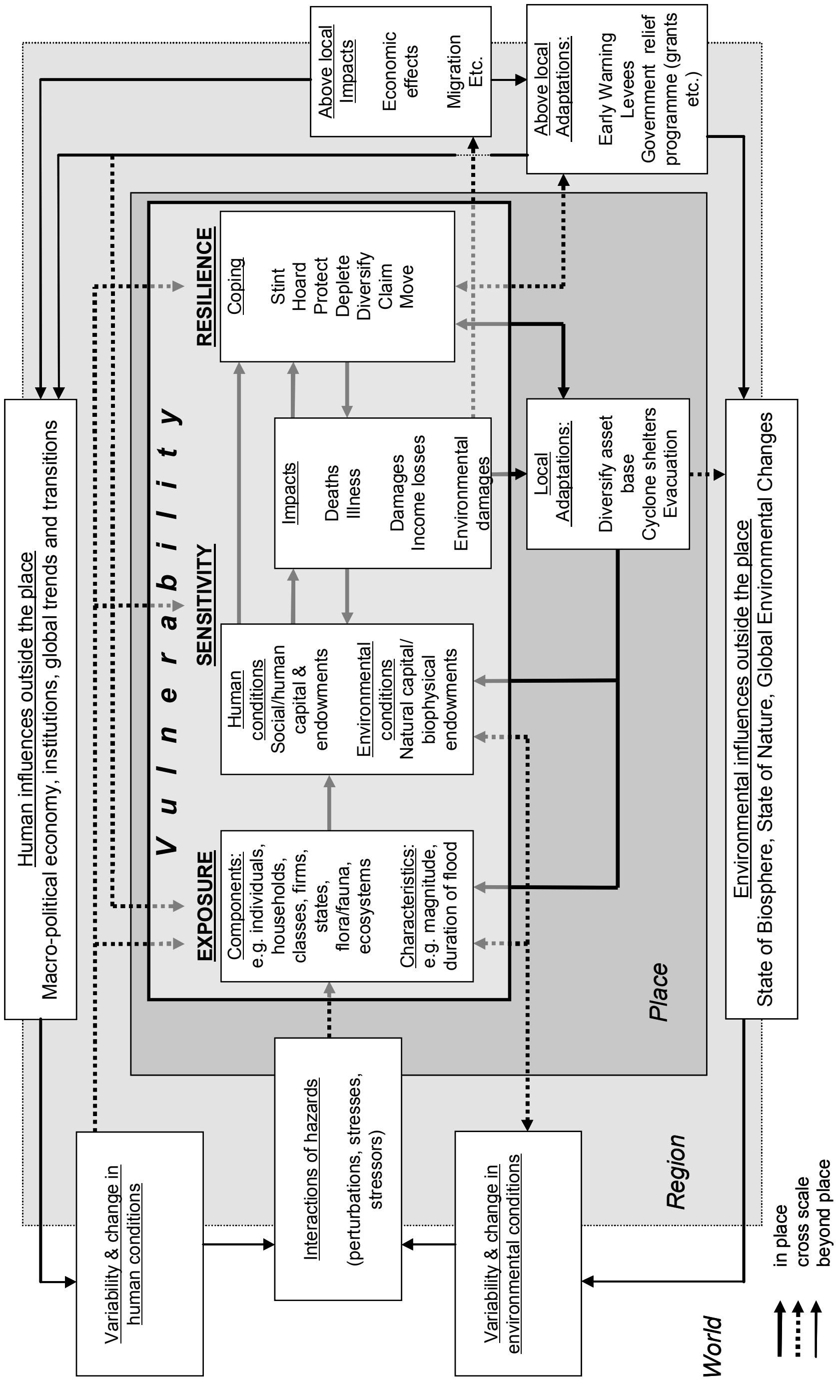


Figure 36 Conceptual Vulnerability Model (adapted from Turner et al., 2003)

This does not imply that vulnerability is completely independent from the hazard probability. For instance, if a community is frequently impacted by a hazard, its overall vulnerability in time could be different from a situation in which the community is rarely impacted. We therefore have to take into account that the structure of the community for which a vulnerability assessment is prepared is 'consolidated' by (or adapted to) the past hazards. For future situations we have to consider this effect too: a significant reduction in hazard frequency could lead to increased population density and economic activity. People become less adapted to the hazard and vulnerability increases.

The hazard in our model is the cyclonic storm. Therefore I have summarised in Box 6 the essential characteristics of this hazard.

Box 6 Cyclones as hazard

What is a cyclone? And what makes it a hazard? Along the East coast of India tropical cyclones originate in the Bay of Bengal as a result of meteorological processes: low pressure systems that can deepen in intensity when moving over sea water that is warmer than 26.5° C. But not all depressions turn into a cyclone: there are at least 6 conditions that have to be met for a tropical cyclone to develop, besides the water temperature this includes an atmosphere which cools fast enough with height so that it is potentially unstable to moist convection and a distance of at least 500 km from the equator so that there is enough Coriolis force (NOAA website, accessed 27 June 2008). The India Meteorological Department uses a classification of storm intensities (Table 24) based on the maximum surface wind speed.

As long as the cyclone moves over the warm ocean waters, it can increase in strength. There the high winds can create huge and precipitous waves. Near to the land the wind-driven waves combined with the low pressure can result in a storm surge, one of the most hazardous elements of the cyclone. The height of this surge depends on the severity of the cyclone combined with the local bathymetry at the landfall position. In Andhra Pradesh storm surges can be as high as 6 metres (O'Hare 2001; Bohle et al. 1994). Over a flat coastal plain the surge can extend many kilometres inland. Once on land the cyclone will gradually decrease and eventually fade out (because it is no longer being fuelled by the warm ocean water), but it can still cause much damage through rainfall and high wind speeds. Often heavy rainfall accompanies the cyclonic storm, that can cause flooding additional to the inundations from the storm surge. The effect of the storm surge is by far the most destructive element of a severe cyclonic storm causing the most casualties and damage, although the excessive rain that sometimes accompanies a cyclone can also cause devastating flooding. High winds create much damage to crops by flattening them, high winds can also blow down electrical and telegraph lines, uproot trees and kill and injure people by causing structural failures in buildings (Winchester 1992).

Table 24 India Meteorological Department classification of cyclonic disturbances

weather system type	Maximum sustained surface wind speed
1. Low (L)	< 17 knots (< 9 m/s)
2. Depression (D)	17 – 27 knots (9 – 14 m/s)
3. Deep Depression (DD)	28 – 33 knots (14 – 17 m/s)
4. Cyclonic storm (CS)	34 – 47 knots (17 – 24 m/s)
5. Severe cyclonic storm (SCS)	48 – 63 knots (25 – 32 m/s)
6. Very severe cyclonic storm (VSCS)*	64 – 119 knots (33 – 61 m/s)
7. Super cyclone (SuCS)*	120 knots (62 m/s) and above

*VSC and SuCS were included in a single category called 'severe cyclonic storm with a core of hurricane winds (SCSCHW) prior to 1998. Source: (Raghavan & Rajesh 2003)

3.3.2 Exposure

Exposure is a major element of vulnerability and is often mentioned either explicitly or implicitly. For instance, in the PAR theory, 'fragile physical environment' (as a component of 'unsafe conditions') denotes the spatial interaction between geographical plus social conditions and an external hazard, just as the Hazard-of-Place model does. Turner et al. (2003), Bohle (2001), Dow (1992), Adger (1999), Buckle et al. (2001), Chambers (1989) explicitly use exposure as part of vulnerability. Exposure forms the interface between the physical environment and the vulnerable entities. To describe exposure, we use information on the hazard event (e.g. flooding extent, depth, velocity and duration) and on the existence of elements (receptors) that are exposed. As such it does not say anything about a possible consequence of this exposure. Just as the exposure of a person to direct sunlight does not tell us if this person get sunburnt.

3.3.3 Sensitivity

Sensitivity is used explicitly by Turner et al. (2003) and is determined by the human-environment conditions of the system. Often used synonyms are resistance (Dow, 1992) and susceptibility (Cutter & Emrich 2006). Other frameworks do not use this term, possibly because the delineation between sensitivity and coping / impact response is not always clear. However, there is a good reason to maintain the distinction as it explains the need for response. For instance, the more earthquake resistant buildings are, the easier recovery and coping will be. Similarly as the person, who is less sensitive to direct sunlight, does not have to bother protecting his or her bare skin to the same extent as someone who is more sensitive. Sensitivity does not only refer to physical aspects (such as the strength of houses), but also – and not in the least – to social, mental and emotional elements.

Combining the hazard with exposure and sensitivity results in what I will call the *direct impact* of a disaster. Impact can be anything that a storm provokes, in terms of damages to property and crops, casualties, destruction of infrastructure, or loss of habitat. Note that in many vulnerability assessments, the calculation of damage or deaths is the end product. In our framework, however, this is only part of the output and an essential input to the determination of resilience.

3.3.4 Resilience

Resilience is the third component of vulnerability and is in itself a 'container' concept. Originating from ecosystems theory (Holling 1973) it refers to all kinds of mechanisms through which dynamic systems respond to external perturbations. In vulnerability theory, resilience and similar terms are often used, such as coping, response, adjustment, adaptive capacity, adaptation, recover, etc. In our analogy of the sunbathing person, resilience is the ability of the person's body to recover from the burned skin. Note that recovery is the process, while resilience denotes the ability to recover (i.e. resilience is a system characteristic).

In the framework of Turner et al. resilience is represented by three components of responses: *coping*, *impact* and *adaptation*. However, it is not quite clear how impact is defined. I prefer to consider 'impact' as resulting from exposure and sensitivity (see above) that provides input to determine coping and adaptation. Coping is how the people, or society as a whole, can minimise the consequences of a certain impact. Also adaptation can be a form of coping, but I use this word for a different time frame than coping: it is the adjustment of the human-environment system that is provoked by a certain impact. I therefore do not include it in my definition of vulnerability (see section 3.3.5). Adaptations are long-term management strategies (Scott 2006; Moser 2008). In other words: coping is how people deal with a disaster in a given human-environment system at t_0, and adaptation is changing the human-environment system that could lead to a different coping capacity on t_{0+x}.

There are many mechanisms for coping with losses, such as money from the bank; remittances from family not affected; grants from governments, food/clothes/bedding etc. aid from NGO’s and churches; food for work programmes, migration; selling assets for consumption; reducing consumption; reciprocal labour, using ‘claims’ (such as insurances) and loans. Chambers & Conway (1991) use the following categories of coping strategies:

- **Stint**: reduce current consumption; shift to lower quality foods; draw on energy stored in the body;
- **Hoard**: accumulate and store food and other assets;
- **Protect**: preserve and protect the asset base for recovery and reestablishment of the livelihood;
- **Deplete**: draw upon household stores of food; pledge or sell assets;
- **Diversify**: seek new sources of food – wild food, gleanings, wild animals, food stored by rats and other animals; diversify work activities and sources of income, especially in off-seasons;
- **Claim**: make claims on relatives, neighbours, patrons, the community, NGO’s, the government, the international community, variously by calling in debts, appealing to reciprocity and good will, begging, and political action
- **Move**: disperse family members, livestock, and assets; and/or migrate.

Evidences of the existence of these coping strategies for floods and cyclonic storms are given by Winchester (1992), Del Ninno et al. (2003), Ahmed (1992) and O’Hare (2001). And it is with regard to the coping ability that we see large differences in societies. For instance O’Hare describes that after the 1997 cyclone in Andhra Pradesh, the great majority of the landowning farmers in the Godavari Delta were able to rely on savings and other resources, whereas especially the landless agricultural labourers were much more affected and had to diversify work activities including (seasonal) migration (O'Hare 2001). A household with good access to capital (via markets or via informal social arrangements) can borrow against future earnings to immediately rebuild asset stocks. Such a household might be expected to recover quickly. A household without this access may face a doubly slow recovery process, or even fall into the poverty trap (Carter et al. 2007). Because of these large differences in coping capacity, vulnerability is not equally distributed among people, even if they are exposed to the same hazard. This should therefore be reflected in a measure of vulnerability.

3.3.5 A working definition of vulnerability

The above considerations brings us to an operational definition that I will use throughout the research on modelling vulnerability:

Vulnerability to a hazard is an attribute of a person or social system determined by a combination of the exposure, sensitivity and short term resilience of that person or social system. Short term resilience is determined by the coping capacity of a person or social system to the disaster impact.

This implies that in order to measure vulnerability, such a method should include – either explicitly or implicitly – the measurement of exposure, sensitivity and resilience. Furthermore, the measurement of resilience should identify coping capacity. However, we choose not to include long term resilience, which is determined by the adaptation capacity of a person or social system to recurring disasters, in vulnerability at any given moment in time. In the next section I will look into a number of currently available measurement methods and evaluate to which extent they take these elements into account.

3.4 Measuring vulnerability

Now that I have conceptualised vulnerability, I will look for ways to quantify vulnerability. I reviewed literature to find examples of quantification and evaluate their usefulness for modelling.

The need to measure vulnerability arises in the context of a vulnerability assessment (VA). A VA can be described as a systematic evaluation of the vulnerability of an entity (a household, a community, region, nation, etc.) with respect to different types of hazards, often with the aim to reduce that vulnerability. The procedure and approach of a VA logically depends on the specific context as well as on the definition of vulnerability that is chosen. In some cases, however, the opposite is true: some approaches narrow down the definition of vulnerability to a format that allows for its assessment using available data (Villagran De Leon 2006).

First a number of existing methods are given of assessments, based on the author's experiences and a literature review. These methods are evaluated with respect to their scope and their usefulness for a vulnerability model.

3.4.1 Existing vulnerability assessment methods

Recently a number of indicators have been developed for assessing vulnerability at a national level. With these indicators the relative vulnerability between countries can be measured. Examples include the Disaster-Risk Index of the Bureau for Crisis Prevention and Recovery of UNDP (Pelling 2004), a Natural Disaster Vulnerability Indicator for Small Island Developing States (Pelling & Uitto 2001), a Social Vulnerability Index for Africa (Vincent 2004) and the Prevalent Vulnerability Index (Cardona 2005). What they all have in common is that these indices use a number of socioeconomic variables that are mostly available through national statistics, such as GDP per capita, adult literacy, social disparity (Gini coefficient) and unemployment rate or indices derived from these statistics, such as the human development index. These methods assume that there is a close relation between the ability to cope with a disaster, or the level of resilience, and the overall socioeconomic situation of a country. Some methods are based on an empirical relation. For instance the Disaster Risk Index includes those socioeconomic variables that best explain recorded mortality to individual hazard types. But mostly these relations remain rather implicit, also because most of these indices do not focus on a specific hazard. In other words, they measure intrinsic vulnerability: no specific hazard type or scale of impact is required (Pelling 2004). Therefore, these methods are useful mainly for comparing existing vulnerabilities between countries.

Two interesting methods at national level aim at assessing the vulnerability of the representative of the nation itself, i.e. the national government. The first is the Disaster Deficit Index developed for the Inter-American Development Bank. This index measures the ratio between the expected losses received by the state and the capacity of the state to generate construction funds from private, government and international sources when hit by a maximum considered disaster event. Events are considered with return periods of 50, 100 and 500 years. A DDI value greater than 1.0 indicates a lack of financial capacity to cover the costs of disaster impact (Pelling 2004). In a similar fashion, but then in the form of a model that can be used for a specific disaster, the Catastrophe Simulation Model (CATSIM) has been developed. by the International Institute for Applied Systems Analysis (IIASA). It can be used to assess the financial vulnerability of country governments to disasters of natural origin, and to examine pre-disaster financial measures for increasing the coping capacity and resilience of the public sector. The question underlying the CATSIM tool is whether a government is financially prepared to repair damaged infrastructure and to provide adequate relief and support to the private sector for the damages of specific hazards. It calculates for a given hazard, such as a flood or earthquake the potential asset losses based on frequency and magnitude of the hazard, the elements at risk and the susceptibility of these elements to physical damage. The financial vulnerability is measured as a ‘financing gap’ i.e. the difference between the available funding and the government’s post-disaster financial obligations (Mechler et al. 2006).

In analogy with the vulnerability indices for nations, also methods have been developed for sub-national and local level. In the USA and based on the Hazard-of-Places model, Cutter et al. (2003) developed the Social Vulnerability Index on a county level. Socioeconomic and demographic data were used in a factor analytic approach that resulted in 11 independent factors, which were placed in an additive model to compute a summary score: the SoVI. In the SoVI each factor is viewed as having an equal contribution to the overall vulnerability (Cutter et al. 2003). Based on similar theory, Tapsell et al. (2002) developed for the UK a Social Flood Vulnerability Index (SFVI), which measures the more intangible impact that floods could have upon the communities potentially affected. The SFVI is a composite additive index based on three social characteristics (the long term sick, aged over 75, lone parents), and four financial-deprivation indicators (unemployment, overcrowding of households, non-car ownership and non-home ownership). These parameters were chosen by the developers as proxies for vulnerability and because of pragmatic reasons (availability of census data with sufficient level of resolution). The SFVI was applied for two floodplain areas in the UK where flood-alleviation schemes have been implemented in the recent past (Tapsell et al. 2002).

An example of a Social Vulnerability Index is supplied by Rao et al. (2007), who apply such a the method to cyclonic storms occurring along the Andhra Pradesh coast. In a study parallel to, yet independent from, the Andhra Pradesh project in which the EDSS was developed, an overall vulnerability map of the coast was prepared. Eleven socioeconomic parameters ranging from ‘Senior citizens, ‘Type of housing’, ‘Income’ and ‘Women’ to ‘Backward caste population’were each given a weighing. Depending on the socioeconomic parameter values for a mandal and its spatial location in a hazard zone (based on the physical vulnerability to surges and high winds), a vulnerability index was assigned. The rationale of the weighings determining vulnerability remains unclear, however, and the method is largely descriptive. Many of the socioeconomic parameters are dependent to each other, such as ‘Income level’, ‘Type of housing’ and ‘Backward caste population’. Although it allows for analysing different scenarios for the physical vulnerability, this is not possible for the socioeconomic conditions since no causal relationships between the parameters are given.

Whereas most of the previously mentioned methods focus on the social vulnerability and mostly are of a descriptive nature, a wide range of methods has emerged that models the hazard and its direct consequences (but leaving out the longer term consequences). Covering only a part of the vulnerability equation, these damage and casualties assessments do provide *essential quantitative information* to assess vulnerability. And they are probably the most widely used quantitative assessments worldwide. Examples are damage and casualty assessments (DCA) of a large scale flooding in the low lying parts of the Netherlands (Anonymus 2005; Van der Veen & Logtmeijer 2005), flood risk maps for the Scheldt river in Belgium (Strubbe et al. 2005); high-resolution inundation and loss modelling for New Zealand (Reese & Smart 2009). The use of these sophisticated models is mostly to identify areas at risk, which can then be published as ‘hazard maps’ and used in spatial planning, for insurance purposes and for evacuation plans. An example is the Flood Insurance Rate Map (FIRMS) of FEMA (USA). A recent modernization of these maps includes the effects of a tsunami (Wong et al. 2005). Also ‘HAZUS-MH’ needs to be mentioned here. HAZUS-MH is a nationally standardized risk assessment model developed by FEMA to estimate damage and loss from natural and man-made hazards. It includes modules to assess the damage and economic loss by earthquakes, hurricanes and floods (FEMA 2007). Specific models for the insurance companies have been developed over the past decade, such as MRFlood from Munich Re (Kron 2005). However useful these models are in risk management and planning purposes, the specific social vulnerability elements, as found in the national and sub-national indices mentioned earlier, are not included.

One example in which a strong relation has been forged between the physical hazard (the flood itself) and social vulnerability, is the resilience indicator for flood risk. In her thesis, De Bruijn (2005) has developed a set of indicators to describe the system’s reaction to floods in a river basin. Basically the river system can react either through resistance (defined as the ability of a system to withstand disturbances without reacting at all) or resilience (defined as the ability of a system to recover from a response to a disturbance). These indicators relate to:

- The direct and indirect impacts (damages) immediately after a flood;
- graduality of the increase of damage with increasing discharges, and
- recovery rate from flood impacts.

The method for assessing the recovery rate is based on the existing vulnerability frameworks of CVA, PRA and sustainable livelihood approach. It involves a *qualitative* analysis based on physical, economic and social factors, each given marks between 1 and 10. The physical factors relate to the flood duration and relief. The economic factors are grouped in three categories: financial situation before the flood, aid from other areas and spreading of impacts to other areas. The social factors are arranged in three groups, namely human capital, preparedness and social capital.

The achievement of this method is that it integrates both physical and socioeconomic aspects of floodplain resilience into one evaluation framework. Its weak point is the scoring method for the socioeconomic factors, which is rather intuitive.

Very few approaches exist that have a high level of resolution, i.e. up to the level of impact on households or individual enterprises. An example is the Household Sector Approach CIMDEN 2001. Vilagran de Leon has developed a procedure to assess different types of vulnerabilities associated with the housing sector at the local level: physical or structural, functional, social and economic income. In this method, each type of vulnerability is measured through parameters which are directly related to the type of vulnerability in question. For example, in the case of volcanic eruptions, the structural vulnerability of a house is analysed through five parameters: walls, roof materials, roof inclination, roof support material, doors and windows. The VA can be employed to assess the vulnerability of a single house, but can be aggregated at the community, municipal, province and national level. The method requires a specific survey at the household level (Villagran De Leon 2006). Another example is the identification of farm level vulnerability (Brémond et al. 2008). It makes use of a conceptual model of the direct effects on the farming system and also of the distribution chain which, if damaged by a flood, prohibits the selling of farm products even if the farm itself is not damaged.

3.4.2 Evaluation of existing methods

In order to evaluate the methods for measuring vulnerability described above I will first review the methods with respect to the operational definition of vulnerability (see section 3.3). In this definition I distinguished the three basic elements of vulnerability: exposure, sensitivity and resilience. Each of these elements can be further described with the following indicators or variables (note that these are not necessarily exclusive):

Exposure	hazard location or pathway (e.g. 'areas liable to flooding')
	people at risk
	elements at risk
Sensitivity	preparedness (incl. evacuation plans)
	human physical harm (casualties/health problems)
	economic loss
	construction fragility
	social susceptibility
Resilience	coping/recovery rate (socioeconomic)
	general socio-economic level as potential for resilience

The methods are scored against this list thereby showing the degree of coverage of the concept of vulnerability (Table 25). It shows that very few, if any methods cover all components of vulnerability at some depth. Typically, there are generic vulnerability assessments that do not specify the type of hazard, which by definition leave out the exposure part. They provide an indication of the social vulnerability, usually at a high level of scale (e.g. countries). Examples are NVDI and PVI. At the other end of the spectrum we find Hazard Mapping, that only covers the exposure part of the vulnerability equation. The Damage and Casualties Assessment methods cover both exposure and susceptibility, but rarely include the resilience aspects.

Quantification of vulnerability has progressed, evidently, mainly with respect to exposure and sensitivity. For instance, damage and casualty risk calculations for flood hazards have greatly benefited from enhanced hydraulic modelling capacities, combined with geographical and demographic data. Sensitivity is often approximated through relatively simple exposure-response curves (‘fragility’ curves). The more difficult to quantify social sensitivity is often derived indirectly by the general socio-economic conditions of a nation or region. The least dealt with and quantified element is resilience. Most often this is approximated, as social sensitivity, by the general socio-economic condition.

Almost absent are methods that directly link specific exposure of hazard with sensitivity and resilience in a fully quantified way that enables modelling of vulnerability. One of the few examples is the earlier mentioned work of De Bruijn (2005), who developed resilience indicators (RI) to assess resilience of floodplains, that measures recovery capacity depending on physical, economic and social factors.

Table 25 Scope of a number of quantitative methods for vulnerability assessment

	Hazard maps	Hazus	DCA	DRI	CATSIM	NDVI	SVI - Africa	DDI	PVI	CIMDEN	SoVI - USA	SFVI	RI
exposure													
pathways/location	x	x	x							x		(x)	x
people at risk	x	x	x	x									x
elements at risk	x	x	x		x			x					x
sensitivity													
preparedness													
human physical harm(casualties/health)		x	x	x									x
economic loss		x	x		x			x					x
construction fragility		x	x		x					x			
social susceptibility				x					x	x	x	x	x
resilience													
coping/recovery rate (socioeconomic)					x								x
general socioeconomic level				x		x	x	x	x	x	x	x	x
scale level													
national/international			x	x	x	x	x	x	x	x			
regional/provincial		x	x							x	x	x	x
municipal/local		x	x							x			
household/individual										x			
hazard types													
Earthquakes	x	x		x	x					x			
Volcanoes	x									x			
Droughts													
Floods	x	x	x	x	x							x	x
Storms/cyclones	x	x	x	x	x								
not specified / other						x	x	x	x		x		

Legend:

CATSIM	: Catastrophe Simulator	NDVI	: Natural Disaster Vulnerability Indicators
CIMDEN	: Household Sector Approach	RI	: Resilience Indicator
DCA	: Damage and Casualties Assessment	PVI	: Prevalent Vulnerability Index
DRI	: Disaster Risk Index	SFVI	: Social Flood Vulnerability Index
DDI	: Disaster Deficit Index	SoVI-USA	: Social Vulnerability Index-USA
Hazus	: FEMA - HAZUS model	SVI-Africa	: Social Vulnerability Index – Africa

3.5 From assessment to modelling

3.5.1 Why should we model vulnerability?

As we have seen in the previous section, most vulnerability assessments enable comparison in a spatial sense, reflecting the need to compare the vulnerability of regions, countries and sectors. Decision makers are often interested in knowing which countries, regions, communities or sectors are most vulnerable, so that they can prioritize their activities (Hinkel 2008). Accordingly the Hyogo Framework for Action prioritized the development of indicator systems for disaster risk and vulnerability as one of the key activities enabling decision makers to assess the possible impacts of disasters (Bogardi 2006 in Birkmann 2006)

But in addition to this, there is a need to compare vulnerability in time: past, present and future. This requires a model. Vulnerability is a dynamic phenomenon. It can change because of many factors. For instance, the environmental conditions change (example sea level rise, loss of protective mangrove forests). Population growth and migration patterns lead to an increase in the number of people that live in hazardous places. Economic growth puts more investments at risk. These are more or less autonomous developments that change the pattern of vulnerability. In anticipation to this, communities and stakeholders demand protection measures, especially in the wake of a recent disaster. Governments react by developing disaster mitigation policies and programmes. For *ex ante* assessment of these measures, support tools, such as explorative models, are needed.

In summary, the advantage of a vulnerability model is that it can simulate changes in vulnerability when a system changes. Modelling vulnerability can be useful for:
- Analysing the societal impacts of changes in hazards;
- Analysing the effectiveness of measures aimed at reducing vulnerability;
- Assessing the impact of exogenous developments, such as climate change or macro-economic development on vulnerability.

3.5.2 What makes vulnerability modelling difficult?

There are people who say that vulnerability cannot be modelled. For instance Twigg (in Twigg & Bhatt 1998) has stated that '*vulnerability is too complicated to be captured by models and frameworks. There are so many dimensions to it: economic, demographic, political, and psychological. There are so many factors making people vulnerable: not just a range of immediate causes but – if one analyses the subject fully – a host of root causes too …*' (Twigg & Bhatt 1998). Indeed, vulnerability is a complex issue, as we saw in the previous sections. Many attempts to assess vulnerability as a metric do so by defining indices or indicators based on quantitative parameters describing these physical and socioeconomic conditions. Some of these methods cover the three components of vulnerability: exposure, sensitivity and resilience. Very few of these methods actually come to the point where changes in the human-environment system are modelled. The reason for this could be that, as these indices cover so many aspects (such as location, housing condition, economic structure, income, gender, age, education level etc.) it would imply modelling of the entire human-environment system at a level of detail and complexity that has not been seen before. In other words: the *theoretically* defendable argument that vulnerability should be treated in a holistic and integrated way makes it *practically* almost impossible to apply it in a modelling context.

On the other hand, the complexity of the concept is an argument in favour of modelling vulnerability. This seems to contradict the previous statement that it seems practically impossible to apply the concept in a model. But as models can assist us particularly in those situations where many components of a system interact in such a way that the human brain is not able to oversee all possible consequences of change, this certainly applies for our vulnerability concept. Our experience in the Andhra Pradesh project is that the model indeed enabled an effective structuring of the large amount of data and provided improved insight in the behaviour of the human-environment system. That this model does not cover all aspects of vulnerability (as we will see later), but has deliberately focused on its differential aspect at household level, was a necessary limitation without which the model could not be developed.

Modelling vulnerability can be seen as a logical extension of the hazard –vulnerability modelling chain: looking at the scientific and technological developments, there is a visible trend moving from modelling of the hazard towards damages and casualties (Table 26). A logical next step would be to extend this chain of models by including the sensitivity and resilience aspects of vulnerability. The reason that this has not yet become the state-of-the-art in disaster modelling lies in the increasing complexity of the components and their inter-linkages requiring an interdisciplinary modelling approach.

Table 26 The hazard - vulnerability modelling chain

model	example / use	main disciplines	complexity
hazard probability modelling	Q-h relations, frequency duration curves	meteorology, hydrology, hydraulics	
hazard pathway modelling	flood modelling	meteorology, hydrology, hydraulics, geography	
damage modelling	flood damage modelling, wind damage modelling	meteorology, hydrology, hydraulics, geography, engineering science, economics	
casualties modelling	flood casualties modelling	meteorology, hydrology, hydraulics, geography, engineering science, economics, behavioural science, health science	
vulnerability modelling	flood vulnerability modelling	meteorology, hydrology, hydraulics, geography, engineering science, macro-economics, resource economics, behavioural science, health science, environmental science, political science etc.	

3.5.3 Model building blocks

Based on the review of the existing measuring methods for vulnerability (section 3.4) we can now take stock of the components available for exploratory modelling of vulnerability to floods and storms.

- Exposure: hazard pathway modelling gives us a reasonable good insight in where inundation could take place. Large range of models is readily available. Depending on the type such models provide just the inundation pattern and depth (e.g. combined 1D river model with GIS) or also flow velocity and duration of the inundation (1D/2D hydrodynamic models).
- Sensitivity and impact: damage models are available using fragility curves for buildings and infrastructure, damage functions for crops, etc. Also a variety of casualty models are available (cf. Jonkman & Vrijling 2008). For social sensitivity indices exist but are not yet available as part of a prediction or exploratory model.
- Resilience: very few modelling approaches exist that model resilience along a range of scale levels.

3.6 Conclusions

The literature on vulnerability shows a variety of theories and definitions, but with a development towards a multi-faceted, integrated perspective that includes both physical, socioeconomic and cultural conditions. There is an internationally accepted way of thinking about vulnerability in the context of disaster management (cf. the Hyogo framework for action). This gives at least some guidance, but of course there remains a great deal of variation in the scientific approaches to making vulnerability assessment operational.

As I have shown there are three components in most of the definitions and theories: exposure, sensitivity and resilience. It can be expected that a certain standardisation of methods will emerge that combine these components for use in disaster management and decision making (White et al. 2001). I will use these elements in the evaluation of the vulnerability model described in the previous chapter.

The expanded vulnerability framework of Turner et al. (2003) explicitly denotes the three common elements in a logical order, acknowledging the interaction between the physical (environmental) conditions and human conditions. It also positions the various elements at three spatial levels: world, region and place. It therefore integrates many aspects of the other conceptual models for vulnerability, described in the previous sections, which makes it a suitable candidate as reference for the model evaluation. For reasons expressed earlier, some modifications to the framework have been made, which makes it more comprehensible and useful as a conceptual model.

The literature review on vulnerability measurements shows that these are mainly developed for describing the current state of vulnerability (at different scale levels). Quantitative modelling is still largely lacking. Turner et al. (2003) stress that vulnerability analyses 'must be comprehensive, treating not only the system in question but also its many and varied linkages'. According to Polsky et al. (2007) 'adopting a vulnerability perspective demands a thorough investigation of biophysical, cognitive, and social dimensions of human-environment interactions. Strictly speaking, to conduct a vulnerability assessment means that no element of the human-environment system may be simplified away or considered a mere boundary condition.' This poses a tremendous challenge to the design of a vulnerability assessment model. In the next Chapter we will see what the state-of-the-art in integrated assessment modelling can offer to meet this challenge.

Coming back to the research question we see that the following components are of relevance:

RQ1: What are the characteristics of vulnerability and how can these be conceptualised?

- Vulnerability is a multi-faceted and dynamic concept that includes both physical, socioeconomic and cultural conditions. There is no single universally accepted definition. I use a working definition based on three elements: exposure, sensitivity and resilience;
- These elements are linked in a conceptual, place-based model, adapted from literature.

RQ 2: How can we model vulnerability?

- Modelling vulnerability requires an integrated, interdisciplinary approach;
- Quantitative vulnerability models are lacking.

4 Choices in integrated modelling

This chapter describes integrated modelling and its state-of-the-art. The focus is then turned towards key methodological issues in integrated modelling. Five essential types of integration problems are identified that influence choices in integrated modelling. The chapter ends with a list of generic validation criteria. Both the integration problems and validation criteria will be used later in the analysis and evaluation of the design and application of the EDSS.

4.1 Vulnerability and the need for integration

In Chapter 2 I presented an integrated model for analysing the effects of development scenarios and policy measures on cyclone vulnerability of the Andhra Pradesh coast. I showed that in order to be able to develop this model many choices had to be made, with respect to the output variables, the temporal and spatial scales of the simulations, the level of integration and so on. For practical reasons, these choices are inevitable when constructing such a model. But at the same time these choices tend to reduce the integral character of the vulnerability concept which, as we concluded from Chapter 3 requires an integrated and interdisciplinary approach. The question thus is how these choices affect the overall quality of the model.

To answer this question I will need to go deeper into these choices, especially those that relate to the aspects of integration. In this chapter I will show that many of these choices are typical for integrated modelling and I will search in the literature for ways to deal with these choices. In addition I will need to find ways to evaluate the overall quality of the model, in order to determine the impact of the choices which were made.

In this chapter use is made of the knowledge gained in the broad field of integrated assessments, policy analysis, decision support systems and integrated modelling. The chapter is structured in four sections: i) the origin of integrated modelling, ii) characteristics of integrated models, iii) methodological issues in integrated modelling and iv) model validation.

4.2 The origin of integrated modelling

As I am dealing in this research with the design and evaluation of a computerised, mathematical model for vulnerability, I will limit the description of models in this chapter to systems designed to run on a computer such as simulation models and decision support systems. Hence, other types of models, such as mental models and physical scale models are not considered here.

Ever since the potential role of computers has been recognised as an instrument to study complex systems, recent history shows an expanding diversity of models in various stages of integration. In the field of environmental decision making, these models are the analytical tools that help us to study the interconnected physical, biological, economic and social systems (Sharma & Norton 2005). One of the first examples of an integrated model – however not called that way – was The Limits to Growth model (Meadows et al. 1972). This study looked at the prospects of population growth and industrial production in the global system over the next century. More recent examples are the climate change models IMAGE (Rotmans 1990) and TARGETS (Rotmans & Vries 1997). TARGETS (Tool to Assess Regional and Global Environment and Health Targets for Sustainability) consists of sub-models that deal with population and health, energy, economic projections, biophysics, land and soil, and water. The RAINS model for acid rain in Europe (Hordijk 1991) was a successful example of the use of an integrated model for policy negotiations. Integrated models have become recognized as an appropriate tool to generate policy-relevant insights into the climate change problem (Toth 2003). But they are also criticized as being exponents of 'science as problem solver': *'IMAGE treats the questions as if science can and should provide an –ultimately calculable – answer with unshakable authority*' (Sluijs 2001).

In the field of policy analysis and water and coastal management we also find many examples of integrated models developed for decision support, such as PAWN (Pulles 1985), DIVA (Hinkel & Klein 2009), Catchment2Coast (Monteiro & Marchand 2009), WADBOS (Engelen et al. 2003), RAMCO (De Kok et al. 2001). This list can easily be expanded with hundreds of examples from similar environmental fields, such as land use management, air quality management etc.

As common to a typical emerging scientific field, integrated modelling is conducted in various different scientific communities of practice, each using a slightly different terminology and scope. There are many examples of modelling activities in science-policy interfaces (such as policy analysis) that are not always labelled as 'integrated models' but do not essentially differ from those who are. I will use 'integrated model' in the broadest sense possible, not restricted to a certain scientific community. In order to get a better understanding what integrated models are, it is however necessary to be acquainted with some of the most important (applied) research fields from where these models emerged.

There are at least two strands of origin from which integrated models have developed: from *systems analysis* and from the integrated assessment *research on climate change*. Systems analysis is the multidisciplinary problem-solving activity that has evolved to deal with the complex problems that arise in public and private enterprises and organizations. It thus overlaps with policy analysis, a term that is often used as a synonym for system analysis, especially in the USA. Although systems analysis is broader than modelling, modelling often plays an important role. Systems analysis needs models to predict the consequences that would follow were an alternative to be chosen and implemented (Miser & Quade 1985). These models need not necessarily be highly integrated, since the goal of systems analysis is to be as comprehensively relevant as necessary to produce useful results. From the very first studies on military cost-effectiveness analyses to highly complex problems in the human-environment relationship, systems analysis models have become more integrated. In the field of water resources planning for example, already more than two decades ago existing hydrological, hydrodynamic and water quality models were integrated in a computational framework based on systems analysis (Koudstaal 1985).

Closely related to the emergence of system analysis is the development of decision support systems (DSSs). Probably the earliest examples of decision support systems date back to the '70s of the last century. At that time most of the DSSs were developed for business decisions and can be considered as a spin off from operations research (Turban 1983; Doukidis 1988; Kettelhut 1991). They are used to support strategic decisions involving allocation of resources, logistics, external markets, new products and changing competitors. Nowadays, many DSSs are developed for the public decision domain, such as for infrastructure, energy and environment policy development (Courtney 2001; Westmacott 2001)

Systems analysis can be considered as basically emerging from a demand – from the manager of a company to the decision-maker within a national administration – to use scientific knowledge to solve a problem or support a decision. It is therefore closely related to the emerging field of policy analysis, which I will discuss in more detail in the next chapter.

'Integrated Assessment' (IA) can be considered to have emerged from a more basic scientific urge to describe and understand the human-environment complex. Influenced by serious environmental concerns related to acid rain, climate change, land degradation, water and air quality, forest and fisheries management and public health, scientists turned their attention to the possible causes of these problems. This contributed to their emergence on the political agenda, and are thus an example of the science-policy interface through agenda setting (Van den Hove 2007). Integrated assessment and modelling is currently still considered as a 'problem-focused area of research' but with the connotation that the research is often *project-based*, and undertaken on a *demand-pull*, or *stakeholder needs* basis. IAM projects are generally undertaken to address specific sustainability or management issues, in contrast to previous modelling when research was often science driven and focused on providing complex systems descriptions and prescriptions for decision makers (Parker et al., 2002). Hence, both strands seem here to come closely together.

The Integrated Assessment Society (TIAS) on their website, defines IA as '*the scientific "meta-discipline" that integrates knowledge about a problem domain and makes it available for societal learning and decision making processes*' (www.tias-web.info, accessed 24 July 2007). Rotmans provides the following definition: '*Integrated Assessment is a multi- or interdisciplinary process of structuring knowledge elements from various scientific disciplines in such a manner that all relevant aspects of a social problem are considered in their mutual coherence for the benefit of decision-making'* (Rotmans 2001). Other definitions of IA circulate, but most have three elements in common: multi-or interdisciplinarity, structuring of knowledge and decision-support.

IA fits well in the current developments in the world around us: globalization, self-conscious civilians, an open information society, interdependencies between sectors and countries and environmental problems. With this rapidly changing world comes the need for a new science. Governments and society now require more accountability – and they require not just outputs (scientific papers), but also outcomes – science must make a difference (Harris 2002). As Funtowicz & Ravetz (1993) aptly formulated: *'After centuries of triumph and optimism, science is now called on to remedy the pathologies of the global industrial system of which it forms the basis [...] New styles of scientific activity are being developed. The reductionist, analytical worldview which divides systems into ever smaller elements, studied by ever more esoteric specialism, is being replaced by a systemic, synthetic and humanist approach'.* Integration thus follows from the growing understanding that the various pieces of the societal puzzle can no longer be examined in isolation (Rotmans 2001).

Clearly IA is not fundamental science. It is applied and focused on problem-solving or is at least problem driven[14]. Or as Harris (2002) states: it is 'science in the context of its application'. This has a wide number of implications, that inextricably belong to the peculiarities of science-policy interfaces. It means for instance, that some processes, such as problem definition, choices of boundaries, variables and methods, are not isolated from social processes. Hence, issue-driven science is a value-laden social process (Van den Hove 2007). Many consider IA as a blend of art and science (Toth 2003), meaning that it does not only adhere to a rigid scientific method, but that also other virtues are required (such as social learning).

In conclusion, we see that integrated models are increasingly being used in management and policy decisions through operations research and systems analysis. In this explicitly value-laden context, scientific knowledge is called in to provide objective information that is used in the decision-making process. As we will see in the next chapter on policy analysis, this 'rational', modern analytical concept has not proven to be without serious fundamental problems. On the other hand, we see that models firmly rooted in scientific rigour, such as the climate change models, while becoming more integrated and policy relevant, also face problems with objectivity and rationality. What these problems are will be elucidated in the next two sections.

4.3 Characteristics of integrated models

Model types

Integrated Assessment Models can be defined as computer models in which knowledge from many different disciplines is combined to assess the problem at hand in an integrated fashion. Both the natural system and the socioeconomic system are simulated (Sluijs 2001). In fact, there are many methods and instruments being used, such as, GIS, mathematical models, remote sensing techniques, fuzzy logic, expert systems, system dynamics, decision-tree approaches, etc. Techniques and models can be linked into a Decision Support System (DSS). Each discipline brings its own typical models (Parker et al. 2002; Schneider 1997), for instance from the biophysical domain we find a wide array of computer programmes capable of simulating physical processes (global circulation models, hydrodynamics, rainfall-run-off, water quality, etc.) and (agro-) ecosystem relations (food web models, predator-prey dynamics, succession models, crop production models etc.). Economic science produces input-output models, macro-economic equilibrium models, resource economic models etc. But we have to realise that not all disciplinary sciences are equally suitable for modelling. Therefore, knowledge relevant for the problem might be excluded from the modelling exercise, because it is difficult to quantify. Hence much of the cultural, political and institutional detail that characterises and defines societies gets left out of IA models (Risbey et al. 1996).

Model performance

Typically, the Global Circulation Models that are used in climate change research are an example of the most complex integrated models currently designed, and require

[14] However, we should not overemphasize the 'curiosity' versus 'policy' driven dichotomy between disciplines and integrated assessment models, as these models in itself can enlighten the behaviour of complex and interconnected physical, biological and social systems regardless of their potential social utility (Schneider 1997).

extremely powerful computers. Likewise, sophisticated 3D hydrodynamic models have long run times and cannot be built in directly in a decision support system. Therefore, they are difficult to use directly in a policy analysis context. Ideally, IA models should be flexible and enable rapid simulation, to explore interactions, feedback mechanisms and uncertainties (Rotmans 2001). We therefore see the emergence of hybrid systems, using libraries of model output from these 'heavy' models combined with on-line fast running modules (e.g. for analysing economic aspects). In this way the fields of client-driven systems analysis models and science-driven models are joined together. Examples of such models are DIVA (regional socio-economic implications of sea level rise based on GCM scenarios (Hinkel & Klein 2009) and the tsunami vulnerability model (damage and risk assessment based on an ocean tsunami model (Marchand et al. 2009).

Explorative versus predictive models
Many models used in policy relevant studies have an explorative character (Bankes 1993). Because of the complexity and non-linear feedback character of the systems that are being modelled, the models do not intend to forecast or predict the future. IA model simulations do not provide one answer but a range of results. And by comparing one simulation result against the other, the model will serve its intended purpose (Ford 1999). Other (less ambitious) uses of a model include that of structuring large amounts of different data, increasing the understanding of the complexity, a training aid and an aid to thinking and hypothesizing (Hodges 1991).

Dealing with socio-cultural aspects
Particularly the inclusion of socio-cultural aspects of human-environment systems in models is difficult because human behaviour is highly unpredictable. Historical data on the processes related to human activities are poor in predicting the future state of the system (Nguyen & de Kok 2007). A well known example of including the role of cultural perspectives is the use of cultural theory in the earlier mentioned TARGETS model (Rotmans & Vries 1997). Although the use in integrated modelling of the cultural theory of Thomson et al. (1990) has expanded over the last decade, it is not without methodological problems (Risbey et al. 1996). The role of humans is twofold: either as decision-makers or as agents causing environmental change (Parker et al. 2002). At present no predictive analysis can incorporate the impact of shifting social perspectives and values on the evolving social situation when communities, nations and the world face risks (Sharma & Norton 2005). Hence, most models are limited to impact models, although some examples of decision models exist, such as optimisation-based approaches, using the assumption that individuals and firms act to maximise profits or utility, and decision tree approaches, where decisions are simulated using empirically or theoretically derived 'rules of thumb' (Letcher et al. 2007). But more often than not the decision-making process is made external to the model by way of scenario-assumptions and strategic choices to be made by the model user.

Despite the wide diversity in integrated models, many of them share a number of methodological problems or characteristics stemming from the integration paradigm. These key issues will be discussed in the next section.

4.4 Key methodological issues in integrated modelling

Aiming at a synthetic and holistic study rather than a reductionist approach of societal problems, integrated models are based on the integration paradigm. This term is rather ill-defined and often used in many different connotations. Following Parker et al. (2002) I will distinguish 5 different types of integration: i) an integration of different issues and their interactions (opposed to a fragmented approach), ii) the inclusion of multiple stakeholders as part of the research process, iii) integration of disciplines, iv) a range of scale levels and v) an integration of models. These integration aspects are not independent axes, as for instance the interaction between different issues determines most of the other aspects. But for a better understanding of how these issues influence the development of a vulnerability model I will deal with each of these issues separately below.

4.4.1 Integration of issues and interactions requires a system approach

In the previous chapter we have seen that vulnerability to natural disasters can essentially be described as an attribute of a complex human-environment system. System components, such as the hazard, local topography, demographic conditions and social entities are interconnected through a myriad of relationships. Therefore it is tempting to use a systems approach to describe and model this human-environment system. But what does this mean? Have we solved the integration issue by rephrasing it into a systems approach with concomitant tools? Not exactly, as we still have the difficulty describing and delineating the system before we can model it.

An often used definition of a system is the following: A system is a set of interacting units or elements that form an integrated whole intended to perform some function. The whole of a system is more than the sum of its parts. It exhibits order, pattern and purpose (Skyttner 2005). Especially since the publication of Von Bertallanfy's General Systems Theory in 1968, the study of systems has resulted in many descriptions, hierarchies and ontologies about systems. And for the design of simulation models for (bio)physical phenomena, a system's approach, using a hierarchy of systems, has proven highly successful. For instance for a water allocation problem, the entire system can be split up into several subsystems, such as the hydrological system, which can be further decomposed in the river, storage reservoirs and the groundwater systems, and the social system, subdivided into water demand sectors (domestic, industrial, agricultural etc.). For each of these subsystems separate models can be developed and linked with each other (Loucks & Beek 2005)

The *entire* human-environment system is not easily defined and framed in a single system. Rather the subject of study includes a number of elements that are interconnected *to a certain extent.* The human-environment system contains elements that are related both by weak and strong links and therefore are difficult to delineate and describe. It can be described as a *nearly decomposable* system, in which the interactions between subsystems are weak but not negligible compared to those within subsystems (cf. (Simon 1996). The hierarchy of systems can help in defining the boundaries of the various subsystems.

Trying to capture everything in a single framework could end up with a far too general and therefore useless model (Toth 2003). More sophisticated models are not necessarily better. As Schneider formulated it, '*IA models can diminish openness of the decision-making process when (in a haze of analytical complexity) IA models obscure values or make implicit cultural assumptions about how nature or society works* (Schneider 1997). Because the vulnerability problem field typically consists of many subsystems and relations between them, the challenge is to define the relevant and essential boundaries and aspects of systems and to explicitly neglect less relevant relations. This is essential for all modelling exercises, as models are simplified representations of reality.

While delineating and simplifying systems for modelling, we have to be careful not to step into the pitfall of only including in our model what is quantifiable. As Sterman formulated: '*Omitting structures or variables known to be important because numerical data are unavailable is actually less scientific and less accurate than using your best judgment to estimate their values*' (Sterman 2000). It is therefore appropriate first to sketch an 'ideal' conceptual model without thinking of the data need. There is a crucial relation with data availability and the issue of scale and aggregation (see section 4.3.4.): as we have seen in the Andhra Pradesh example, choosing the spatial scale was highly influenced by the availability of data. In other words: the craftsmanship of model design lies foremost in closely following the essential system relations as described in the conceptual model and at the same time choosing a practical level of scale from the point of data availability without falling into the pitfall Sterman mentioned.

Choosing the appropriate scale unit and resolution can also help to delineate and identify strong relations: for instance, I will show later that the choice of a household instead of a family is more appropriate in vulnerability modelling, since the household has stronger relations with a hazard than a family (this of course does not imply that the bond between family members is necessarily weaker than between members of a household). We do have to keep in mind, that such choices are not completely free from a subjective or normative bias, as is further discussed in section 4.4.4.

4.4.2 Stakeholder involvement

Due to the intricate connection to social processes, the importance of involving stakeholders in policy analysis and integrated assessments is undisputed. Their cooperation and input is required in the problem framing as well as evaluation of the outcome (Parker et al. 2002). Furthermore, stakeholders are often an important source of local or specialised knowledge (Pahl-Wostl et al. 2008). Having said this, there remains much confusion and discussion as to the most effective ways to involve stakeholders in the modelling studies (Toth 2003). Nevertheless, there are an increasing number of examples of successful stakeholder involvement in model design (for example (Stave 2003; Beall & Zeoli 2008; Antunes et al. 2006; Videira et al. in press). Indeed, there is a tendency towards stakeholder participation in the development of models for decision support, supported by the most recent regulatory frameworks, such as the Water Framework Directive in Europe (Matthies et al. 2007). Approaches such as Group Model Building (GMB) and Mediated Modelling (MM) typically consist of a series of workshops where stakeholder groups collaborate in the interactive and iterative development of a simulation model (Videira et al. in press). The advantages of such approaches are that they foster consensus and commitment to the model and allow the inclusion of local knowledge more easily. Cognitive mapping tools and causal loop diagrams are used to structure the problem at hand and identify the most important causalities (van Kouwen et al. 2008).

In the field of vulnerability assessments the participatory modelling approach has not yet emerged in the way described above. Involvement of stakeholders in flood risk management for instance is still in its infancy, but there are promising approaches (see for instance Slinger et al. 2008a). As we have seen in chapter 2, the set-up of the Andhra Pradesh study did not use participatory modelling techniques such as GMB for designing the EDSS. Hence, we cannot really learn from this study with regard to these techniques. However, I will refer to this issue again when I discuss recommendations for future vulnerability model development.

4.4.3 Integration of disciplines: interdisciplinarity

Interdisciplinarity is a kind of integration that distinguishes environmental science and IA from monodisciplines. But what does it entail? What distinguishes it from a multidisciplinary approach?

Signs of interdisciplinary work in the academic society can be traced back to the early decades of the previous century. But it was in the sixties and seventies that it gained momentum (Apostel et al. 1972; Klein 1990). Although various types of interdisciplinarity can now be distinguished (Groot 1984), I will restrict myself to two basic forms:
a) interdisciplinarity at the interface between two basic disciplines
b) interdisciplinarity beyond and at a higher level than existing (mono)disciplines

ad a). When two disciplines focus on a common subject, interesting new fields of research can be explored. Examples are environmental economics and cultural ecology. Methods to include non-market environmental impacts into the economy of a region or nation (e.g. the green national product, total economic value) are typical interdisciplinary products of environmental economics. Explaining the demise of past civilizations through human induced ecological disasters is an example from cultural ecology. Eventually, these interactions between disciplines can evolve into a new discipline.

Ad b). The second type of interdisciplinarity evolves through a discovery of systematics of systems that cannot be described by one discipline. There are far less examples of this kind of interdisciplinarity. Often what we see is that system characteristics conceptualised in one discipline are transferred to another system, from the belief that 'all systems work that way'. A well known example is the use of the resilience concept, which was originally developed for ecosystems by (Holling 1973) but is applied to more complex human-environment systems, such as inhabited floodplains (Vis et al. 2003; De Bruijn 2005). Although the use of analogies between systems can be useful, care should be taken that the applicability in a new type of system is verified.

Both types of interdisciplinarity are of high relevance for integrated modelling, but no single recipe or method for it exists. Interdisciplinarity plays an important role in the diagnosis of environmental problems, their analysis and solution. Both scientists and stakeholders have to engage in this process in order to formulate a problem and provide alternative solutions that go beyond the boundaries of individual disciplines.

Interdisciplinarity is often hampered by limitations in time, money and social networks as research team composition is often determined by acquaintance and availability (Jeffrey 2005). Furthermore, there is a general lack of unified concepts and methods to guide the actual process of integrating knowledge. Team members of problem-solving efforts 'usually come together and *somehow* put together what they know. […] Frameworks usually come in the form of box and arrow diagrams. Their interpretation, however, differ greatly, lying somewhere between semantic networks, influence diagrams and causal loop diagrams. They aim at guiding the assessment without however prescribing the specific concepts and methods to be used' (Hinkel 2008). Developing simulation models is part science and part craft; there are no general, infallible rules. Instead, heuristics may be used as guiding principles for good interdisciplinary work (Nicholson et al. 2002). This is exactly why I use the *Context* perspective for reflecting on the model design during the Andhra Pradesh study so that we can learn from the experience and contribute to a know-how of designing vulnerability models.

4.4.4 Scale issues and aggregation

The understanding of the human-environment complex as well as its modelling is greatly influenced by the multi-scale nature of biophysical and human systems and the interactions between them across scales. Scale is considered one of the main methodological problems in integrated assessments and modelling (Parker et al. 2002). Scale can be defined both by extent and resolution, where extent refers to the boundary setting and resolution to the amount of detail taken into account (Karstens et al. 2007).

Cash & Moser (2000) distinguish three different scale issues: (1) matching the scales of the biophysical system and the management system – an institutional fit problem; (2) matching the scales of the assessment and the management system – a scale discordance problem; and (3) understanding the linkages between scales, and how they affect decision-making, information flows, and the integration of information into the decision-making process – a cross-scale dynamics problem. For instance in global modelling exercises, different spatial scales are important, as local scale data can increase the accuracy and predictive capabilities of global climate models. Inversely, policy makers are interested in potential local impacts of global climate change (Cash & Moser 2000). But the scale issue goes further than being a modelling problem that can be solved in a technical way.

Scale choice affects the problem addressed, the options found and the impacts evaluated (Karstens et al. 2007; João 2007). It is therefore not politically neutral and not only a matter of scientific inquiry. Karstens et al. (2007) showed that different actors in a policy analysis setting may have different views on the study boundary.

Also with respect to vulnerability assessment the scale matters. Normally, disasters occur at the local level, for instance at low coastal deltas or floodplains. In some instances, for example the Netherlands or the Maldives, the potential extent of a flood can reach national disaster proportions, not so much because the flooding is very large, but because the country is small. Hence, the spatial extent of the flooding relative to the size of a country determines the vulnerability at country scale. The type of vulnerability, such as the elements at risk and coping mechanisms, also differs greatly depending the scale one is interested in. Households will have different coping mechanisms and a different resilience than for instance a regional or national economy.

Then there are the interactions of scale within each of the different domains. To understand the hazard level at a specific location, one needs to know the larger geographic context (for instance the rainfall characteristics for an entire watershed determines a flash flood risk for a given village). This is rather well studied within hazard science (e.g. the source, pathway, receptor framework for flooding (Samuels et al.

2009b). The cross-scale dynamics that are relevant for the social vulnerability, however, are probably more complex and less well studied.

In more general terms we can say that the hazard is described following primarily the physical hierarchy of scales (e.g. catchment, river, floodplain), whereas the social vulnerability is described at different social levels (such as country, administrative community, household, individual, see (Schneiderbauer & Ehrlich 2006). Table 27 shows differential vulnerability at different scale levels, split up between exposure, sensitivity and resilience. For instance, at the individual level, vulnerability assessments should take into account differences in occupation, health, age and gender. Of course, there is a certain hierarchy in scales: the individual vulnerability not *only* depends on these mentioned aspects, but *also* on the household in which he or she is part of, the home village where he or she lives, the enterprise where he or she works and the region and country where this all takes place.

Aggregation can result in the loss of essential information. For instance there can be huge differences in vulnerability at the level of households (as some are living in a hazardous area and others not), whereas at the level of administrative communities we hardly see any difference at all. This is what Cash & Moser call the scale discordance problem and illustrate it for climate change impacts: *'At large scales [...] the overall impacts (costs) of climate change are relatively small. Assessments which focus on more local scales, however, reveal an underlying pattern of widely ranging costs and benefits, with some large winners and some large losers'*(Cash & Moser 2000).

The vulnerability framework of Turner *et al.* (which is one of the few vulnerability frameworks that include the spatial scale aspect – see figure 35), shows several cross-boundary dynamics. The framework includes linkages between the local situation to macro-economic conditions, global environmental changes, global trends and the like. However justified these arrows may be, it does not show how these linkages work out. They illustrate what Turner *et al.* call '*Nested scales and scalar dynamics of hazards, coupled systems, and their responses*'.

Table 27 Different aggregation levels with their typical vulnerability aspects

aggregation scale	exposure	sensitivity	resilience
individual	location of daily activities, occupation	health, age, gender	health, age, gender, access to social network
household	location of house, movable assets	strength of house, preparedness, type of livelihood	livelihood, assets, access to resources, insurance
enterprise	location of firm, movable assets	strength of building, special preparations	assets, linkages, insurance, liquidity
village/community	location of village, topography, natural shelterbelts	community based preparedness	neighbourship, access to regional government centre
region	location vis-à-vis cyclone paths	fragility of different economic sectors	diversity of regional economy; access to central government
country	climatic zone; size of the country	fragility of different economic sectors; preparedness, disaster management	diversity of national economy, GDP, financial reserves, linkages with international community

But the most important aspect of this extended vulnerability framework is the acknowledgement of the place-based character: '*The strong variation in vulnerability by location, even to hazards created by global-scale processes and phenomena [...], elevates the role of "place-based" analysis. The term "place-based" implies a spatially continuous distinctive "ensemble" of human and biophysical conditions or coupled human-environment systems'* (Turner et al. 2003). However, this does not determine the spatial scale of analysis. It is the coupled human–environment system, whatever its spatial dimensions, that constitutes the object of analysis. Nevertheless, the framework positions the location of this system below the regional level.

4.4.5 The integration of models

The integration of models or linking of discrete modules is a common method used in integrated assessment and modelling. Models are often considered as a means to reach a required level of integration in a situation of complexity. The use of a modular approach is useful as it allows the complexity in certain modules not to appear in higher hierarchical model levels thus simplifying analysis and interpretation of results (Parker et al., 2002). At the same time there are no generally accepted standards for model integration. The problem of model integration is usually considered from a technical, software engineering point of view and leads to ad hoc decisions regarding the choice of models and data. All too often choices will be made on the basis of the preferences of the designers or practical considerations such as the availability of data. This makes the design of a DSS strongly case dependent and difficult to transfer to other cases (de Kok & Wind 2003). Hence, a paradoxical situation surfaces here: models are a means to tackle integration, but at the same time we do not know how to do it. In fact, this problem triggered the use of a Context perspective of my research.

Modelling guidelines have been drafted for the design of integrated model systems (e.g. (Jakeman et al. 2006; Refsgaard & Henriksen 2004; Scholten et al. 2007; Scholten et al. 2000). But a closer inspection of these guidelines reveals that they are more focused on quality assurance and validation than on assisting how to design such models. In other words, they ask for greater scrutiny in (scientifically or otherwise) justifying choices in model design rather than helping to make these choices in the first place. One of the reasons why it is so difficult to prepare guidelines for model design is the fact that this activity is part science and part craft (Nicholson et al. 2002). At the end of this thesis I will come back to this issue. But first we need to take a closer look at validation, since this is closely related to model design.

4.5 Model validation

4.5.1 Why is validation of an integrated model difficult?

Although it appears simple in straightforward software applications (e.g. in the administration or bookkeeping world), validation of integrated assessment models poses some fundamental difficulties (Schneider 1997; Parker et al. 2002):

- Validation of the models is often very difficult due to their interdisciplinary nature, inherent uncertainties and explorative rather than consolidative purpose.
- Validation in terms of usefulness requires judgements from the end users, who are not always clearly defined

- IA models often include subjective judgements that cannot be validated on rational grounds.
- IA integrates non-scientific knowledge (Mode-2 science), for which no validation method is available yet.

The openness of real world systems that are modelled make it fundamentally impossible to validate these models, as Oreskes et al. (1994) argued. Models can only be 'confirmed' by the demonstration of agreement between observation and prediction, but confirmation is inherently partial. The primary value of models is therefore heuristic: useful for guiding further study but not susceptible to proof (Oreskes et al. 1994). This is all the more important for IAM's: they are useful for a better understanding of the working of the human-environment system, especially when they are used in a participatory and interdisciplinary working context, where the process is more important than the product (see Parker et al. 2002).

4.5.2 Defining validation

Three terms are frequently used – and sometimes abused – when models are evaluated: calibration, verification and validation. Therefore, before drafting validation criteria for our vulnerability model, I will first define each of these terms.

We first start with *calibration*. Model calibration should not be confused with validation and verification. Calibration of a model is the process of adjustment of parameter values to reproduce the response of reality within the range of accuracy specified in performance criteria (Refsgaard & Henriksen 2004).

Verification literally means assessing the truth. Verification of a model is only possible in the sense of checking if the model exactly does what the developer has intended, i.e.: does the program code exactly what the technical specification describe? This is called code verification (Refsgaard & Henriksen 2004) and usually implies testing and debugging of the computer program. In this respect, the truth is limited to the technical description or conceptual model; whether or not this description is a truthful resemblance of the real world cannot be ascertained.

Validation, however, does not necessarily denote an establishment of the truth either. A valid contract is one that is in agreement with certain juridical standards. A valid argument is one that does not contain obvious errors of logic (Oreskes et al. 1994). Interpreted in this way, validation refers to agreement with certain common standards, be it juridical, scientific or otherwise. This matches the type of evaluation we want to perform with respect to integrated assessment models. Because the models are explorative (Bankes 1993) and play a role in the science-policy interface, they should comply to the criteria which are used both by stakeholders and scientists. In this way, a valid model is a model that is accepted by all parties to play a role in the decision making process. Nguyen & De Kok (2007) formulated this as the validity of an integrated systems model being the equivalent to the user's confidence in the model's usefulness. Others phrase validity as the likely extent to which the anticipated software will satisfy user requirements (Opiyo et al. 2002). I would like to define this a little bit sharper as:

Validity of an integrated assessment model is the acceptance of that model by the users using certain agreed criteria and standards.

In this definition the term ‘users’ includes a wide group of people, such as scientists, decision makers and stakeholders. Agreed standards include scientific performance criteria, but could also refer to user friendliness or the usefulness of the output. This would imply that the validity of a model can only be ascertained in communication with the users. Consequently, no universal or generic validation of an integrated model is possible, because the set of users is open ended. Indeed, these criteria differ from case to case and may be adjusted in a sort of adaptive project management context (Refsgaard & Henriksen 2004; Pahl-Wostl 2007). This may seem to be unsatisfactory, compared to natural process models, but as Oreskes et al. (1994) argued, also the validation of these ‘hard’ models is only partial.

Other authors define a valid model as ‘serving its intended purpose’ (e.g. Parker et al., 2002). One could argue that my definition, which can be summarised as ‘user acceptance’, would be overly restricted. For instance, a model could be useful despite the fact that for instance one party doesn’t accept it. However, if the intended purpose of the model is to reach agreement on an issue between parties, including the one who rejected the model, this goal will not be reached. In other words the model is not fit for its purpose, hence not valid. Or suppose that the intended purpose of a model is to put an issue (such as climate change) on the political agenda. And assume that this goal has been reached, but not without a lot of discussion after which some people still question the assumptions or causality used in the model. Couldn’t we say that these people pose doubts with regard to the validity of the model?

4.5.3 Validation criteria

Validation criteria depend on the type of model we want to evaluate. Models that strive for accurate prediction of future values for a relatively simple system can use validation tests against independent data, i.e. data that have not been used for calibration (Refsgaard & Henriksen 2004). As the complexity of integrated models increases, the usefulness of quantitative validation approaches based on the comparison between model output and observed data decreases (Nguyen et al. 2007). Being more of an explorative than predictive nature, our integrated model coastal vulnerability therefore has to rely on a different validation method. Based on the working definition of validation we have to formulate the criteria and standards against which we can judge the model. Ideally, these criteria and standards have to be developed and agreed upon by the users. Does this mean that no general criteria can established? Is it always site, problem and user specific? The answer is no, it is still useful to develop generic criteria. These criteria can guide users in order to judge the validity of the model. Whether or not these criteria are accepted by users in a specific situation depends on the users that are involved. But in order to derive at this general set of criteria, we first have to further identify the different types of users. It is important to note that the term ‘user’ should be interpreted in its widest sense as anyone who (potentially) makes use of the model or its results. Refsgaard et al. (2007) distinguish four different type of actors:

- The problem owner, commissioning the modelling study, ‘the client’
- The modeller, i.e. a person or an organisation that develops the model, conducting the modelling study, ‘the consultant’
- The reviewer, a person conducting some kind of external review of a modelling study

- The stakeholders/public, not directly involved in the model development and modelling.

Of course, these categories are not mutually exclusive and static. But in a particular case or problem situation, each of these groups can be defined as playing different roles (although there is not always a separate reviewer). Based on this typology I have tried to characterise these groups (except for the reviewer as not being a typical user) in terms of their role in modelling, interests, knowledge domain and possible validation criteria (Table 28).

Table 28 User categories of models and their characteristics.

	Modeller	Problem owner, end user, client	Stakeholders, the wider public
role in model development and use	builds the model, executes calibration and performs model runs for specific cases	model user; formulate model purpose and sometimes detailed functionality	most often not directly involved in model development, reactive role
interests	earning money and status from building models; maintaining professional recognition	models are a means to support his/her policy or to help make choices	private or group interests regarding the issue or policy at stake; no direct interest in the model
specific knowledge	'formal' scientific knowledge	political sensitivity; feasibility	local knowledge; non-formal knowledge
criteria for model validation	scientific criteria	usability criteria	transparency criteria

The importance of model validation lies ultimately in the role models play in the endeavour for solving problems and reaching consensus with stakeholders. According to Habermas, consensus means accepting statements as valid according to three shared validity criteria: normative acceptability, correct empirical knowledge and sincerity (Habermas, 1984, pp. 286-318, cited in Gezelius & Refsgaard 2007). From the table we see how difficult it is to arrive at these shared validity criteria. For example, 'correct empirical knowledge' can have different meanings for each of the three groups. 'Sincerity' of scientists could be shrouded by personal status attached to the model, whereas for a policy maker it could be compromised by the wish for confirmation of his or her policy. Therefore, the only way to get out of this potential deadlock situation is to explicitly acknowledge the interests of the different groups and try to agree on all three types of criteria 'belonging' to each of the groups. This requires an arrangement of the policy setting within which the model is to be used according to a multi-actor setting.

In such a multi-actor policy analysis setting a 'Scientifically sound analysis' is replaced by what Van der Riet (2003) calls a 'Trustworthy analysis' which is required to produce *useful* knowledge. In her opinion, trust relates to the general requirement that stakeholders perceive the analysis (or in our case the 'model') to be scientifically sound and trustworthy. The former means that the analysis takes scientific norms into account. The latter means that the stakeholders must also believe that the analysis was done in a sound way. This soundness can be enhanced by involving analysts who are trusted; establishing a system of checks and balances via internal checks, a quality guidance group or second opinions, giving stakeholders a voice in the analysis and making the analysis accessible for the stakeholders (Riet 2003). In other words: making the analysis transparent.

For a model to be used in a trustworthy analysis this would mean that it should conform to the following criteria:

- Scientifically sound: scientific criteria
- Useful for the end user: usability criteria
- Acceptable for stakeholders: transparency criteria

Based on these three categories I defined the following list of validation criteria using elements from Refsgaard & Hendriksen (2004), Nguyen & De Kok (2007), Parker et al. (2002) and Sterman (2000):

<u>Scientific criteria:</u>

- Criteria pertaining to the *model concept*: does the model follow an (internally consistent and generally accepted) theory? Is the model concept adequate for the domain of the intended application? Are the important concepts for addressing the problem endogenous to the model? Is the model concept in agreement with generally accepted scientific laws, free from logical flaws and rational errors? Is the level of aggregation appropriate?
- Criteria pertaining to the *model implementation*: has the model been verified, tested and calibrated? Are parameter values consistent with relevant descriptive and numerical knowledge of the system? Is each equation dimensionally consistent without the use of parameters having no real world meaning? Have a sensitivity analysis and extreme conditions test been executed?

<u>Usability criteria:</u>

- Criteria pertaining to the *model application*: is there sufficient data to populate the model? Does the model simulation generate plausible results? Does the model generate previously unobserved or unrecognized behaviour? Can the model generate the behaviour observed in other instances of the same system?
- Criteria pertaining to the *user friendliness* of the model: is the model performance (run time of calculations) fast enough? Is the model transparent and is the documentation understandable?
- Criteria pertaining to the *purpose of the model*: Does the model fulfil its designated task(s), or serve its intended purpose? Were the users satisfied with the model? Has the model been transferred to the client? Has there been training of users?

<u>Transparency criteria:</u>

- Criteria pertaining to *stakeholder involvement*: have stakeholders been defined, identified and approached? How active was stakeholder involvement in the development of the model? Has the model output been discussed with stakeholders? Has the model been independently reviewed?
- Criteria pertaining to the *wider dissemination*: is the model and its documentation available for the wider public (e.g. via Internet). Is the model easy to understand or use by lay people?

4.6 Conclusions

I started this Chapter with a question about how the choices that are inevitable in designing a model for vulnerability affect the overall quality, and especially the level of integration, of the model. I entered the body of knowledge regarding integrated assessments and integrated models to find clues that can help in answering this question. I found that integrated assessments are specifically geared towards solving complex societal problems, which surely includes the problem of vulnerability to natural hazards, as described in Chapter 3. Integrated models are often an indispensable tool in integrated assessments, because they can explore interactions, feedback mechanisms and uncertainties of the complex system under study. But in the development of these models, I identified five essential types of integration problems.

The first problem deals with the integration of issues and interactions, that asks for a system approach to the problem-in-context. This raises a new question: how can we delineate and describe the complex human-environment system? As we cannot capture all elements and links, we have to look for the key components and strong links that are essential to include in a model. I also indicated that the choice in scale and resolution can help us to find a good match between strong system relations and data availability.

The second issue is about stakeholder involvement. A participatory modelling approach, although probably a promising path, has not yet emerged in the field of vulnerability assessments. Also the Andhra Pradesh experience cannot be regarded as the first stride in this path, so I deferred this unresolved issue for discussion at the end of our research.

Then I touched upon the interdisciplinary character of integrated modelling, which poses tremendous challenges to the team that has to design a model. Interdisciplinarity is often hampered by practical factors, such as time, money and availability of expertise. Therefore, model design is part science and part craft, which implies that heuristics are important to find our way through the dynamics of interdisciplinary work.

Next I discussed the problems of scale that are inextricably linked to integrated modelling. The human-environment complex simultaneously operates at many different scales. Dealing with these scale effects poses both scientific, technical and political problems. Scale choice affects the problem addressed, the options found and the impacts evaluated. This is equally important in vulnerability modelling. With regard to the physical hazard, recent developments in modelling show great advancements in dealing with different scale levels. For the broader vulnerability framework, such as developed by Turner et al. (2003), these scale issues are acknowledged but hardly treated operationally yet.

And finally I found that models are important tools that can help in integration. But at the same time there are hardly any methods how to build them. Most existing guidelines are focused on quality assurance and validation rather than on assisting how to design such models.

With respect to the overall quality of the model I had to enter into the problem of validation of integrated models. I concluded that model validation is ultimately something that has to be agreed upon by all groups that are more or less involved with the model, either as developer or as user. Still, a list of generic criteria can and has been formulated, subdivided into criteria relevant for each of these groups. Because model validity cannot be divorced from the policy context in which the model is developed, the next chapter will explore the experience and knowledge in the field of policy analysis.

Coming back to the research questions we see that the following components are of relevance:

RQ 2: How can we model vulnerability?

- Using a system approach requires defining strong relationships between elements of the human-environment system and should not be determined by the (non)availability of data;
- A participatory modelling approach is a promising path, although it has not yet emerged in the field of vulnerability modelling;
- Interdisciplinarity is an important character of integrated modelling, but its methodological basis is yet weak. Heuristics play an essential role in reaching interdisciplinarity;
- Scale effects in modelling should be acknowledged and choices should be made explicit;
- Modelling guidelines are more focused on quality assurance and validation than on assisting how to design models.

RQ 3: How useful (valid) is our model?

- To determine the validity of an integrated model, it should be scientifically sound, useful for the end user and acceptable for stakeholders. On the basis of this, three groups of criteria have been formulated.

5 Policy Analysis: linking context with content

This chapter introduces Policy Analysis as the link between the context of policy making and scientific content. Theory and practical experiences on policy analysis are reviewed as the background against which the design of the model for vulnerability assessment can be evaluated. The chapter concludes with the identification of process factors that influence model design in a policy analysis.

5.1 Introduction

After I have been diving into the theories of vulnerability and integrated assessment modelling in the previous two chapters, it is now time to turn to theories on policy analysis for the last of the three research perspectives: the Context perspective. I need this perspective because I want to answer the question: how does the process of a study influence the design of our model? In other words: would the model have been much different if the context – but not the objective – within which it is designed was different?

The project in which the model has been designed had a clear policy analysis character: it was the task of the consultant to provide advice on the long term planning of the coastal zone, based on internationally accepted standards of integrated coastal zone management. The project used a framework for policy analysis (see figure 3 in Chapter 2). This framework describes the phases of the study as a sequence in steps that have to be taken one after another. It also prescribes the development and application of a model. Questions that arise are: why has this framework been chosen and was it an appropriate choice? Did the actual study process deviate from the framework and if so, why and what were the consequences? How did the model design and application evolve within the framework?

To answer these questions it is necessary to understand what a policy analysis is and to know the diversity in methods and implementations. This knowledge can help in evaluating the chosen method.

I will not evaluate the policy analysis as such, in terms of its ‘quality’, ‘success’ or ‘added value’ (Thissen & Twaalfhoven 2001), but I will use the policy analysis approach as the independent variable that has a certain impact on the model. In terms of the conceptual structure to evaluate policy analytic activities from Thissen & Twaalfhoven I therefore only use the first three steps, i.e. *input*, *policy analytic activity* and *result* (see Figure 37). In order to do so, we need to know which different policy analysis methods and styles are potentially available and how the AP study was positioned in this respect.

5.2 A brief introduction to policy analysis, with emphasis on the Dutch experience

Policy analysis (PA) has its roots in the United States of America, where in the sixties scientific support was increasingly being used for decision making, first in the Depart-

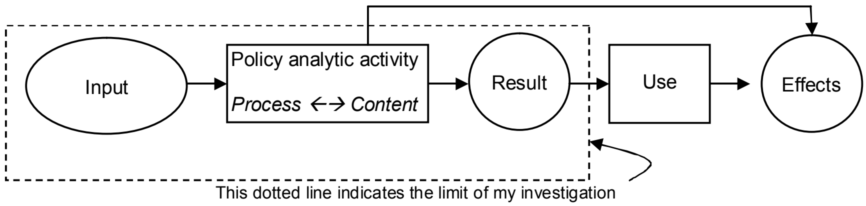


Figure 37 Conceptual structure to evaluate policy analytic activities (Thissen & Twaalfhoven, 2001)

ment of Defence, but later also in other public policy domains (Radin 2000). It can be described as a purposeful and systematic activity to assist decision makers and to enlighten policy discussions (Thissen & Twaalfhoven 2001). In the early days of PA it was mostly a rational activity, based on the essence of decision making consisting of intelligence, design and choice (Simon 1960). PA was seen instrumental in supporting the intelligence phase and proposing a range of alternatives for the design phase. The final choice is explicitly left out from the PA, because that belonged to the realm of the policy makers and not of the policy analysts. It fitted in the positivist belief of both science and politics as activities of a 'community united by the quest for answers to shared problems' (Hoppe 1999). In these earlier years, most attention was given to methods for assisting decision makers in choosing between given alternative actions. Later, the scope was broadened to include methods supporting problem definition and structuring, alternatives design, impact forecasting and assessment, and comparative evaluation (Thissen & Twaalfhoven 2001).

Over the last four decades the aims, approaches and methods for PA show an increasing divergence. New clients and policy fields gave rise to increased specialization and application within the discipline. But more importantly, the rational actor model on which PA was founded and that assumes that action is based on explicit choices and aims of actors, started to become criticized (Radin 2000). Also the supposed objectivity of science was questioned, and the importance of a more participative policy-oriented process was stressed. Somewhere around 1980, PA's original wave of success subsided. The understanding that scientific knowledge is fallible, and that researcher's assumptions and theories can have large effects on what they find, had put them in an intellectual crisis. This led to a *post-positivist* turn in policy analysis (Hoppe 1999). Radin (2000) uses a somewhat different terminology when she talks about the '*rational'*, modern analyst of the 1960s and 1970, and the *post-modern* analyst of the 1980s and 1990s, but she means the same (Radin 2000). And it coincided with the conversion to market-oriented thinking and the start of a cultural reappraisal of the forces of chaos and unpredictability commonly referred to as post-modernity (Daalen et al. 2002).

It is important to note that in the Netherlands this turn in policy analysis became also visible, but somewhat later than in the United States. In the late 70's one could still speak of the heydays of 'positivist' policy analysis. For instance, the policy analysis of the Oosterschelde (POLANO study) had just shown '*how a policy analysis of complex environmental questions can be carried out*' and '*offered something all too rare: a description of the approach and results of a study that contributed in a direct and substantial way to the making of a major and highly controversial political decision'* (Preface to the report (Goeller et al. 1977). The storm surge barrier alternative to a closed dam that was chosen by Cabinet and Parliament fulfilled the demands of the different parties that hitherto stood fiercely against each other. The study used a straightforward concept of policy analysis (Figure 38) and it introduced a methodology for assessing ecological impacts that uses mathematical concepts new to ecology at that time. '*POLANO needed the objective and systematic approach of models rather than an intuitive or ad hoc approach'* (Goeller et al. 1977). Many people considered the POLANO study the start of policy analysis in the Netherlands. It was followed by another large study, this time on the water management of the entire country: the PAWN study (Policy Analysis for the Water management of the Netherlands). It was a major undertaking, involving 125 man-years of effort from the RAND Corporation, Rijkswaterstaat and Delft Hydraulics (Pulles 1985; Goeller 1983).

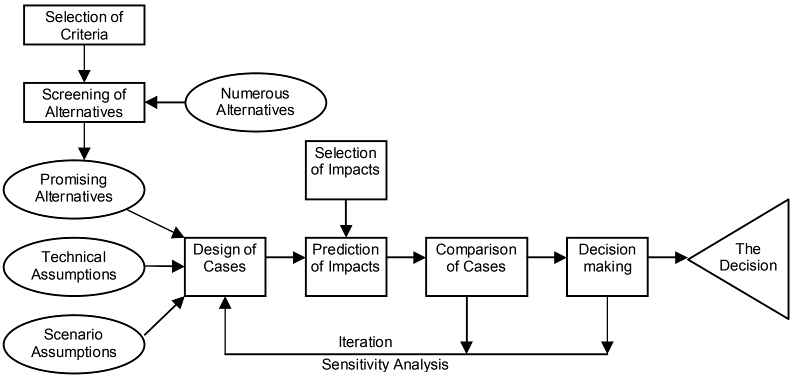


Figure 38 Stages of Analysis in the POLANO study (Goeller et al., 1977)
(note the complete absence of stakeholders and other context factors)

The 90s of the past century showed similar success stories of the use of policy analysis to highly disputed water management problems, such as the Boertien I and II studies for the Dutch river dike enforcements (Walker et al. 1994). Again Delft Hydraulics was heavily involved in these studies and was seen as among the most authoritative policy analysis institutions in The Netherlands (Mayer et al. 2004). So when Delft Hydraulics in 1997 decided to bid on the tender for the Andhra Pradesh Cyclone Hazard Mitigation Project, it was in this tradition of policy analysis that the project proposal was written. Compared to POLANO framework (Figure 38) the proposed framework for analysis for the Andhra Pradesh project (figure .. in chapter 2) showed more procedural steps and – remarkably – the first signs of stakeholders. But nevertheless the legacy of the previous PA experiences is clearly visible.

It must have contributed considerably to the success of the POLANO study that the decision making process was concluded very soon after the study was finalized. This is rather the exception than the rule: often a timespan of a decade or more is needed to see the 'enlightenment function' of policy research (Sabatier 1988). And the experience that often the direct relevance or impact of a policy analysis was hardly recognizable (Monnikhof 2006) contributed to a gradual change in thinking about PA.

The POLANO study could be described as a badly structured problem (Hisschemöller et al. 2001), which is characterized by a situations where a decision in favour of alternative A may cause irreversible harm to alternative B. The scientific knowledge and models made it possible to assess the consequences of each alternative, thus translating value conflict into an issue of technical complexity (Turnhout et al. 2008). A typical example of the 'positivist policy analysis'. And it worked. Not in the least because there was a technical solution that seemed to satisfy all different interest groups (except for the tax payer, but that only became apparent much later)[15].

A more or less similar controversy, about the gas mining in the Wadden Sea at the end of the 1990s evolved in a very different way, however. Scientific evidence was contested and contra-expertise led to a 'report war' without a true winner (Turnhout et al. 2008). The world of PA was changing. Even in technical and engineering institutions the call for social sciences and more communication with stakeholders was heard. The last remaining artefacts of the positivist-technical approaches of PA – decision tools made in the framework of the large Dutch Research programme LWI ('Land and Water Impulse') – withered away on the offices' shelves of the proposed end-users[16].

5.3 Styles of Policy Analysis

Nowadays many different roles or styles of PA can be distinguished. I refer to the conceptualisation of six general activities that policy analysts perform when it comes to supporting policy ((Mayer et al. 2004) and Figure 39): 1) research & analyze; 2) design & recommend; 3) provide strategic advice; 4) clarify arguments & values; 5) democratize; and 6) mediate. In the figure, activity clusters are arranged in a hexagon so that activities that can be considered most akin are shown alongside each other. The further away activities are from each other, the greater the field of tension for uniting the activities will be. Combinations of two adjacent clusters of activities give rise to specific policy analysis styles: 1) the rational style, 2) the client advice style, 3) the process style, 4) the interactive style, the participatory style and 6) the argumentative style (Mayer et al. 2004). It must be said that these styles are not per se opponents of each other: an interactive style is not necessarily irrational. Rather, they denote the differences in emphasis that exist in the role of the policy analyst. But the larger the distance between two styles, the more difficult it will be in practice to combine them into one policy analysis study.

Although largely based on different PA studies in the Netherlands, the conceptual model is probably also valid for other countries and situations. That does not imply that the approaches within one style and the applied methods and tools are necessarily uniform as well: the PA-discipline is contextual and this context is largely culture-bound. Policy analysts should 'sharpen their crafts and adapt their tools taking into account different cultural contexts of policy subsystems or countries' (Mayer et al. 2002). There will probably also be differences in dominance of one style over others in different countries. In the next chapter I will discuss the implications the Indian context could have on doing a PA. But first I will use the model to characterise the activity of vulnerability assessments in general.

[15] Interestingly, the Oosterschelde discussion also was personally my first acquaintance with policy analysis. Being a high school student I assembled arguments in favour and against the closure of the estuary. Till today I have never been convinced that the storm surge barrier was the best alternative. Instead, strengthening the existing embankments would serve all interests for a fraction of the costs of the barrier.

[16] A typical example of a technology-based marketing. cf. (Walker 2000).

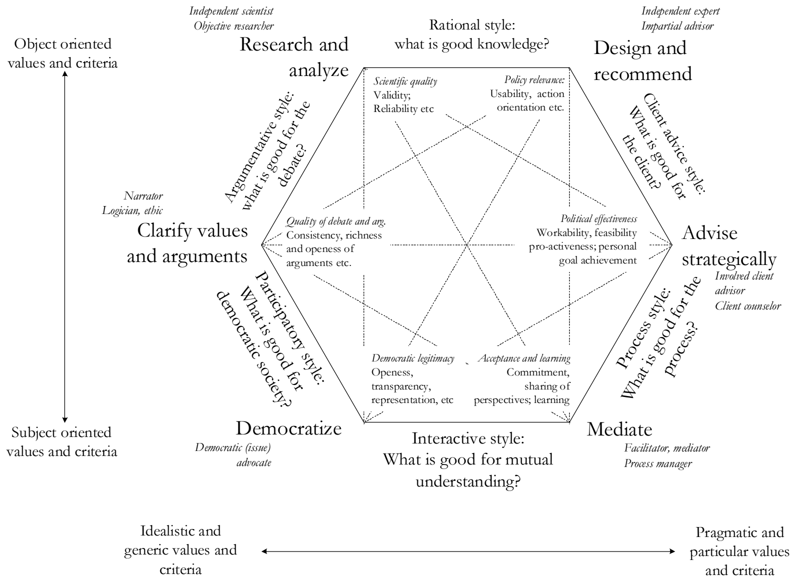


Figure 39 The hexagon: a conceptual model of policy analysis styles (source: Mayer et al. 2004)

5.4 The decision making context of vulnerability assessments

Many of the vulnerability assessments that have been described in Chapter 3 are typical examples of research and analyse activities: they aim at knowledge generation for policy purposes. Translation of the results of this research into a political design or recommendation (cf. Mayer et al., 2004) is often not included in a VA. Their results, however, are mostly intended to raise awareness and to trigger a policy response. For instance, the Global Vulnerability Assessment (Hoozemans et al. 1993) showed the potential consequences of a worldwide 1 metre of sea level rise, indicating the seriousness of the problem and identifying where the hot spots in terms of vulnerability are. Because of the large uncertainties and global nature of the research, a direct application for any of the countries was not envisaged. Other VA's can lead to more practical policy recommendations, for instance when specific hazard zones are identified that could be used in spatial planning exercises (e.g. the Hazard-of-Places model of Cutter et al. 2003). In such a VA an extension of activities towards 'Design and recommend' is visible.

The virtual absence of other policy styles within the set of vulnerability assessments can be explained by the fact that vulnerability is hardly seen as a societal issue, as a dispute between stakeholders. Most people are not aware of the hazards and risks they face or see it as an external threat. They see the hazard as the responsibility of the government and do not feel inclined to participate in its assessment.

Seen from the perspective of the overall aim, VA is an example of an ill structured problem situation (Dunn, 1981) in a sense that there is not a clear description of goals and alternatives. Science mainly plays a role as problem signaller and policy development is a learning process (Turnhout et al. 2008). In this type of problem situation (in which many people even do not recognize a problem) it is extremely difficult to organize participation of actors. Hence, even if a participatory approach is desirable, it often remains limited to some representatives of some interest groups.

Things change when the government is planning an intervention to reduce risks. At that stage conflicting demands and interests may call for a mediator or democratize style. For instance, a dyke reinforcement project can cause a NIMBY effect and could raise questions on the analyses and assessments. Scientific and policy assumptions that preceded the decision of the intervention can be questioned, leading to significant delays and fierce discussions.

Such situations illustrate that a vulnerability or risk assessment is not a value free or objective exercise. Also when we see the gradual shift in the interpretation of vulnerability – from hazard dominated to a social and political issue – one could argue that a more participatory style of doing vulnerability assessments is desirable, especially when the study area has a local or regional scale.

5.5 Styles and models for policy analysis

Because our main interest is in model design and evaluation, a logical next question is: does a PA style determine the choice of a model type? The answer is: to a significant extent, yes. Models are often used in the analysis step of a PA. Models are (merely) the tools of the policy analyst and a means to an end, not the end in itself (Walker 2000). But nevertheless, choosing appropriate ones is one of the central tactical issues of systems and policy analysis (Miser & Quade 1988). The question then arises, from which models or model types can we choose? Figure 40 shows the relative position of some major model types in the styles of PA diagram.

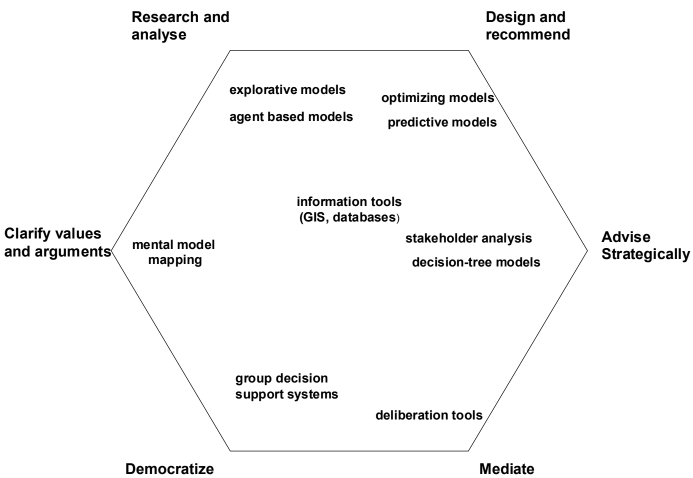


Figure 40 Examples of model types with their relative location in the style diagram

Explorative models and system dynamics typically belong to the rational style, whereas deliberation tools can be found on the opposite side, where the interactive style is located. Of course, this is very indicative and the choice of models depends on many factors. For instance, one could imagine that explorative models can be used in other situations than Research and analyse, such as mediation or strategic advice. A good example is the 'Rational style' RAINS model, that was used to assist policy makers in gaining consensus on the issue of 'acid rain' in the European region (Daalen et al. 2002). But what the picture shows is that most model types have their home base in one of the corners of the diagram. Some models are placed more in the middle of the diagram, indicating that they are less closely linked to a certain style. For instance a GIS is of such generic nature, that it can be used in many situations.

The representation of models in the hexagon in Figure 40 is by no means meant to be complete or exhaustive. The recent proliferation of model types in integrated assessments and policy analysis (cf. Daalen et al. 2002) is such that it is very difficult to produce a comprehensive and systematic picture. Instead, what is aimed at is the notion that there are many different model types and that some types are more useful for a specific policy analysis style than others. And that ideally speaking an explicit choice has to be made in a concrete policy analysis for one type of model or a combination of models. The factors that influence this choice are discussed in the next section.

5.6 Factors influencing model design in PA

In the preceding Chapter I have defined criteria for the evaluation of integrated models: are they useful and suitable for their task? In this Chapter I turn towards the opposite direction: how does the context of policy analysis influence the choice and design of the model? Policy practice is flooded by different thinking styles, diverging interpretative frames, competing policy belief systems, different world views, contrasting images of man and nature, and so on (Hoppe 1999). Model choice and, more generally, analytical methods in policy analysis appear to be idiosyncratic and based on practical or pragmatic judgements (Howlett & Lindquist 2004). But what are then these judgements and how has this worked out in the case of Andhra Pradesh?

Hence I am not searching for evaluation criteria for policy analysis, such as developed by Thissen & Twaalfhoven (2001), but factors that can explain how the policy analysis and broader context can influence the model development. I have therefore adopted four of their main categories in order to organize the range of potential factors that influence model design in policy analysis, i.c. *Input, Process, Content* and *Result* (see also Figure 37). For each of these categories potential factors have been identified that specifically relate to model development and use:

Input to the policy analysis: factors that relate to aspects that precede the policy analysis.

- *Policy objectives of the study*
  As the model is intended to support the study, its design should clearly reflect the over-all policy objectives. These objectives are usually defined explicitly in the terms of reference of the study, but also hidden or implicit objectives of the client could play a role here.

- *Formal directives*
  The contract with the client could include certain formal directives for the model design, such as the compulsory use of a model concept (e.g. an I/O model or system dynamics) or the prescribed use of a certain software package.
- *Data availability and accessibility / assumptions*
  Evidently, models need data and a data poor situation will put a significant limitation to the level of sophistication of a model. On the other hand, when many data are available (and accessible, which is often not the same!) the tendency to use all these data could influence the model design.
- *Expertise of the team*
  Team composition often plays a decisive role in the scope and – eventually – the success of the entire policy analysis. Often the team composition is specified in advance by the Client, without a clear idea on the type of model that will be developed. Mostly, a list of requested disciplines is prepared, based on a perception of the problem and its diverse multidisciplinary aspects, as well as some technical specialists, such as GIS-experts and computer programmers.

Process: These factors relate to the analysis process and its organisation.
- *Team dynamics*
  Teams consist of people, interacting with each other during the project. Besides the epistemological difficulties that arise in interdisciplinary team work, also sociological and psychological aspects will play a role in the design of a model. Some experts can (will?) exert a decisive influence because of their dominance in the group. Besides, cultural different backgrounds of the team members will play an important role in the team dynamics, especially if they come from different countries.
- *Procedural blueprints*
  Usually a project will follow certain phases or steps that are sometimes formally prescribed, such as a definition-, a design-, programming- and testing phase. But there are also alternative, non-linear procedures, that follow a more interactive pathway. The selected procedure will have an influence on the model design.
- *Time and budget constraints*
  It is obvious that time allotted to the model development as well as the total budget available can greatly determine the type of model and its complexity.

Content: Factors that relate to the content of the analysis**.**
- *Policy analysis style*
  Each style of the policy analysis has its own suite of models (see Figure 40). Hence the appropriate model type should be chosen that fits best for the style of the study.
- *Conceptual model or theory*
  The team as well as the client usually works within a certain paradigm, which determines the way one approaches the policy problem, which theories are en vogue and which methods and models one uses. In interdisciplinary study teams different paradigms can be present, which could hamper or retard model design. Probably a fruitful study and model development is only possible after an agreement has been reached on paradigm issues.

Results: factors that relate to the products of the analysis.

- *Usefulness of the model*
  Once the model has been designed and verified its output should support the analysis. If for whatever reason this is not the case, the model needs adaptation or a more rigorous makeover.
- *Model transfer*
  If the model is intended to be used by the Client or third parties during or after the study, this will lead to certain extra requirements. For instance, user friendliness and simplicity of model structure become major design criteria.

5.7 Conclusions

The choice and design of a model in policy analysis is determined by both practical, epistemological and subjective/normative factors. First of all the policy style has a significant influence. There are different policy analysis styles, each of them requiring different models and tools. From a purely 'positivist', rational actor paradigm, over the years policy analysis diversified into a range of styles, varying from Research and Analyse to Mediate and Democratize. The main contractor of the Andhra Pradesh project, Delft Hydraulics executed many PA studies in the rational style, formalised in a 'Framework of Analysis'. Although many vulnerability assessments are conducted from a rational style perspective, it is not a value free or objective exercise. Particularly the combination of a vulnerability assessment with long term planning is an ill structured problem in the sense that there is no clear description of goals and alternatives to choose from.

Coming back to the research questions we see that the following components are of relevance:

RQ 5: Which factors played a crucial role in the design of the model?

- In order to find out which contextual factors proved to be crucial in the design of the Andhra Pradesh model I will use the Input, Process, Content and Result factors formulated in this Chapter.

Part 3
Evaluating the model

An evaluation framework for the Andhra Pradesh model

Now that we have finished our excursion into the theoretical backgrounds and knowledge domains of vulnerability, integrated modelling and policy analysis, it is time to go back to the Andhra Pradesh model. In contrast to Chapter 2 in which I *described* the model and the project within it was designed, I will *dissect* in the next Chapter the model, its applications and design process using the theoretical background of the preceding chapters. I will scrutinize the model in all its aspects, basically for three reasons: first to ***evaluate the model***. It is not the intention to completely validate the model since this is only possible through direct interaction with the end-users and client. Instead, evaluation in this thesis is regarded as identifying strengths and weaknesses of the model, forming a contribution towards the science and craftsmanship of building vulnerability models. I will use Scientific criteria from Chapter 4 as a guidance for this evaluation. More specifically I will use the adapted place-based framework for vulnerability of Chapter 3 as the conceptual model against which I will compare the EDSS. I will also use Usability criteria from Chapter 4 as guidance.

The second reason for dissecting the Andhra Pradesh experience is to ***learn from the model application***. That is: how can the model output be useful for generating policy advice for reducing vulnerability. This is the Applications perspective of our research and brings us back from the bounded mathematical model domain to the unbounded domain of the 'real' world. Scientific and Usability criteria from Chapter 4 are used as guidance.

And finally I will look for ***decisive choices*** in the model design, which could affect its more generic value. It is not my intention to show that the model was the best attainable under the practical conditions of the project. I am not evaluating the project performance. Instead, I want to know if the model that has been designed is a useful instrument for modelling vulnerability of coastal areas prone to cyclones in a policy context. For identification of these decisive choices I will use the Context perspective mentioned in Chapter 1, and I will use the Policy Analysis factors from Chapter 5 (see Table 29 for a summary).

Chapter 7 describes the application of the EDSS to the Bac Hung Hai polder in the Red River Delta, Vietnam as a test case for the model. In this test the scientific and usability criteria of the Application perspective are used: model data input, calibration and plausible results. These results are compared with those from the Godavari Delta.

In Chapter 8, a synthesis of the model evaluation is given, together with the results of the Expert Panel workshop. The findings from the evaluation are arranged according to the three research perspectives.

Table 29 Factors of influence and evaluation criteria

Model perspective	Section 6.1
Scientific criteria: model concept	
Usability criteria: performance and simulations	
Application perspective	Section 6.2
Scientific criteria: calibration	
Usability criteria: model data input, user friendliness, plausible results	
Context perspective	Section 6.3
Input factors: policy objectives; formal directives; data availability and accessibility; team expertise	
Process factors: team dynamics; procedural blueprints; time and budget constraints	
Content factors: PA style; conceptual model or theory	
Result factors: model usefulness; model transfer	

6 Dissecting the Andhra Pradesh Experience

In this chapter the experience of the Andhra Pradesh Expert Decision Support System for ICZM is critically examined, using the theoretical notions from the previous three Chapters. It follows the three research perspectives Model, Application and Context.

6.1 Analysing the EDSS model (Model Perspective)

6.1.1 Evaluating the boundaries and structure of the model

In their book *The Electronic Oracle*, Meadows and Robinson (1985) have compared nine different mathematical models of large scale socioeconomic systems. All models tried to simulate at least a considerable part of the human – natural resources system. Despite the relatively old age of the models (all of them are from the 1970s), the conceptual methods by which Meadows and Robinson have compared and analysed the models are still valid. Two of their methods are exceptionally illustrative for describing and analysing these kinds of models. These are the Boundary Diagram and the Reference Structure.

The *Boundary Diagram* shows three sets of variables: endogenous variables are listed in the inner circle and are determined or calculated within the model. Exogenous elements are placed in the outer circle and affect the state of the model system but are not affected by it. They are either constants or driving functions that must be specified as inputs to the model. Omitted elements are completely absent for the model and are listed outside both circles. The list that could be included in this section of the diagram is obviously endless. Therefore, only those elements are depicted to draw attention to the assumptions that define the model's boundary and to indicate the most fruitful areas for possible model expansion (Meadows & Robinson 1985).

The *Reference Structure* has been drafted after having studied the causal diagrams of all nine models and presents the most basic and important aspects of general population-production systems. It emphasises the decision points in the system by enclosing them in rounded boxes. For instance, 'Labour allocation' decisions include the distribution of labour between industry and agriculture, but could also include a decision to migrate. This does not mean that a specific model includes such elements always as decisions. For instance, 'population increase' might be exogenous in one model, it might respond to food availability and family planning services in another, and in a third it might be an extremely complex function of social norms, education, female employment rates and income distribution (Meadows & Robinson 1985).

6.1.2 The Boundary Diagram of the EDSS

In Figure 41 the Boundary Diagram of the EDSS is given. The main endogenous elements are the output variables that belong to each of the main evaluation criteria categories (social, economic, environment and vulnerability)(see Chapter 2). It also shows the main exogenous parameters. Most of them denote a group of parameters. For instance, 'asset distribution' in the model is a set of asset value parameters for each rural and urban income quartile and the distinguished asset types, which makes 120 parameters in total.

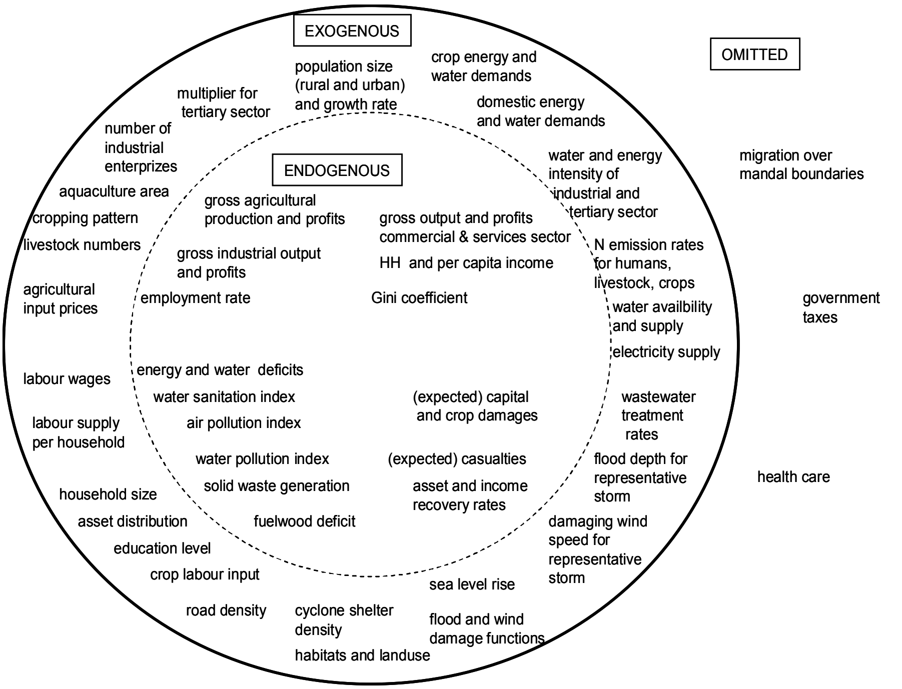


Figure 41 Boundary Diagram of the EDSS

Some interesting observations can be made from this diagram:

1. a relatively detailed representation of the primary economic sector (agricultural crops, livestock, aquaculture) and simple representation of the industry, commercial and services sector (the latter only by using a multiplier).
2. Largely lacking in this diagram is the role of the government in the economic system. Taxes are not taken into account as a cost of production and also subsidies are not included.
3. Health care is not included in the model, although the health situation of people is very important in both economic terms as with respect to cyclone vulnerability.
4. As the unit of calculation is one mandal, the model assumes 'autarky' of the economy, which of course is not realistic. One result of not taking into account labour migration is for instance the large difference in employment levels between mandals. In some mandals there is a high unemployment, while in others there is a great shortage of labourers. The reason for not including migration over mandal boundaries was pragmatic: the programming structure calculates the labour demand and supply sequentially for each mandal. Including cross-boundary migration would require additional spatially referenced algorithms, making the model significantly more complex. The same holds for not accounting for other spatial relations between mandals, such as the air and water compartments.

6.1.3 The Reference Structure and the EDSS

In Figure 42 the structure of the EDSS is visualized using the Reference Structure. This clearly shows which key elements are included in the model (arrows and boxes in bold) and which are left out (arrows and boxes in thin lines). The EDSS models the relations between production (both industrial and agricultural) and the allocation of inputs, i.e. labour requirements, investments (assets) and resources. Output is allocated to the different population classes (rural/urban income quartiles) through the asset distribution. Resource availability is indicated through the deficit variables for water and energy. The population size determines the labour force as well as the income per capita. Population growth is an exogenous parameter that can be modified through a scenario setting.

It is also clear from the figure that 'government', 'technology' and 'consumption' are not addressed. The reasons for not including these elements is because the model only needs to represent the stocks and flows of the economy in *one year*, in order to assess the impact of storm damages on these stocks and flows. Typically, the technology improvements and investments can be seen as parts of feedback loops to the industrial and agricultural production potential, which work on a longer time frame. Indirectly, these aspects are addressed, though, through scenario and measure settings of the model.

The conclusion that can be drawn from this is that the EDSS model fits the basic Reference Structure quite well. The relations are logical and what is not included can be explained by the fact that the model simulates only one year. An omission is the lack of government taxes, that make the per capita income a bit too high.

6.1.4 Analysing the EDSS model using the vulnerability framework

Our brief excursion into the wide field of vulnerability acquainted us with the vulnerability framework of Turner et al. (see Figure 36). This framework provides a useful instrument to analyse the EDSS model. The reason for choosing the framework of Turner is twofold: first, it encapsulates current scientific thinking on vulnerability. Second, it was unknown to the designers when designing the EDSS, facilitating an independent test and adding objectivity to the evaluation.

What I will do is using all elements and linkages between the elements of the framework by way of a check-list. With this check-list the EDSS will be examined, looking at the way in which each of the elements and their linkages are implemented (or not) in the model. In Table 30 and Table 31 an overview is given of this examination. Figure 43 shows the EDSS design as a construct according to the Turner framework. In the next sections a closer description is given of each of the findings from these tables.

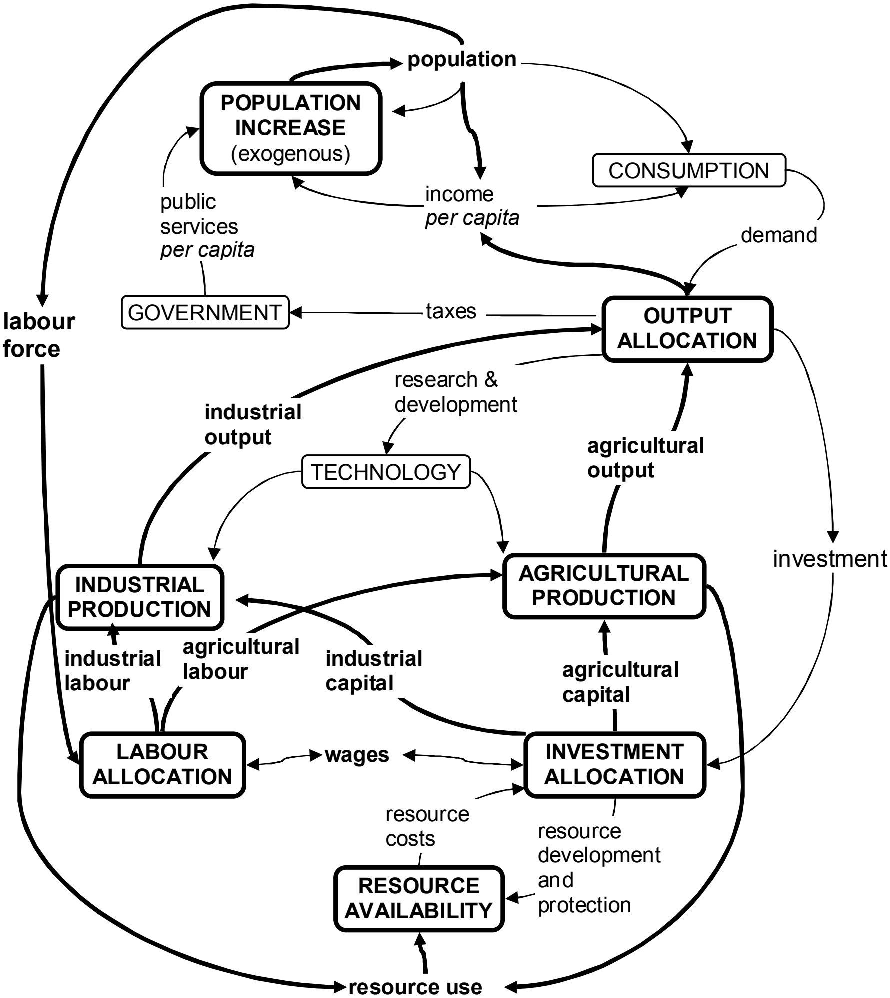


Figure 42 Reference Structure of the EDSS
(arrows and variable names in bold are included in the EDSS, others are excluded)

6.1.4.1 Exposure

The framework distinguishes between the components that are exposed and the characteristics of the hazard such as magnitude and duration. Also the relation between the two has to be made clear. Exposure is to be defined in time and space: the question here is *which* entities are *when* and *where* exposed to *what* hazard.

Components
In the EDSS basically 6 categories of entities potentially exposed to the hazard are distinguished:
- People (numbers)
- Crops (crop types, area)
- Livestock (animal types, numbers)

- Houses (three types) and other assets (several types) (per income class)
- Public assets (such as road infrastructure and administration buildings)
- Habitats (habitat types, area)

The choice of components reflect the dominance of agriculture in the livelihood and local economy of coastal Andhra: crops and livestock are essential assets for local people and are at the basis for the economy. Note that a household, although used as an important component in the economic submodel, is not a component that is directly exposed. A household can become impacted by a hazard through either the people directly or through the loss of their belongings.

Industry is not included in the list, which could be regarded as an omission. Although factories are less vulnerable than private houses, these buildings can nevertheless be heavily damaged by winds and floods, as happened during the Nov. 1997 cyclone (Shanmugasundaram et al. 2000). Nevertheless, this damage contributed only marginally to the overall damage, of which the agricultural and housing sector shared the most. More in general it can be argued that the agricultural sector is more susceptible to climatic hazards than the industry (Benson & Clay 2003).

Hazard characterization

Hazard in the model is defined as flooding and strong winds that are the result of a cyclonic depression. Hence, it does not take into account the potential impact of locally heavy rainfall causing flooding – a significant cause of damage according to Winchester (1992, page 134) –, coastal erosion or other accompanying hazards. Although there is a benefit of using integrated multi-hazard numerical models in coastal storm modelling (Watson 2002), the ICZM team within the AP project was practically bounded to use the models that were developed in the other parts of the system. The EDSS uses the results of a storm surge model (SSM) to estimate the potential extent of an inundation as well as inundation depth. A 'representative storm' was used that has a frequency of occurrence of once in 50 years (see Box 7). Damaging wind speeds are derived from the results of the wind hazard model (WHM) for the same representative storm. The spatial resolution of both the SSM and WHM is much higher than of the EDSS: these models use a grid with a cell size of 6.25 ha. Which means that for an average size of a mandal (10,000 ha) there are 1,600 grid cells.

Box 7 Characteristics and probability of cyclone 07B

For the Andhra Pradesh model application the cyclone 07B of November 1996 was used as basis for the representative storm. This was a storm of the category 'severe cyclonic storm with a core of hurricane winds', with core wind speeds of up to 175 – 220 kmh^{-1} (O'Hare 2001). Under the present typology (see Table 24) this storm would be called a 'Super Cyclone'. Between 1971 and 2000 20 tropical cyclones made landfall at the Andhra Pradesh coast, of which 7 had a maximum sustained wind speed of more than 32 m/s, i.e. belonging to the category Very Severe Cyclonic Storm (VSC) or Super Cyclone. 2 out of these 20 were located in the Godavari Delta: a cyclone storm (category CS) in 1982 and the cyclone 07B of 1996 (official category SCSCHW) (Raghavan & Rajesh 2003).

Because of the very limited historical data on cyclone intensities in India, it is not possible to give a statistically evidenced probability or recurrence time of the Nov. 1996 cyclone. An estimation of once in 50 years, however, seems reasonable, and is in agreement with the neighbouring state of Orissa, where super cyclones also have a return period of approximately 50 years (Chittibabu et al. 2004).

Table 30 Implementation of vulnerability in the EDSS (place level elements)

Elements of Framework	EDSS application
Exposure	
Components	- People - Crops - Livestock - Houses & household assets - Public assets - (Habitats)
Characteristics of the hazard	Storm surge and wind hazard model provide: - flooding & wind - magnitude Other characteristics of flooding (e.g. current velocity, duration) not included
Relation between components and characteristics	Components defined per mandal. Scale of place rather coarse: within one mandal still much differentiation in exposure
Sensitivity	
Human conditions	- Population size - Simple economic model based on HH income and 3 production sectors - Asset distribution - Distinction between movable and immovable assets
Environmental conditions	- Model of resource use and deficits for land, water, air, energy - Model for water and air quality
Relation between human and environmental conditions	- Land resources (RDU) - Model calculates deficits in water and energy - Model calculates Water Sanitation Index There is no feedback from environmental condition to human condition in the model
Relation between exposure & sensitivity	- Casualties functions - Damage functions for crops and assets - Early warning No other human impacts considered (such as injuries, physical trauma)
Resilience	
Coping	Model assumes that damages in assets are compensated for by using financial reserves, grants or loans
Impact	Model calculates damages and income 'after storm'
Measures and scenarios that reduce vulnerability	
Adaptation (local level)	User defined 'measures' for: - Evacuation improvement & cyclone shelter construction - Cropping patterns
Relations between coping/ impact / response and adaptation	There is no dynamic link between the impacts and adjustments
Relation between adaptation and sensitivity	Measures relating to changes in human and environmental conditions can be defined in the EDSS

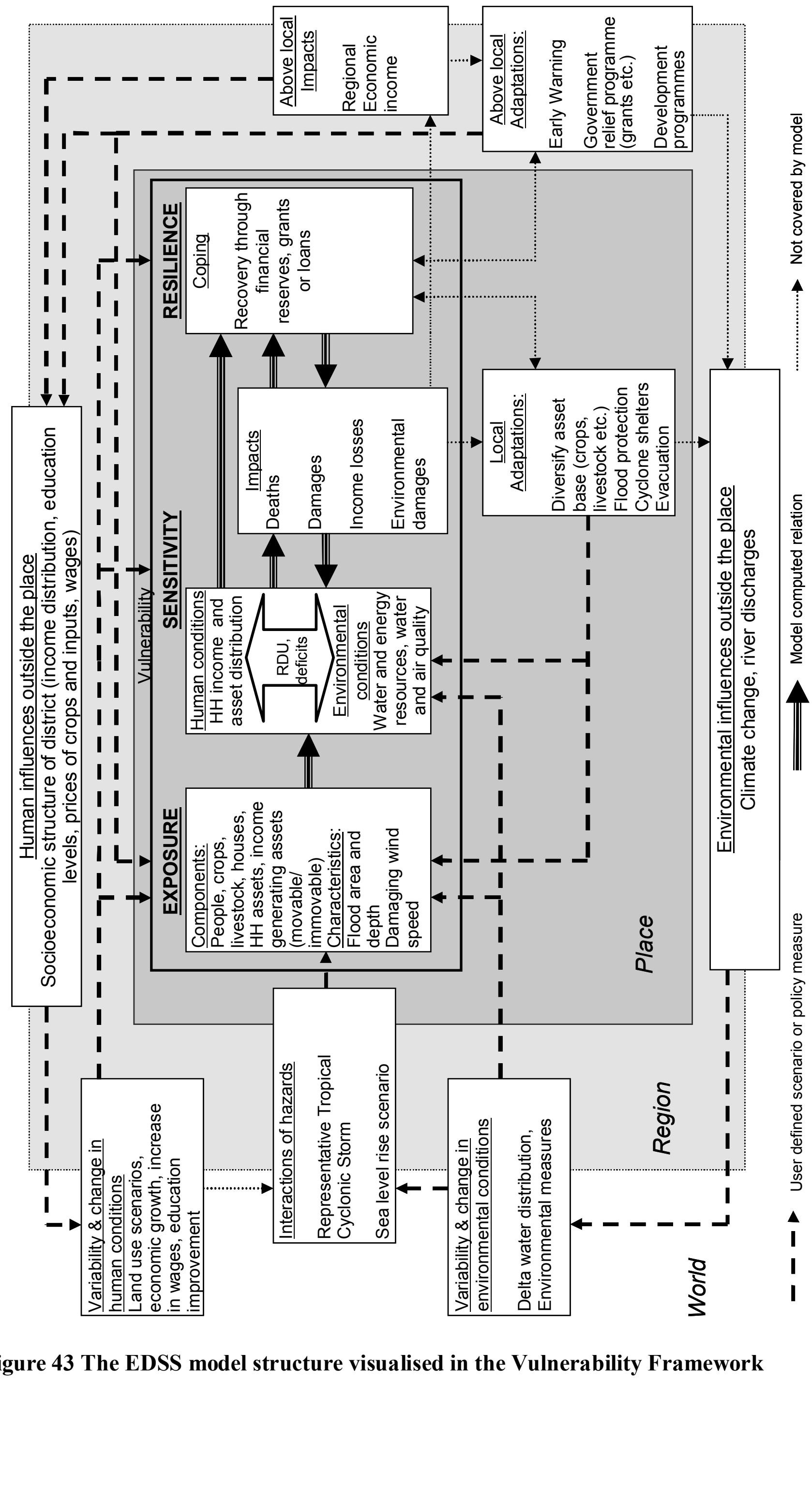


Figure 43 The EDSS model structure visualised in the Vulnerability Framework

The critical question here is how to define a 'representative' storm[17]. In reality the hazard is erratic in terms of severity, frequency and the location of landfall. This makes every cyclonic storm unique. Defining a representative event depends on both the temporal and spatial scale on which we would like to calculate vulnerability. In the case of coastal deltas such as the Godavari Delta, we would like to capture vulnerability to a 'Super Cyclone' at the entire delta level but also with an insight in the spatial differentiation between vulnerability. Since the cyclone such as the one used for the calibration could have made landfall at practically every location along the coast, we cannot use simply that actual storm for our calculations. If we do that it would not make a difference for the delta as a whole, but for the spatial vulnerability pattern it would look like if many of the coastal mandals would be less vulnerable than the ones where the cyclone made landfall. Therefore, we have made use of 5 hypothetical storm tracks covering the entire delta (see Figure 13). This enables the calculation of vulnerability for the 'maximum' area liable to flooding and high winds. However, this procedure would exaggerate the impact at the Delta scale: in reality the area which is affected by one event would be lower. Therefore an algorithm has been used to calculate the percentage of the inundated area with corresponding inundation depth for the representative storm (see Box 8). Central to this approach is that the contribution for each storm to the severity of inundation depends on the relative weight of the severity of each storms.

As can be seen in Box 8 for the example of Kakinada mandal, the inundation severity used for the representative storm are smaller than the maximum possible severity (which occurs as a result of storm 4). Hence, the vulnerability for that mandal calculated by the representative storm is lower than maximally possible. This procedure does allow for a sensible comparison between the vulnerabilities of each mandal and at the same time provides a good estimate of the vulnerability for the whole delta. I will come back to this issue of defining the event for which vulnerability is modelled in our conclusions Chapter.

Relation between components and hazard characteristic
This relation is about the exposure of components vis-à-vis the identified hazards. The sensitivity of the components is dealt with in the next section. Here it is about what makes the components exposed, which is very much a question about their location.

In terms of spatial heterogeneity the mandal is used as smallest scale. Hence a uniform distribution is assumed of people, houses, crop areas etc. over the entire mandal. Because the mandal has an average surface area of around 10,000 ha, this is a rather coarse aggregation, that lead to inaccuracies particularly for those mandals that are closest to the sea. Here, flooding owing to the storm surge is most intense and the heterogeneity of both occupation and local terrain differences can make a large difference in the expected damage and casualties. The effects of scale choice are further discussed in section 9.1.2. Note that at the scale of the entire delta region, we have 75 different mandals that provide insight in the spatial heterogeneity of exposure.

[17] Note that the 'representative storm' has nothing to do with a 'design storm', i.e. a storm intensity which a certain protection system is designed to withstand.

Box 8 Calculation of the weighted average inundation depth for a representative storm

The weighted average inundation depth is calculated as the average of the weighted inundation depth per storm. The weighted inundation depth per storm is the inundation depth multiplied by the corresponding inundation percentage divided by the average inundation percentage for all storms:

$$AreaP = \sum A_i / n$$

and

$$d = \sum (A_i/AreaP \times d_i)/n$$

in which

A_i = percentage inundated area for storm i
n = number of storms
d = weighted average inundation depth
d_i = inundation depth for storm i

For the mandal Kakinada for instance, the average inundation percentage is 38.7%. The inundation depth for storm 3 is 1.95m and the inundation percentage for that storm is 43.6%. The weighted inundation depth for that storm is 1.95m x 43.6%/38.7% = 2.20m.

Example for Kakinada:

runs Storm Surge Model (n)	percentage area inundated (A_i)	average inundation depth (m)	weighted average inundation depth (m) (d_i)
storm 1	38.2%	0.72	0.71
storm 2	41.7%	1.22	1.31
storm 3	43.6%	1.95	2.20
storm 4	46.3%	3.01	3.60
storm 5	20.2%	0.84	0.44
storm 6	42.6%	0.83	0.91
representative storm	AreaP = 38.7%	(average = 1.65)	d = 1.52

6.1.4.2 Sensitivity

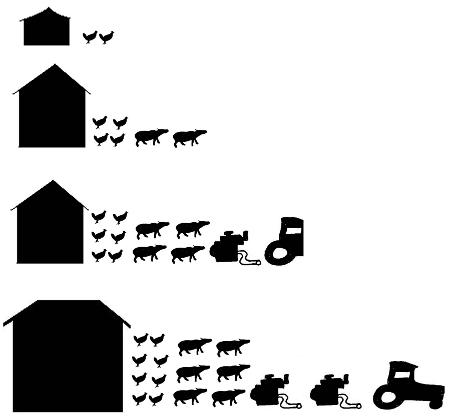
Sensitivity is used here as the potential direct harm to the entities distinguished in the model, i.e. people, crops, livestock, houses & private assets, public assets and habitats. First I will describe the human conditions in terms of social and human capital, institutions and economic structure. Then the environmental conditions will be described in terms of the natural resources and ecosystems. Also the interaction between the two are analysed. And the last section discusses the way the model has implemented the sensitivity of both human and environmental conditions through casualties and damage functions.

Human conditions

The model describes the human condition in purely economic terms. The population is described as numbers of people living in a mandal and as members of a household. Households are a basic social and economic unit in which many people interact and organize themselves for shelter, sustenance and reproduction (Preston 1994). A household is the basic unit of many economic models and theories. And although modern societies have become more individual based, for many countries the household still remains the cornerstone of society. In Asian countries the family of a household often act as the decision-making unit for many aspects of life, including work (Chen & Korinek 2006). Because household, and not family[18], denotes a house with its inhabitants with specific characteristics on a specific location, this unit is also ideal to relate it to vulnerability: a house and household assets can be damaged.

However, in rural India, relations between household and family are varied. For instance, two families can live under the same roof and sharing the same food. But also common is the household of an extended family in which some members live separately but do share resources (Winchester 1992). The model does not take into account such complexities.

The model uses 4 household income categories, based on their relative wealth in terms of their assets (Figure 44 and Table 9). We could also have chosen any other number of income categories. In principle there is no preference, but in economic statistics often use is made of income deciles or quintiles. This would favour the use of 5 or 10 categories. Note however, that deciles or quintiles by definition have a fixed percentage of population, whereas the income categories of the model are flexible in size, i.e. the percentage of the population belonging to a category can be given as input for each spatial unit (mandal). Thus the model can distinguish between areas with high and low poverty incidence.



poor: hut, no land

medium: small house, livestock, ½ to 3 acres of land

medium high: small house, livestock, 3-10 acres of land, waterpump, share in tractor

rich: pucca house, livestock, >10 acres of land, waterpumps, tractor

Figure 44 Household categories used in the EDSS

The macro-economic structure that is used in the model to determine the sensitivity and coping capacity (see next section), is simple and straightforward. It allows for the calculation of key economic variables such as production, labour requirements and distribution of profits and income for both a 'normal' year and an 'after storm' year. Hence, it is an example of a simple model with linear equations in the form of

net output = gross output – (labour + non-labour inputs)

The different economic sectors are linked through labour and ownership to the households. What it leaves out are: external relations (import/export), government taxes, price elasticity. Only simple, linear relationships are included. For instance, a rise in

[18] Members of a family can live in places wide apart, even in another country.

average wages will show an increase in costs, a reduction of profit and increase in income for the labour household. In reality, the market forces will show a slightly different picture: increased wages could force employers to invest in labour-saving machines so that there will be less employment and a smaller increase in income than could be expected.

Environmental conditions

The environmental conditions are modelled in the Environmental Assessment Module (EAM) based on the resource demands and waste generation estimated in the Resource Demand and Waste Generation Module (RWM). This produces a state-of-the-environment picture through indicators on resource deficits, water quality and air quality indices.

The model set up for the calculation of the water balance is highly aggregated and simplified. However, use is made of the results of a much more refined water distribution and allocation model, made by 'Study A' (Babtie International 2003). Similar to the use of the storm surge model and wind hazard model, the EDSS uses the results of the analyses done by this water distribution model for the large irrigation command area.

For the water quality, a three compartment approach was developed: i) the soil/groundwater compartment, ii) the surface water compartment and iii) the coastal water compartment (Figure 45). For each of the mandals (except for the coastal water) this schematization is used, whereby water volumes of the compartments and outflow characteristics have to be organized as input. Because the model only determines an equilibrium concentration as output for one year, no detailed hydro-dynamic model is required. At present the internal degradation rate is a fixed parameter for all mandals.

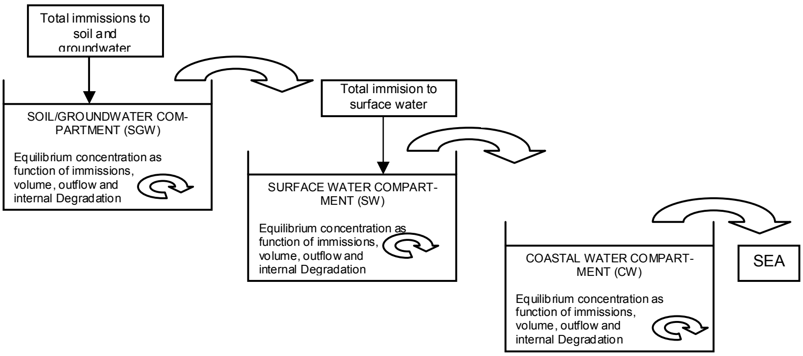


Figure 45 The compartments of the water quality model

Relation between human and environmental conditions

The way human and environmental conditions influence each other is complex and consist of myriad relationships. These relations are not modelled in the EDSS as such. In other words, there is no direct link or feedback between these environmental conditions and human conditions. Instead, the model uses the conditions in a certain year as being constant. For instance, cropping patterns and livestock numbers are considered a given fact and are extracted from the annual district statistics. They resemble the way the farmers use the available land and water resources at that time.

However, indicators of the environmental condition (for instance a shortage of fresh water in several mandals) can be interpreted by the model user and could give rise to modifications in the model input either as a scenario or measure formulation. Then new runs can be made to assess the impacts of these scenarios and measures. In this way critical aspects of the human-environment relationship can be identified.

The same holds for the potential changes in the use of land. Land resources are described through the Resource Development Units (RDU) concept. These units determine alternative land development for each mandal, based on the soil and water characteristics. The model requires these land use alternatives as scenario inputs.

The Water sanitation index that is used by the EDSS is a combination of the availability of clean drinking water and water pollution. This seems a good choice, as the most important environmental hazards, particularly for urban populations is faecal contamination of water and food resulting from inadequate sanitation systems, compounded by unreliable and unsafe water supplies (Scott 2006).

Air pollution can be a health hazard. For instance, worldwide, approximately 1 billion people are affected by problems caused from using traditional biomass fuels (indoor air pollution)(Scott 2006). The EDSS model calculates emissions of RSPM (Respirable Suspended Particulate Matter) from traffic and fuel use. Because the model does not include an air pollution transport model, air quality is approximated roughly by calculating the local atmospheric pollution density, defined as the emission of RSPM divided by surface area of the mandal. Local hotspots of severe pollution can thus be identified.

Relation between exposure and sensitivity

For the category ‘people’ no further distinction is made in terms of sensitivity to flooding and wind damage. Population numbers are used at the spatial level of the mandal to determine potential casualties. This is a weak point in the model, because we know that not all people are equally sensitive to the hazard. Age, sex, economic and health status are considered to be important attributes to the human condition that determine the chances of drowning during a flooding event (Jonkman et al. 2008). Also occupation can be an important determinant to differentiate the risk among the population. For instance, fishermen are more exposed and also more sensitive to the cyclone hazards because their work bring them to the most hazardous places. The model uses only two categories of labour: skilled and unskilled and no further specification in occupation is made. Although the difference in economic status of households is distinguished in the model, this is not used for the calculation of casualties.

The above implies that the model cannot be used as a guidance for explicitly targeting measures that reduce the vulnerability for those within the population that are most vulnerable (e.g. measures that increase the accessibility to, and effectiveness of, cyclone shelters).

Early warning, evacuation and shelters can reduce the sensitivity of people and assets to the hazard, even when they are living in highly exposed locations (for instance closest to the sea). Hence, they act as a ‘filter’ in the vulnerability framework between exposure and sensitivity. In the model early warning, shelters and evacuation are used in the same way as a filter: information on the local situation with respect to the road infrastructure (percentage of villages that are connected to the road system by metalled roads) and availability of cyclone shelters within the mandal is used to calculate the remaining population at risk and potential damages. The effectiveness of early warning is input to the model as an overall factor on evacuation effectiveness. The evacuation filter is also applied for those assets that are characterised as movable.

The model allows a range of different crops to be defined, including their tolerance to flooding and high wind speed (see Figure 46 for an example). Susceptibility to flooding depends on many factors, including the timing of the event: for nearly mature grain crops the potential damage can be much higher than for crops that have just been sown. The model assumes a worst case situation for all crops alike, as it does not differentiate in timing of the event. Sensitivity coefficients are chosen on the notion that agricultural crops will respond differently to flooding. Basically there are two mechanisms that cause flood damage: crops can wash away or break, collapse etc. and plants die because of the saline waters. Because of the salinity of the flood water, even a modest inundation depth can cause high crop damages. The sustained high salinity of the soil which could affect future crops is not included in the flood damage calculations. Most sensitive crops include rice, maize, sugar and pulses.

Three different types of houses are defined, each with a different sensitivity to flooding and wind. Also for public, private and income generating assets damage functions are defined and used for immovable assets and movable assets that are considered not to have been evacuated (see section 2.2.2). Because the model links the house types and asset values to the four household income categories, it facilitates expressing the difference in sensitivity between these categories. For instance, the poorer households in a heavily impacted area will probably loose almost everything they possess because their houses cannot withstand the forces of wind and flooding. The higher income classes in the same area will live in stronger houses that will most probably only be partially damaged. Their total damage could nonetheless be higher in absolute value, because they have more to loose.

Several of the damage functions used in the model are evidence based (for instance, the wind damage factor for crops and houses (Specific Risk Coefficients from the Wind Hazard Model, see Figure 46). But most of the parameters lack experimental or observational evidence. Instead the damage parameters are tuned to data on damage during the calibration phase.

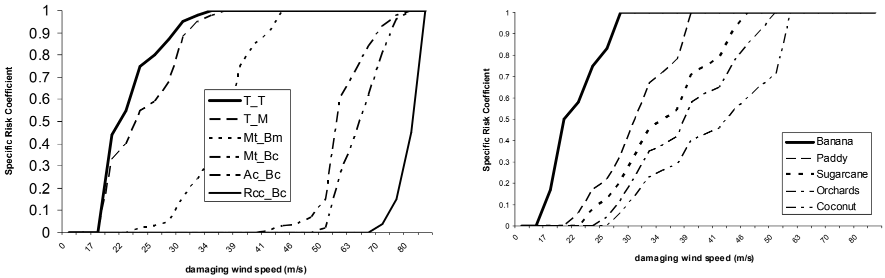


Figure 46 wind damage functions for buildings (left) and crops (right)(source: IIT-Chennai 2002)

No specific sensitivity has been modelled for the industrial and commercial sectors. For the medium and large industrial enterprises that are distinguished in the model this is probably appropriate, as they are not very vulnerable to cyclones. They will have taken their own precautions to minimize damage by natural calamities. Investors, very likely, will have considered construction requirements in such a way as to outweigh the cost of cyclone damage recurrence by the cost of additional protection measures. It is up to them to establish sufficiently strong buildings and internal infrastructure or to take the risk of damage by rain, wind or inundation. It can also be assumed that most have insured their assets. In this sector, impacts of cyclones will be indirect, mainly by malfunctioning of surrounding infrastructure (power supply, roads, bridges, communication facilities) and absence of labour, but may entail considerable economic losses. Much more vulnerable are small-scale industrial enterprises, scattered throughout the study area (weavers, workshops, rice-mills etc.), and based on low-capital investments. Cyclone impacts may entail total damage of assets, and recovery potential is often low (Mulder 2001). However, the model does not allow this kind of differentiation since it uses only one standard damage factor that represents sensitivity of income generating assets for the industrial and commercial sectors.

Impact

Earlier (section 3.3.4) I defined 'impact' as resulting from exposure and sensitivity that provides input to determine coping and adaptation. In terms of the model this relates to damages and casualties directly caused by the representative storm. The model output consists of damages to standing crops as well as damages to assets, broken down into income generating assets and private assets per income quartile for both urban and rural households. These aggregated variables are based on the calculations of losses for the discerned crop, livestock and asset types. Casualties are calculated solely by using the casualty function based on flood class (i.e. flood depth).

Loss of land, animal losses and damage to houses are considered to have the most serious consequences for households (Winchester 1992). Loss of land is not included in the model because it is considered only a temporarily inability to use the land (e.g. damage through sand-casting and salinisation from sea inundation), although local cyclone induced coastal erosion could lead to permanent land loss[19]. Animal losses also have a serious impact since many people depend on them for an income one way or another. They are included in the model as 'movable income generating assets', so their loss is counted both as asset loss and as a reduced potential for income generation. House and domestic losses can have dramatic consequences for the households (Box 9).

Box 9 House and domestic losses in Andhra Pradesh

Winchester (1992) writes: '*the loss of a house can be a major set-back, depending on the house-type. In this climate the houses are used less for living in but more for keeping things in. Food stores, jewellery and household utensils are kept inside even the humblest mud and thatch house. […] The loss of a traditional 'pucca' house (two- and four- truss roof with clay tiles and stout walls) is a severe blow. […] The replacement costs for traditional houses are very high (25 percent of the average income of a typical 'pucca' house-owning family) and require specialist skills that cannot be arranged on a reciprocal basis.*'

Crop losses represent a property loss to the farmers who own them and a loss of income for the people who would have been employed harvesting them (Winchester 1992). Both effects are included in the model. The timing of the disaster is an impor-

[19] Loss of land in earthquake and tsunami impacted coastal areas can however be a major problem: large scale coastline changes and permanent waterlogging due to tectonic subsidence has been observed along the Sumatra coast as a result of the 2004 tsunami.

tant factor, but not included as variable in the model. The model assumes a worst case situation: the crop is destroyed at the moment of harvesting.

6.1.4.3 Resilience

Besides the direct impact of a storm in terms of damages and casualties, the model also calculates the economic effect one year after the storm has passed. By re-calculating the economic module (SAM) taking account of the damages and possible coping measures, the income and asset situation after storm is assessed (see chapter 2). This is called the *recovery factor* in the model output.

The model assumes *as coping strategy* that damages in assets are compensated for by using the financial reserves of a household, in as far these reserves allow. Also other financial resources, for instance loans and government grants can be used, if available. The availability of these loans and grants is a parameter of the model, enabling to analyse the effect of these financial compensating mechanisms. At a macro-economic level this implies that all available financial reserves will be applied to reduce the economic impact of the loss of income-generating assets, so that the loss of income one year after the storm will be reduced as much as possible. Only grants and savings can lead to a recovery of total asset value. In effect, there can (and will be) a shift from non-fixed capital to assets. Although this shift and entering into loans will not benefit the total asset value, it can lead to a more rapid recovery in terms of income. In Box 10 these calculations are explained through an example.

What we can learn from this example is that:
- the poorest households have the lowest recovery on assets. Even if their losses are relatively small in absolute value, they nevertheless are disproportionally affected.
- once a household owns some land, its recovery on assets is much higher. Land is not vulnerable to storms. It can be used as collateral against which money can be borrowed against normal interest rates.
- the more farmers rely on income from their crop, the lower their recovery on income.
- full recovery depends on the savings a household can make in the years after the storm. For most households this probably take several years. However, for the poorest sections of the population, it may well be impossible to fully recover if they are not able to make some savings at all.
- Diversification of the agricultural sector with crops with a lower vulnerability or faster growth could reduce the overall vulnerability for cyclonic storms.

One should remember that the description of the fate of these households in times of such a disaster show an ‘average’ picture. Indeed, some households will have much more damage and would be far less able to recover than the calculated recovery factors indicate. O’Hare (2001) mentioned that a small number of landowning farmers in the delta were bankrupted by the severe agricultural losses they suffered. At the same time the picture of the poor household that was able to start working again does not include the migrant, scheduled (low) caste women from the state of Orissa who perform most of the agricultural work in the rice fields of the Godavari Delta. Many of them had to subsist by begging or by selling their meagre possessions just to stay alive (O'Hare 2001).

Box 10 How does the model calculate recovery?

Using the percentage of damage of annual household income as indicator for vulnerability, this would give the impression that the medium high and rich are the most vulnerable (see table below). However, when looking at assets lost and ability to recover, the poor are more vulnerable. Households with land have a much firmer basis with respect to asset loss. Their recovery on assets is high, as we will see later. On the other hand, because their income relies heavily on the harvest, these households show a considerable dip in their income directly after the storm. Also households that mainly rely on wage labour income could be affected by this loss of agricultural production. Some of them will therefore seek alternative labour opportunities in regions not affected by the storm. We will explain below how the model calculates these differences in vulnerability. We do this by following two hypothetical households living in the mandal I. Polavaram, close to the point where Cyclone H07B made landfall in November 1996.

income class	total damage	annual income	damage as % of annual income
poor	3,748	27,129	13.8%
medium	16,009	40,412	39.6%
medium-high	97,810	108,941	89.8%
rich	205,658	315,764	65.1%

Of the total annual agricultural production in I. Polavaram (around 560 million Rs), the cyclone has destroyed nearly half: 305 million Rs. Although the crops of the entire mandal were badly affected either by the flooding from the sea (around 16 % of the area was flooded by the storm surge), or by the wind, this accounts for about half the annual production, because aquaculture and rice have two crops. It is assumed that after the storm the conditions are such, that the second crop of the year can still be harvested. This is an optimistic scenario, because in reality it probably will take longer to reconstruct the damaged fish ponds and to drain the fields. On the other hand, the model assumes a worst case in the sense that a complete first crop is lost just before harvesting. This obviously depends on the timing of the cyclone and losses could be less.

Now look at two different households. The first is a poor family of five living in a hut with some chicken and a share in a cow. The husband has a bicycle which he uses to go to his work as a land labourer. The wife and sometimes the oldest son work on a small lease-hold shared piece of land. Their total assets comprise (price level of 2001) :

- Income generating assets: 1 667 Rs (land) + 667 Rs (chicken, share in cow)
- Private assets: 4 067 Rs (hut, cooking utensils, bicycle)
- Non-fixed capital: 1 600 Rs (gold and jewellery)
- Total: 8 001 Rs.

A cyclone has badly hit the village and destroyed the hut, the chicken and household essentials, totalling 3 748 Rs. Luckily the family with the bicycle and the cow were able to evacuate in time. Hence, their total value of remaining assets directly after the storm is 4 253 Rs. Because they need to have somewhere to live again, their first priority is to rebuild the hut and to buy new cooking utensils. They receive a government relief grant of 1 000 Rs. (official relief paid after the Nov. 1996 cyclone, Reddy 2000). Because this is not enough for buying all the necessary equipment, they sell their gold and jewellery and also need to take a loan from moneylenders that ask 30% on an annual basis.
Summed up: 1 000 Rs Grant + 1 600 Rs Gold + 1 148 Rs Loan = 3 748 Rs

With this money they can rebuild their house and start cooking again. How is their asset value one year after the storm? Of the initial remaining asset value only 1 000 Rs can be added (the government grant from the relief fund). The rest of the asset value has not changed. The gold is transferred into goods and the loan has to be deducted from the assets they have. Hence their total asset value one year later is 5 253 Rs. Their recovery factor on assets is: 5 253 / 8 001 = 0.66. (without the government grant this would be 0.53).

Because the husband and wife were able to get work again, although after some difficult weeks without labour opportunities, they still were able to get some income. The model calculates income from labour as the average employment rate times the number of people working per household

Box 10 How does the model calculate recovery? (Cont.)

times the average wage. Due to the storm the labour opportunities are reduced because of losses in the agricultural sector and damages of income generating assets. Therefore the employment rate after the storm will be lower than before (from 96% to 74%). Their household balance is negative (recovery factor 0.73) as can be seen below:

income component	**Before the flood**	**After the flood**
income from labour	26 749 Rs	20 187 Rs
income from IGA	139 Rs	-14 Rs
income from non-fixed capital	240 Rs	0 Rs
negative income (interest on loans)	0 Rs	- 344 Rs
Total	27 128 Rs	19 829 Rs

The model calculations thus take into account i) the reduced labour demand after the flood, ii) the reduced value of income from income generating assets due to damage, iii) reduced annual return on non-fixed capital because this is used for compensating the damage and iv) interests to be paid for loans that had to be taken to compensate damage.

Now let us look at a household belonging to the richest part of the population. This household also has five members, owns 10 acres of land, have a 4 pole *pucca* house, a waterpump and several livestock animals. Their total assets comprise:

- Income generating assets: 1 500 000 Rs (land) + 350 000 Rs (livestock, equipment)
- Private assets: 430 000 (house, cooking utensils, luxury, bicycles, scooters)
- Non-fixed capital: 50 000 Rs (money on bank)
- Total: 2 330 000 Rs.

The cyclone damaged the house and many luxury goods that could not be saved. The total damage to private assets was 185 000 Rs. Also parts of the equipment were lost and the damage to these income generating assets was 20 658 Rs. Luckily the family was able to evacuate in time with their animals, bicycles and scooters. Their total remaining assets directly after the storm was 2 124 342 Rs. They received 500 Rs. for their partly damaged house from the government. The remainder of the damage was replenished by their capital and a loan (because this household is sufficiently credit worthy, it can take a loan against a low interest rate): 500 Rs Grant 50 000 Rs Capital 155 158 Rs Loan = 205 658 Rs. Hence, their recovery on assets is (2 124 342 + 500)/2 330 000 = 0.91.

Although the annual income from the farm has drastically reduced, due to the crop loss, the household could still make some profit from the second crop and from the interest it has in the secondary and tertiary sectors. Their recovery on income is 0.32.

income component	**Before the flood**	**After the flood**
income from labour	51 942 Rs	31 696 Rs
income from IGA	256 322 Rs	83 941 Rs
income from non-fixed capital	7 500 Rs	0 Rs
negative income (interest on loans)	0 Rs	-15 515 Rs
Total	315 764 Rs	100 122 Rs

As soon as the farm works normal again, the household can start making savings again, in the order of 25 000 Rs per year (around 8% of the income), which means that it would take around 8 years to have fully compensated for the damages. Should the farm receives its major income from coconut groves, this period could take four extra years, before the new coconut palm trees can be harvested again.

We thus see a reversal of the picture on recovery factors: for the poor household the recovery on income is higher than the recovery on assets. Whereas for the high income household this is the other way around. The recovery on income is lower than the recovery on assets. The considerable difference between the recovery on assets of the two families can be largely attributed by the ownership of land, which retains its value after a storm.

Two choices underlie this assessment require closer examination:

Why take one year as a time span?
For instance Carter et al. (2007) use a 30 month period following hurricane Mitch for their resilience model (because their samples were taken 30 months after the hurricane). For our model using one year of the period of recovery is quite practical: because the economic model calculates annual input and outputs, we can use the same part of the computer code for the 'after storm' calculations.

Why use asset and income as vulnerability parameters?
The explicit differentiation between asset and income recovery is important because it reflects two different aspects of the economy: asset and asset distribution determines wealth on a structural basis. Disaster induced changes can upset this structure and for certain people could change their future entirely. A household can be pushed into a poverty trap, which is a minimum asset threshold below which accumulation and livelihood growth are not possible (Carter et al. 2007; Azariadis & Stachurski 2006; Gehlich-Shillabeer 2008; Dercon 2001). On the other hand, income recovery tells us something about the more short term economic situation of a household. Income, not asset value, is an often used measure of poverty.

The EDSS produces as output the *'Number of people financially vulnerable'*. This variable expresses an aggregated vulnerability. People are considered vulnerable if income recovery factor or total asset recovery factor is less than specified critical value. However, the problem here is to define the threshold, the critical value of the recovery factor. It is difficult to arrive at such a definition. Other vulnerability indicators that would be more easy to define are for instance the number of people falling below the poverty level or the number of people that fall into the poverty trap. The poverty trap is defined as a critical minimum asset threshold, below which families are unable to successfully educate their children, build up their productive assets and move ahead economically over time (Carter et al. 2007).

Adaptation
Adaptation is not a part of vulnerability. Following the definition by Scott (2006) of adaptation as long-term management strategies, we are looking beyond the immediate adjustments and coping strategies of households, that can be taken within the time step of the model, i.e. one year. Examples of such adaptations *at the local level* (households and villages) that can be found in the literature are:

- Local safety measures, such as the construction of cyclone shelters
- Damage reduction measures, e.g. changes in crop selection (e.g. growing rice varieties that can withstand floodings, see Bangladesh: (Del Ninno et al. 2003).
- Increasing coping capacity, e.g. asset accumulation, micro-insurances (Coburn & Winchester 2008)

Adaptation is not calculated by the model. Instead, it is implemented as user defined 'measures' or 'scenarios', the effects of which can be determined by running the model several times and comparing the results in terms of asset and income recovery. From the examples of adaptation listed above, the EDSS enables the user to analyse the effect of evacuation improvement / cyclone shelter construction and a different cropping pattern. The unit level of the mandal used by the EDSS does not allow for detailed spatial adaptation measures at the village level.

Relations between coping, impact and adaptation
Coping and impact are linked in the model in the way that the impact one year after the storm is dependent both on the initial impact (damage) and the coping mechanisms as described above. Because the adjustments/adaptations are user defined (see above), there is no direct link in the model with coping and impact.

Relation between adaptation and sensitivity
Several user-defined measures in the EDSS can affect the sensitivity of the human and environment conditions. Sensitivity reduction implies measures that would reduce the direct damage to crops, houses and other assets. Examples are:

- stronger houses
- crops that are less sensitive to floods and high winds
- changes in livelihood strategies (making income less dependent on activities that can be harmed by the storm)

It is tentative to introduce economic growth or poverty reduction as a way to reduce the sensitivity of a community to natural hazards. This would indeed lead to stronger houses, more diversity in income producing resources and a general increase in coping capacity. But poverty reduction is a too general term here, because it can also lead to an increase in sensitivity. For instance, when a farmer decides to plant banana trees instead of growing rice, it could well increase its income position on a longer term, but it could also increase his risk of loosing the entire banana plantation (banana trees are very sensitive to winds).

Most measures and scenarios in the EDSS are of a global character and do not differentiate at the local level. These will be discussed in the next section.

6.1.4.4 Cross scale vulnerability relations

Table 31 provides the list of elements and relations that work at the regional or world level that exert an influence on the place level vulnerability. For each of these elements and cross scale relations a description will be given to which extent they are implemented in the EDSS.

Impact
The model calculates the regional damages and income after the storm by adding up the mandal damages and incomes. Also the total number of casualties is given for the entire region. It is evident that, when aggregating the damages and economic effects, the appreciation of seriousness depend on the scale of the region. For instance, the impact a storm has on a country differs considerably from the impact on the world economy. Therefore, the choice of the area to be modelled is not entirely without consequence and should be given good thought. In the case of the EDSS, the region is defined as the study mandals of the project which fall within the Godavari Delta. This involved two districts, but both of them were only partially included. This does make sense from a physical point of view (it more or less covered the delta as a geomorphological unit), but from an economic or administrative perspective it is not very practical.

Table 31 Implementation of vulnerability in the EDSS (cross scale relations)

Elements of Framework	EDSS application
Impact	Model calculates regional casualties, damages and income after storm
Adaptation	user defined measures for: - grants - loans - early warning system
Human influences outside the place	Macro-economic and social structure of Andhra Pradesh is part of system parameters (e.g. production structures, education levels, prices of crops and inputs). These are ‘fixed’ for a specific district. Basic structure of the model reflects current situation. The EDSS is limited in analysing mega-trends.
Environmental influences outside the place	River discharges and volumes Climate Change / Sea level. The external delta water model (Babtie) accounts for spatial differentiation within the delta.
Variability & change in human conditions	Scenarios and / or policy measures for: - land use - economic growth - education improvement - increase wages - increase agricultural production - increase supply of drinking water and electricity - increase in surface- & groundwater supply capacity (irrigation)
Variability & change in environmental conditions	Scenarios and / or policy measures for: - sea level rise - reduce operational losses in PWS and irrigation - reduce water/energy demands for HH and production sectors - reduce waste loads of HH and production sectors (water & air pollutants and solid waste) - improve waste water treatment facilities - enhance natural and engineered flood protection
Interactions of hazards	Cyclone hazard is modelled with respect to storm surge and wind as a representative storm. In reality no two cyclones are the same. There is much difference in hazard, with respect to severity, point of landfall. Also no rainfall is included. And no interaction with river stages. No other natural hazards.
Relation between variability & change in human and environmental conditions and hazards	One relation is explicit: sea level rise will cause larger floods during a storm. No other relations made explicit, e.g. climate change could require a redefinition of the representative storm. However there is no conclusive scientific evidence for this.

Adaptation

Adaptations to cyclonic storms at the above local level include those measures that are organized at the regional, state or national level. An example of such adaptation is the Cyclone Contingency Plan of Action (CPA) that was approved in 1981 (and updated in 1987) as the official policy document governing cyclone mitigation of the State of Andhra Pradesh. The CPA set out what the duties and responsibilities are for all levels of administration in the event of a cyclone threat (Winchester 1992). As part of this CPA, immediate relief is provided consisting of paying gratuities to the affected persons. For this purpose, Collectors are empowered to sanction Rs.5,000/- to the next of kin of person dead and Rs.500 per house completely damaged and certain quantity of rice as relief. The distribution of relief is to be done by Relief Teams in consultation with the Village Committees (Sreeram 2001). Typically, this kind of adaptation strengthens the coping capacity of households at the local level. Another example of an overarching, regional adaptation measure is an early warning system, that enables rapid identification of areas to be evacuated.

The EDSS provides user defined measures on grants, loans and the supposed effectiveness of early warning. The availability of grants is to be specified as a policy variable in terms of the fraction of total asset damage that will be restored from grants (by rural and urban income class). The use of grants always has priority. Second, if non-fixed capital is available, this will be used to the extent possible to restore income generating and private assets by rural and urban income class. The use of loans is regarded as an external input (an 'assumption' variable) to be set to any fraction between 0 and 1. If set to 1, all remaining money needed to fully restore the damage to income generating and private assets will be borrowed; if set to 0, no money will be borrowed at all.

The warning efficiency is a parameter that can be put from 0 to 1 for the entire region. Together with the evacuation efficiency it determines the number of people at risk that are expected to have moved out of the risky area (only flooding included here).

Human influences outside the place

There are potentially many contextual aspects that influence the local vulnerability. It encompasses the macro-economic and social structure of Andhra Pradesh and is represented in the EDSS as a set of system parameters (e.g. asset levels and distribution, education levels, prices of crops and inputs). These are ‘fixed’ for a specific district (and therefore are not easily adjusted by a superficial user, but could be changed nevertheless for another region or district). But it is also represented in a deeper, less easy to modify, structural design of the EDSS: the fact that the primary economic sectors of agriculture, livestock and fishery are worked out in far more detail than the industrial or commercial sectors, reflects the specific AP macro-economic structure of the end of the last century.

Macro-economic changes, global trends and transitions as supposed by Turner et al. in their framework, are not easily accounted for in the EDSS, because this requires changing many system parameter settings.

Environmental influences outside the place

Here we find numerous relations that are transferred at a landscape or larger scale level. Examples of such relations include: the hydrological cycle, groundwater flows, rivers, sea level, animal migrations, air pollutants etc. The EDSS has been developed on a firm knowledge basis of both the land and water resources of the Delta. For the land use, reference is made to the Resource Development Units (see Section 2.2.3). For the water resources, the EDSS has extensively used the acquired knowledge from Study ‘A’ on the Delta Water Management. Much of this information is embedded in the structure of the model (equivalent with the human structure). For instance, each mandal has been given a status with respect to irrigation water reliability. These kinds of relations can only be changed with some difficulty, except for some key parameters that can be changed in the scenario or measures settings (which are described under the next two headings).

Variability & change in human conditions

I interpret this box in the Framework of Turner et al. as more short-term, proximate changes that become visible at the local level. The origin of these changes and variability can come from the macro-economic trends, global markets etc., or from specific government plans. In the EDSS this box is represented by the settings of scenario and policy measures. The user can select changes in:

- land use
- economic growth
- education improvement
- increase wages
- increase agricultural production
- increase supply of drinking water and electricity
- increase in surface- & groundwater supply capacity (irrigation)

Of course the ranges in which parameter settings can be changed is limited by the way they are implemented in the model. For instance, education improvement will only be reflected by a shift in the ratio between skilled and unskilled labour.

Variability & change in environmental conditions

Similarly to the variability in human conditions, the variability and change in environmental conditions is represented in the model by scenario and policy measures for:

- sea level rise
- reduce operational losses in PWS and irrigation
- reduce water/energy demands for HH and production sectors
- reduce waste loads of HH and production sectors (water & air pollutants and solid waste)
- improve waste water treatment facilities
- enhance natural and engineered flood protection

Some of these scenarios and measures have a direct, logical impact on vulnerability. For instance an improved flood protection is likely to reduce the number of casualties, whereas sea level rise has the opposite effect. For other measures and scenarios, the relation is more indirect and the relation with vulnerability is not crystal clear. For instance, an improvement in waste water treatment facilities will probably improve the water sanitation index. But the EDSS does not contain a feedback towards improved health and reduced vulnerability.

Interactions of hazards

This is an important and potentially quite complex aspect of vulnerability. Households have to cope with many different hazards, both natural and human induced. If we limit this to environmental hazards potentially leading to disasters ('shocks of nature'), still a respectable number of problems and risks remain, including floods from storm surges and tsunamis, floods from heavy rainfall, high winds, droughts, extreme temperatures and epidemics of crop pests and livestock diseases (Scott 2006).

It becomes particularly problematic when several of these shocks cluster or happen together in a sequence, each event decreasing the household's ability resources and lowering their ability to recover, combining to produce a multiplier effect. A complete picture of vulnerability should therefore ideally include all of these hazards. In practice, this is difficult because there are many combinations of probabilities involved, so that many potential situations should be analysed. As we have seen earlier, even in the case of a cyclone, the hazard is a function of many probabilities (such as the position at landfall, the intensities of rain, the timing in view of the crop growing season, the severity of the cyclone etc.). The EDSS works with a 'representative' storm or flood (see earlier description) and does not include other hazards.

Relation between hazards and variability & change in human and environmental conditions

Again, this is a very complex issue and could be tackled at many different time and spatial scales. There are many examples of (human induced) environmental degradation that increase natural hazards (for instance landslides as a consequence of deforestation). There is limited and often contradictory knowledge regarding the impact of environmental changes on the occurrence and severity of cyclonic storms. The impact of climate change on cyclones is rather disputed (Mitchell et al. 2006; Pielke Jr. 2007). The only relation that is implemented in the EDSS is the effect of a climate induced sea level rise on the extent of flooding during a representative cyclonic storm. This effect has been calculated with the Storm Surge Model, the output of which is used in the EDSS.

6.1.5 Conclusions pertaining to the Model Perspective

Coming back to the research questions we see that the following components are of relevance:

RQ 2: How can we model vulnerability?

- Modelling of vulnerability as implemented in the EDSS fits in the place-based vulnerability framework presented in Chapter 3. Many of the *in place* relations are simulated by the model. Most of the *cross-scale* relations have been implemented in the form of parameter settings for scenarios and/or strategies.
- The choice of the storm and flooding event is a critical factor determining the output of the model

RQ 3: How useful (valid) is our model?

- The EDSS model matches the basic Reference Structure of Meadows & Robinson (1985) for large scale social systems. The relations are logical and what is not included can be explained by the fact that the model simulates only one year. An omission is the lack of government taxes, that make the per capita income slightly too high.
- Strong points of the EDSS are the computational linkages between exposure, sensitivity and resilience with respect to cyclone vulnerability.
- Integration of the environmental conditions and adaptations with vulnerability is weakly implemented (no dynamic feedback).
- The industry as economic sector is implemented in a straightforward manner which leads to an underestimation of sensitivity and resilience capacity.
- The choice of the hazard for which vulnerability is calculated has a significant influence on the results

6.2 Analysing the Application of the EDSS for Andhra Pradesh

6.2.1 Data availability and reliability

The following data sources are used for preparing the Godavari Delta application:

- Official statistics from the Government (mainly the District Handbooks of Statistics)
- Questionnaires (a survey of thousand households and a survey in all study mandals on income, labour and industrial activities)
- Literature data (such as the FAO Sourcebook on agricultural input parameters)
- Expert sources (for environmental input parameters)

- Data from other models (such as the SMM and WHM)
- Data from the GIS of the AP Disaster Management Society

A list of input files for the model is given in Appendix 3. I make a distinction between input data and parameter data. Input is associated primarily with data that describe the reference (base case) system and the external driving forces that have an influence on the system and its performance. Parameters are constants in the model, supposedly invariant within the chosen context and scenario (Walker et al. 2003). Input data are mostly location specific and a new set is required for each application. Parameter data are less location specific, but often have to be changed when applying the model to a completely different location (e.g. another country or another climatic zone). Considering the large amount of input and parameter data needed for the EDSS, it is not feasible to describe its reliability in great detail. Model documentation of the Godavari Delta Application is however available which provides all sources of data as well as inferences for input for which no primary data was available (Marchand et al. 2008).

Preparing the input data for the EDSS is often straightforward (for instance crop areas per mandal are readily available), but can also need some considerable pre-processing. For example to get mandal-wise input data on electricity capacity, the total installed capacity for the entire district has been divided over the mandals per ratio of the population distribution. These kinds of calculations derive secondary input data which are not completely accurate. Because the errors that are generated by this method are non-systematic the influence they have on the regional outcomes are quite limited. At the mandal level, however, rather large deviations from reality could occur.

The District Handbooks of Statistics provide an overwhelming amount of data, often with considerable detail. For instance, in the 1991 Census, every house type in every mandal was accurately described in terms of wall and roof material. This provided highly valuable insight in the quality of the houses, enabling a good assessment of the susceptibility of the houses for wind and flood damage. Unfortunately, this type of data has not been updated in the 2001 Census.

A problem in preparing input data for models such as the EDSS is that ideally one would like to have all data for the same base year (in our case 2001), but that much data is only available for other years. For some rapidly changing or developing entities this could be a serious problem. In those cases, additional surveys or fact finding missions have been executed, for instance regarding the area of rapid expanding aquaculture in the coastal mandals.

For two groups of input data it was relatively difficult to obtain data:
- Socioeconomic data, esp. labour data, income distributions and asset value distribution
- Environmental parameters, such as emission coefficients and treatment efficiencies

For the distribution of income and asset value, use was made of the household survey in combination with the experience of the sociologist within the team, Dr. Winchester.

It was particularly difficult to generate information on the labour supply per household, because aggregated data had to be disaggregated over three dimensions: urban/rural; income category and skilled/unskilled.

Although many environmental parameters were not readily available for the study area and had to be estimated by expert judgement (Dr. Baderinath), the rather coarse and aggregated level of the model simulation for the resources and environment reduces the impact of uncertainty on the output. Furthermore, ‘omitting structures or variables known to be important because numerical data are unavailable is actually less scientific and less accurate than using your best judgement to estimate their values’ (Sterman 2000).

6.2.2 Model calibration

The model was calibrated with respect to the output of the Socioeconomic Assessment module, the Environmental Assessment module and the Cyclone Vulnerability Module. The possibilities for calibration depend on the availability of (statistical) data that reflect the actual situation (in the case of the Andhra Pradesh application the year 2001 is used as ‘basecase’). The extent to which these data are a correct representation of the ‘real’ economy, environment and vulnerability in the delta has not been part of the research. The choice of 2001 as calibration year was logical from the fact that this coincided with the data of 2001 that became available from the Indian Census which is performed every 10 year. Model results were compared with official key macroeconomic data of the two districts that cover the Godavari Delta and showed reasonable agreement. With respect to the Environmental Assessment module, sufficiently detailed and reliable data of the current environmental quality was lacking, unfortunately. Casualties and damage calculations of the Cyclone Vulnerability Module could be calibrated remarkably well against data of the November 1996 cyclone, especially for the two important damage categories crops and houses.

6.2.3 Scenario and strategy choices

The model allows for four types of scenarios: population growth, land use changes, economic growth and sea level rise. For the population and economic growth scenarios annual growth rates can be chosen, with which a new socioeconomic can be calculated for a defined time horizon. The current model has one scenario for sea level rise (1 m), which uses the output of a scenario run of the storm surge model with a 1 m higher sea level.

For the land use scenarios entirely different model data input is required with respect to mandal-wise cropping patterns, livestock numbers, urban areas, habitats etc. For the Andhra Pradesh application use could be made of the ICZM study of the AP project, in which a wide range of land use opportunities and limitations were assessed. Out of this analysis four different land use scenarios were synthesised (see Table 19). The rationale for these scenarios is documented in Marchand & Mulder (2007).

With respect to the selection of measures, no specific strategies have been defined for the Andhra Pradesh application. Instead, the model has been used to analyse the sensitivity of vulnerability with respect to each of these measures separately.

6.2.4 Interpretation of the model results

In this section I will answer two questions: 1) can the model results be explained and are they in agreement with theory? (inductive); 2) what do these results signify for the development and vulnerability of Andhra Pradesh? (deductive). From the analyses with the model by running various cases (see Chapter 2) the following general conclusions with regard to vulnerability can be drawn:

- The model shows differential vulnerability between income classes
- Landuse scenarios do not significantly change vulnerability

- Economic development reduces vulnerability
- Poverty reduction reduces vulnerability even more
- Of all measures the government can take, the issuing of grants after a disaster results in the greatest reduction in vulnerability

First I will show that these model results can be explained and that the model shows plausible behaviour. And at the end I will discuss the implications of these results for vulnerability and disaster management in Andhra Pradesh.

Model shows differential vulnerability
Vulnerability in the model is expressed as a recovery factor (RF) for income and assets. From the calibration run, which simulates the impacts of the 1996 Cyclone 07B the model output shows the following vulnerability pattern (see Figure 26 in Chapter 2): RF on income decreases from poor to rich, whereas RF on assets is high for all income classes except for the rural poor (about half as high as the other classes).

An interesting question is why the recovery factors on income behave differently over the income classes than the recovery factor on assets. For this we have to understand how the model exactly calculates these factors. For assets this is relatively simple: it subtracts the losses and damages sustained for each household and assumes a recovery by using capital reserves of the households. Because of the differences in non-fixed capital between the poor and the rich, it is easy to understand that the higher income classes can more easily restore their asset values.

For the recovery in income, a completely different mechanism is simulated. Income is generated either through labour or profits. The income of the poor people are virtually completely stemming from the wages they get from their labour. The model assumes that after a storm agricultural activities are picked up again as before, generating a labour demand somewhat lower to the pre-storm condition because of the loss of income generating assets. For the households in those income classes that are also dependent for their income on the profit, the loss in production value (especially crop losses) imply an extra burden to their financial situation (see section 6.1.4.3 for a more detailed explanation).

Landuse scenarios produce marginal effect on financial vulnerability
There are relatively small differences in vulnerability between the four land use scenarios (Table 32). This seems logical because after all the shifts in crops and land use are quite limited. But on the other hand, these relatively small changes in landuse do show a difference in crop vulnerability, which can be seen in the differences in damage to crops between the scenarios Figure 47. The maximum land development scenario shows the highest damage, due to an increase of horticulture (e.g. bananas, coconut palms and mango trees) and aquaculture. Trees are more vulnerable to high winds than rice and aquaculture presents a higher standing value of crops. This effect is also visible in the spatial differentiation of vulnerability: mandals with a monoculture of Banana plantations for instance are more vulnerable than those with amore balanced economy (see Box 11).

But why then is the financial vulnerability in the Maximum development scenario not also higher than in for instance the Autonomous Development scenario? This can be explained by the fact that in the in the Maximum land development scenario the per capita income is highest of all scenarios, which makes people (slightly) less vulnerable. Hence, this result shows the complex and non-linear relationship between land use and vulnerability.

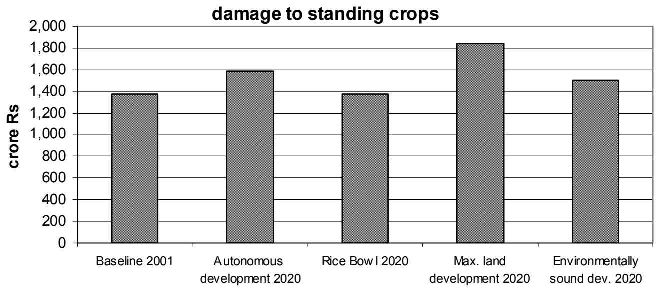


Figure 47 Differences in damage to standing crops for Basecase and landuse scenarios

Table 32 Model output for the Basecase and four land use scenarios

	Basecase 2001	Autonomous Development 2020	Rice Bowl 2020	Max. land develop-ment 2020	Environ-mentally sound develop-ment 2020
population size	7,193,754	9,368,644	9,368,644	9,368,644	9,368,644
per capita income (Rs)	14,253	11,642	11,362	12,848	11.034
net agricultural profit (mill. Rs)	17,502	21.920	18,617	27,857	21,316
net industrial profit (mill. Rs)	15,539	15,539	15,539	15,539	15,539
net profit comm. services (mill. Rs)	21,550	23,001	22,423	25,494	21,184
capital damages (mill. Rs.)	27,636	30,122	28,057	32,750	29,276
crop damage (mill. Rs)	13,745	15,840	13,784	18,412	14,990
savings rural poor (Rs per HH)	0	0	0	0	0
savings rural medium high (Rs per HH)	34	0	0	2	0
Recovery Factor on income	0.69	0.67	0.70	0.66	0.67
Recovery Factor on assets	0.95	0.95	0.95	0.95	0.95
fraction people financially vulnerable	0.34	0.37	0.33	0.36	0.35

From the vulnerability perspective, the Rice Bowl scenario seems the most promising: it has the least crop damages of all, and the highest RF on income. However, as has been discussed in Chapter 2, for this scenario the irrigation system would need a considerable upgrade, the investment of which is economically hardly justifiable.

Economic growth reduces vulnerability.

The EDSS model allows for defining different economic growth percentages. The user can define an annual growth of the household capital values and of the non-agricultural production values. Hence, these scenarios can be used separately from the land use scenarios, to simulate an economic development that is generated by other mechanisms external to the model.

Box 11 Spatial vulnerability explained

The riddle of Atreyapuram and Peravali

The mandals Atreyapuram and Peravali have a high vulnerability, even though they are not close to the sea (see model result in the map below). Hence they do not have the highest exposure to flooding or wind. Why are the adjacent mandals much less vulnerable? How can this be explained? The answer is that the economies of Atreyapuram and Peravali rely heavily on a monoculture of banana, which is highly vulnerable to wind damage. Banana crops contribute around 40% of the total mandal income. In neighbouring Kadiam, for instance, banana accounts for only 5% of total income, which besides agricultural products is largely derived from several industries.

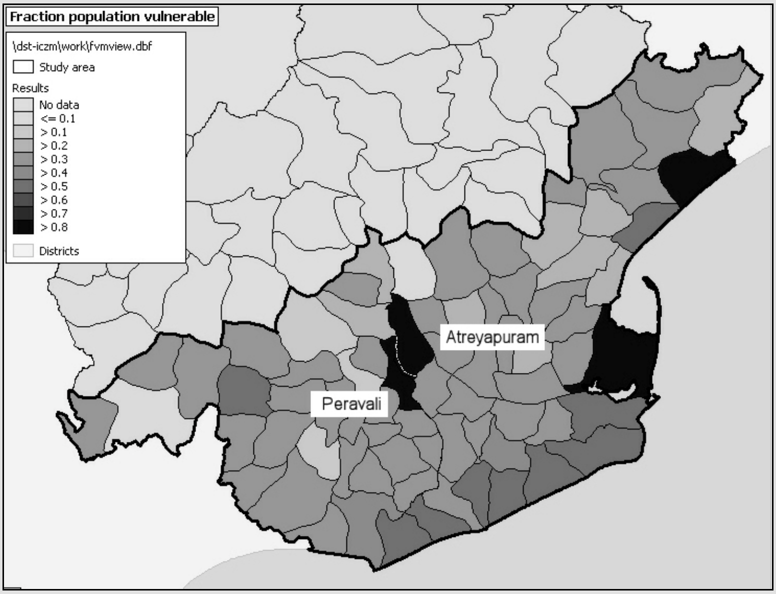


Figure 48 Map of the fraction of population that is vulnerable (basecase situation)

I compare four different cases of which the model output is given in Table 33 :

- Basecase 2001
- Autonomous development 2020 + 1.4% ann. pop. growth
- Autonomous development 2020 + 1.4% ann. pop. growth + 3% ann. econ. growth
- Autonomous development 2020 + 1.4% ann. pop. growth + 5% ann. econ. growth

Without economic growth we see an increase in vulnerability, but with economic growth the model results show a gradual decrease in the percentage of people financially vulnerable from 37 to 31%. Still the capital damages are increasing from 27.6 billion Rs. (Basecase) to 49.5 billion Rs. (Autonomous development with 5% annual economic growth), whereby the crop damages rise only slightly. Per capita income reduces in the Autonomous Development case without economic growth, which shows that the current trend in agricultural production cannot meet the population growth. However, with increasing economic growth also the per capita income increases above the 2001 level. The bulk of this income is earned in the industrial and commercial sectors. Increasing asset values result in a significant increase in losses (capital damages) of income generating and private assets for all income categories.

But interesting is that the increase in income particularly in the 5% annual growth scenario results in significant savings in the medium high and rich income categories. This greatly improves the recovery potential of these income groups. However, for the lowest income category this effect is negligible.

Thus the model results tend to be in agreement with the hypothesis that economic growth that improves the income position will lead to a reduction in financial vulnerability. More invested capital increases the damage potential, but higher income levels make people less financially vulnerable.

Table 33 Model output for the Basecase and three economic growth scenarios

	Basecase 2001	Autonomous Development 2020	Autonomous Development 2020 + 3% econ. growth	Autonomous Development 2020 + 5% econ. growth
population size	7,193,754	9,368,644	9,368,644	9,368,644
per capita income (Rs)	14,253	11,642	15,622	19,805
net agricultural profit (mill. Rs)	17,502	21,920	21,920	21,920
net industrial profit (mill. Rs)	15,539	15,539	28,065	41,230
net profit comm. services (mill. Rs)	21,550	23,001	30,445	38,268
capital damages (mill. Rs.)	27,636	30,122	39,575	49,509
savings rural poor (Rs per HH)	0	0	0	0
savings rural medium high (Rs per HH)	34	0	124	438
Recovery Factor on income	0.69	0.67	0.74	0.78
Recovery Factor on assets	0.95	0.95	0.96	0.96
fraction people financially vulnerable	0.34	0.37	0.34	0.31

Poverty reduction leads to significant lower vulnerability

The Government of Andhra Pradesh has several poverty reduction programmes running. Its potential impact on vulnerability can be analysed with the EDSS through changing the fractions of the population belonging to each of the income quintiles. Two model cases have been simulated, with different rates of poverty reduction (Table 34).

What we see in this result is that an upward shift in income that leads to a reduction of the number of people in the category 'poor' also leads to a very strong reduction in the fraction of people that is financially vulnerable. This sounds logical, as the poor are the most vulnerable. Interesting to see is the fact that the overall vulnerability in terms of the RF on income and assets hardly changes at all. The explanation can only be that whatever happens in the lowest income category does not count in the overall recovery factors, simply because there is so little income and asset value involved. A significant improvement of recovery of the poor counts marginally in absolute terms.

We also see that poverty reduction leads to an improvement of the Gini coefficient, an improvement in employment, a slight improvement in per capita income, reduced incomes for the income classes other than poor (which is logical because agricultural and industrial production does not change: the same profit has to be shared with more people), a significant increase in asset value (because higher income households have more assets) and subsequently higher capital damages. Conclusion: increased wealth does lead to increased damages, but also to a significant reduction in vulnerability!

Table 34 Model results of the effect of poverty reduction on vulnerability.

	Autonomous Development 2020 + 3% econ. growth	same as previous, but with poverty reduced	same as previous, but with poverty more reduced
population size	9,368,644	9,368,644	9,368,644
per capita income (Rs)	15,622	15,720	16,111
HH income rural poor (Rs)	23,122 (0.36)*	23,978 (0.25)*	25,949 (0.2)*
HH income rural medium (Rs)	34,193 (0.36)	33,790 (0.45)	31,378 (0.4)
HH income rural med. high (Rs)	91,962 (0.23)	87,497 (0.2)	67,942 (0.3)
HH income rural rich (Rs)	275,234 (0.05)	259,876 (0.1)	190,705 (0.1)
Gini coefficient	0.43	0.40	0.37
employment rate	89%	92%	99%
total asset value	606,436	625,415	828,145
capital damages (mill. Rs.)	39,575	39.534	47.102
savings rural med. high HH (Rs)	124	96	18
savings rural rich HH	1604	1347	411
Recovery Factor on income	0.74	0.74	0.75
Recovery Factor on assets	0.96	0.96	0.96
fraction people financially vulnerable	0.34	0.24	0.18

* between brackets is the fraction of the population belonging to each income category

Providing grants as relief funds

The analysis of measures used the feature in the EDSS to implement one or more measures under a selected scenario and time horizon. Similar to the land development scenarios I have defined a number of cases and then compared each case with the 'zero alternative', that is the Autonomous Development scenario for 2020 without any measures. A scorecard with the results of these cases is given in Table 35.

Table 35 Comparison of model results for several measures

	Autonomous Development 2020 + 3% econ. growth	Full flood protection	Evacuation improvement	Medium grants	Loans
population size	9,368,644	9,368,644	9,368,644	9,368,644	9,368,644
per capita income (Rs)	15,622	15,622	15,622	15,622	15,622
Expected casualties (people/year)	34	7	14	34	34
capital damages (mill. Rs.)	39,575	20,573	38,356	39,575	39,575
Recovery Factor on income	0.74	0.75	0.74	0.74	0.74
Recovery Factor on assets	0.96	0.99	0.96	0.96	0.96
fraction people financially vulnerable	0.34	0.31	0.33	0.13	0.34

Protection from storm surges could be improved through flood control measures, such as a combination of dykes, embankments and where possible new mangrove forests. Of course a complete protection can never be reached, as there will always remain a residual risk. However, in the model it is easy to simulate a 'full' protection level against flooding. The results show that this would reduce about half of the damages (mainly assets). But crop damage and damage to housing remains high due to wind damage. The number of vulnerable people reduces with only 7%. By far the greatest effect of a full protection against tidal surges is the reduction in casualties (expected casualties reduce from 34 to 7 per year).

Several measures can be taken to reduce the gap between actual and maximum evacuation rates, such as improvements in road system, warning improvements and the provision of more cyclone shelters. In the Baseline situation, the average evacuation rate is 92 percent, but can be as low as 72% in some mandals. A moderate improvement, simulated as reducing the gap between actual and maximum evacuation with 60% has a large impact on casualties (expected casualties reduce from 34 to 14 per year). Because the majority of assets are immovable, the damage remains almost as high as without evacuation improvement, hence also the number of people vulnerable to financial loss also remains high.

Relief funds given as grants to households that have suffered losses greatly reduces the vulnerability in terms of assets and income. In the EDSS several levels of grants can be implemented as measures. A ‘medium grant’, defined as the provision of relief funds that compensate for 70% of losses incurred by poor households and 50% compensation for medium income households would cost on average 2 billion Rs and would reduce the number of people vulnerable to financial loss with 60%. A complete compensation to everyone, i.e. 100% compensation for losses incurred by all affected households would cost around 24 billion Rs but would reduce the number of people vulnerable with 65%. Clearly, compared to the medium grant option, a full compensation is very expensive and the impact hardly noteworthy. Full compensation would bring a complete recovery on assets, but there still remains a problem in recovery on income.

The Medium Grants strategy shows a large reduction in the fraction of people financially vulnerable while there is no change in the *average* recovery factors. Closer inspection of the recovery factors per income group show that the grants result in an increase in recovery of *only* the poor: their RF goes up from 0.51 to 0.85. This brings them above the vulnerability threshold. For all other income classes there is no change. And because the absolute value of the assets of the poor is very low compared to the overall value of assets in the region, the average recovery factors do not change significantly.

What do these results mean for Andhra Pradesh?

The model results have been used to prepare recommendations of the ICZM study to the Andhra Pradesh government. These recommendations have been reported in a Resource Management Plan (Marchand & Mulder 2007) and Framework for ICZM in Andhra Pradesh (Marchand et al. 2002) and involve:

- Promotion of land use development and diversification, including horticulture, livestock and sustainable aquaculture development, innovative land use on marginal lands, water saving techniques and sustainable groundwater exploitation;
- Continuation of improvements of the socioeconomic situation in order to reduce poverty, including public water supply, primary health care, education and microcredit facilities;
- Continuation of efforts in flood mitigation and disaster mitigation measures, esp. early warning, cyclone shelters renovation and construction, road infrastructure, river embankment and drainage improvements. Relief measures (grants) will remain a vital government intervention.

Although these recommendations may seem rather straightforward and obvious, they also exclude some interventions and strategic development roads, such as large-scale government interventions in the irrigation and flood protection sector. Here the model results definitely support the lack of significant contributions of these measures towards reducing vulnerability.

6.2.5 Conclusions from the Application Perspective

Coming back to the research questions we see that the following components are of relevance:

RQ 4: What can we learn from the model applications?
- The majority of the input data for the model were available. Absent data could be inferred from existing data or could be estimated.
- Model calibration for the Godavari Delta showed a good fit for socio-economic key figures, resource balances, cyclone casualties and damages. Environmental quality output was difficult to calibrate because of lack of calibration data.
- Model results are in agreement with what could be expected logically and are in line with the general theories of differential vulnerability.
- Scenario and strategy analysis with the model supported the selection of promising vulnerability reduction measures, including coastal development planning.
- Land use scenarios for the Godavari Delta produce marginal effect on financial vulnerability
- Economic growth and poverty reduction reduces vulnerability
- Grants as relief after a disaster result in greatest reduction in vulnerability

6.3 Analysing the design process (Context perspective)

6.3.1 The policy analysis style of the Andhra Pradesh study

The objective of the AP project (viz. '*to envisage optimum utilisation of coastal resources, minimisation of impacts due to natural disasters and improvements in equitable quality of life levels while ensuring environmental protection and ecology'*) implies a combination of a vulnerability assessment with a long term planning making context, using the principles of ICZM. This can be regarded as a complicated, unstructured problem for which potentially there are many different solutions possible. We started therefore in a situation where i) no clear definition existed of vulnerability, ii) other (potentially conflicting) development objectives needed to be accommodated; iii) the scale of study was not clearly defined and iv) no measures could be excluded beforehand.

The Delft Hydraulics Framework for Analysis – as we have seen in the previous Chapter – was born out of the earlier PA experience in which the problem was complex but clear and in which science and models served a useful purpose in screening and evaluating a limited set of measures. It is therefore not surprising that the Framework proved much less of a guidance to the development of the model than was expected.

To classify the policy analysis style of the Andhra Pradesh study I use the 'hexagon' typology presented in the previous Chapter. Two types of activities can be recognized in the Andhra Pradesh study:
- *Research and Analyse*: the Description of Services (DoS) required a comprehensive inventory of environmental and socio-economic conditions and problems along the coast;

- *Design and Recommend*: the DoS stipulated the preparation policy plans, viz. a resource management plan and a disaster prevention and impact minimization plan.

Although the DoS requested the preparation of an ICZM plan based on the concepts of carrying capacity and community involvement, the entire set-up of the study as well as the scale of the study area precluded a real participatory planning approach. I therefore conclude that the Andhra Pradesh study is a rational style policy analysis, using applied research, but within a direct client advisory role, since the analysis results needed to be translated to a policy advice for the Government of Andhra Pradesh (see Figure 49)

Considering the AP study as somewhere in the upper part of the diagram (encompassing the rational and client advise style), we find the following subset of models that are most appropriate: explorative models, system dynamics, optimizing models, design tools, CBA models, predictive models and information tools. And when we look at the models that have been developed in the AP project, examples of most types are present. The Storm Surge Model and the Wind Hazard Model are examples of predictive models and the EDSS is an example of an explorative model. Also several information tools, such as GIS and databases (e.g. a database on historic cyclones) were used in the project. The absence of optimizing, design and CBA models can be explained by the nature and scale of the project: it was not the intention to advise on concrete, individual measures (such as a flood protection design).

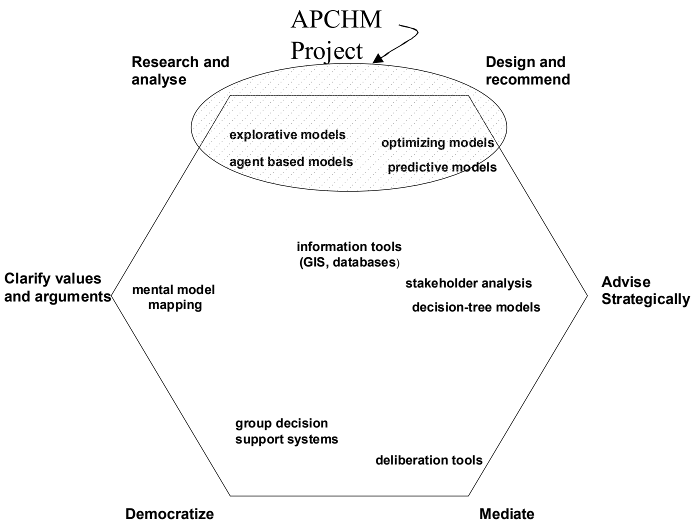


Figure 49 The position of the Andhra Pradesh Cyclone Hazard Mitigation Project (APCHMP) indicated in the hexagon diagram of policy analysis styles

6.3.2 India as context of the study

The policy analysis and design of the model was executed by an international team in India. Hence, intercultural differences have necessarily played a role in the process of the study, and probably in its product. The project team (the ICZM part) consisted of persons with Indian, Dutch, English and US nationality. Indeed, signs of diverging value judgments were visible at times during the course of the project. For instance, when presenting the synthesis of the diagnosis phase of the ICZM study during one of the Technical Advisory Committee meetings, I stated that the coast of Andhra Pradesh was clearly in a state of environmental crisis. This, I substantiated with reference to the frequent shortages in fresh water, the widespread deforestation of the mangroves over the past decades, the firewood shortage and other signs of an overstressed environment. However, I was immediately reprimanded by the chairman of the Committee, stating that this was the first time he had heard of such a thing and was not inclined to believe that it was that serious. And from a broader Indian perspective, he was probably right. Coastal Andhra Pradesh, and especially the delta regions, can be considered relatively prosperous as farmers can make use of the fertile soils and distributed water from a century old irrigation system of which other AP districts could be jealous. Certainly, I was judging the environmental situation through my 'western' eyes and was not able to see it in the Indian context.

From my experience in working abroad, and with working in my own country, I became increasingly aware of the unawareness a (foreign) expert has when it comes to knowledge of the local situation. I think this fact is of more importance than the difference in culture in general. For instance, when I joined a field visit of Indian experts to Pulicat Lake (in November 2000), I witnessed an interview of the experts with a local fisherman. Because he talked in a local language only, the interpreter translated what he said to the experts who came from different parts of the country. What struck me was that most of these experts were not really listening to this man, but were trying to convince him of their viewpoint of the matter at hand. I remembered that I thought that the distance (in language, in culture, in power, etc.) between these experts and the fisherman is almost the same as the distance *I* had with the local person. And maybe I would have been even in a better position to communicate with this person, because I was more inclined to listen as an 'objective' outsider. This example illustrates the relatively high Power-Distance Index of India (77) compared to the world average (55) as defined by Hofstede (2001). The Power-Distance Index is indicative of a high level of inequality of power and wealth within a society, and is not necessarily forced upon the population, but rather accepted by the society as a cultural norm (Enserink 2006).

The outsider's perspective could have its merits too for a policy analysis. While some might argue that 'effective' policy analysis arises out of congruence between a nation's governance traditions and policy analytic style, a contrasting view suggests that some distance is desirable if policy analysis, no matter what style predominates, is to speak truth to power and challenge policy actors (Howlett & Lindquist 2004). In other words: doing a 'foreign' PA approach in a different context, such as India, can have benefits, as long as the knowledge of the local context is sufficiently embedded in the project team. Therefore every effort was made in the project to involve as much local expertise as possible. Hence almost all of the technical reports were written by Indian experts (either as first or second author).

This local context also pertains to the Andhra Pradesh state level policy making traditions and performance. Perhaps this aspect has been the most difficult and complex part of the study, because here both the formal and informal relationship between Client (the AP Government) and Consultant (the international consortium led by Delft Hydraulics) played a role. Was the study a partnership between analysts and policymakers, in the sense Walker (2000) describes? Was there a clear division of responsibility and differentiation of roles? Yes, because the Consultant (the analyst) did the data analysis and modelling, while the Client (policymaker) defined the objectives and was (is) responsible for the implementation. In fact, the partnership was even more than that: a number of counterpart staff members from the Client worked together with the Consultant to do the analysis and run the models. Interaction was close and frequent, which was considered necessary in order to transfer the knowledge and models to the Client's organization so that its analysis and planning capacity would considerably improve.

However good the partnership idea was and was promoted through the study set up, the problem remains that the two partners are not on the same level. The Client is paying the Consultant for services, which sometimes interferes with the ideal of a partnership serving a common goal. Although this is common practice in many PA projects, the fact that in this case Client and Consultant do not share a common cultural, historic and institutional background gave rise to many (mostly small) misunderstandings, miscommunications and misinterpretations, that cannot be evaded through unambiguous contracts or descriptions of services. Most of these issues were non-technical by nature, but sometimes controversies existed that had a direct influence on the content. Because of the wide interdisciplinary scope of the ICZM component, there have been lengthy discussions with respect to the level of detail that had to be reached vis-à-vis the DoS. Especially when there was a shortage of data on an issue, the Client would favour the collection of new data, which was considered not feasible by the Consultant because it was not budgeted. Much discussion was also needed to reach an agreement on the scope, functionality and eventual design of the EDSS. The extent to which these problems can be attributed to cultural, financial or technical factors is difficult to unravel. Sometimes, it was just a matter of the English language that was used, which for both Client and Consultant was not their mother tongue. For example, in many paragraphs of the DoS the word 'delineation' was used, which gave rise to much interpretation controversies.

Nevertheless, the primarily rational style of the assignment made it relatively easy for the international team to work in a culture that is different from theirs. If the project had had a more interactive and participatory style, these differences would probably have given rise to more miscommunications.

6.3.3 Decisive factors in the EDSS model design process

Using the factors of influence from the Context perspective derived in Chapter 5, I will describe for each of them the role they played in the model design. Some factors proved to be more important than others and I will conclude at the end which of them were most decisive.

Policy objectives of the study

The Description of Services clearly stated the objectives of the study as well as the model. In the formulation of the study objectives (see section 2.1 of Chapter 2) indications were given with respect to the strategic direction of coastal development, i.e. optimal use of coastal resources, while minimising impacts due to natural hazards, ensuring improvements in equitable quality of life levels and ensuring environmental protection and ecology. Here the three basic elements of sustainable development can be distinguished, i.e. economic efficiency, social equity and ecological integrity, complemented by the desire to reduce vulnerability.

The EDSS design has explicitly followed this policy objective by formulating output criteria and indicators under these four categories: social, economic, environmental and vulnerability (see table 3 in Chapter 2).

Formal directives
As per DoS the EDSS should enable '*Evaluation of alternative scenarios through consequence analysis modelling in terms of carrying capacity indicators viz. equitable quality of life levels, environmental status degradation and ecological loading including hazard/vulnerability reduction*'. This clearly favoured the design of an explorative model, whereby scenarios and strategies would be analysed with respect to their consequences on the main policy fields which have been described under the policy objectives of the study. As its architecture shows (see figure 4 in Chapter 2), the EDSS closely followed this functional requirement.

Data availability and accessibility / assumptions
The lack of detailed GIS data greatly influenced the EDSS design with regard to spatial scale and aggregation choices. This prompted the use of the *mandal* as spatial unit for the calculations. Other data, e.g. on the landuse, socioeconomy and flood hazard, was relatively abundant and did not greatly influence the model design. Wherever data was needed which was not readily available, it was inferred from available data or expert judgements were used during the application process.

Expertise of the team
A wide range of disciplines was included in the ICZM study team (see table 2 of Chapter 2). During the project the input of disciplines was quite flexible. Whenever it was perceived that certain expertise was lacking, it was common practice to contract a specialist in this field. In such a way the ICZM study and EDSS design was not directed in a certain direction because of the composition of the team. Most of the team members were highly skilled in their discipline, with many years of experience and seniority.

Team dynamics
Two different periods need to be distinguished during the project, which I will call the 'ICZM inventory phase' and the 'EDSS design phase'. During the first phase the work was done during intensive working periods with a duration of two or three weeks, interspersed with longer periods of lower activity. During the intensive periods most of the Indian and foreign experts would work together, discuss progress and make work plans for the next period. In between these working sessions, the permanent team members went to the field or other institutes to collect data and prepare documents. This set-up was maintained during the first 2 years of the project. The EDSS design phase started after these two years and was executed by a small team of only three experts (see section 2.2.1 in Chapter 2). During both periods the team dynamics went remarkably well.

We know from experience elsewhere that good experts do not necessarily make good interdisciplinary teamwork, since scientists are trained and socialized from their graduate school days to focus on narrow problems within clearly defined boundaries. (Nicholson et al. 2002). In this case, however, it was not merely the problem of too much focus and detail that separated the experts work, but the difficulty of obtaining a common goal and problem description. 'ICZM' was for most members a too unfamiliar and vague concept. Which made it very difficult to link this concept with cyclone hazards and vulnerability. Hence, although excellent work was delivered with regard to the different environmental problems (such as 'biodiversity' or 'water resources'), it proved difficult to synthesise and use it for the model design. In this interdisciplinary haziness the seniority and scientific authority of some members did significantly influence the direction of the model. Particularly the role of Dr. Winchester, who contributed with more than 20 year of experience with regard to the vulnerability of communities to tropical storms in the region, is worth mentioning here. He introduced to the team the notion of differential vulnerability. Without his participation in the project, vulnerability in the EDSS would have probably been limited to the calculation of casualties and damages.

Procedural blueprints
The Description of Services (part of the Contract) did not prescribe a design procedure for the EDSS. However, the Contractor used his own approach, the Framework for Analysis. As already noted in section 6.3.1 this Framework provided less guidance than was originally planned.

Time and budget constraints
Although the initial project duration was projected to be two years, eventually the finalisation of the ICZM study and EDSS design took much longer. The latest version of the EDSS was submitted to the Client some five years later than originally planned. This was not only because the design process took much more time than was anticipated, but because of contractual issues between the Contractor and the Client. In the end, one can conclude that time limits did not greatly influence the design of the EDSS.

Policy analysis style
As has been demonstrated in Section 6.3.1., the exploratory character of the EDSS fits well with the rational policy analysis style.

Conceptual model or theory
At the onset of the study the dominant paradigm on vulnerability, at least with the majority of the team members, more or less followed the Risk-Hazard model, as described in Section 3.2.2 of Chapter 3. Most attention was given to the physical aspects of the hazard (such as potential flooding pathways and patterns) and factors that determine potential damage (such as exposure and sensitivity of houses and crops). It was mainly through the influence of the social scientists within the team that the societal aspects of a disaster slowly gained importance. As part of the team and through his previous work on vulnerability in the Krishna Delta, Dr. Winchester was able to successfully introduce the concept of differential vulnerability, which gave important guidance to the implementation of vulnerability modelling in the EDSS.

Usefulness of the model
During the project period the model was applied by the Consultant to the Godavari Delta (see Chapter 2 section 2.3). The model results have been used as input to the Resource and Environmental Management Plan for the Delta (Marchand & Mulder 2007). With the help of the model various alternative land use scenarios and measure combinations were analysed (see section 2.5 of Chapter 2). The model worked well in the sense that it permitted the analysis of a potentially unlimited number of combinations and showed the impact on the sustainable development criteria. Hence it fulfilled the requirements as per the Description of Services.

Model transfer
Much attention was given to the user-friendliness of the EDSS. The graphic interface (see figure 3 in Chapter 2) enables quick and intuitive navigation through the model.

The basic sequence of Compose – Compute – Analyse is easy to understand and the calculation and response times are fast. The counterpart staff of the Client was able to follow the design process step by step during which they gave responses and suggestions that were picked up by the designers. Finally a three day training course was given during which 17 staff members of user departments and the Client (APSDMS) participated. Extensive documentation (user manual, functional design and scientific background report) was provided to the participants.

6.3.4 Conclusions from the Context Perspective

Coming back to the research questions we see that the following components are of relevance:

RQ 5: Which factors played a crucial role in the design of the model?

The following factors were found crucial:
- The rational style policy analysis of the project, with *research and advice* activities;
- The policy objectives of the study, stipulated by the Client, demanding a model that integrates socioeconomic, environmental and vulnerability aspects;
- The formal directives from the Client, favouring an *explorative* type of model;
- Team dynamics, that promoted a shift from a 'Risk-Hazard' towards a 'Differential Vulnerability' paradigm;
- Data availability, the absence of a detailed GIS prompted the use of administrative units as unit of calculation.

7 Test case Red River Delta, Vietnam

In this chapter the Vulnerability Model is tested for a flood prone area of the Red River Delta in Vietnam. After a brief introduction to the study area, the chapter continues with describing the model input and calibration. The results of the model application for several scenarios and measures are discussed and compared with those of the Godavari Delta.

7.1 Introduction

The Red River Delta in Vietnam has been chosen as a test case for the Vulnerability model for the following reasons. Because the general structure of the land-use and socio-economic modules of the Vulnerability Model are tailor made for predominantly agricultural based economies, the case study area should also reflect this agricultural dominance. The Red River Delta largely fulfils this requirement, although, as we will see later, an increasingly significant part of the regional economy is based on industrial and trade activities.

A second selection criterion was the existence of a flood risk, that preferably has been quantified already. As it happened, a recently executed study had collected data on flood risk and had subsequently conducted a thorough flood risk modelling exercise for the Bac Hung Hai polder in the Red River Delta (Sweco-Groner & Delft Hydraulics 2005). This area was selected an excellent candidate to act as testing ground for the model.

For the Red River Delta test case only four of the six Vulnerability Modules have been used, namely the Land use Module, the Socio-economic Module, the Flood Probability Module and the Flood Vulnerability Module. The Resource use and Environmental Assessment Modules have been 'switched off'. It would have been too labour intensive to collect data and calibrate the modules within this PhD research context. Of course, this implies that the case study concerns a partial testing of the model only, albeit with respect to the most essential parts when vulnerability is concerned.

7.1.1 A geographic and socio-economic profile of the Red River Delta

The Red River Delta (RRD) is located in the Northeast part of Vietnam . The capital Ha Noi lies at its apex, where the Duong River branches off from the Red River. It measures around 16,654 km^2 and together with the Mekong Delta in the south it holds around 50 % of the entire population in Vietnam. Most of the Delta lies between 0 and 5 metres above sea level, with a distinct slope decreasing gradually from the northwest to the southeast. Four soil texture types can be found in the delta, i.e. sand, sandy-loam, loam and clay, their distribution reflecting the history of river dynamics, floodings and the influence of the sea. (Fontenelle et al. 2001). In striking contrast to the Mekong Delta, the rivers in the RRD have been embanked with a network of earth dikes, dividing the delta into 30 primary hydraulic units, or polders, that are independent of each other in terms of drainage and irrigation (Fontenelle et al. 2001). The very first flood control and irrigation infrastructure dates back to the pre-European colonial period, when for large periods a (sometimes Chinese colonial) central government of Vietnam had strong control over land tenure and water regulation in the lowlands (Adger 1999b).

The RRD has a tropical climate and is influenced by the monsoons. These provoke a clear seasonal pattern with a cold and dry season from October to April and a hot rainy season from May to September. Average annual rainfall in the Delta is 1500 mm. The Delta produces approximately 20% of Vietnam's total rice production (Son & Nghia 2001)

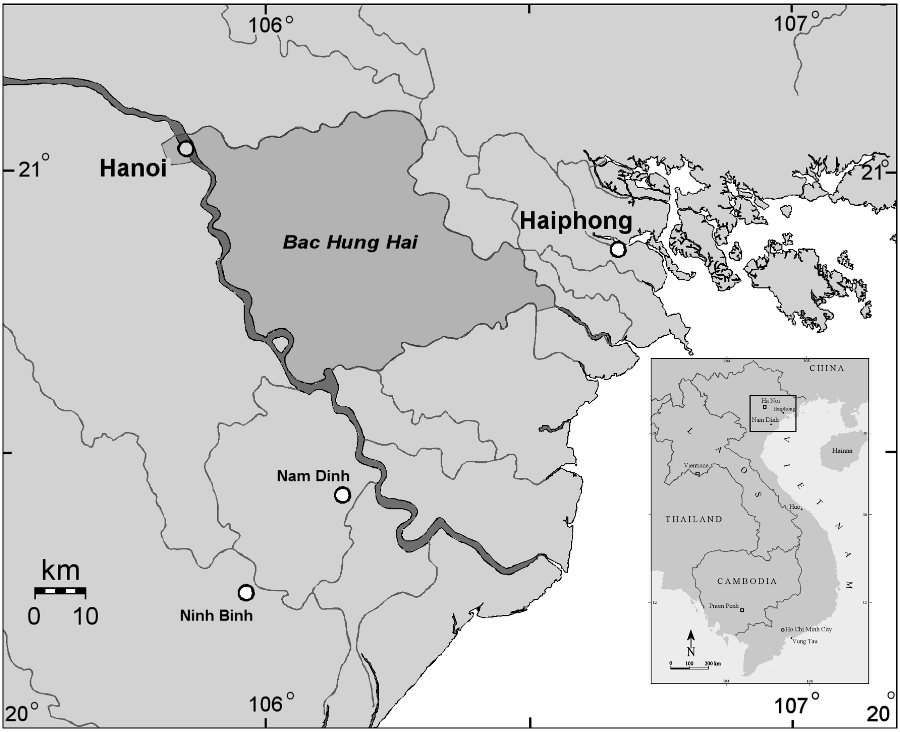


Figure 50 Map of the Red River Delta showing the Bac Hung Hai Polder

The population in the Red River Delta is mainly rural. Population density is among the highest in Vietnam and measures around 1300 persons/km^2. Because of the high pressure on land the average farm size is well below 1 hectare (Vu & Shozo 2006) (page 93) and the agricultural area per capita is very small (around 360 m^2) (Fontenelle et al. 2001).

The economic structure, income level and sources of income in the Red River Delta are characterised by contrasts: for instance, compared to other regions in Vietnam the incidence of poverty is intermediate, but the number of poor people per square km is greatest in both the Red River and Mekong Delta (Minot & Baulch 2005). The poverty rate in the Red River Delta (as percentage of households) reached 10.36 % in 2004, whereas the national average was 24.1% (Vu & Shozo 2006). We can find traditional agricultural practices next to concentrations of national and foreign enterprises, especially along the Hanoi – Haiphong corridor.

7.1.2 The Bac Hung Hai Polder

The Bac Hung Hai polder is located south-east of Hanoi in the lower area of the Red River Delta and is surrounded by the Duong river in the north, the Red river in the west, the Thai Binh river in the east and the Luoc river in the south (see Figure 50). The dikes along the rivers protect around 2.8 million people (year 2003), most of them living in small villages. Main urban concentrations are in the district of Gia Lam (part of Ha Noi municipality), Hai Duong and Hung Yen cities. The polder itself is about 225,000 ha of which most is agricultural land situated within the Ha Noi, Bac Ninh, Hung Yen and Hai Duong provinces. The polder consists of 21 districts (Figure 51). The land in the polder is mainly used for rice production. But other crops such as maize, soy bean, sweet potato are also grown. Residential land occupies a considerable amount (15%) of space. The National Highway No. 5 and the National Railway connecting Ha Noi via Hai Duong with the port city of Hai Phong crosses the Bac Hung Hai polder. This major transportation axis is part of the 'Industrial Corridor' along which many (international) factories and businesses are located.

Figure 51 Map of the districts in Bac Hung Hai Polder

7.2 Model input

7.2.1 Land use and socio-economy

For the distribution of land use a digital land use map at a scale of 1:50,000 provided by the National Institute for Agricultural Policy and Planning (NIAPP) was used. This provided district-level input of broad land classifications (such as agricultural fields, residential area, rivers and streams) that together make up the total of 211,000 ha for the entire polder. Data on cropping patterns were derived from the District Statistics (General Statistics Office 2006a). Rice, the dominant crop in the polder, is grown as spring and summer crop. Often farmers also grow a 3rd crop in winter, such as maize, potatoes and vegetables. Based on the occurrence of main crops given by the district data, the following crops have been included in the model: rice, maize, sweet potato, soy bean and peanut. Also a category 'other cops' is included thereby assuming that these are high input and high value crops such as vegetables. Figure 52 shows the cropping pattern of the BHH polder for the year 2003.

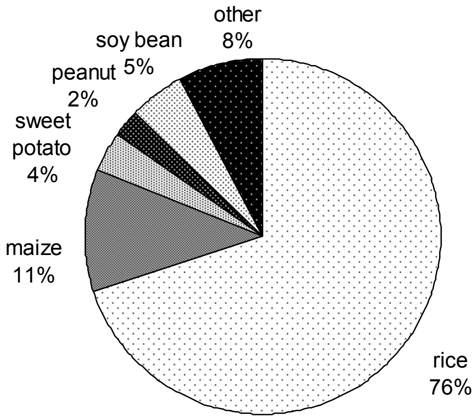


Figure 52 Cropping pattern for the Bac Hung Hai polder (2003)

Parameter values for crop inputs and prices are based on data provided by the National Institute for Agricultural Policy and Planning (NIAPP). Because most of the labour required for the crop production is provided by the farmers and their family themselves, the unskilled wage labour days used in the model have been estimated as 10% of the crop labour days given by NIAPP (this is for instance a significant difference with the situation in Andhra Pradesh, were most of the labour is provided by landless labourers).

With approximately 20% of agricultural output, livestock plays an modest role in agricultural production. Cattle, pigs and poultry are predominantly raised in small-scale household production units. A small but increasing proportion of livestock production comes from (collective or private) large-scale farms. Most of these are concentrated in the South-eastern region of Vietnam, but some are beginning to flourish in the Red River Delta as well (Lapar et al. 2003). Livestock parameter data are inferred from Lapar et al. (2003), Suzuki et al. (2006), Lemke et al. (2006) and Young (1994).

Aquaculture plays an important role in the Red River Delta. According to the data of the ministry of Fisheries, the total area of freshwater[20] aquaculture in the Red River Delta in 2003 was about 66,888 ha. This area is scattered over the different type of water bodies including flooded paddy-field, small ponds and lakes, irrigation canals,

[20] Due to its distance from the coast, brackish aquaculture and mariculture does not play a role in the Bac Hung Hai polder.

reservoirs and fallow land (Nguyen & Cao 2005). Because of this diversity in aquaculture types it is difficult to get accurate data on the aerial extent. The district statistics provide production values for aquaculture, which have been used to approximate the areas per district by assuming an average yield of 1.99 t/ha. The cold weather in winter creates unfavourable conditions for fisheries species. Therefore, it is impossible to operate two crops per year. Aquaculture input parameters are based on Nguyen & Cao (2005).

7.2.2 Industry and commercial sector

Industrial development is at the heart of the Vietnamese government's program of economic growth and modernization. Privatization and marketization are driving changes in the industrial sector (Sikor & O'Rourke 1996). There are three main categories of enterprises in the secondary sector: State owned enterprises, Non-state enterprises and Foreign direct invested enterprises. Although State owned enterprises still comprise half of the total investments in Vietnam, their share is reducing over the years. Foreign investments take up around 15 % of the total (General Statistics Office 2006b).

Within the BHH polder there is a differentiation between districts with regard to the number of industrial enterprises and output volume. There is a majority of typical 'rural districts' that contribute only a few percent to the provincial output volume, whereas there are four typical industrialised districts, providing more than 50% of the provincial total (i.e. Cam Giang, Hai Duong, Hung Yen and Van Lam) (General Statistics Office 2006a).

The labour requirement for industrial production and the commercial/services sector has been inferred from country-wide totals. These data showed that commercial and services sector is roughly twice as labour intensive as the industrial sector.

Provincial data provide number of enterprises by size of employees, which have been recalculated into enterprise size classes (very small, small, medium and large). Using the average annual turnover of 41 million VND per industrial labourer, the annual gross production values of the defined enterprise classes have been calculated.

Typical wages for unskilled labour are 400,00 VND/month (agricultural labourer) up to 800,000 VND/month in industry. An average of 600,000 VND/month gives 7.2 million VND per year. For skilled labour in the industry wages range from 900 – 1,600,000 VND/month which gives an average of 15 million VND/year (Vietnam Institute of Economics 2000).

7.2.3 Labour supply and income distribution

Around 60% of the Vietnamese population belongs to the age group between 15 and 65 years. Of this workforce 56% is working in the agricultural and fisheries sector, 26% is employed in the industry and commercial services sectors whereas 18% is self-employed. Table 36 shows the country-wide labour participation by income quintile and type of work. Also the situation for the Red River Delta is given. These statistics clearly show:

- That farm wage employment is very small, i.e. most agricultural labour is performed by the farmers themselves;
- That lower income categories are predominantly active in the agricultural sector, whereas the higher income categories find employment in the non-farm sectors;

- That farm wage labour in the Red River Delta is well below the national average and almost negligible (1%);
- That non-farm wage labour in the Red River Delta is somewhat above the national average.

Table 36 Labour division by type of work and quintile and wage labour participation (year 2000)

	Total	By type of work				*LP* = labour participation*
National		Non farm wage employment	Farm wage employment	Farm self employment	Non farm self employ-ment	for wage employment only
Quintile 1	100%	8.1	7.3	78.1	6.5	9.4
Quintile 2	100%	17.8	7.9	60.9	13.4	15.7
Quintile 3	100%	23.5	5.8	52.5	18.2	17.9
Quintile 4	100%	33.9	3.5	39.2	23.4	22.8
Quintile 5	100%	45.8	1.6	22.6	30.0	28.9
average	*100%*	*25.8*	*5.2*	*50.7*	*18.3*	*18.9*
RRr Delta	100%	33.4	1.0	45.0	20.6	21.0

Source: GSO Labour and Job Survey, 2000

*: labour participation for wage employment denotes the percentage of the entire population that has either farm or non-farm wage employment (assuming that the workforce is 60% of the total population)

Overall education levels in Vietnam are as follows: around 90% of the population has general education, while around 10% has an undergraduate or higher education level. For urban areas such as Hanoi these percentages are 75 and 25%, respectively (GSO, 1999).

In order to calculate the labour participation rates per income group and education level, I have used the labour participation rates *LP* per income category from Table 36 (after rescaling the percentages of the quintiles into quartiles) and the education level percentages given above for urban and rural population.

Farmland size has been used as a proxy for income distribution (Table 37), although it is acknowledged that this is not ideal. Many other factors (such as land suitability) mean that it is not at all usable for making comparisons between regions of a different physical geography. However, within the Red River Delta the land conditions are relatively uniform.

Table 37 Land distribution per income class

income classes	land situation	percentages of households	Fraction of rural households used in model
poor	< 0.1 ha	10	0.10
medium	0.1 – 0.5 ha	55	0.55
medium_high	0.5 – 1 ha	30	0.30
rich	> 1 ha	5	0.05

Source: (Marsh et al. 2006)

7.2.4 Flood probability and vulnerability

Flood hazard in the Bac Hung Hai polder depends on maximum water levels in the rivers surrounding the polder and the probability of one or more dike breaches. For the model two different potential flood events were used. The flooding characteristics were derived from a flood modelling exercise executed as part of the Red River 2nd Red River Basin Sector Project (Sweco-Groner & Delft Hydraulics 2005). The 2D flooding model was set up in the SOBEK modelling package of Delft Hydraulics, using 90m x 90m digital elevation data with a vertical accuracy of 1m.

A necessary input for the flood model is the location of a dike breach. Flood simulations were executed for several locations in order to identify the relation between flood extent and breach location. The moment of the breach was assumed to take place when the peak river water level was attained, leading to a maximum inflow. Also a breach-growth equation has been used to simulate the volume of water entering the polder. The dikes around the polder are classified as Grade I with a design safety level of 1/100 year.

It appeared that breaches in the upstream part of the Red River dike cause largest flooding in the polder, while flooding through breaches in the other river dikes are less voluminous and cause inundations at a smaller scale. The road/railway infrastructure, in particular in the Hanoi – Haiphong corridor, plays an important role in this respect. For testing the vulnerability model I used two different flooding scenarios:

- 1/100 yr flood through a breach at Song Duong (labelled as ‘Duong flood’)
- 1/100 yr flood through a breach at Song Hong (labelled as ‘Hong flood’)

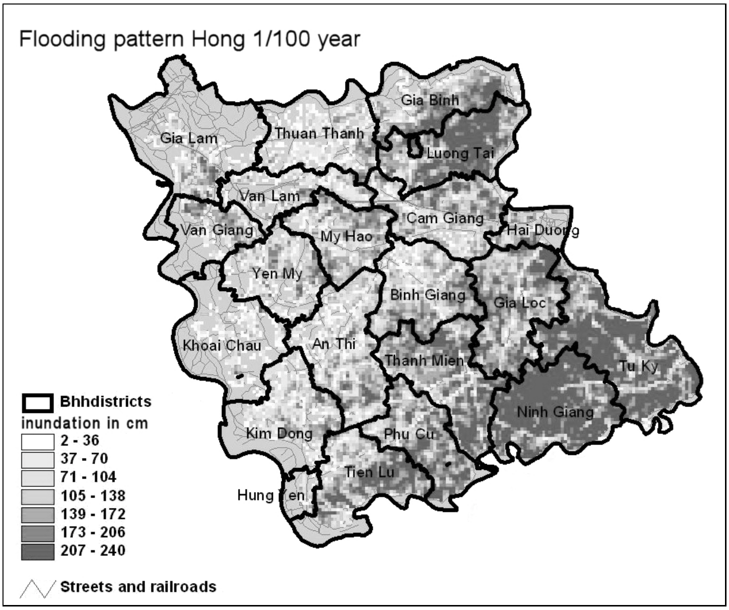
The Hong flood inundates a very large part of the polder, whereas the Duong flood shows a much restricted flood pattern (Figure 53 next page).

7.3 Model calibration

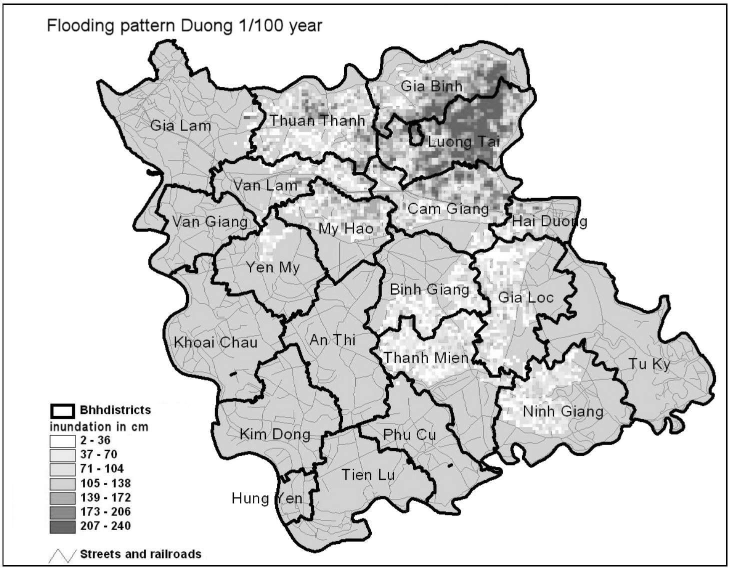
7.3.1 Socio-economic module

Calibration was done on the Hung Yen province, that falls entirely within the BHH polder. The advantage for running the model on this subset of polder districts is that the results can be directly compared with provincial statistical data. As can be seen from the data in Table 38 the model results do not perfectly match the statistical data for Hung Yen province. Particularly the production value of the industry seems to be underestimated by the model. It proved to be quite difficult to estimate the parameter ‘labour requirement’ for the secondary production. This varies considerably for the different types of industry (see Table 39). For instance the non-state enterprises need almost 8 times as many employees for the same gross output value. With approx. 44,000 labourers in the province of Hung Yen, the model calculates around 2,795 billion VND, based on the state-owned labour productivity. However, according to the statistical yearbook for the districts, there are only non-state enterprises in the province of Hung Yen, which together have a gross output of 3,994 billion VND. Should the national average for non-state labour productivity be used, the model would show a very large shortage of labourers.

Considering the imperfect knowledge of economic data on the district and provincial level, the calibration result is satisfactory, whereby the main parameters of the economy, i.e. per capita income, Gini coefficient, GDP are in the right order of magnitude. For the employment rate no statistical data for Hun Yen was available to compare with the model result.



a. Hong flood (1/100 year)



b. Duong flood (1/100 year)

Figure 53 Modelled flooding patterns for two flood events in the BHH polder (a and b)

Source: (Sweco-Groner & Delft Hydraulics 2005)

Table 38 Key macro-economic data of Hung Yen province compared with EDSS results (basecase 2003)

parameter	statistical data for 2003 Hung Yen province	EDSS results basecase 2003 Hung Yen province
GDP per sector	*in billion VND*	*in billion VND*
Primary (agriculture)	2,645	2,003
Secondary (industry)	3,994	2,795
Tertiary (commerce/services)	2,573	2,722
per capita income	5,156,000 VND	5,278,000 VND
Gini coefficient	0.31	0.38
labour force	44,000	46,657
employment rate	n.d.	0.94

Table 39 Labour requirement based on country-wide data (2003)

type of industry	employed population	gross output in billion VND	labour requirement per 1000 VND
state owned	4,035,400	239,736	0.00001683
non-state	36,018,500	284,963	0.00012640
foreign investment	519,900	88,744	0.00000586

The model produces large differences in employment per district (see Figure 54). Especially the urbanised district of Hung Yen and the district of Van Lam, which lies in the Hanoi – Haiphong industrial corridor have considerable shortages of labourers. Which implies labour migration from the other districts that have a surplus of labourers. This picture is consistent with the observations of Vu & Shozo: 'Especially in the delta and coastal areas, where population density is very high and cultivated land is very limited, farmers can only work in the agricultural sector for 3-5 months per year. Labourers have to find work outside their villages. Migration flow from rural areas to urban centres and to less-crowded rural areas happens in terms of both permanent and seasonal migration '(Vu & Shozo 2006)(page 115).

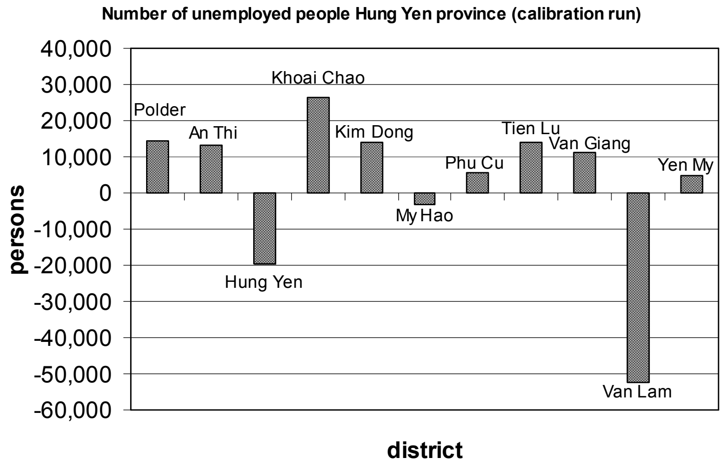


Figure 54 Number of unemployed people (positive) or labour shortage (negative) in Hung Yen province (calibration run)

7.3.2 Flood vulnerability module

One of the biggest floods in recent history occurred in 1971, inundating around 250,000 ha of land in the Red River Delta and killing over 500 people. As can be seen on the flood map, this event partially flooded the Bac Hung Hai polder, but also led to inundations in other parts of the delta (Figure 55). In absence of more detailed, location specific damage data, and because the population density and economic situation is more than 30 years older than of the modelled base case, this event could not been used for calibration. Information on more recent floods in the polder is lacking.

Instead of a calibration with observed data, I have compared and analysed the flood vulnerability between the two different flood model results (Table 40). Explaining the differences in outcome can thus provide some level of confidence in the model results.

Table 40 Comparison of vulnerability between two modelled floods

	Duong flood	Hong flood	difference
% area inundated	26%	71%	+173%
number of casualties	2,000	8,234	+ 312%
crop damage (VND)	0.6 x 10E12	1.7 x 10E12	+183%
total capital damage (VND)	5.9 10E12	20.2 x 10E12	+242%
damage as percentage of annual production	27%	91%	
damage as percentage of total capital assets	10%	36%	
Recovery Factor on income	0.88	0.71	
Recovery Factor on assets	0.93	0.68	
Number of people financially vulnerable	236,593	1,246,064	+426%

The number of people vulnerable to financial losses for a large flood (i.e. Hong flood) is more than 5 times that of a small flood (Duong flood), whereas the inundation area is less than 3 times. This difference can be explained by the fact that the calculation of the financially vulnerable people uses a threshold value for each income category. If the recovery factor of an income group falls just below this threshold, the entire income group for a district is considered financially vulnerable. If it stays just above the threshold, the group is considered not vulnerable. Because the income position in the polder is not homogenous and the Duong flood would affect comparatively richer districts, it is logical that this flood produces comparatively less vulnerable people than the Hong flood. Nevertheless, the choice of the threshold also determines the number of people financially vulnerable.

One could argue if this non-linearity which is induced by this calculation method is realistic. The answer could be that in reality people can indeed be pushed over a certain threshold in case they suffer great losses. The earlier mentioned poverty trap can be considered as such a threshold: once people are confronted with heavy loans which they cannot pay back they are trapped in continuous poverty. The difficulty here is of course where to put this critical value.

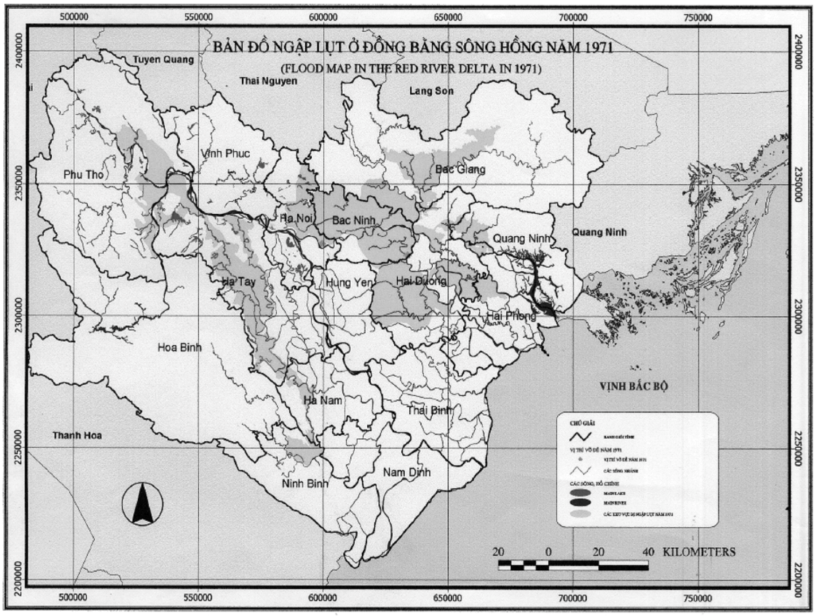


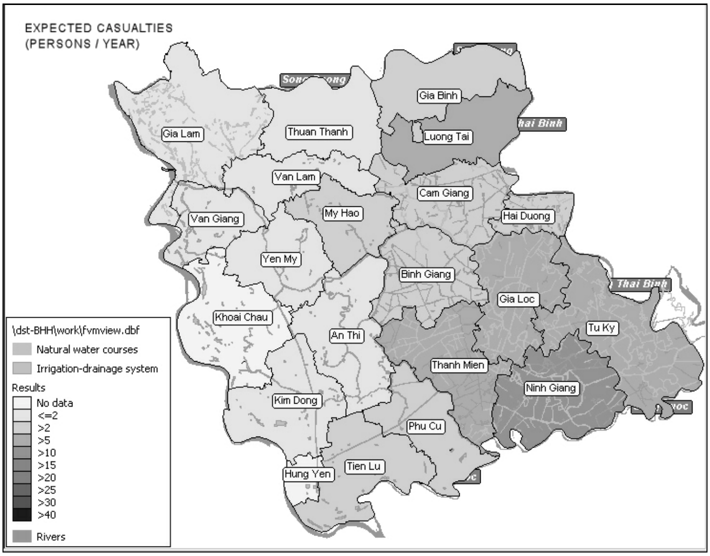
Figure 55 Map of the August 1971 flood in the Red River Delta

Table 41 gives a detailed overview of the potential impacts of the Hong flood. The calculated number of casualties seems relatively high compared to the 500 people that were killed by the 1971 flood. Nevertheless, the mortality rate from the model is still in de order of 10^{-3} which is given for river floods (Jonkman, 2008). The damage to capital assets of around 20,000 billion VND is in the same order as the average annual losses by natural disasters in the entire country over the last 5 years.

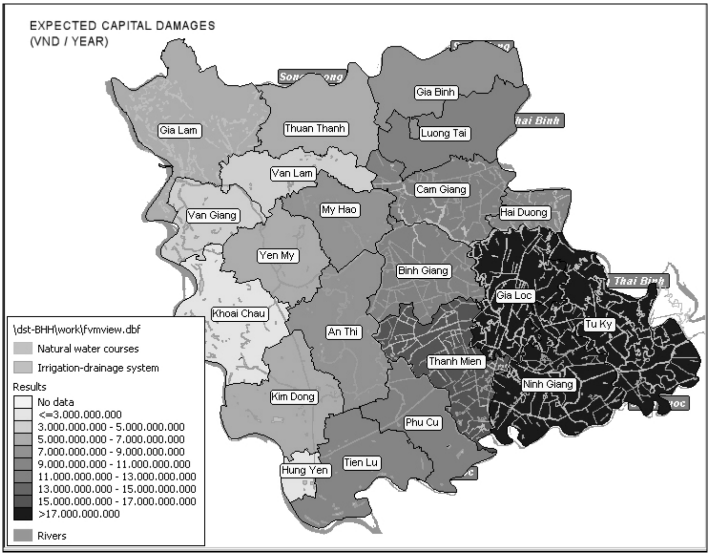
Table 41 Modelled impacts of the Hong flood

Hong flood 1/100 yr	Before the flood	After the flood	percentage
people	2,796,218	8,233 casualties	0.3%
	total value (billion VND)	damages (billion VND)	% value lost
capital assets	56,861	20,254	35%
crops	1,962	1,693	86%
houses	35,915	15,489	43%
livestock	1,711	116	7%
other assets	17,273	2,956	17%
Economy	annual production (billion VND)	annual production (billion VND)	% reduction
gross economic production	22,200	17,000	-23%
agricultural sector	4,400	2,300	-48%
industrial sector	9,500	8,300	-13%
comm./services sector	8,300	6,400	-23%

The table also shows the impact of the Hong flood on the economy. Total capital damage of the flood is approx. 91% of the annual production in the polder. Typically, the agricultural sector suffers large losses. With 86% of the entire standing crop lost, the annual agricultural production is almost halved (assuming that for the rice crop a second harvest is still possible). Livestock losses are relative small, assuming a timely evacuation of most of the animals. Also the housing sector is badly hit, with more than 40% of the house value lost. In absolute value, the losses in the housing sector are even responsible for the lion's share of the capital damages.



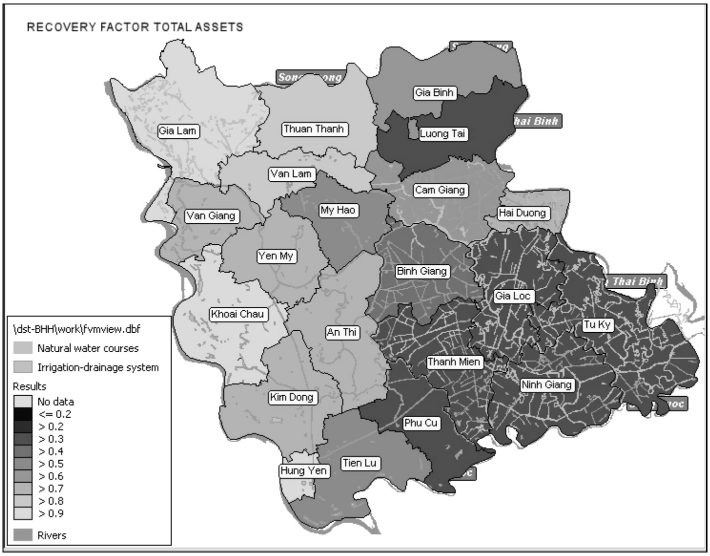
a. expected casualties (persons/year)



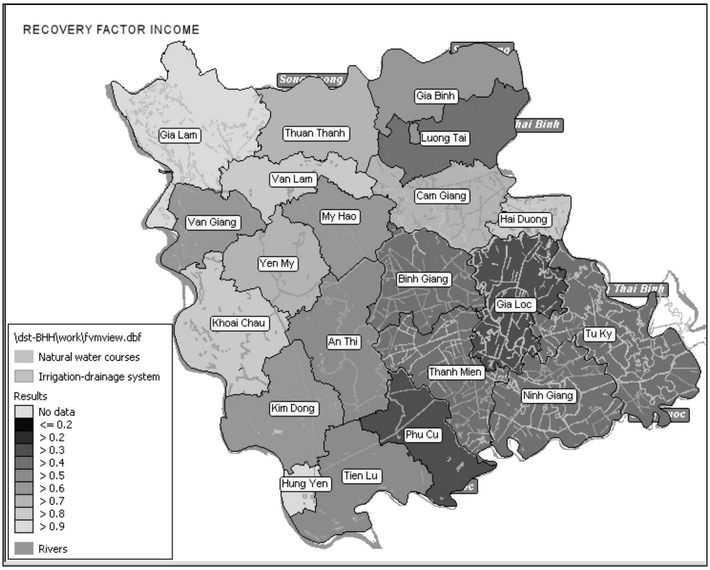
b. expected damages (VND/year)

Figure 56 Flood vulnerability patterns of Bac Hung Hai Polder (Hong flood / Basecase)

The vulnerability patterns of the polder follow the severity of the flood (Figure 56). There are some remarkable differences in vulnerability between the districts, however. Compare, for instance, the districts of Cam Giang and Binh Giang. Both experience more or less the same flooding intensity (flood class 3), although Bing Giang has 12% more area flooded. However, it has 56% higher fraction of people financially

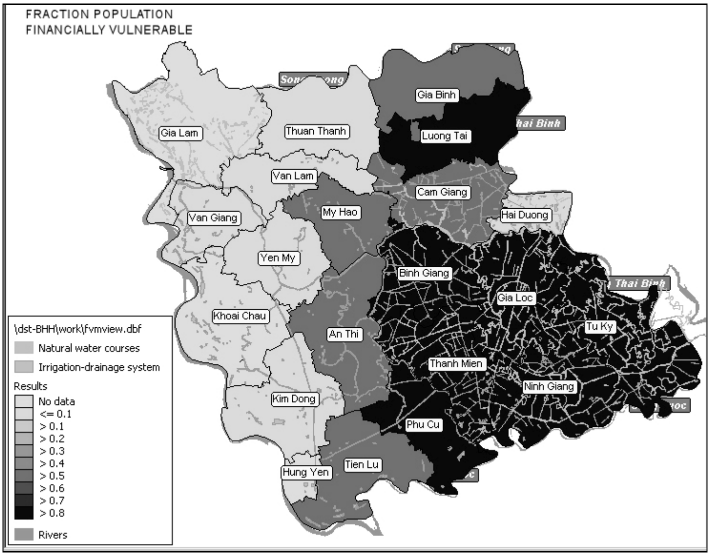


c. recovery factor for total assets



d. recovery factor on income

Figure 56 (cont.)



f. fraction of people financially vulnerable

Figure 56 (Cont.)

vulnerable. This is also reflected in the difference in recovery on income: Cam Giang has a RFI of 0.72, while Binh Giang has a RFI of 0.49. These differences are easily explained when one realises that Cam Giang, with a per capita income of 22 million VND is the richest district in the polder. In comparison, per capita income in Binh Giang is only 5.5 million VND.

7.4 Scenario and strategy analysis

7.4.1 Scenarios

The model enables the analysis of three types of scenarios: population growth, land use and economic development. Annual population growth rates for the years 2004 and 2005 were estimated to be 1.2 and 1.0 %, respectively (UNFPA Viet Nam 2007). For the next 20 years the trend of 1.0 % growth has been extrapolated.

Within the framework of my research it was not feasible to execute a similar in-depth analysis of land use developments for Vietnam as has been done for Andhra Pradesh. Therefore only two distinctly different scenarios have been produced using the trends of the last couple of years as guidance: an autonomous development scenario (Table 42) and a diversification of crops and intensification of land use scenario. The latter scenario stems from the fact that the Red River Delta land use system is still heavily biased towards the production of rice. Therefore, the production of other crops (especially vegetables) receives special attention in the National Master Plan for Agriculture for the period 2000 – 2010. According to the plan, the RRD could become the second vegetable producer of the whole country, with a projected area of 140,000 ha in 2010 (Hoi et al. 2002).

Table 42 Change in crop area between 2000 and 2006

Crop	percentage change in crop area
Paddy	- 1%
Maize	- 3%
Sweet Potato	- 10%
Sugarcane	- 5%
Peanut	0%
Soya-bean	+ 8%
Aquaculture	+ 6% (+3% used in scenario)

Source: Statistical Yearbook of Vietnam 2006

For the autonomous development scenario changes in crop areas have been implemented according to the trends. Furthermore, a 10% increase in cropping intensity for rice is assumed. For livestock a moderate increase in intensities is assumed.

For the maximum diversification and intensification scenario crop areas were changed according to the trend, except for rice, which is reduced more strongly to the benefit of aquaculture (1.5 times the area of the autonomous development scenario) and vegetables. Also the livestock intensities have been assumed to increase significantly.

Four difference cases were modelled that show a combination of population growth, land use changes and economic development. A summary of model results is listed in Table 43. These results show that current trends in land use (autonomous development) seem not to be capable of keeping pace with the population growth, hence per capita income declines. The maximum land development scenario does provide higher agricultural profits, but is also not capable of maintaining the present income levels. A simulated economic growth of 4 percent per annum does substantially increase the income levels, leading to higher labour demands, which cannot be met by population growth (leading to employment rates above 1). Because of the imbalance on the labour market, wages will increase, stimulating enterprises to invest in capital intensive production techniques (but these mechanisms are not included in the model).

With respect to vulnerability, all scenarios show a slight decrease in the fraction of people vulnerable to financial loss (from 45 to 42%). The model results show that a considerable increase in income in the economic growth scenarios is favourable for the recovery on income (RFI increases from 0.72 to 0.76), but this advantage is off-set by a doubling in potential capital damages. The recovery on assets remains the same which can be explained by a substantial increase in savings (made possible by the higher income levels) compensating for the larger sustained losses.

7.4.2 Flood risk and vulnerability strategies

The National Strategy for Natural Disaster Prevention, Response and Mitigation of Vietnam (2007) has formulated specific strategies that differ between the regions. For the Red River Delta this Strategy stipulates an approach to '*radically prevent floods, and to take initiatives in prevent and respond to storm, drought and storm surge'* (Government of Vietnam 2007). This basically implies the enhancement of the flood prevention capacity of the river and sea dyke system in the Delta. These measures would certainly reduce the flood risk, but not the vulnerability of the inhabitants. The model allows the implementation of measures that could reduce vulnerability if things do go wrong. One of them, evacuation improvement, could certainly be relevant, but did not produce large differences in model output, since the evacuation coefficients in the model basecase are already quite high (0.9 for people and 0.8 for movable assets).

Table 43 Model output of baseline and four scenarios for Bac Hung Hai

	Baseline 2003	Autono-mous Develop-ment 2020 + 1% annual population growth	Autono-mous Develop-ment 2020 + 1% annual population + 4% annual econ. growth	Maximum Land Devel-opment 2020 + 1% annual population	Maximum Land Devel-opment 2020 + 1% annual population + 4 % annual econ. growth
Key socio-economic figures:					
Population	2,796,218	3,411,917	3,411,917	3,411,917	3,411,917
Per capita annual income	5,998,847	4,952,931	8,736,168	5,373,636	9,156,874
employment rate	0.94	0.82	1.4	0.94	1.52
Net agricultural profit (billion VND)	3,064	2,916	2,916	3,338	3,338
Net industrial profit (billion VND)	4,719	4,719	10,341	4,719	10,341
Vulnerability to a major flood (Hong flood):					
Damage to crops (billion VND)	1,693	1,650	1,650	1,721	1,721
total capital damages	20,254	20,190	40,581	20,264	40,656
Recovery factor on income	0.71	0.72	0.76	0.72	0.76
Recovery Factor on assets	0.68	0.68	0.68	0.68	0.68
Fraction people vulnerable to financial losses	0.45	0.42	0.42	0.42	0.42
Number of people financially vulnerable	1,246,064	1,428,599	1,444,301	1,428,599	1,444,301

For financial measures, the output picture is more complicated. Two measures have been analysed, using the Autonomous Development as reference: loans and the provision of grants (relief funds). The model allows for three settings of the fraction of the damage that is compensated by loans: 0, 0.5 and 1. For the grants, four different settings can be applied: no grants, medium, high and full grants. In case of 'full grants' the entire damage is compensated for all income categories. For the intermediate settings it is assumed that the lower income categories have a higher compensation than the more affluent categories. The model assumes that for the compensation of lost assets grants are used first, then non-fixed capital and for the remainder a loan can be used.

The effects of the different combinations of financial measures is shown in the bar chart below (Figure 57). What we see is that using loans to compensate the losses has a beneficial effect on the gross economic production after the flood. The replacement of lost income generating assets results in a higher production than in the reference situation. However, this does not result in the reduction of the number of financially vulnerable people, because a high interest rate reduces the income after the flood. This is especially troublesome for the poor income groups, who lose half of their income in paying interest (see Table 44).

Table 44 The impact of loans on the income after flood in the Bac Hung Hai polder

income category	total damage (million VND)	non-fixed capital (million VND)	loan fraction	total loan (million VND)	interest rate	interest paid (million VND)	annual income (million VND)	interest as % of income
poor	13.7	0	0.5	6.85	30%	2.06	3.6	57%
med	41.6	1	0.5	20.3	20%	4.06	11.3	36%
med_high	49.9	2	0.5	23.95	15%	3.59	17.4	21%
rich	79.8	5	0.5	37.4	10%	3.74	48.3	8%

Grants do significantly reduce the number of vulnerable people, because this does not burden the people with interest rates. However, as can be seen in Figure 57 only a full compensation of capital damages has a considerable effect. But that would require a total volume of relief funds of the same order as the annual economic production in the polder.

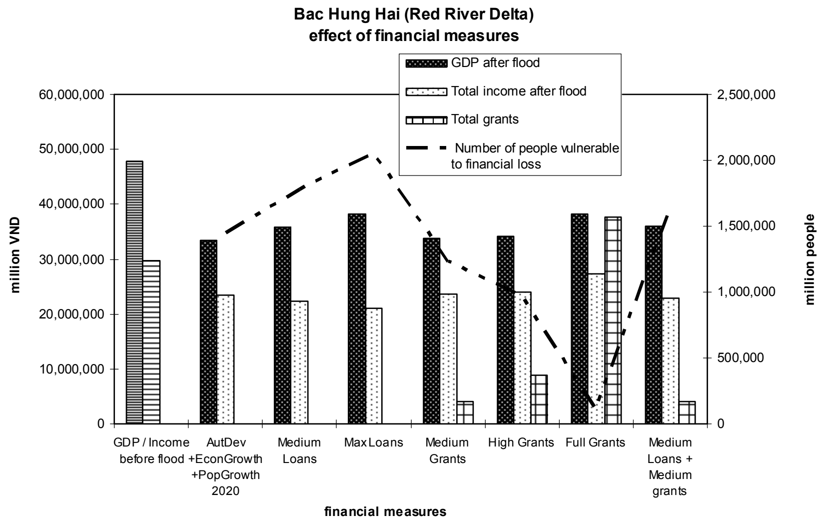
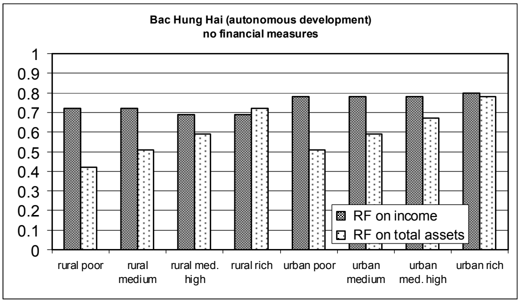
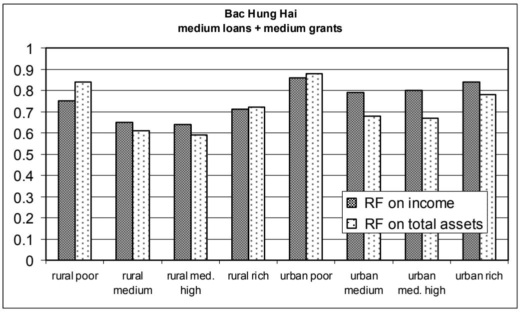


Figure 57 The effect of financial measures on vulnerability in the Bac Hung Hai polder

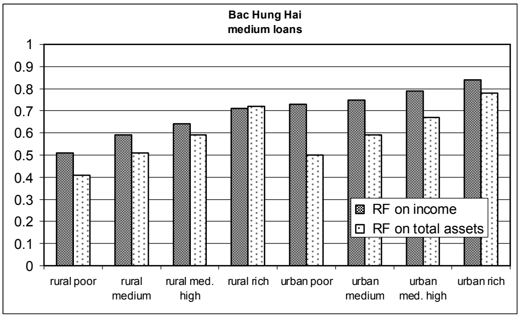
A combination of medium grants and medium loans more or less reflects the usual way of recovery: the poor are given some compensation for the losses and some of the remaining damage (but not all) is recovered by loans within the first year. The model shows no significant effect on the total number of vulnerable people. There is even a slight increase compared to the reference situation. How can this be explained? In Figure 58 recovery profiles are plotted for the financial measure strategies. Figure 58b shows a significant improvement for all recovery factors on assets for the combination of medium loans and grants, compared to the reference (a). For most income categories the recovery factor on income remains more or less unchanged. But particularly for the rural medium and medium high income groups the recovery on income reduces from approx. 0.7 to 0.65. Since for these groups the critical recovery factor is set at 0.6 and 0.5, respectively, it could mean that for some districts these groups can become financially vulnerable. And indeed, we observe that in the case with financial measures some districts become less vulnerable, while others become more vulnerable (Figure 59)



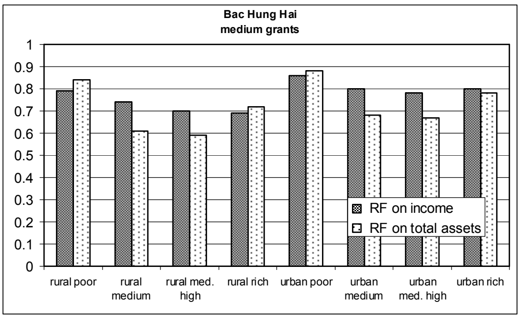
a. no financial measures



b. medium loans and medium grants

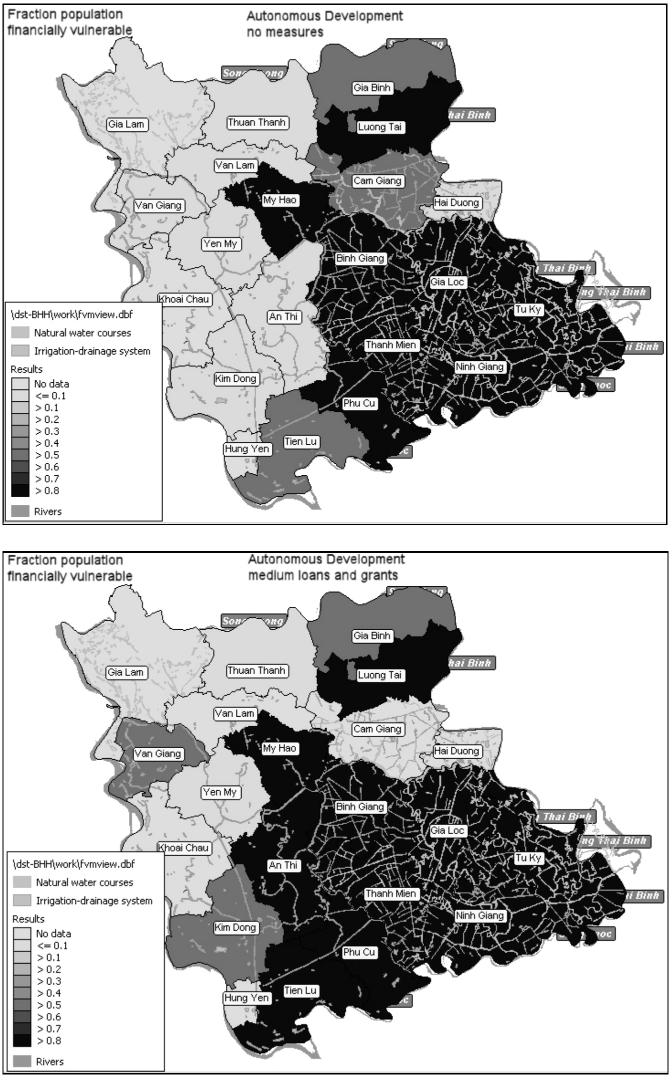


c. medium loans



d. medium grants

Figure 58 Recovery factors for financial measures (a to d) after flooding of Bac Hung Hai (Hong flood event)



a. no measures

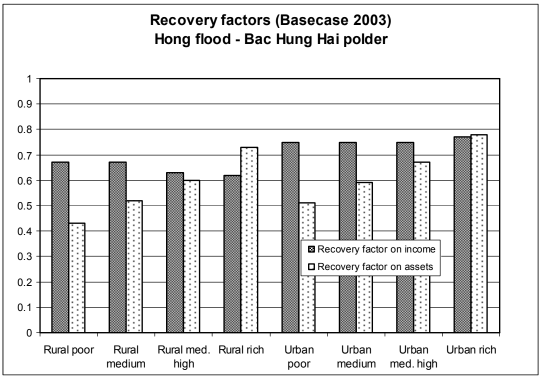
b. medium loans and grants

Figure 59 Financial vulnerability without and with financial measures (a and b)

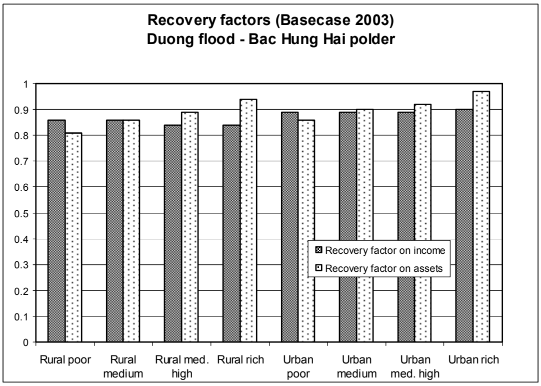
These different recovery profiles show how important it is not to look only at aggregated numbers of vulnerable people. Although the total numbers are more or less similar, the impact of the medium grants and loans does reduce the difference in recovery between the income groups. But having said this, one should also analyse district by district how these measures work out.

7.5 Comparison with the Godavari Delta, India

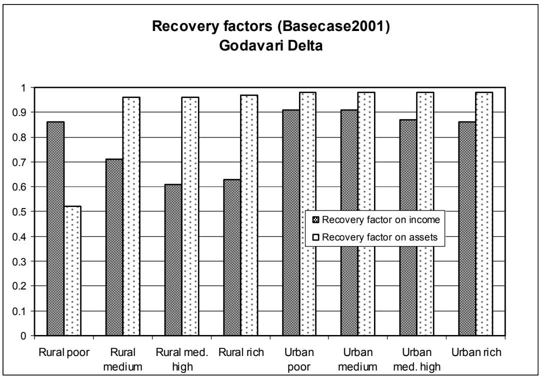
The comparison of the model results for Vietnam with India improves our insight in both the working of the model and in the differences in vulnerability between the two deltas. When we look at the recovery factors for each income group (Figure 60) we see that the rural poor in both India and Vietnam show the same vulnerability profile: the recovery on assets is (much) lower than on income. As in India, in Vietnam the recovery on assets increases with higher income levels and recovery on income decreases.



a. Basecase, Hong flood, BHH polder (Vietnam)



b. Basecase, Duong flood, BHH polder (Vietnam)



c. Basecase, Godavari Delta (India)

Figure 60 Comparison of recovery factors (model output)(a to c)

On the whole, recovery factors for the Hong flood in Vietnam are lower than in the India case. This does not indicate a fundamental difference between India and Vietnam. Rather it is attributable to the magnitude of the flooding event compared to the entire modelled area. We see this reflected in the two different flood events in Vietnam: the percentage of damage to total regional gross income for the Hong and Duong floods is 91 and 27%, respectively. This results in a marked difference in recovery between the two flood events (Figure 60a and b).

There is a difference in recovery, however, between the representative storm event in Godavari (Figure 60c), which gives a damage of around 20% of the total regional (gross) income, and that of the Duong flood which has a similar damage percentage. Particularly the recovery on rural income in India is lower than that of Vietnam. This can be explained by the fact that in Vietnam the crop damages are small compared to the total damage (around 8%) whereas in India crop damages account for half of the total damage. Because crop damage cannot be ‘repaired’, rural households in India experience a sharper drop in income than their Vietnamese counterparts. Another important explanation is that the Duong flood occurs in an area with high district incomes compared to the average of the polder: for instance Cam Giang District has an income of 2.673 billion VND, whereas most of the districts in the polder are in the range of 400 – 600 billion VND.

Differences in crop losses also explain the difference in the effect of loans on the gross production after the flood between the two deltas. In India the recovery of income generating assets through loans or grants does not show a significant increase in delta production, since the lost crop is gone. In Vietnam, however, a rapid recovery of income generating assets does result in a significant increase in gross delta production. It reflects the relative importance of the industrial sector in Vietnam compared to a more agricultural dominated economy of the Godavari Delta.

The Andhra Pradesh application showed a marked reduction in vulnerability (fraction of people financially vulnerable) with an economic growth scenario (Table 33). This is not the case in the Vietnam application, where an economic growth scenario does not result in a lower fraction of vulnerable people (Table 43). The reason is that in India the *overall* recovery factor on assets is higher than the recovery factor on income. And in Vietnam it is the other way around. In both cases economic growth leads to an improvement of the recovery on income. In India this translates into an overall reduction of vulnerable people, because the recovery on income is the most critical (it has the lowest value of the two recovery factors). In Vietnam also the recovery on income improves, but the recovery on assets remains the same (largely because the higher income is offset by the higher losses). And since in Vietnam the recovery on assets is the lowest of the two recovery factors, the total fraction of vulnerable people remains the same.

7.6 Conclusions

The application of the EDSS in a context quite different from India proved to be very functional in terms of a practical test as well as for interpreting the usefulness of the model results. Comparisons are notoriously difficult, not in the least because of differences in flood events as well as socioeconomic differences between the deltas. Nevertheless, the test has yielded important insights on the research question 4:

RQ 4: What can we learn from the model applications?

- Most data for the model was collected within a 2 weeks visit.
- Model calibration for the socioeconomic module proved more difficult because of the heterogeneity of the industrial sector. Therefore, the model does not simulate employment very well.
- The model was used for two different flooding events which differ significantly in flood characteristics depending on the location of a dike breach.
- Compared to the Godavari Delta, the model results from the Red River Delta showed similar vulnerability profiles for income groups. But there are also some striking differences. These relate to i) differences in damages (more crop damage in India than Vietnam); ii) differences in event (magnitude of flood; whether or not combined with wind damage) and iii) differences in socioeconomic conditions (more even distribution of land ownership in Vietnam).
- Aggregated model results, such as average recovery factors for the entire polder or indifference to income groups, neglect the underlying heterogeneity of deltas and could give rise to false conclusions. Measures such as loans and grants work out quite differently for different income groups and between districts.

8 Synthesis of the model evaluation

In this chapter the experiences of designing and working with the model, the dissection of the model and the review by an Expert panel workshop are synthesised, according to the three research perspectives. It includes an overview of strengths and weaknesses of the model and draws conclusions from the model results that are relevant for planning and disaster management.

Now that I have analysed the Andhra Pradesh experience and tested the model in Vietnam, it is time to synthesize the conclusions from the insights these activities provided. But before we do this, I still have to report on another contribution to the model evaluation: the Expert Panel Workshop.

8.1 Expert Panel evaluation workshop

The reason to have the EDSS evaluated by an independent panel of experts is to add an impartial and independent dimension to the analysis of the validity and practical usefulness of the model. Because the panel members were not in any way connected to the Andhra Pradesh Project, their judgment can be viewed as unprejudiced, i.e. having no previous knowledge of the model design as well as having no interest in the project or model outcome. The choice of the panel members reflected a combination of practical and professional considerations. Diversity in disciplines, but also in professional background, was important to cover the multidisciplinary character of the model. All members had at least some affiliation with either the concepts of 'vulnerability' or 'integrated modelling', or both. A geographical diversity was also taken care of, in order to avoid too much of a cultural bias. A list of the participants is provided in Appendix 1.

The evaluation concentrated on the three research perspectives used throughout this research. The members were sent a short introductory document of the EDSS. Also the model itself was available one week in advance in the form of a set-up file that could be downloaded and installed by the workshop members themselves. The Expert Panel comments on the model and their recommendations are included in the synthesis which follows.

8.2 The Model perspective

The main conclusion of the Expert Panel regarding the strengths and weaknesses of the EDSS model was: integration of many relevant domains is the model's main strength, together with a flexibility of use and the household detail. Simplicity of the economic model and the lack of investment costs were identified as the main weaknesses of the model. There was ambiguity as to whether the model can be applied in other countries or regions: many of the conceptual mechanisms on which the model is based are sufficiently generic to be used elsewhere, but the boundaries of applicability were not sufficiently clear.

The model's strengths and weaknesses – or limitations – are described below, based on both the Expert Panel comments and the analyses of the experiences from Andhra Pradesh (Chapter 6) and Vietnam (Chapter 7). The Expert Panel comments are stated explicitly in the text wherever relevant.

8.2.1 The model's strengths

Model concept: Innovative characteristics

The model shows evidence of three major innovations:

- Quantification of the entire impact chain of hazards to consequences
- A high level of integration between hazards and the human-environment system
- Quantification of differential vulnerability

The model is innovative because it includes and quantifies the complete model chain from hazard through potential direct impacts (damages and casualties) up to and including indirect impacts, quantified as the recovery potential, taking account of differences in coping mechanisms between households:

Hazard → Exposure → Damage / Casualties → Consequences

The analysis of the current state-of-the-art (see Chapter 1, section 1.3) revealed models that only cover part of this chain. The explorative character of the model also allows for analysing a range of measures that could reduce these consequences.

Integration was considered essential for a vulnerability model (Chapter 3). In this respect the *Expert Panel* praised the model as having a high level of integration. It shows environmental sustainability aspects such as land use options, resource limitations, waste generation and environmental quality, in relation to vulnerability. It also accounts for both flooding and wind damage, which is important as wind damage accounts for a significant part of the total storm damage and cannot be prevented by flood protection, evacuation and early warning measures. The model is not data driven in the sense that not only those relations are included for which data exist. This would have resulted in an unbalanced, biased model. Instead, formulations were made of all causal relations which were considered necessary. If there was a lack of data to quantify these relations, parameter values were either inferred from existing data (as proxies) or expert judgement was used.

The model proved to be able to integrate a large number of interactions and relations such as provided by the place-based framework for vulnerability (Figure 36). Choices have been made as to which of the components (variables) and relations (functions) would be internal c.q. external to the model. The essence of the model is a marriage between the framework of Turner *et al.* (2003) and that of Winchester (1989). Winchester's framework is centred around the *household characteristics* using *assets* which are prime modes through which vulnerability is expressed. Turner *et al.* uses the triple structure of vulnerability exposure, sensitivity and resilience. This triple structure proved to be essential because differences in vulnerability are linked to each of these. The differential aspect does not only relate to resilience, but also expresses itself in differences in exposure and sensitivity.

The *Expert Panel* considered the household level of the model a useful addition to existing coarser scale (region, country) vulnerability assessments. The household as a unit for modelling differential vulnerability also has advantages to a family approach. A family is not an appropriate unit, because a family does not need to be restricted to one location. It can be dispersed. Still the family can be important for coping with consequences – for instance an extended family as a social network. However, it is a house and household assets that are vulnerable to a flood. Assets are an essential component in modelling differential vulnerability. Assets are resources and stores (tangible assets) and claims and access (intangible assets), which a person or household commands and can use to ensure their livelihood (Chambers & Conway 1991).

Good calibration opportunities
Many of the output variables have real world counterparts, i.e. are available in relatively standard socioeconomic statistics of a country or region (for example per capita income, Gini coefficient). This makes it possible to calibrate the socio-economic calculations. Also the damage and casualties calculations can be calibrated, by using a model simulation of a historic cyclone or flood, provided that impacts of such event have been recorded in sufficient detail. The socioeconomic calibrations for both the Andhra Pradesh and Vietnam applications show a reasonably good fit with observations. Calibration of the environmental quality module was, however, difficult to obtain for the Andhra Pradesh application because the output quality indicators did not have a counterpart in regional statistics.

8.2.2 The model's limitations

Socioeconomic calculations
For the socioeconomic components of the model the calculations leading to an employment rate and Gini coefficient were questioned by the *Expert Panel*. To calculate the employment rate one has to have a good definition of the total available workforce, which is not always easy to obtain. Indeed, the model proved to be difficult to calibrate for employment (see section 7.3.). Further, the Gini coefficient is the result of a complex interaction between demand and supply and between production and expenditures leading to a distinct pattern of income. Since the model does not have a 'demand' side, this complex interaction is not simulated. Instead, the Gini-coefficient is calculated by a simple relationship between a (fixed) asset structure and a supply scenario (e.g. a landuse scenario). This means that the model cannot be used to simulate economic development over a period of time. The model is therefore not capable of determining which scenarios or measures are effective for stimulating economic growth. Another consequence of the lack of a demand side is that wage rates and prices are fixed variables. This implies that the changes in these variables which usually occur in the aftermath of a cyclone also cannot be modelled. It is important that the user understands these limitations of the model. *'Don't ask questions to the model that the model cannot answer'*, as one member of the *Expert Panel* put it.

Simplified damages model
The disruption of the economy due to a storm is modelled as a damage, leading to a loss of a certain amount of economic output. In reality many backward and forward linkages in the economy exist that could result in a higher indirect loss, but also in a lower loss due to compensation effects (unharmed factories that compensate for part of the lost productivity, migration of labour etc.). These linkages (e.g. inter-mandal relations) are not included in the model. This is not necessarily wrong, but should be acknowledged. Particularly the fact that (temporary) migration between the spatial units (mandals or districts) is not included in the model is of relevance here, because this is an often used coping strategy in rural societies in India (Winchester 1992).

No trade-off analysis possible
A third issue regarding the socioeconomic side of the model is that investment costs of the measures are not included. Therefore, no trade-off or cost-benefit analysis can be undertaken with the model. As the *Expert Panel* concluded, this does not make the model wrong, but is a limitation in a decision-making context.

Choice of hazard event
As discussed in section 6.2.4.1 the model is critical for the definition of the representative storm for which the vulnerability is calculated. In the case of the Andhra Pradesh application a recent super cyclone was chosen, enabling calibration of the model. In the Vietnam test case, two different flooding events were analysed.

It was remarked during the *Expert Panel* discussion that some important characteristics of a tropical storm were not included. This especially pertains to the timing and duration of the storm and the length of the inundation period, which are often important determinants of the magnitude of damage and the recovery speed of the economic production. Also the accompanying heavy rainfall and subsequent rainfall-induced flooding is not included in the hazard model. With respect to the latter factor, the model can easily be fed with alternative flooding scenarios. Timing and duration of the flood are not yet accounted for in the damage and recovery calculations and would necessitate a model design adaptation (e.g. including an extra parameter).

Other limitations
Some of the relations *in place* have not been included in the model simulations (see Figure 43). For instance a degradation in environmental conditions would probably affect the overall vulnerability, either through reduced income levels and/or health status. However, this feedback relation is not implemented in the model computations. Coping mechanisms in the model are limited to financial instruments such as the use of reserves, grants and loans. Also the differential aspect of vulnerability is expressed in financial terms only (income and assets). Hence other factors, such as age, gender, pre-existing health conditions (Green et al. 1994) and education level are not used in the model. Furthermore, apart from calculating human casualties, the most serious of health hazards, the model does not include injuries and psychological trauma arising from a storm. These impacts are extremely difficult to quantify and therefore not included in the model. This does not justify ignoring them, however (Tapsell et al. 2002).

8.3 The Application perspective

Ease of preparing an application
Despite the fact that the model requires a large set of input parameters and variables (over 800), the set up of an application for a specific region is quite feasible. For the Andhra Pradesh application, the majority of the input data for the model was more or less readily available from statistics. Absent data proved to be easily inferable from existing data or was estimated by expert judgement. Also for the Vietnam application there were no practical problems in populating and running the model. In fact it proved possible in about one month for one person to have the core model (without the resource and environment modules) up and running.

User friendliness
The model has a graphic user interface (GUI), through which selections can be made easily between different pre-set scenarios as well as between a large range of meas-

ures. The *Expert Panel* regarded the interface easy to use and user friendly. However, the GUI does not allow easy access to system parameters. The *Expert Panel* raised a question with regard to the possibility of changing parameters, such as the casualty rate. Although it is technically very easy to change them, because they are all stored in a Microsoft Access database, one does need to have substantial knowledge about the functional design in order to do so.

Another advantage is the fast response time of the model. Results of calculations are available within seconds. This makes it suitable for use in interactive sessions with experts or interested stakeholders. All calculations for one mandal can be done in a spreadsheet as well, which makes it transparent (users can follow the calculations step by step if they so desire).

Multiple uses
According to the members of the *Expert Panel*, there is potential of the model to be used as a communication tool at a local (community) level. The visualisation of vulnerability on a map is a strong point of the model. Local people can better understand a concept or a hazard when they can recognise the place where they live and see what the potential impact can be. Also the linkage of vulnerability to different land use options is something that is easily understandable: people know the crops and their specific sensitivity to winds or floods. However, to maximise this opportunity, the model would probably need to be used on a higher resolution level, e.g. the village level instead of the mandal or district level.

According to the *Expert Panel*, the model has high potential for awareness raising/participatory planning purposes and for enhancing integration in planning (managing and relating large data sets). It enhances system understanding through organising and linking data from different domains (i.e. it supports the process of integration).

Generic applicability
The EDSS is developed for economies that are dominated by agricultural, livestock and fisheries production. The model is not suitable for modern, highly urbanised and industrialised deltas or service-oriented open economies. The main reason is that the economic model is not sufficiently detailed with respect to the secondary and tertiary sectors, which hampers a good prediction of the potential damages in these sectors.

The test case showed that the model concept is applicable in Vietnam, but that modifications were needed. For instance, there is a marked difference between India and Vietnam with regard to wage labour in the agricultural sector: in India there is a huge landless labour force that works in agriculture, but in Vietnam most of the work is done by farmers and their families themselves. Therefore, the wage labour days per crop had to be adapted. We also saw in section 7.3.1 that it was difficult to calibrate the model with key economic data for the Hung Yen province. There appeared a large difference in labour requirement between different types of industry (state-owned, foreign etc.). Because the EDSS only works with an average labour requirement, this difference could not be accounted for. The relatively simple model representation of the industrial sector therefore showed its limitations in the application for the Red River Delta, where the economy is in a transition state from predominantly agricultural to industrial.

Model results are relevant for planning and disaster management
A crucial model output from the Andhra Pradesh application is the rather steep recovery curve relative to household income: whereas the rural poor income class showed a recovery factor on assets of 0.5, all higher income classes showed a recovery factor on

assets of 0.95 or more (see Figure 26). The recovery on income shows a more or less opposite trend: the poor are better able to restore their income than the other groups. Although it may seem that the poor are relatively well off in terms of their income recovery, we must realise that a 15 - 20% reduction of their already very meagre income could bring them well below the minimum livelihood level. And it certainly leaves them no room to compensate (e.g. by savings) for the lost assets. For the other income classes, the opposite is valid: although they experience a significant drop in their annual income, they have sufficient income left to stay well above the minimum livelihood level. And when the next year's crop is successful again, they are probably able to compensate for their asset loss.

The implications one can draw from this output are that:

1. the poor suffer *disproportionally* from a cyclonic disaster;
2. a small improvement in the income situation would *dramatically* reduce their vulnerability

The model results for Andhra Pradesh also show that only two measures significantly reduce the vulnerability of the poor sections of the population: the provision of relief funds (grants) to affected people and a reduction of the number of people in poor conditions. Loans do not have a positive influence on recovery, even though they could lead to a more rapid restoration of productivity.

The Vietnam application reveals a similar phenomenon of the poor sections having the lowest recovery on assets and a relatively high recovery on income. However, the differences with the other income groups are less pronounced. A plausible explanation for this dissimilarity is that, compared with India, land is more evenly distributed between the income groups. In the Red River Delta almost all poor families have at least some piece of land, whereas in India the poor mostly consist of landless labourers.

Land use and economic development scenarios for both deltas show a similar effect on vulnerability. Economic growth leads to an improvement on the recovery on income. Crop diversification and agricultural intensification leads to significant higher crop damages, but this effect on vulnerability is largely offset by the increased per capita income. Furthermore, the model results clearly display a spatial differentiation in vulnerability, which is not only determined by differences in exposure to the hazard, but also by economic differentiation. Examples are the vulnerable economies of Atreyapuram and Peravali mandals in India because of their dependence on the banana monoculture (Box 11) and the different recovery factors between richer and poorer districts in Vietnam (Figure). These findings can provide guidance to regional planning aimed at minimizing vulnerability.

8.4 The Context perspective

Reviewing the actual model design from the Context perspective, I showed that five factors have proven decisive in the type of model and its development: the *policy analysis style*, *policy objectives* of the study, *formal directives* from the Client, the *team composition* and the model *scale/resolution*.

Policy analysis style, objectives and directives from the Client

Because the Andhra Pradesh project represented a rational policy analysis style with a clear planning paradigm, the choice of an explorative type of model through which the impact of scenarios and measures on vulnerability can be simulated is considered appropriate. The study objectives formulated by the Client, encompassed socioeconomic, environmental and vulnerability aspects.

The absence of active involvement of stakeholders other than the client (the Andhra Pradesh Government), was a constraint that could have implications for the wider acceptance of the model, as one member of the Expert Panel voiced. Interestingly, though, some Expert Panel members indicated that the model could be of use in supporting participatory planning and decision making.

Team composition and dynamics

The team consisted of both natural and social scientists, between whom discussions were held regarding the definition of vulnerability. These discussions eventually led to a shift in the dominant paradigm from 'Risk-hazard' towards 'Differential vulnerability'.

Model scale and resolution

The absence of a detailed GIS prompted the use of the administrative units called 'mandals' as spatial units. Differential vulnerability led to the use of households as main economic unit. These choices yielded a model for small-scale household vulnerability. The consequences of this choice in scale and resolution for the model results are elaborated in section 9.1.2.

9 Conclusions and discussion

In this Chapter the research questions posed in Chapter 1 are answered. Their contribution to the advancement in the state-of-the-art in vulnerability modelling is also discussed. The Chapter ends with a reflection on the methodological aspects of the research.

9.1 Conclusions

Now is the time to answer the research questions posed in the beginning, combining my experience from the two studies of India (Chapter 2) and Vietnam (Chapter 7) with the theoretical notions on vulnerability (Chapter 3), integrated modelling (Chapter 4) and policy analysis (Chapter 5). I have dissected the Andhra Pradesh experience using the three research perspectives (Chapter 6) and synthesized my findings together with those of the Expert Panel (Chapter 8). The answers given in this chapter on the research questions reflect my learning. The answers do not pertain only to the EDSS, nor only to Andhra Pradesh nor only to Vietnam. Instead, I tackle the challenge of determining how generic the findings and conclusions are. Where possible, I provide boundaries of applicability.

9.1.1 Question 1: What are the characteristics of vulnerability and how can these be conceptualised?

As the main objective of my research was to advance the state-of-the-art in modelling vulnerability, descriptions and definitions from literature were screened on their potential use for modelling. And since the research objective also focused on the integration between disaster management and planning, specific attention was given to theoretical notions and conceptual frameworks of relevance in a planning context. The results of this search are documented in Chapter 3 and the main conclusions are presented below.

Vulnerability is a composite of exposure, sensitivity and resilience
Literature on vulnerability reveals a large variety of theories and definitions. But there is increasing consensus that vulnerability of a social system (which can be anything ranging from an group of people up to a nation), is a multi-faceted concept. Understanding vulnerability requires an integrated perspective that includes both physical, socioeconomic and cultural conditions. The many definitions and descriptions of vulnerability have three elements in common: exposure, sensitivity and resilience. Based on these elements, I formulated a working definition of vulnerability to a hazard as an attribute of a person or social system determined by a combination of the exposure, sensitivity and short term resilience of that person or social system. I explicitly include only *short term* resilience – that is the coping capacity of a person or social system – as part of the definition. This leaves long term resilience – that is the adaptation capacity of a person or social system – outside the definition of vulnerability. This makes the definition useful in a planning context: an assessment of vulnerability at

any given moment in time can then be used to determine the need for adaptation measures to reduce vulnerability in the future.

Planning requires insight in the differential character of vulnerability
Because coastal planning is about the distribution of (scarce) resources and space, the differential aspect of vulnerability is crucial. Literature contains descriptions of the differential aspect of vulnerability, linking it to characteristics of an individual (such as age, gender and race) or social structures. And if we want to integrate disaster management with regional planning, these characteristics are essential: Who should be given financial incentives? Which sector requires government support? Where should urban development be situated? All these questions require insight in who the most vulnerable people are, where the most vulnerable areas are and which activities are most sensitive. In the next section (9.1.2) we will see that the appraisal of the differential character of vulnerability is strongly influenced by the scale and resolution at which the analysis is carried out.

Vulnerability assessment requires an integrated, place-based conceptual model
In view of the potentially broad nature of vulnerability and its site specific character, a conceptual model should be integrated and place-based. Most existing conceptual vulnerability models and frameworks focus on specific (partial) aspects of vulnerability. Some frameworks clarify the root causes of vulnerability (e.g. Blaikie et al. 1994), while others focus on the geographic context (e.g. Cutter et al. 2003) or on the factors determining coping capacities (e.g. Anderson & Woodrow 1998). The expanded framework for vulnerability of Turner et al. (2003) is an example of a broad conceptual model, but not necessarily the only one. Any framework could be useful as long as it includes the three basic elements of the definition of vulnerability I use in this research (*exposure*, *sensitivity* and *resilience)* and if it accounts for differences in scale that produce differential vulnerability. Based on the framework of Turner et al., I proposed a conceptual model which is place-based and includes the three basic elements (Figure 36).

9.1.2 Question 2: how can we model vulnerability?

We concluded in Chapter 3 that modelling vulnerability requires an integrated, interdisciplinary approach. The ‘Expert Decision Support System’ (EDSS) for ICZM in coastal Andhra Pradesh is an example of a vulnerability model for tropical cyclonic storms that uses such an approach. Through its explorative character it enables the user to assess the impact of certain development scenarios and strategic planning choices on vulnerability. This model, which is described in Chapter 2, shows that it is indeed possible to model vulnerability in an integrated way, despite the complexity and multi-faceted character of vulnerability. It includes the three components exposure, sensitivity and resilience, it shows differential effects between income groups and it is place-based.

The fundamental idea underpinning the EDSS is that in order to determine the impact of a cyclonic disaster on coastal society, first the structure and functioning of this society needs to be modelled under ‘normal’ conditions. Only by understanding the dependencies between the use of land, its resources, socio-economy and environmental conditions, is it possible to simulate the impacts of a disruption of these dependencies by a cyclone. Hence the model captures the economic and environmental conditions of a coastal area for one year without a cyclone and again one year after this area is struck by a representative cyclonic storm. Vulnerability is then calculated as the difference in assets and income in the area at the end of both years.

By linking the socio-economic character of the coastal zone to the land use and all related activities that generate income the model is sensitive to both planned (crop selection) and unplanned (cyclone disaster) land-use changes. It uses a spatial resolution of administrative units (e.g. districts or municipalities) and calculates the estimated annual incomes for different income groups (households) based on their private and income generating assets. The model shows the differential economic effect as a function of rural or urban household income and according to a range of impact scenarios and environmental conditions.

The EDSS has a modular architecture and a graphical user interface that allows the boundary conditions of the model to be changed through scenario definition, a selection of strategic measures or a combination of both. Exposure to hazard is determined for both storm surge and damaging wind speeds, each originating from separate (off-line) mathematical models. Distinctions in sensitivity (damage curves) have been made for movable and immovable private and income generating assets. In this way impact calculations on household wealth as well as income are made possible. Resilience is measured as the extent to which households are able to restore their income position and to replace their lost assets (recovery factors on income and assets) in one year.

Of course this model is not the one and only way to model vulnerability. The choice of a model type and its implementation is determined by practical, epistemological and subjective/normative factors. The EDSS is an example of an explorative model for planning in the context of integrated coastal zone management. It is certainly not without flaws, as is discussed in the next section. From this experience we can draw a number of more general lessons for modelling vulnerability. These lessons have been triggered by two methodological key issues in integrated modelling (described in Chapter 4): the use of a system approach and scale/aggregation effects. In addition, two other issues have been identified as being of special relevance for vulnerability modelling: the choice of a metric for vulnerability and the choice of the hazard event.

System approach: start model description with place based relations

Because vulnerability is highly context dependent, the simulation model does not follow automatically from a conceptual system description. The translation of the relations from the conceptual model into a computer model requires interaction within the research team as well as with stakeholders. A crucial task of this interaction is the identification of the most important relations that can and should be modelled. This identification process needs interdisciplinary teamwork, in which heuristics play a crucial role (Nicholson et al. 2002), as concluded in Chapter 4.

The differentiation in the conceptual model between types of relations into *in place*, *cross scale* and *beyond place* can be helpful in choosing which relations should be considered as internal to the model and which could be used as external and/or boundary conditions. Drafting a boundary diagram (cf. Figure 41) is insightful in this respect. Since vulnerability is a place-based phenomenon, a good guideline is to start with internalizing the *in place* relations in the model and assuming all *cross scale* relations as boundary variables. The specific context of the area then determines whether or not this initial representation holds. For instance, in a very open economy, resilience could be more dependent on the cross scale interactions with the wider region than with the human conditions within the locality where the flooding occurs. This could lead to the choice to internalizing this cross scale relation. One way – and according to Nicholson et al. (2002) the only way – of determining what goes into the model is through a sensitivity analysis. Such an analysis should not merely be an automated process that tests all parameters, but an important part of the culture of modelling that is used for the thoughtful exploration of assumptions (Nicholson et al., 2002). Hence an iterative process of making a first version of the model, then checking and improving and so on.

An example of model choices is the detailed modelling of the agricultural sector in the Andhra Pradesh model. By distinguishing 14 different types of crops it was possible to add much detail to cropping patterns with respect to sensitivity to flooding and wind, water demand, and labour requirements. The model has a simplified structure for the industrial sector and for the commercial / services sector it uses a readily conceivable relation (a multiplier over the other two sectors). This works well in a predominantly agricultural society, but would be too simple for a highly industrialized or services based economy such as the Netherlands.

Choices in scale and resolution determine vulnerability model results

From the theory of vulnerability (Chapter 3), we saw that exposure, sensitivity and coping capacities are not uniformly distributed over social groups or systems. Instead, there are differences in capacities that lead to differences in vulnerability. The way in which these differences can be made visible largely depends on the resolution of the model. In the EDSS model, heterogeneity of the spatial vulnerability is clearly shown in its results: there is differential vulnerability between income categories and there is differential vulnerability between districts or mandals. In general, aggregation leads to blurring of the differential aspect. Solving these scale issues is therefore essential to building an appropriate vulnerability model.

Scale choices do not necessarily derive from the conceptual model. For instance, although the 'Turner framework' explicitly includes spatial scales in the framework, it does not determine the spatial scale. The strong variation in vulnerability by location has highlighted the role of so-called place-based analysis, implying explicit cross-scale relationships. 'The coupled-human environment system, *whatever its spatial dimensions*, constitutes the place of analysis' (emphasis mine)(Turner et al. 2003).

One should not confuse scale with resolution. Although for a large area a high resolution is more difficult to obtain, it is not impossible. Hence, if we would like to make a vulnerability model at the scale of a country or region, it is still to be decided whether or not we use an individual, household or village as the unit of calculation (i.e. the resolution).

But, is there an ideal scale and aggregation level for vulnerability modelling? No, this depends largely on the purpose of the model and the type of decision context. But whatever choice is made, one should always be beware of the fact that aggregation can obscure essential impacts of vulnerability and mitigation measures at lower aggregation levels. For instance, impact on average income levels does not reveal the often unequal distribution of costs or damages. The model for Andhra Pradesh showed that it is entirely feasible to differentiate at the level of households, while still producing a vulnerability model at a large (delta) level with 7 million inhabitants.

For vulnerability to natural hazards, the lowest aggregation level possible is recommended. The main reason lies with the need for a place-based analysis, instigated mainly by the rather localized impact of a tropical cyclone. Disasters affect people, enterprises and farms first, then the local and regional economy and not the other way around. Eventually, the impacts of a disaster for a region or country are essentially determined by the way the affected people ('victims') are, or are not, able to cope with the consequences. Early warning systems, developed at a country level, are as strong as their weakest link, and that is often at the village and household/individual level. Community preparedness significantly reduces the need for outside (government) rescue and relief. Recovery of economic activities largely depends on the ability of individuals to take up their occupation or enterprises and to start operating again. Therefore, the assessment of vulnerability of individuals, households and enterprises is more informative than whether a country has sufficient financial means to cope with a major disaster, because the magnitude of this disaster depends largely on this detailed level of vulnerability.

Define relevant metrics for vulnerability

The model uses three output variables that indicate the level of vulnerability: recovery on assets, recovery on income and the fraction of people financially vulnerable. The two applications for Andhra Pradesh and Vietnam showed how differently these variables can behave (Chapter 7 sections 7.4 and 7.5). Each of these variables indicates a different aspect of vulnerability. The distinction between the two recovery factors proved to be important in understanding how vulnerability differs between income groups. The fraction of people financially vulnerable is the most aggregated variable that is useful to capture the vulnerability of a region in one figure. However, it blurs the differential character of vulnerability. Most strikingly, this has been illustrated by the fact that in two situations this aggregate variable can be the same, but with a significant difference in the vulnerability profile across income groups (cf. Figure 58).

In retrospect one could argue that these variables are still abstractions of what really happens with people. These proxies could be translated into more meaningful concepts, such as the time it takes before a household has fully recovered from a disaster. For instance the farmer in the example of Box 10 could have damages compensated in 8 years. This would make it clear that it takes more than one year before the full effects of a cyclone are shown[21]. Similarly it would be politically relevant to calculate the number of people that would fall into poverty ('poverty trap'). The difficulty in doing this, however, is – again – the scale effect: damages are distributed over all households in the spatial unit used for calculation (i.e. a district or mandal). Hence, when not all households experience the same flooding, the financial drawback of the households that are affected by the flood is averaged out by the non-affected households.

Most importantly, the chosen vulnerability indicators and their differentiation both in income groups and in spatial extent (as shown in sections 6.4.4. and 7.4) open up a fundamental debate on disaster management. Would crop diversification lead to reduced vulnerability? Should we provide grants, how much and to whom? Do low in-

[21] This , inter alia, questions whether one year as the time frame of the model is suitable. Other time frames could be used as well. Most importantly, however, is that the magnitude of damages and coping mechanisms are captured by the time frame of the first year after the cyclone. This is most probably the case, since the total direct damage does not increase after a year, government grants are probably (or should be) paid within a year and farmers will replenish income generating assets within one year in order to sow and harvest the second crop. What happens in this first year largely determines how long complete recovery will take.

terest loans contribute to a faster recovery? And if so how can we reduce existing barriers, e.g. through micro-credit or micro-insurances for the low income groups (Coburn & Winchester 2008)? By using the model to analyse various scenarios and strategies, the way the vulnerability indicators behave provides essential information to answer such questions.

Choice in storm or flood event determines vulnerability model results
Risk and vulnerability are different concepts. As we know, a protected area with consequently a low risk of flooding can still be highly vulnerable *should* the levees break. In contrast to a risk calculation – which should include all possible events on a range of probabilities – a vulnerability calculation, in the definition used throughout this thesis, requires a *choice* of a certain event. In the model developed for Andhra Pradesh we used a 'representative storm'. In the Red River Delta test case, I used a dike breach with the highest possible flooding. It is clear that this choice is influencing the outcome of the calculation. It also depends on the purpose of the vulnerability calculation. For instance, using a recent disaster is particularly useful for calibration purposes of the vulnerability model. A 'worst case' event is useful if one is interested in the need for preparedness measures. The event that causes the maximum annual damage is a typical choice for macro-economic and regional planning purposes.

Ideally, all attributes of a storm event relevant for damages and casualties should be included in the simulation. For instance, inundation depth, timing, duration, flow velocities and water quality are all influencing the impacts on society. In practice, it will be difficult to implement in a vulnerability model such a full scale simulation of a flooding event, not in the least because of a shortage of empirical damage functions for factors other than flood depth and velocity.

9.1.3 Question 3: How useful (valid) is the model?

As we have seen in Chapter 4, assessing the usefulness in the sense of the validity of an explorative, integrated model is not a trivial matter. Acknowledging the fact that a complete scientific validation is impossible (Oreskes et al 1994) we should nevertheless strive for an open, transparent and objective validation procedure. Such a procedure should lead to acceptance of the model in question by its users, be they scientists, clients or stakeholders. This certainly holds for a model of vulnerability. To determine its validity, it should be scientifically sound, useful for the end user(s) and acceptable to stakeholders. On the basis of this, three groups of criteria have been formulated: scientific, usability and transparency criteria (section 4.5.3). Since I was not in the position to discuss these criteria with the end users and stakeholders, the model evaluation in this thesis remains restricted to an academic exercise using the scientific and usability criteria[22].

Scientific validation
With respect to the scientific validation of the Andhra Pradesh model, I performed a number of tests that are described in the literature (cf. Refsgaard & Hendriksen 2004; Nguyen & De Kok 2007; Parker et al. 2002; Sterman, 2000). These pertain to the boundary of the model (boundary adequacy) using the Reference Structure of Mead-

[22] It is noteworthy to state, however, that at the end of the Andhra Pradesh Cyclone Hazard Mitigation Project, the model was ultimately accepted by the client after a tedious process of improvements, negotiations and training sessions. Hence, the end users regarded it as a valid tool for their planning purposes, although no explicit validation criteria were used.

ows & Robinson (1985), a model structure assessment, using the Extended Vulnerability Framework of Turner et al. (2003), and a Family member test, by comparing with the Vietnam application. Because thresholds for these tests are absent (no agreed criteria), it is not possible to say whether or not the model has successfully passed these tests. Nevertheless, these evaluation exercises as well as the comments of the Expert Panel did provide insight in the model's strengths and the limitations which have been reported in Chapter 8.

Usefulness of the model

Although the conclusions deduced from the model may seem obvious for experts, they are certainly not so for most others. The model enables quantification of vulnerability, adds transparency to the conclusions and can deal with complexity beyond what most human brains can handle. The extra value for policy making is the ability to calculate a whole range of cases (combinations of scenarios and measures) and assess the impacts on vulnerability. The fact that the model shows a direct link between cropping pattern and vulnerability, for instance, is a novelty that can be used for planning purposes. The model has been used for analysing land use scenarios, the output of which was subsequently used for drafting the Resource Management Plan for the Godavari Delta. There is also a scale issue here: the model is able to show on the scale of mandals how vulnerability differs in the spatial dimension.

The usefulness of this model as a contribution to the wider scientific, disaster and coastal management community thus lies in *three innovations* the implementation of which has been proven feasible (see model evaluation in Chapter 8). I can therefore conclude that the added value of this model lies in:

- The modelling of the *entire impact chain* of hazards to consequences, including exposure, sensitivity and resilience;
- A high level of *integration between hazards and the human-environment system*, enabling explorative analyses of 'typical' disaster management measures as well as land use planning and environmental management measures and scenarios.
- Its ability to *quantify differential vulnerability* at household level, enabling the analysis of measures targeted at critically vulnerable groups.

The model approach can therefore more than any other tool contribute to the mainstreaming of disaster management into sustainable coastal development. Enhanced perception of the consequences of planning on the vulnerability in the two deltas in India and Vietnam through the model application has been documented in the previous Chapter (section 8.5) and is included in the next section.

As any model, also this one has limitations, described in section 8.2.2 .When using the model, these shortcomings should be acknowledged. Model application needs to be embedded in a broader policy analysis process, with due consideration of vulnerability aspects that are not addressed by the model (such as gender and health considerations).

9.1.4 Question 4: What can we learn from the model applications?

This research question leads us back from the model itself to the wider perspective of vulnerability assessment and planning. Do the analysis results for the applications give new insights in vulnerability reduction measures or policies? And how generic are these results for other, similar coastal areas?

Mitigation and preparedness are increasingly being given attention in official policy documents alongside post-disaster relief and rehabilitation. For example, the incorporation of vulnerability as part of long term planning has recently being identified as a main objective for India's new (proposed) National Policy on Disaster Management: '*The broad objectives of the policy are to minimize the loss of lives and social, private and community assets because of natural or manmade disasters and contribute to sustainable development and better standards of living for all, more specifically for the poor and vulnerable sections by ensuring that the development gains are not lost through natural calamities/disasters'* (Government of India 2004). However laudable these intentions, this policy still focuses primarily on reducing casualties and damages and ignores the potential increase in resilience as a measure to reduce vulnerability. The model application to the Godavari Delta in Andhra Pradesh has clearly shown that increasing resilience is an important factor in reducing vulnerability (section 8.5).

The Andhra Pradesh application indicates that the poor suffer disproportionally from a cyclonic disaster and that a small improvement in the income situation would dramatically reduce their vulnerability. The poor also have the lowest recovery factors in Vietnam, but the differences with the higher income categories are less dramatic than in India. Hence, in situations where a significant portion of the population living in hazardous places is around or below the poverty line, the only short term measure for reducing vulnerability is the provision of relief funds. Also improvement of credit and insurance facilities for the poor as well as medium income groups (micro-credit, micro-insurance) could directly enhance the resilience capacity in two ways: firstly, by reducing the negative effect of interest on income and secondly, by helping in starting up the production again.

Both of the model applications for India and Vietnam showed that economic growth, although increasing the damage due to more invested capital, can result in some decrease of vulnerability. This is in agreement with the '*Lessening hypothesis'* that development in societies and nations reduces the social costs of hazards to a society (White et al. 2001). At the same time the model shows that economic growth alone (without taking into account redistribution effects) hardly reduces the vulnerability of the poorest sections of the population. The increase in savings – leading to increased resilience – is significant for the medium high and rich income categories, but negligible for the lowest income categories. Therefore, poverty reduction remains an important means to reduce vulnerability, although it does not necessarily show as an improvement in aggregated recovery factors for the *entire* population. This is an example of the distorting effect of aggregating output, explained in section 9.1.2.

Perhaps the greatest achievement of the model application for the Godavari Delta is the finding that reducing vulnerability to cyclonic storms requires a broader set of measures than is usually taken into account by disaster managers. The model illustrates not only the need for flood protection and early warning, but also the need for measures that reduce the sensitivity and increase the resilience of households. For example, by diversifying cropping patterns and broadening the economic basis (cf. Benson & Clay, 2003). Flood protection, early warning and evacuation measures do reduce the number of deaths, but cannot prevent wind damage, which still accounts for approximately half of the total damage. This insight is made possible both by including wind hazard as an inextricable part of the cyclone hazard and by linking damage to household livelihoods.

The model also shows place vulnerability. Because the outputs are presented in map form, the user becomes aware that the most vulnerable places are not only found along the coast, but also locally more inland. Wind hazard combined with a monoculture of sensitive crops could lead to a relatively large fraction of vulnerable people. This creates new insights at the level of the entire delta vulnerability which probably would have gone unnoticed without the model.

In conclusion, the model is able to deal with the complexity of the human-environment system by quantifying of the complete chain through which a hazard is translated to differences in vulnerability, i.e. via exposure, sensitivity and recovery in a particular region. The outcome of a single measure, let alone of a set of measures, is not directly obvious and could not have been known without the model.

9.1.5 Question 5a: Which factors played a crucial role in the model design?

The Context Perspective I took in this research enabled me to distinguish clearly which choices were important in the model design, especially the implicit ones. Five factors proved decisive in the type of model and its development: the policy analysis style, policy objectives for the study, formal directives from the client, the team composition and the model scale/resolution. The first three factors determined to a large extent the (implicit) choice for a *Planning model paradigm*. The interdisciplinary team composition invoked discussions regarding the definition of vulnerability and eventually led to a shift in the dominant paradigm from *'Risk-Hazards'* to '*Differential Vulnerability'*. The consequences of both the Planning Model and Differential vulnerability paradigms for the general applicability of the model will be discussed below. The consequences of model scale and resolution have been discussed already in section 9.1.2.

The planning model paradigm

It is not always obvious that we need a model to solve a societal problem. Making a model is a process of making choices: you leave something out and put another thing in. And it also requires quantification. Quantification has its trade-offs: it has positive effects (it forces one to integrate and come to the essence), but you also lose something. Sometimes a qualitative description (essay, impressions) is needed. The action perspective of humans is something you can hardly describe quantitatively. We saw that the model developed in Andhra Pradesh expressed resilience in two recovery factors (one for income and one for assets). There are many more coping strategies that lead to resilience, most of which cannot easily be quantified. That does not mean that these strategies are not important. A strategy that enables these human capabilities (e.g. the examples of 'abilities to adapt' given by Winchester et al. (2006), stimulating mental acuity, strength of character etc., could be equally useful. The Capacities and Vulnerability Analysis concept developed by Anderson & Woodrow (1998) can be brought to mind again, because it explicitly includes the motivational element of vulnerability. It is therefore very important first to know for which type of decision environment (or policy analysis situation, see Chapter 5) solutions are required. For instance, if are we looking at solutions at the level of system design (cf. Bots 2007) (e.g. land use planning, flood embankment design) models can be a useful tool. But on an institutional level, issues of empowerment, decentralization and local resource management require attention, for which mathematical models are less obvious tools.

The model developed in Andhra Pradesh is an example of the rational planning model paradigm: policy strategies and scenarios are analysed and the strategy that best meets the policy preferences and criteria can be chosen. This is often what a government client wants (in the Andhra Pradesh experience the client was in search for 'the preferred option'). But of course the model, and indeed the entire policy analysis, only produces an output, not an outcome. In other words, even if the client (in this case the Planning Department of the AP Government) made a decision based on the analysis results, this would not automatically lead to changes in the preferred direction. For instance, a shift in cropping pattern is not something you can plan top-down, because it is a farmer's decision. Or the decision to give grants to those who are affected by a disaster does not mean that the most in need are reached. Eventually there is a difference between analysing, deciding and doing, between modelling, policy making and implementation. For policy making, models can provide suitable support, for implementation the institutional design approach might prove more effective.

As long as we realize the limitations of applicability of the planning model approach, there is no objection to using this approach. Some of these limitations could potentially be alleviated by engaging stakeholders in the planning process, including model design (see section 4.4.2 for a review of stakeholder involvement in integrated modelling). In the last section of this Chapter I will come back to this interesting perspective.

Differential vulnerability paradigm
During the Andhra Pradesh project, a shift from Risk-Hazard to the Differential Vulnerability paradigm took place. The consequence of this shift for managers and planners lies in the way one should deal with natural hazards. Is it the exposure to hazard that should be contained or is it vulnerability? Or both? In this thesis I have shown how vulnerability assessments can be made for both present and future conditions. But what do these assessments tell us about risk? Surely, when coastal vulnerability is reduced, the risk also becomes smaller. But risk can also be reduced by a reduction of the exposure to hazard. In countries such as the Netherlands flood protection has reached high levels of safety with low risks. Nevertheless, the vulnerability to a flood should the dykes be breached (the worst case scenario) is extremely high.

Risk can be used for economic cost/benefit analyses. A remaining problem is that in the perception of people, the risk of a small chance with great consequences is not perceived as equal to the risk of a great chance with small consequences. Here, the vulnerability assessment comes into view. Risk alone does not unveil the vulnerability of a community. And since communities are not homogenous, the differential character of vulnerability has been introduced as well.

Since vulnerability and risk are two sides of a coin, both approaches have their value. Which of the two to choose would ideally be part of an explicit discussion before the model design starts. This should be a lesson for future efforts of interdisciplinary teams and align to what Nicholson et al. (2002) have formulated as their second heuristic: *Invest strongly in problem definition early in the project.*

9.1.6 Question 5b: Have crucial factors in the design of the model influenced its general applicability?

In the previous section we saw that five factors proved crucial in the design of the model: the policy analysis style, policy objectives for the study, formal directives from the client, the team composition and the model scale/resolution. The first three factors have led to the planning model paradigm. The team composition led to the differential vulnerability paradigm and the scale and resolution led to the choice of the mandal or district level as the unit for calculation. The question here is if these factors influenced the general applicability of the model. The answer is negative. The factors shaped the model into a tool that has an applicability beyond its genesis context. As long as the limitations of the model, discussed in Chapter 8, are taken into account, it has its value in policy endeavours to integrate disaster management with coastal planning. The planning model paradigm is generally accepted as useful alongside other approaches, as long as one acknowledges the limitations of the paradigm. And the differential vulnerability paradigm is a useful and much needed additional approach to the widely used risk approach. Finally the choice of scale does not make a fundamental difference in usability. For instance, the model could just as easily be applied on a village level if one wishes so.

9.2 Advancements and improvements in modelling vulnerability

We started this research with the objective to contribute to the advancement in the state-of-the-art in modelling vulnerability of coastal zones to cyclonic storms and floods. Now it is time to take stock of what we've found. To what extent have the conclusions drawn in the previous sections contributed to this objective? In the first place the model itself can be regarded a useful contribution to the practice of vulnerability assessments. It can be used in predominantly rural coastal communities where agriculture, livestock rearing and aquaculture dominate their economies. Many countries in the developing world have coasts that correspond to this description. The model's focus on the agricultural sector is still highly relevant, as some 70 percent of the world's poor people currently depend on agriculture for their incomes (Benson & Clay 2003). Further detailing of the model description for the industrial sector would significantly increase its geographic applicability to coastal areas that are in a transitory development stage.

The experiences with the model and its critical evaluation have led to a number of general observations that contribute to the knowledge base on vulnerability model development. This includes:

- Vulnerability modelling can be instrumental in the integration between disaster management and coastal planning. Because coastal planning is about the distribution of (scarce) resources and space, the differential aspect of vulnerability is crucial and should therefore be a guiding principle for the model design.
- Differential vulnerability favours the use of a place-based integrated conceptual model that includes exposure, sensitivity and resilience. Distinguishing the types of relations in this conceptual model into in place, cross scale and beyond place can be helpful in choosing which relations should be considered as internal to the simulation model and which could be used as external and/or boundary conditions.
- Vulnerability modelling does not imply a specific scale and resolution. However, the lowest possible resolution level is recommended in order to avoid blurring of the differential character of vulnerability.
- The choice of a storm or flood event influences the outcome of the calculation and should depend on the purpose of the vulnerability calculation. Using a recent disaster is particularly useful for calibration purposes of the vulnerability model. And a worst case scenario is useful if one is interested in the need for preparedness meas-

ures. The event that causes the maximum annual damage is a typical choice for macro-economic and regional planning purposes.

Future improvements and extensions of the model include:

- A further refinement of the damage calculations, esp. by including a refined description of the hazard event (e.g. by including the flood duration, water velocities).
- A more sophisticated economic model that includes more interdependencies between economic sectors and that accounts for spatial relations (e.g. between the spatial units of calculation).
- A dynamic linkage between the socioeconomic model calculations, resource basis and environmental quality calculations (e.g. feedback mechanisms between crop growth and water availability).
- Inclusion of cost estimates in the measures, allowing for a more balanced evaluation (trade-off) of strategies.

9.3 Methodological considerations

The methodological essence of this thesis is the dialectic tension between design and evaluation. It runs through the entire thesis. And it caused the struggle I experienced when writing this rational, science-based thesis on the development of a model on vulnerability that would contribute to the body of knowledge on integrated vulnerability assessments. A struggle between rationale and heuristics. Since model design is part craft and part science, an evaluation on scientific grounds simply cannot cover the full quality of the model. Quality is not something that can be objectively assessed. Quality is not an attribute of an object or a subject, but it becomes manifest in the relation between the two (Pirsig 1974). Personally I felt this quality growing while developing the model.

When I started with the Andhra Pradesh project, ten years ago, I hadn't the slightest idea how I could fulfil the model requirements of the client: to prepare a tool that integrates almost everything in order to assist long term coastal planning that reduces vulnerability to cyclones. The multidisciplinary study team started working according to general ICZM principles: integrated approach, stakeholder consultation, sustainability and equity. Each expert worked out his or her field of expertise into a report, also stating its relevance to cyclone vulnerability. This resulted in 13 separate reports. Although several linkages between the different domains were identified, initially there was no unifying concept available to enable their integration. It was only after the concept of differential vulnerability was embraced as a guiding principle that it became clear how the integration between the domains could be given shape. But still no contours of a model were visible.

Initially the project was expecting to use a detailed GIS for the entire 1,000 km long coastline. Soon it became clear that these data could not be made available for political and practical reasons. This was first viewed as a serious drawback hampering the development of the modelling tool. Eventually it turned out to be a blessing in disguise as it forced me to find an alternative solution for capturing the spatial heterogeneity. In a stage of almost transcendent lucidity during a long and lonely hotel night I worked out the concept of land use and cropping patterns that would lay the foundation of the model. Suddenly, the previously collected data could logically be arranged and made useful. All the pieces of the jigsaw puzzle fell into place. This must have been the craft part of design.

But how should we draw lessons from this? At most, it proves that developing models in the field of environmental sciences is an art. 'One must have a special feel for it to do it well' (Scholz & Tietje 2002). Classical, structured, rational knowledge is not sufficient to repair a motorcycle. Neither is it sufficient to build a good model. One also needs a feeling for the quality of one's work, as Robert Pirsig wrote in 1974. The Context Perspective enabled me to identify critical factors in the design of *our* model. But another situation would have other forcing factors influencing design and would lead to another model. There is no question but that, with all the knowledge I now have, a second model would be different from the first one. The question is, however, would it be a better one? I am tempted to say yes, but only on one condition. And that is by including stakeholder participation.

As yet, we have looked at model development from three research perspectives. But we almost forget the fact that at the end, the ultimate goal of model development is to contribute to a reduced vulnerability of people. It is about people and their situation that the model should tell something. But what perspective do these people have? What is their local perspective? Unless we know something about that, we cannot really judge if this model could be of any help. The best way to assure that the model addresses the lives, expectations and prospects of the people living in coastal Andhra is to involve them. This local perspective would provide the legitimacy of participatory model development. And it would create unique conditions in which to develop a high quality model, since 'quality' only emerges in the relation between subject and object.

Stakeholder involvement throughout model development in a true partnership is currently acknowledged and practiced by several authors (e.g. Gaddis & Voinov 2008; Siebenhuner & Barth 2005; Jakeman et al. 2006; Stave 2003; Beall & Zeoli 2008; Antunes et al. 2006)(see also section 4.4.2). For instance, Jakeman et al. (2006) provide two main reasons, aside from equity and justice: the first is to improve the modeller's understanding, allowing a broader and more balanced view of the management issue, and the second is to improve adoption of results from the assessment. In view of the above reasoning about quality, I would say that there is a fifth, more fundamental, reason. And that is that quality only exists when subject (in this case model users) and object (the model) come together. The model as such does not have intrinsic 'quality'.

But if quality of a model is assured only by the quality of its production, as also Ravets (1997) stated, can we then provide methodological guidance for model design? Several attempts have been devoted to providing these guidelines, many of which are essentially focused on quality assurance and validation rather than on model design itself (see Chapter 4). However, Jakeman et al. (2006) provide an example of a checklist aimed at improving the modelling process itself. Although there is much rationality in following the ten steps they formulated, there are several places in which craftsmanship, and not science, emerge. And at these places, guidance becomes hazy. For instance, the decision on the model boundary and degree of aggregation is qualified as '*a critical but difficult step. It can only be learnt through trial and error'*. And on how parameter values are found ('*expert opinion'*) and how a suitable model structure is found ('*this step ideally involves hypothesis testing of alternative model structures'*) (note that hypotheses do not emerge from the scientific method). These are exactly the steps for which I tried to provide rationalities when it comes to vulnerability modelling. And found that in hindsight only partial rationalities can be given.

Another rather pragmatic problem of such design steps for a good modelling practice is that they are often not used because of practical factors (e.g. time and budget constraints, lack of expertise in the team and so forth). This implies that even in those steps where a rational, scientific justifiable approach is theoretically possible, also craftsmanship is called upon: providing pragmatic shortcuts and alternatives that come from experience rather than rationale. In fact, this happens all the time in many facets of everyday work and life. Modern society is loaded with quality standards and procedures, for manufacturing up to medical health care. If these were all followed strictly, the entire society would probably come to a standstill. This is of course not to say that these standards are not important, but rather that an effective and efficient use of these standards requires experience, a feeling and craftsmanship.

Participatory modelling will not make the life of a modeller easier. On the contrary, design conditions will be more complicated. Group instability and dominance of some participants, differences in knowledge levels and expectations, and obstacles in communication are some potential problems to reckon with (see for instance Van Asselt & Rijkens-Klomp 2002; Ker Rault 2008). Combined with time and budget constraints these problems will pose high demands to all participants in terms of flexibility and trust. This will make the craftsmanship of the modeller more important than ever. Learning by doing will in time increase our experiences and skills in participatory modelling.

Since vulnerability modelling is in its infancy, it is too early to formulate a ‘best way’ of how to do it. Rather an open minded, diverse and unconventional attitude is required. This research provides hints and suggestions, rather than recipes or guidelines. The use of the three different research perspectives allowed for a critical examination of the model that was developed. And it produced a contribution to the knowledge of modelling vulnerability: on the differential character of vulnerability being essential for linking it to planning issues, on choice of storm event being dependent on the planning question, on a place-based approach of vulnerability favouring a lowest scale level of analysis as possible and on finding vulnerability metrics that most closely have real world counterparts. The developed model acts as proof that modelling coastal vulnerability is possible and useful, nothing more, nothing less.

References

Abramovitz, J., Banuri, T., Girot, P. O., Orlando, B., Schneider, N., Spanger-Siegfried, E., Switzer, J., and Hammill, A. (2002) Adapting to Climate Change: Natural Resource Management and Vulnerability Reduction. World Conservation Union / Worldwatch Institute / International Institute for Sustainable Development / Stockholm Environmental Institute (Boston). Background Paper to the Task Force on Climate Change, Adaptation and Vulnerable Communities.

Acharya, T. (2001) Solid waste management in Andhra Pradesh. 11. Hyderabad / Delft, Delft Hydraulics. Technical Reports Integrated Coastal Zone Management - Andhra Pradesh Cyclone Hazard Mitigation Project.

Adger, W.N. (1999a) Social Vulnerability to Climate Change and Extremes in Coastal Vietnam. *World Development*, **27**, 249-269.

Adger, W.N., Hughes, T.P., Folke, C., Carpenter, S.R. and Rockstrom, J. (2005) Social-ecological resilience to coastal disasters. *Science*, **309**, 1036-1039.

Adger, W.N. (1999b) Evolution of economy and environment: an application to land use in lowland Vietnam. *Ecological Economics*, **31**, 365-379.

Ahmed, S. (1992) Disaster management: socio-economic perspectives. Cyclone Disaster Management and Regional/Rural Development Planning - UNCRD-CIRDAP Seminar Phase III. United Nations Centre for Regional Development. 27-1-1992.

Alcantara-Ayala, I. (2002) Geomorphology, natural hazards, vulnerability and prevention of natural disasters in developing countries. *Geomorphology*, **47**, 107-124.

Anderson, M.B. and Woodrow, P.J. (1998) *Rising from the ashes: development strategies in times of disaster.* Intermediate Technology Publications, London.

Anonymus (2004) Megacities - Megarisks: trends and challenges for insurance and risk management. Knowledge Series. Munchen, Munich Re Group.

Anonymus (2005) Veiligheid Nederland in Kaart: Hoofdrapport onderzoek overstromingsrisico's. DWW-2005-081. Delft, Rijkswaterstaat DWW.

Antunes, P., Santos, R. and Videira, N. (2006) Participatory decision making for sustainable development--the use of mediated modelling techniques. *Land Use Policy*, **23**, 44-52.

Apostel, L., Berger, G., and Briggs, A. (1972) Interdisciplinarity: problems of teaching and research in universities. CERI and French Ministry of Education seminar on Interdisciplinarity. Paris, OECD 1970.

Arthurton, R.S. (1998) Marine-related physical natural hazards affecting coastal megacities of the Asia-Pacific region - awareness and mitigation. *Ocean & Coastal Management*, **40**, 65-85.

Azariadis, C. and Stachurski, J. (2006) Poverty Traps. *Handbook of Economic Growth* (eds. Ph. Aghion and S. Durlauf), pp. 295-384.

Baarse, G. and Marchand, M. (2006) Expert Decision Support System ICZM: Functional Design Report. Version 4. Delft, Delft Hydraulics. Expert Decision Support System - ICZM Reports Andhra Pradesh Cyclone Hazard Mitigation Project.

Babtie International (2003) Delta Water Management Part 1: Review Report. BWA 020277. Hyderabad, Babtie International.

Bankes, S.C. (1993) Exploratory modeling for policy analysis. *Operations Research*, **41**, 435-449.

Beall, A. and Zeoli, L. (2008) Participatory modeling of endangered wildlife systems: Simulating the sage-grouse and land use in Central Washington. *Ecological Economics*, **68**, 24-33.

Benson, C. and Clay, E.J. (2003) Disasters, vulnerability and the global economy. *Building safer cities - The future of disaster risk* (eds A. Kreimer, M. Arnold and A. Carlin), The World Bank, Washington, D.C.

Birkmann, J. (2006) *Measuring vulnerability to natural hazards - towards disaster resilient societies*. United Nations University Press, Tokyo, New York, Paris.

Birkmann, J. and Wisner, B. (2006) Measuring the Un-Measurable - The challenge of vulnerability. 5. Bonn, United Nations University - Institute for Environment and Human Security. SOURCE.

Blaikie, P., Cannon, T., Davis, I. and Wisner, B. (1994) *At Risk - Natural hazards, people's vulnerability, and disasters*. Routledge, London.

Bockarjova, M. (2007) *Major disasters in modern economies. An input-output based approach at modelling imbalances and disproportions*. PhD University of Twente.

Bohle, H.G. (2001) Vulnerability article 1: vulnerability and criticality. *Update, Newsletter of the International Human Dimension Programme on Global Environmental Change*, **2**.

Bohle, H.G., Downing, T.E. and Watts, M.J. (1994) Climate change and social vulnerability : Toward a sociology and geography of food insecurity. *Global Environmental Change*, **4**, 37-48.

Bots, P.W.G. (2007) Design in socio-technical system development: three angles in a common framework. *Journal of Design Research*, **5**, 382-396.

Brammer, H. (2000) Controversies surrounding the Bangladesh Flood Action Plan. *Floods* (ed D. J. Parker), pp. 302-315. Routledge, London and New York.

Brémond, P., Bauduceau, N., and Grelot, F. (2008) Characterizing agricultural vulnerability for economic appraisal of flood management policies. 4th International Symposium on Flood Defence: managing flood risk, reliability and vulnerability. Toronto, May 2008.

Brooks, N., Neil Adger, W. and Mick Kelly, P. (2005) The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environmental Change Part A*, **15**, 151-163.

Bruijn, K.M. de (2005) *Resilience and flood risk management. A systems approach applied to lowland rivers*. PhD Delft Technical University.

Bryant, E. (2005) *Natural Hazards*. Cambridge University Press, Cambridge.

Buckle, P., March, G., and Smale, S. (2001) Assessing resilience & vulnerability: principles, strategies & Actions. Emergency Management Australia.

Burton, I., Kates, R.W. and White, G.F. (1993) *The environment as hazard*. The Guilford Press, New York.

Burton, I. (2001) The intergovernmental panel on natural disasters (IPND). *Global Environmental Change Part B: Environmental Hazards*, **3**, 139-141.

Cannon, T. (2000) Vulnerability analysis and disasters. *Floods* (ed D. J. Parker), pp. 45-55. Routledge, London, UK.

Cannon, T., Twigg, J., and Rowell, J. (2003) Social vulnerability, sustainable livelihoods and disasters. Chatham, University of Greenwich.

Cardona, O. D. (2005) System of Indicators for disaster risk management. Manizales / Washington, D.C., Instituto de Estudios Ambientales - IDEA and Inter American Development Bank.

Carter, M.R., Little, P.D., Mogues, T. and Negatu, W. (2007) Poverty Traps and Natural Disasters in Ethiopia and Honduras. *World Development*, **35**, 835-856.

Cash, D.W. and Moser, S.C. (2000) Linking global and local scales: designing dynamic assessment and management processes. *Global Environmental Change*, **10**, 109-120.

Chambers, R. and Conway, G. (1991) Sustainable rural livelihoods: practical concepts for the 21st century. [296]. IDS Discussion Paper.

Chen, F. and Korinek, K. (2006) Household economy and life transitions in China and Vietnam. Annual Meeting of the American Sociological Association. Montreal, August 2006.

Chittibabu, P., Dube, S.K., Macnabb, J.B., Murty, T.S., Rao, A.D., Mohanty, U.C. and Sinha, P.C. (2004) Mitigation of flooding and cyclone hazard in Orissa, India. *Natural Hazards*, **31**, 455-485.

Clark, G.E., Moser, S.C., Ratick, S.J., Dow, K., Meyer, W.B., Emani, S., Jin, W., Kasperson, J.X., Kasperson, R.E. and Schwarz, H.E. (1998) Assessing the vulnerability of coastal communities to extreme storms: the case of Revere, Ma., USA. *Mitigation and Adaptation Strategies for Global Change*, **3**, 59-82.

Coburn, A. and Winchester, P. (2008) Overcoming barriers to micro-insurance for catastrophe risk mitigation: lessons from micro-finance operations. The 14th World Conference on Earthquake Engineering. Beijing October 2008.

Courtney, J.F. (2001) Decision making and knowledge management in inquiring organizations: toward a new decision-making paradigm for DSS. *Decision Support Systems*, **31**, 17-38.

Cutter, S., Boruff, B.J. and Shirley, W.L. (2003) Social vulnerability to environmental hazards. *Social Science Quarterly*, **84**, 242-261.

Cutter, S.L. and Emrich, C.T. (2006) Moral hazard, social catastrophe: the changing face of vulnerability along the hurricane coasts. *Annals, AAPSS*, **604**, 102-112.

Cutter, S.L., Emrich, C.T., Mitchell, J.T., Boruff, B.J., Gall, M., Schmidtlein, M.C., Burton, C.G. and Melton, G. (2006) The long road home: Race, class, and recovery from Hurricane Katrina. *Environment*, **48**, 8-20.

Daalen, E. van, Dresden, L. and Janssen, M.A. (2002) The roles of computer models in the environmental policy life cycle. *Environmental Science & Policy*, **5**, 221-231.

Damm, M. (2008) A socio-ecological vulnerability assessment for Germany. Simonovic, S. P. and Bourget, P. 4th International Symposium on Flood Defence. Managing flood risk, reliability and vulnerability, Toronto, May 2008.

De Kok, J.L., Engelen, G., White, R. and Wind, H.G. (2001) Modeling Land-Use Change in a Decision-Support System for Coastal-Zone Management. *Environmental Modeling and Assessment*, **6**, 123-132.

De Kok, J.L. and Wind, H.G. (2003) Design and application of decision-support systems for integrated water management: lessons to be learnt. *Physics and Chemistry of the Earth, Parts A/B/C*, **28**, 571-578.

Del Ninno, C., Dorosh, P.A. and Smith, L.C. (2003) Public Policy, Markets and Household Coping Strategies in Bangladesh: Avoiding a Food Security Crisis Following the 1998 Floods. *World Development*, **31**, 1221-1238.

Dercon, S. (2001) Assessing Vulnerability. Workshop on social protection for the poor. ADB Headquarters, Manilla.

Doukidis, G.I. (1988) Decision support system concepts in expert systems: An empirical study. *Decision Support Systems*, **4**, 345-354.

Dow, K. (1992) Exploring differences in our common future(s): the meaning of vulnerability to global environmental change. *Geoforum*, **23**, 417-436.

Dunn, W.N. (1981) *Public policy analysis: an introduction*. Englewood Cliffs: Prentice-Hall, London.

Eekelen, W. van. (2006) National and international disaster preparedness strategies. (pers. comm.)

Enarson, E. and Fordham, M. (2001) From women's needs to women's rights in disasters. *Global Environmental Change Part B: Environmental Hazards*, **3**, 133-136.

Engelen, G., Uljee, I. and Ven, K.v.d. (2003) WadBOS: Integrating knowledge to support policy making in the Dutch Waddensea. *Planning Support Systems in Practice, Advances in Spatial Science* (eds S. Geertman and J. Stillwell), pp. 513-537. Springer-Verlag.

Enserink, B. (2006) The ants in the kingdom of elephants. An explorative study into public participation in policy making in India and China. XVI World Congress of Sociology. Durban July 2006.

Farvar, M.T. and Milton, J.P. (1972) *The careless technology - ecology and international development*. The Natural History Press, New York.

FEMA. HAZUS-MH (2007) Hurricane Wind Model Validation Study - Florida. Report: FEMA HMTAP 440.

Fontenelle, J.-P., Dao The, A., Dao The, T. and Defourny, P. (2001) *Atlas of the Bac Hung Hai Polder (Vietnam). Irrigation and Drainage Management and Agricultural Diversification in the Bac Hung Hai Primary Water Control Unit, Red River Delta - Vietnam.* Agricultural Publishing House, Hanoi.

Ford, A. (1999) *Modeling the environment - An introduction to system dynamics models of environmental systems*. Island Press, Washington, D.C.

Fordham, M. and Ketteridge, A.-M. (1995) Flood disasters - dividing the community. Emergency Planning '95 Conference. Lancaster, July 1995.

Friedman, K. (2003) Theory construction in design research: criteria: approaches, and methods. *Design Studies*, **24**, 507-522.

Gaddis, E.J.B. and Voinov, A. (2008) Participatory Modeling. *Encyclopedia of Ecology* (eds E. J. Sven and F. Brian), pp. 2651-2655. Academic Press, Oxford.

Gehlich-Shillabeer, M. (2008) Poverty alleviation or poverty traps? Microcredits and vulnerability in Bangladesh. *Disaster Prevention and Management*, **17**, 396-409.

General Statistics Office (2006a) *Socio-economic statistical data of 671 districts, towns and cities under the authority of provinces in Vietnam*. Statistical Publishing House, Hanoi.

General Statistics Office (2006b) *Statistical Yearbook of Vietnam*. Statistical Publishing House, Hanoi.

Gezelius, S.S. and Refsgaard, K. (2007) Barriers to rational decision-making in environmental planning. *Land Use Policy*, **24**, 338-348.

GoAP (1999) District Wise Groundwater Resources of Andhra Pradesh. Hyderabad, Groundwater Department, Government of Andhra Pradesh.

Goeller, B. F. (1983) Policy Analysis of Water Management for the Netherlands. Santa Monica, Rand Corporation.

Goeller, B. F., Abrahamse, A. F., Bigelow, J. H., Bolten, J. G., Ferranti, D. M. de, De Haven, J. C., Kirkwood, T. F., and Petruschell, R. L. (1977) Protecting an estuary from floods - a policy analysis for the Oosterschelde. R-2121/1-NETH. Santa Monica, Rand Corporation.

Gouldby, B. and Samuels, P. (2005) Language of Risk. FLOODsite Consortium.

Government of India (2004) Disaster management in India - National report for the World Conference on Disaster Reduction. Ministry of Home Affairs.

Government of Vietnam (2007) National Strategy for Natural Disaster Prevention, Response and Mitigation to 2020. 172/2007/QD-TTg.

Green, C. and Penning-Rowsell, E. (2007) More or less than words? Vulnerability as discourse. *Managing coastal vulnerability* (eds L. McFadden, R. Nicholls and E. Penning-Rowsell), pp. 29-43. Elsevier, Amsterdam.

Green, C., Veen, A.v.d., Wierstra, E. and Penning-Rowsell, E. (1994) Vulnerability refined: analysing full flood impacts. *Floods across europe: flood forecasting, assessment, modelling and management* (eds E. Penning-Rowsell and M. Fordham), Middlesex University Press, London.

Groot, W.T. de (1992) *Environmental Science Theory. Concepts and methods in a one-world problem-oriented paradigm*. Elsevier, Amsterdam, London, New York, Tokyo.

Groot, W.T. de (1984) Fundamenten van oplossingsgerichte integratie. *Basisboek Milieukunde* (eds J. J. Boersema, J. W. Copius Peereboom and W. T. d. Groot), pp. 275-295. Boom, Amsterdam.

Harris, G. (2002) Integrated assessment and modelling: an essential way of doing science. *Environmental Modelling & Software*, **17**, 201-207.

Heijmans, A. (2001) Vulnerability: a matter of perception. Disaster Management Working Paper 4, pp. 1-17. Benfield Greig Hazard Research Centre.

Hinkel, J. (2008) *Transdisciplinary Knowledge Integration: cases from integrated assessment and vulnerability assessment*. PhD Wageningen University.

Hinkel, J. and Klein, R.J.T. (2009) Integrating knowledge to assess coastal vulnerability to sea-level rise: the development of the DIVA tool. *Global Environmental Change*.

Hisschemöller, M., Hoppe, R., Groenewegen, P., and Midden, C. (2001) Knowledge use and political choice in Dutch environmental policy: a problem structuring perspective on real life experiments in extended peer review. [12], pp. 437-470. New Bruswick, Transaction. Policy Studies Review Annual.

Hodges, J.S. (1991) Six (or so) things you can do with a bad model. *Operations Research*, **39**, 355-365.

Hoi, Pham Van, Cuong, Tran Huu, and Phuc, To Xuan. (2002) An overview of vegetable production in the Red River Delta of Vietnam in general and Dong Anh District in specific. The VEGSYS Research Project.

Holling, C.S. (1973) Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics*, **4**, 1-24.

Hoozemans, F. M. J., Marchand, M., and Pennekamp, H. A. (1993) A Global Vulnerability Analysis: Vulnerability Assessment for Population, Coastal Wetlands and Rice Production on a Global Scale. 2nd Edition. Delft, Delft Hydraulics / Rijkswaterstaat.

Hoppe, R. (1999) Policy analysis, science and politics: from 'speaking truth to power' to 'making sense together'. *Science and Public Policy*, **26**.

Hordijk, L. (1991) Use of the RAINS model in acid rain negotiations in Europe. *Environ.Sci.Technol.*, **25**, 596-603.

Howlett, M. and Lindquist, E. (2004) policy analysis and governance: analytical and policy styles in Canada. *Journal of Comparative Policy Analysis*, **6**, 225-249.

IIT-Chennai (2002) Real Time System. Wind Hazard Model Scientific Background Document Version 2.0. Hyderabad, Andhra Pradesh Cyclone Hazard Mitigation Project / Delft Hydraulics.

Ionescu, C., Klein, R., Hinkel, J., Kavi Kumar, K. and Klein, R. (2009) Towards a Formal Framework of Vulnerability to Climate Change. *Environmental Modeling and Assessment*, **14**.

Jakeman, A.J., Letcher, R.A. and Norton, J.P. (2006) Ten iterative steps in development and evaluation of environmental models. *Environmental Modelling & Software*, **21**, 602-614.

Jeffrey, P. (2005) Coming home; a personal re-evaluation of the aspirations and utility of Integrated Assessment. *Integrated Assessment*, **5**, 27-40.

João, E. (2007) A research agenda for data and scale issues in Strategic Environmental Assessment (SEA). *Environmental Impact Assessment Review*, **27**, 479-491.

Jonkman, S.N., and Vrijling, J.K. (2008) Loss of life due to floods. *Journal of Flood Risk Management*, **1**, 43-56.

Karstens, S.A.M., Bots, P.W.G. and Slinger, J.H. (2007) Spatial boundary choice and the views of different actors. *Environmental Impact Assessment Review*, **27**, 386-407.

Kasperson, R. E. and Kasperson, J. X. (2001) Climate change, Vulnerability and Social Justice. Stockholm, Stockholm Environment Institute. Risk and Vulnerability Programme.

Ker Rault, Ph.A. (2008) *Public participation in integrated water management - A wicked process for a complex societal problem*. PhD School of Applied Sciences, Cranfield University.

Kettelhut, M.C. (1991) Using a DSS to incorporate expert opinion in strategic product development funding decisions. *Information & Management*, **20**, 363-371.

Klein, J.T. (1990) *Interdisciplinarity, History, Theory, and Practice*. Wayne State University Press, Detroid.

Klein, R.J.T. and Hinkel, J. (2008) Global Assessment of Coastal Vulnerability to Sea-Level Rise: Experiences from DINAS-COAST. *Assessing Vulnerability to Global Environmental Change* pp. 79-96.

Knutson, T.R., Sirutis, J.J., Garner, S.T., Vecchi, G.A. and Held, I.M. (2008) Simulated reduction in Atlantic hurricane frequency under twenty-first-century warming conditions. *Nature geoscience*, 1-6.

Kok, M., Lammers, I. B. M., Vrouwenvelder, AC. W. M., and Braak, W. E. W. van den (2006) Standaardmethode2006 -beta. Schade en Slachtoffers als gevolg van overstromingen. PR1190.10. Rijkswaterstaat DWW / HKV Lijn in water/TNO Bouw.

Koudstaal, R. (1985) Application of systems analysis in regional economic planning. 341. Delft, Delft Hydraulics Laboratory.

Kron, W. (2005) Storm surges, river floods, flash floods - losses and prevention strategies. *Schadenspiegel*, **48**, 8-13.

Lanjouw, P., Parker, B., and Kjijma, Y. (2003) Andhra Pradesh poverty note: a preliminary profile and emerging issues. Society for Elimination of Rural Poverty (SERP).

Lapar, L., Vu, T. B., and Ehui, S. (2003) Livestock Sector Report Vietnam - Identifying barriers to entry to livestock input and output markets in Southeast Asia. Rome, FAO: Food and Agriculture Organization of the United Nations.

Lemke, U., Kaufmann, B., Thuy, L.T., Emrich, K. and Valle Zarate, A. (2006) Evaluation of smallholder pig production systems in North Vietnam: Pig production management and pig performances. *Livestock Science*, **105**, 229-243.

Letcher, R.A., Croke, B.F.W. and Jakeman, A.J. (2007) Integrated assessment modelling for water resource allocation and management: A generalised conceptual framework. *Environmental Modelling & Software*, **22**, 733-742.

Lewis, J. (1982) Natural disaster mitigation: Environmental approaches in Tonga and Algeria. *The Environmentalist*, **2**, 233-246.

Loucks, D.P. and Beek, E.van (2005) *Water resources systems planning and management. An introduction to methods, models and applications*. UNESCO, Paris.

Mahendra Dev, S. and Padmanabha Rao, P. (2002) Poverty alleviation programmes in Andhra Pradesh - an assessment. Hyderabad, Centre for Economic and Social Studies.

Marchand, M., Baarse, G. and Mulder, J. P. M. (2008) Scientific Background Report Expert Decision Support System ICZM. Delft, Delft Hydraulics. Expert Decision Support System - ICZM Reports Andhra Pradesh Cyclone Hazard Mitigation Project.

Marchand, M., Buurman, J., Pribadi, A. and Kurniawan, A. (2009) Damage and casualties modelling as part of a vulnerability assessment for tsunami hazards: a case study from Aceh, Indonesia. *Journal of Flood Risk Management*, **2**, 120-131.

Marchand, M. and De Groot, W.T. (1986) Divergent principles in Third World rural planning: a case study on impoldering. *International Journal of Environmental Studies*, **27**, 31-43.

Marchand, M., Mulder, J. P. M., Penning-Rowsell, E., Villars, N. and Winchester, P. (2002) Framework plan for integrated coastal zone management in Andhra Pradesh. Delft, Delft Hydraulics. Andhra Pradesh Cyclone Hazard Mitigation Project Reports.

Marchand, M. and Mulder, P. (2007) Resource and Environmental Management Plan for the Godavari Delta region in Andhra Pradesh. Delft Hydraulics. Reports of the Andhra Pradesh Cyclone Hazard Mitigation Project.

Marsh, S. P., MacAulay, T. G., and Pham, V. H. (2006) Agricultural development and land policy in Vietnam.

Matthies, M., Giupponi, C. and Ostendorf, B. (2007) Environmental decision support systems: Current issues, methods and tools. *Environmental Modelling & Software*, **22**, 123-127.

Mayer, I., Daalen, E.van and Bots, P. (2004) Perspectives on policy analyses: a framework for understanding and design. *International Journal of Technology, Policy and Management*, **4**, 169-191.

Mayer, I., Most, H. van der, and Bots, P. (2002) Dam the river or go with the flow? Changing views on policy analysis in Dutch water management. 'Asking What if?' - Assessing the public policy and management implications of social science research. 24th conference of the Association for Public Policy Analysis and Management. Dallas, November 2002.

McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J., and White, K. S. (2001) Climate Change 2001: Impacts, Adaptation, and Vulnerability - Contribution of WG II to the Third Assessment Report of the IPCC. Cambridge University Press. Third Assessment Report of the IPCC.

McFadden, L., Penning-Rowsell, E. and Nicholls, R. (2007) Setting the parameters: a framework for developing cross-cutting perspectives of vulnerability for coastal zone management. *Managing Coastal Vulnerability* (eds L. McFadden, R. Nicholls and E. Penning-Rowsell), pp. 1-28. Elsevier, Amsterdam.

McGahey, C. and Sayers, P. B. (2008) Long term planning - robust strategic decision making in the face of gross uncertainty (tools and application to the Thames). Samuels, P., Huntington, S., Allsop, W., and Harrop, J. The European conference on flood risk management: Research into practice (FLOOD*RISK* 2008). Flood risk management: research and practice. Boca Raton, London, New York, Leiden, Taylor & Francis Group.

Meadows, D.H., Meadows, D.L., Randers, J. and Behrens, W.L. (1972) *The limits to growth*. Universe Books, New York.

Meadows, D.H. and Robinson, J.M. (1985) *The Electronic Oracle. Computer models and social decisions*. John Wiley & Sons, Chichester / New York / Brisbane / Toronto / Singapore.

Mechler, R., Hochrainer, S., Linnerooth-Bayer, J. and Pflug, G. (2006) Public sector financial vulnerability to disasters: The IIASA CATSIM model. *Measuring vulnerability to natural hazards - Towards disaster resilient societies* (ed J. Birkmann), pp. 380-398. United Nations University Press, Tokyo, New York, Paris.

Messner, F. and Meyer, V. (2005) Flood damage, vulnerability and risk perception - challenges for flood damage research. UFZ Discussion Papers [13]. 2005. Leipzig, UFZ–Umweltforschungszentrum Leipzig–Halle.

Messner, F., Penning-Rowsell, E., Green, C., Meyer, V., Tunstall, S., and Veen, A. van der (2006) Guidelines for socio-economic Flood Damage Evaluation. FLOODsite Consortium.

Minot, N. and Baulch, B. (2005) Spatial patterns of poverty in Vietnam and their implications for policy. *Food Policy*, **30**, 461-475.

Miser, H.J. and Quade, E.S. (1985) *Handbook of systems analysis - Overview of uses, procedures, applications, and practice*. John Wiley & Sons, Chichester - New York-Brisbane - Toronto - Singapore.

Miser, H.J. and Quade, E.S. (1988) *Handbook of systems analysis - craft issues and procedural choices*. John Wiley & Sons, Chichester, New York, Brisbane, Toronto, Singapore.

Mitchell, J.F.B., Lowe, J., Wood, R.A. and Vellinga, M. (2006) Extreme events due to human-induced climate change. *Philosophical Transactions of the Royal Society A*, **364**, 2117-2133.

Mohapatra, C. R. and Bech, N. J. (2001) Forestry and Nature Conservation in Coastal Andhra Pradesh. Hyderabad / Delft, Delft Hydraulics. Technical Report No. 5 Integrated Coastal Zone Management - Andhra Pradesh Cyclone Hazard Mitigation Project.

Monirul Qader Mirza, M., Warrick, R.A., Ericksen, N.J. and Kenny, G.J. (2001) Are floods getting worse in the Ganges, Brahmaputra and Meghna basins? *Global Environmental Change Part B: Environmental Hazards*, **3**, 37-48.

Monnikhof, R.A.H. (2006) *Policy analysis for participatory policy making*. Delft University of Technology.

Monteiro, P. and Marchand, M. (2009) Catchment2Coast - A systems approach to coupled river-coastal ecosystem science and management. Delft, IOS Press. Deltares Select Series vol. 2.

Morgan, P. and Taschereau, S. (1996) Capacity and Institutional Assessment: Frameworks, Methods and Tools for Analysis. Quebec, Canadian International Development Agency.

Moser, S. C. (2008) Resilience in the face of global environmental change. Oak Ridge, Community and Regional Resilience Initiative. CARRI Research Report No. 2.

Munich RE. (2002) Topics: Annual Review, Natural catastrophes 2002. Munich, Germany, Munich RE.

Mustafa, D. (2003) Reinforcing vulnerability? Disaster relief, recovery, and response to the 2001 flood in Rawalpindi, Pakistan. *Global Environmental Change Part B: Environmental Hazards*, **5**, 71-82.

Nguyen, C. H. and Cao, L. Q. (2005) Rapid overview on the nature and distribution of benefits from freshwater aquaculture in the Red River Delta in Viet Nam. Viet Nam Institute of Fisheries Economics and Planning. Livelihood impacts of interaction between production and marketing in freshwater aquaculture in Asia.

Nguyen, T.G. and de Kok, J.L. (2007) Systematic testing of an integrated systems model for coastal zone management using sensitivity and uncertainty analyses. *Environmental Modelling & Software*, **22**, 1572-1587.

Nguyen, T.G., de Kok, J.L. and Titus, M.J. (2007) A new approach to testing an integrated water systems model using qualitative scenarios. *Environmental Modelling & Software*, **22**, 1557-1571.

Nicholson, C.R., Starfield, A.M., Kofinas, G.P. and Kruse, J.A. (2002) Ten heuristics for interdisciplinary modeling projects. *Ecosystems*, **5**, 376-384.

Nishat, A. (2003) Flood management in Bangladesh. Marchand, M., Heynert, K., Most, H. van der, and Penning, W. E.: *Dealing with flood risk.* Proceedings of an interdisciplinary seminar on the regional implications of modern flood management , pp. 17-22. 2003. Delft, Delft University Press. Delft Hydraulics Select Series.

O'Hare, G. (2001) Hurricane 07B in the Godavari Delta, Andhra Pradesh, India: vulnerability, mitigation and the spatial impact. *The Geographical Journal*, **167**, 23-38.

Opiyo, E.Z., Horvath, I. and Vergeest, J.S.M. (2002) Quality assurance of design support software: review and analysis of the state of the art. *Computers in Industry*, **49**, 195-215.

Oreskes, N., Shrader-Frechette, K. and Belitz, K. (1994) Verification, validation, and confirmation of numerical models in the Earth sciences. *Science*, **263**, 641-646.

Padmanabhamurty, B. (2001) Air and Noise Quality. Hyderabad/Delft, Delft Hydraulics. Technical Report Integrated Coastal Zone Management - Andhra Pradesh Cyclone Hazard Mitigation Project.

Pahl-Wostl, C. (2007) The implications of complexity for integrated resources management. *Environmental Modelling & Software*, **22**, 561-569.

Pahl-Wostl, C., Mostert, E. and Tàbara, D. (2008) The growing importance of social learning in water resources management and sustainability science. *Ecology and Society*, **13**.

Parker, D.J. (2000) Managing flood hazards and disasters - international lessons, directions and future challenges. *Floods* (ed D. J. Parker), pp. 287-306. Routledge, London and New York.

Parker, P., Letcher, R., Jakeman, A., Beck, M.B., Harris, G., Argent, R.M., Hare, M., Pahl-Wostl, C., Voinov, A., Janssen, M., Sullivan, P., Scoccimarro, M., Friend, A., Sonnenshein, M., Barker, D., Matejicek, L., Odulaja, D., Deadman, P., Lim, K., Larocque, G., Tarikhi, P., Fletcher, C., Put, A., Maxwell, T., Charles, A., Breeze, H., Nakatani, N., Mudgal, S., Naito, W., Osidele, O., Eriksson, I., Kautsky, U., Kautsky, E., Naeslund, B., Kumblad, L., Park, R., Maltagliati, S., Girardin, P., Rizzoli, A., Mauriello, D., Hoch, R., Pelletier, D., Reilly, J., Olafsdottir, R. and Bin, S. (2002) Progress in integrated assessment and modelling. *Environmental Modelling & Software*, **17**, 209-217.

Pelling, M. (2004) Visions of Risk - a review of international indicators of disaster risk and its management. International Strategy for Disaster Reduction / UNDP. A report for the ISDR Inter-Agency Task Force on Disaster Reduction, Working Group 3: Risk, Vulnerability and Disaster Impact Assessment.

Pelling, M., Maskrey, A., Ruiz, P., and Hall, L. (2004) Reducing disaster risk: a challenge for development. A global report. New York, United Nations Development Programme - Bureau for Crisis Prevention and Recovery.

Pelling, M. and Uitto, J.I. (2001) Small Island Developing States: Natural Disaster Vulnerability and Global Change. *Environmental Hazards*, **3**, 49-62.

Pennekamp, H. A. and Wesseling, J. W. W. (1993) Methodology for Water Resources Planning. T0635. 1993. Delft, Delft Hydraulics. Research Reports.

Pielke Jr.,R.A. (2007) Future economic damage from tropical cyclones: sensitivities to societal and climate changes. *Philosophical Transactions of the Royal Society A*, Published online, 1-13.

Pielke Jr., R.A., Gratz, J., Landsea, C.W., Collins, D., Saunders, M.A. and Musulin, R. (2008) Normalized hurricane damage in the United States: 1900 - 2005. *Natural Hazards Review*, **9**, 29-42.

Pirsig, R.M. (1974) *Zen and the art of motorcycle maintenance - an inquiry into values*. William Morrow & Company.

Pragna Consultants(2003) Economic survey of selected mandals in the Godavari Delta. Hyderabad. Report to the Andhra Pradesh Cyclone Hazard Mitigation Project.

Preston, D. (1994) Rapid household appraisal: a method for facilitating the analysis of household livelihood strategies. *Applied Geography*, **14**, 203-213.

Pulles, J. W. (1985) Beleidsanalyse van de waterhuishouding van Nederland / PAWN. 's Gravenhage, Rijkswaterstaat.

Radin, B.A. (2000) *Beyond Machiavelli: policy analysis comes of age*. Georgetown University Press, Washington DC.

Raghavan, S. and Rajesh, S. (2003) Trends in tropical cyclone impact - A study in Andhra Pradesh, India. *Bulletin of the American Meteorological Society*, **84**, 635-+.

Rao, A.D., Chittibabu, P., Murty, T.S., Dube, S.K. and Mohanty, U.C. (2007) Vulnerability from storm surges and cyclone wind fields on the coast of Andhra Pradesh, India. *Natural Hazards*, **41**, 515-529.

Raun, W.R. and Johnson, G.V. (1999) Improving nitrogen use efficiency for cereal production. *Agronomy Journal*, **91**, 357-363.

Ravetz, Jerome R. (1997) Integrated Environmental Assessment Forum: developing guidelines for "good practice". [1]. 1997. ULYSES project (Urban LifestYles, SuStainability and integrated Environmental ASsessment). ULYSSES Working Paper.

Reese, S. and Smart, G. (2009) High resolution inundation modelling as part of a multi-hazard loss modelling tool. Samuels, P., Huntington, S., Allsop, W., and Harrop, J. The European

Conference on Flood Risk Management: Research into Practice (FLOOD*RISK*2008). Flood Risk Management Research and Practice. Boca Raton, London, New York, Leiden, Taylor Francis Group.

Refsgaard, J.C. and Henriksen, H.J. (2004) Modelling guidelines--terminology and guiding principles. *Advances in Water Resources*, **27**, 71-82.

Riet, O. v.d. (2003) *Policy Analysis in Multi-Actor Policy Settings. Navigating between negotiated nonsense & superfluous knowledge*. PhD Technical University Delft.

Risbey, J., Kandlikar, M. and Patwardhan, A. (1996) Assessing integrated assessments. *Climatic Change*, **34**, 369-395.

Rotmans, J. (1990) *IMAGE: an integrated model to assess the greenhouse effect*. PhD University of Maastricht.

Rotmans, J. (2001) Integrative Assessment in Environmental Studies. *International Encyclopedia of the Social & Behavioral Sciences* (eds J. S. Neil and B. B. Paul), pp. 7596-7600. Pergamon, Oxford.

Rotmans, J. and Vries, B.de (1997) *Perspectives on global change: the TARGETS approach*. Cambridge University Press, Cambridge.

Rubin, C., Saperstein, D., and Barbee, D. (1985) Community recovery from a major natural disaster. Boulder, CO, Institute of Behavioural Science, University of Colorado, USA.

Rygel, L., O'Sullivan, D. and Yarnal, B. (2005) A method for constructing a Social Vulnerability Index. *Mitigation and Adaptation Strategies for Global Change*, **11**, 741-764.

Sabatier, P.A. (1988) An advocacy coalition framework of policy change and the role of policy-oriented learning therein. *Policy Sciences*, **21**, 129-168.

Samuels, P., Huntington, S., Allsop, W., and Harrop, J. (2009a) Flood risk management: research and practice. Samuels, P., Huntington, S., Allsop, W., and Harrop, J. The European conference on flood risk management: Research into practice (FLOOD*RISK* 2008). Boca Raton, London, New York, Leiden, Taylor & Francis Group.

Samuels, P., Morris, M. W., Sayers, P. B., Creutin, J.-D., Kortenhaus, A., Klijn, F., Mosselman, E., and Os, A. van. (2009b) Advances in flood risk management from the FLOODsite project. Samuels, P., Huntington, S., Allsop, W., and Harrop, J. The European conference on flood risk management: Research into practice (FLOOD*RISK* 2008). Flood Risk Management Research and Practice. Boca Raton, London, New York, Leiden, Taylor & Francis Group.

Schneider, S.H. (1997) Integrated assessment modeling of global climate change: Transparent rational tool for policy making or opaque screen hiding value-laden assumptions? *Environmental Modeling and Assessment*, **2**, 229-249.

Schneiderbauer, S. and Ehrlich, D. (2006) Social levels and hazard (in)dependence in determining vulnerability. *Measuring vulnerability to natural hazards* (ed J. Birkmann), pp. 78-102. United Nations University Press, Tokyo, New York, Paris.

Scholten, H., Kassahun, A., Refsgaard, J.C., Kargas, T., Gavardinas, C. and Beulens, A.J.M. (2007) A methodology to support multidisciplinary model-based water management. *Environmental Modelling & Software*, **22**, 743-759.

Scholten, Huub, Waveren, R. H. van, Groot, S., Geer, F. van, Wösten, H., Koeze, R., and Noort, J. (2000) Good modelling practice in water management. Proceedings Hydroinformatics2000 . Cedar Rapids, Iowa, USA, International Association for Hydraulic Research.

Scholz, R.W. and Tietje, O. (2002) *Embedded case study methods. Integrating quantitative and qualitative knowledge*. Sage, Thousand Oaks/London/New Delhi.

Schön, D.A. (1983) *The Reflective Practitioner - How Professionals Think in Action*. Ashgate Publishing Limited, Aldershot/Brookfield USA/Singapore/Sydney.

Scott, L. Chronic poverty and the environment: a vulnerability perspective. [62]. 2006. London, Chronic Poverty Research Centre. CPRC Working Paper.

Sen, A.K. (1983) *Poverty and famines - An essay on entitlement and deprivation*. Oxford University Press, Oxford.

Shanmugasundaram, J., Arunachalam, S., Gomathinayagam, S., Lakshmanan, N. and Harikrishna, P. (2000) Cyclone damage to buildings and structures -- a case study. *Journal of Wind Engineering and Industrial Aerodynamics*, **84**, 369-380.

Sharma, M. and Norton, B.G. (2005) A policy decision tool for integrated environmental assessment. *Environmental Science & Policy*, **8**, 356-366.

Siebenhuner, B. and Barth, V. (2005) The role of computer modelling in participatory integrated assessments. *Environmental Impact Assessment Review*, **25**, 367-389.

Sikor, T.O. and O'Rourke, D. (1996) A tiger in search of a new path: the economic and environmental dynamics of reform in Vietnam. *Asian Survey*, **36**, 601-617.

Simon, H.A. (1960) *The new science of management decisions*. Harper & Row, New York.

Simon, H.A. (1996) *The sciences of the artificial*. MIT Press.

Simonovic, S. P. and Bourget, P. (2008) Managing flood risk, reliability and vulnerability. Simonovic, S. P. and Bourget, P. 4th International Symposium on Flood Defence. Toronto, May 2008.

Singh, V.D. (2001) Fisheries and Aquaculture in Coastal Andhra Pradesh. Hyderabad/Delft, Delft Hydraulics. Technical Report Integrated Coastal Zone Management - Andhra Pradesh Cyclone Hazard Mitigation Project

Skyttner, L. (2005) *General Systems Theory: problems, perspectives, practice*. World Scientific.

Slinger, J. H., Cuppen, M., and Marchand, M. (2008a) The policy preferences of citizens, scientists and policy makers. Samuels, P., Huntington, S., Allsop, W., and Harrop, J. The European conference on flood risk management: Research into practice (FLOOD*RISK* 2008). Boca Raton, London, New York, Leiden, Taylor & Francis Group.

Slinger, J. H., Kwakkel, J., and Niet, M. van der (2008b) Does learning to reflect make better modelers? Delft, Delft University of Technology.

Sluijs, J.v.d. (2001) Integrated Assessment Modelling and the participatory challenge: the case of climate change. *Knowledge, power and participation in environmental policy analysis* (eds M. Hisschemöller, R. Hoppe, W. N. Dunn and J. R. Ravetz), pp. 317-347. Transaction Publishers, New Brunswick.

Son, Lam Hung and Nghia, To Trung (2001) Background paper on the Red River Delta. Workshop on Modified Mega-deltas, The Hague.

Sprengers, C. EDSS User Manual (2006). Delft, Delft Hydraulics. Expert Decision Support System - ICZM Reports Andhra Pradesh Cyclone Hazard Mitigation Project.

Sreeram, K. (2001) Cyclone disasters, early warning, communication and disaster mitigation. 1. Hyderabad/Delft, Delft Hydraulics. Technical Report Integrated Coastal Zone Management - Andhra Pradesh Cyclone Hazard Mitigation Project.

Stave, K.A. (2003) A system dynamics model to facilitate public understanding of water management options in Las Vegas, Nevada. *Journal of Environmental Management*, **67**, 303-313.

Sterman, J.D. (2000) *Business dynamics: systems thinking and modeling for a complex world*. Irwin McGraw-Hill, New York.

Strubbe, J., Mostaert, F., and Maeghe, K. (2005) Flood management in Flanders with special focus on navigable waterways. Third International Symposium on Floods Defence. Nijmegen, May 2005.

Suzuki, K., Kanameda, M., Ogawa, T., Nguyen, T.T.D., Dang, T.T.S., Luu, Q.H. and Pfeiffer, D.U. (2006) Productivity and socio-economic profile of dairy cattle farmers amongst rural smallholder communities in northern Vietnam. *Livestock Science*, **101**, 242-250.

Sweco-Groner and Delft Hydraulics (2005) Flooding risk assessment for Bac Hung Hai polder. Prepared for Asian Development Bank and Ministry of Agriculture and Rural Development Vietnam.

Tansel, B. (1995) Natural and manmade disasters: accepting and managing risks. *Safety Science*, **20**, 91-99.

Tapsell, S.M., Penning-Rowsell, E.C., Tunstall, S.M. and Wilson, T.L. (2002) Vulnerability to flooding: health and social dimensions. *Philosophical Transactions of the Royal Society of London Series A-Mathematical Physical and Engineering Sciences*, **360**, 1511-1525.

TERI (2001). Review of past and on-going work on urban air quality in India. TERI project Report No. 2001EE41. Tata Energy Research Institute, New Delhi.

Thissen, W.A.H. (1978) *Investigations into the Club of Rome's World3 Model. Lessons for understanding complicated models*. PhD Technische Hogeschool Eindhoven.

Thissen, W.A.H. and Twaalfhoven, P.G.J. (2001) Towards a conceptual structure for evaluating policy analytic activities. *European Journal of Operational Research*, **129**, 627-649.

Thompson, M., Ellis, R. and Wlidawsky, A. (1990) *Cultural Theory*. Westview Press, Boulder, CO.

Thywissen, K. (2006) Components of Risk - A Comparative Glossary. 2. Bonn, United Nations University - Institute for Environment and Human Security. SOURCE: Studies of the University: Research, Council, Education.

Toth, F.L. (2003) State of the art and future challenges for integrated environmental assessment. *Integrated Assessment*, **4**, 250-264.

Turban, E. (1983) Decision support systems (DSS) a new frontier for industrial engineering. *Computers & Industrial Engineering*, **7**, 41-48.

Turner, B.L., Kasperson, R.E., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J.X., Luers, A.L., Martello, M.L., Polsky, C., Pulsipher, A. and Schiller, A. (2003) A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences of the United States of America*, **100**, 8074-8079.

Turner, R. I.(2004) Livestock Production and the Rural Poor in Andhra Pradesh and Orissa States, India. [9]. Rome, FAO. PPLI Working Paper.

Turnhout, E., Hisschemöller, M. and Eijsackers, H. (2008) Science in Wadden Sea policy: from accommodation to advocacy. *Environmental Science & Policy*, **11**, 227-239.

Twigg, J. (2001a) Corporate social responsibility and disaster reduction: a global overview. pp. 1-84. London, UK, Benfield Greig Hazard Research Centre, University College London.

Twigg, J. (2001b) Sustainable livelihoods and vulnerability to disasters. Disaster Management Working Paper [2]. London, UK, Benfield Greig Hazard Research Centre.

Twigg, J. and Bhatt, M.R. (1998) *Understanding vulnerability: South Asian Perspectives*. Intermediate Technology Publications / Duryog Nivaran, London.

UNFPA Viet Nam (2007) Population growth in Vet Nam - What the data from 2006 can tell us. With a focus on the 'Sex Ratio at Birth'. Hanoi, UNFPA Viet Nam.

UNISDR (2005a) Hyogo Framework for Action 2005-2015. World Conference on Disaster Reduction. United Nations. Hyogo, Japan January 2005.

UNISDR (2005b) Summary of national information on the current status of disaster reduction, as background for the World Conference on Disaster Reduction (Kobe, Hyogo, Japan 18-22 January 2005). Geneva / Switzerland, United Nations International Strategy for Disaster Reduction.

Van Asselt, M.B.A. and Rijkens-Klomp, N. (2002) A look in the mirror: reflection on participation in Integrated Assessment from a methodological perspective. *Global Environmental Change*, **12**, 167-184.

Van den Hove, S. (2007) A rationale for science-policy interfaces. *Futures*, **39**, 807-826.

Van der Veen, A. and Logtmeijer, C. (2005) Economic hotspots: Visualizing vulnerability to flooding. *Natural Hazards*, **36**, 65-80.

Van Kouwen, F., Schot, P.P. and Wassen, M.J. (2008) A framework for linking advanced simulation models with interactive cognitive maps. *Environmental Modelling & Software*, **23**, 1133-1144.

Vatvani, D., Gerritsen, H., Stelling, G. S., and Krishna Rao, A. V. R. (2002) Cyclone-induced storm surge and flood forecasting system for India. International Conference Solutions to coastal disasters. Proceedings Int.Conf.Solutions to coastal disasters , pp. 473-487. Reston, VA, ASCE. 2002.

Veen, J.van (1948) *Dredge, drain, reclaim: the art of a nation*. Martinus Nijhoff, 's-Gravenhage.

Veen, J.van (1953) *Land below sea level: Holland in its age-long fight against the waters*. Trio, 's Gravenhage.

Videira, N., Antunes, P. and Santos, R. (in press) Scoping river basin management issues with participatory modelling: The Baixo Guadiana experience. *Ecological Economics*, In Press, Corrected Proof.

Vietnam Institute of Economics (2000) Database on textile and garment employment survey. Hanoi.

Villagran De Leon, J. C. (2006) Vulnerability: a conceptual and methodological review. 4. Bonn, United Nations University - Institute for Environment and Human Security. SOURCE.

Villars, N., Dhoolappa, G., Subramanian, G. G., and Jain, P. K. (2001) Water Resources and Water Quality in Coastal Andhra Pradesh. Hyderabad / Delft, Delft Hydraulics. Technical Report No. 8 Integrated Coastal Zone Management - Andhra Pradesh Cyclone Hazard Mitigation Project.

Vincent, K. (2004) Creating an index of social vulnerability to climate change for Africa. [56]. Norwich UK, Tyndall Centre for Climate Change Research. Tyndall Centre Working Paper.

Vis, M., Klijn, F., Bruijn, K.M.de and Buuren, M.van (2003) Resilience strategies for flood risk management in the Netherlands. *International Journal of River Basin Management*, **1**, 33-40.

Vrisou van Eck, N. and Kok, M. (2001) Standaardmethode Schade en Slachtoffers als gevolg van overstromingen (in Dutch) (Standard method of damages and casualties from flooding). W-DWW-2001-028. Delft, Dienst Weg en Waterbouwkunde RWS.

Vu, T. A. and Shozo, S. (2006) Actors for poverty reduction in Vietnam. 73. Hanoi, Institute of Developing Economies, Japan External Trade Organisation. Joint Studies on Economic Development Policies in ASEAN and Neighbouring Countries.

Walker, W.E. (2000) Policy Analysis: a systematic approach to supporting policymaking in the public sector. *Journal of Multi-Criteria Decision Analysis*, **9**, 11-27.

Walker, W.E., Abrahamse, A.F., Bolten, J., Kahan, J.P., Van der Riet, O., Kok, M. and Den Braber, M. (1994) A policy analysis of Dutch river dike improvements: trading off safety, cost, and environmental impact. *Operations Research*, **42**, 823-836.

Walker, W.E., Harremoes, P., Rotmans, J., Van der Sluijs, J.P., Van Asselt, M.B.A., Janssen, P. and Krayer von Krauss, M.P. (2003) Defining uncertainty. A conceptual basis for uncertainty management in model-based decision support. *Integrated Assessment*, **4**, 5-17.

Watson, C. C. (2002) Using integrated multihazard numerical models in coastal storm hazard planning. Solutions to coastal disasters 02. San Diego February 2002.

Westmacott, S. (2001) Developing decision support systems for integrated coastal management in the tropics: Is the ICM decision-making environment too complex for the development of a useable and useful DSS? *Journal of Environmental Management*, **62**, 55-74.

White, G.F., Kates, R.W. and Burton, I. (2001) Knowing better and losing even more: the use of knowledge in hazards management. *Global Environmental Change Part B: Environmental Hazards*, **3**, 81-92.

Williamson, O.E. (1998) Transaction cost economics: how it works; where it is headed. *The Economist*, **146**, 23-58.

Winchester, P. (2001) The Socio-economy of the Andhra Pradesh Coastal areas and Cyclone Vulnerability. Hyderabad / Delft, Delft Hydraulics. Technical Reports Integrated Coastal Zone Management - Andhra Pradesh Cyclone Hazard Mitigation Project.

Winchester, P. (1992) *Power, choice and vulnerability - a case study in disaster mismanagement in South India 1977-1988*. James & James Science Publishers, Ltd., London.

Winchester, P., Marchand, M. and Penning-Rowsell, E. (2006) Promoting sustainable resilience in coastal Andhra Pradesh. *Managing Coastal Vulnerability* (eds L. McFadden, R. Nicholls and E. Penning-Rowsell), Elsevier.

Wisner, B. (1993) Disaster vulnerability: scale, power and daily life. *GeoJournal*, **30**, 127-140.

Wisner, B. (2000) The political economy of hazards: more limits to growth? *Global Environmental Change Part B: Environmental Hazards*, **2**, 59-61.

Wisner, B. (2001) Disasters: what the United Nations and its world can do. *Global Environmental Change Part B: Environmental Hazards*, **3**, 125-127.

Wong, F. L., Geist, E. L., and Venturato, A. J. (2005) Probabilistic tsunami hazard maps and GIS. 2005 ESRI International User Conference. San Diego.

Yarnal, B. (1994) Agricultural decollectivization and vulnerability to environmental change : A Bulgarian case study. *Global Environmental Change*, **4**, 229-243.

Yin, R.K. (1994) *Case study research: design and methods*. Sage, London.

Young, P. M. (1994) Red River Delta Master Plan Background Report 10: Livestock. 10. Binnie & Partners, Snowy Mountains Engineering Corporation Ltd., AACM International Pty Ltd., Delft Hydraulics.

Appendix 1

Participants in the Expert Panel

Dr. Richard Klein	Geographer Stockholm Environment Institute, Sweden
Dr. Joop de Schutter	Coastal Engineer Deputy Director of UNESCO-IHE, Delft, the Netherlands
Ms. Susan Taljaard	biochemist, water quality expert CSIR, Stellenbosch, South-Africa
Mr. Tung Tran Thanh	Coastal Engineer PhD student TUDelft and Hanoi Water Resources University, Vietnam
Prof. Anne van der Veen	Economist University of Twente, Enschede, the Netherlands.

Appendix 2

Documentation list of the ICZM Project Andhra Pradesh

I General:	
Framework for Integrated Coastal Zone Management in Andhra Pradesh	i-v, 1-63
Strategic Action Plan (SAP)	i-iii, 1-2, 1-8
II Technical Reports	
Problems and Opportunities for sustainable Coastal development: a synthesis	i-iv, 1-45
Decision Support System on Vulnerability	i-v, 1-25
The Socio-economy of the Andhra Pradesh Coastal areas and Cyclone Vulnerability	i-v, 1-48
The Shoreline management of Andhra Pradesh	i-vi, 1-37
Forestry and Nature Conservation in Coastal Andhra Pradesh	i-vii, 1-51
Fisheries and Aquaculture in Coastal Andhra Pradesh	i-vii, 1-51
Land Use, Agriculture, Tourism and Industries in Coastal Andhra Pradesh	i-viii, 1-80
Water Resources and Water Quality in Coastal Andhra Pradesh	i-xiii, 1-107
Air and Noise quality in Coastal Andhra Pradesh	i-v, 1-46
Solid Waste Management in Coastal Andhra Pradesh	i-viii, 1-43
Cyclone Disasters, Early Warning, Communication and disaster mitigation in Coastal Andhra Pradesh	i-vi, 1-43
Institutional arrangements for Integrated Coastal Zone Management in Andhra Pradesh	i-vii, 1-94
Village Level Institutions: capacity building at Village and Mandal level in Coastal Andhra Pradesh	i-v, 1-59
Resource Management Plan for the Godavari Delta region in Andhra Pradesh	i-iv, 1-50
III Expert Decision Support System –ICZM reports	
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IV AP-CHMP ICZM Supporting Documents	
District Land Use Report Srikakulam	i-iii, 1-69
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Cyclone Hazard; Crop Damage and Mitigation Measures in Coastal Andhra Pradesh	i-iv, 1-35
Siltation and Dredging in the main harbours of Andhra Pradesh	1-50

Appendix 3

List of input files for the EDSS Godavari Delta Application

Name	Description
Mandal specific input data:	
MANDAL_LU	Mandal land use by main land use type
MANDAL_CACROP	Agriculture crop areas and intensities by mandal
MANDAL_AQCROP	Aquaculture crop areas and intensities by mandal
MANDAL_LS	Number of livestock by mandal
MANDAL_HAB	Nature habitat areas by mandal
MANDAL_OTHP	Other production activities by mandal
MANDAL_POP	Population by income class and mandal
MANDAL_EVAC	Mandal evacuation rates: people, livestock and assets
MANDAL_FLOOD	Cyclone probability/ reference to representative flood severity class by mandal (output from Storm Surge Model)
MANDAL_WIND	Cyclone probability/ reference to representative wind severity class by mandal (output from Wind Hazard Model)
MANDAL_WATER	Water supply sources, volumes and outflows
MANDAL_CAPACITIES	Mandal capacities water supply, electricity and roads
Parameter data:	
CROPDATA	Crop data by agriculture crop type
AQUADATA	Crop data by aquaculture crop type
LIVESTOCKDATA	Livestock data by livestock type
INCDATASAM	Income related data by rural/urban income class
LABOURDATA	Labour data by labour class
OTHERPVAL	Production values by industrial production types
TOURPVAL	Tourist night expenditures by tourist origin
PRICESFACTORS	Various one-dimensional prices and factors
HABDATA	Data by habitat type
FLOODCLASS	Casualty rates and damage fractions by flood severity class
WINDCLASS	Casualty rates and damage fractions by wind severity class
INCDATAFVM	Flood damage related data by rural/urban income class
LANDUSEDATA	Data by land use type
GRANT	Grants to alleviate flood damage by income class
SEASONS	Data by water supply season
ATMEMISSION	Atmospheric emission coefficients
ENERGYREQSUP	Energy requirements and electricity supply
POPREQSUP	Population supply of water/energy and pop. mobility
TRANSPORTREQ	Transportation requirements of goods
TRANSPSUPVTG	Transportation supply of freight-related vehicles
TRANSPSUPVTP	Transportation supply of person-related vehicles
WATEMISSAGR	Water-related emission coefficients of crops/livestock
WATEMISSPOP	Water-related emission coefficients of population
WATERREQSUP	Water requirements/supply and solid waste other activities
WATEMISSOTH	Other water emissions, treatment efficiency, degradation
TREATMENTPOP	Treatment fractions and solid waste population
TREATMENTOTH	Treatment fractions water and solid waste (other) sectors
TOTQUANTITIES	Various total (supra-mandal) quantities
WEIGHTROAD	Capacity weights of road types

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When I first went to India in 1999, over a decade ago, to develop an ICZM support system and plan, I could never have imagined the challenge this would become. For me, this was not just another consultancy project. In fact, the whole project was one great endeavour, not only technically, but also culturally, the beautiful rice fields in the Godavari Delta, in such contrast to the deep poverty in places, the bustling economy and the heat. As a project, it shaped my professional career. Many times I told others jokingly that the project was so fascinating that I could write a book about it. It was several years later that I bumped into a former colleague, Marcel Stive, and told him my rather vague idea of writing a thesis on the subject that had kept me busy for so many years. He introduced me to Wil Thissen and several months later I was back in the academic world, after many years working at Delft Hydraulics. The result is this book - not exactly the type of novel I first joked about.

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Curriculum vitae

Marcel Marchand was born in Hoek van Holland, on the 3rd of August 1957. He studied Biology at Leiden University from 1975 till his graduation in 1982. From 1982 till 1990 he was employed at the Centre for Environmental Science at Leiden University, during which period he carried out research on environmental impacts of human activities, particularly those pertaining to wetlands, land reclamation and floodplain development. He wrote various articles about wetland valuation and management, climate change and water management.

In 1990 he joined Delft Hydraulics (which became part of Deltares in 2008) and worked on environmental impact assessments, environmental flows for rivers, coastal zone management and policy analysis studies. His professional experience included assignments in various countries in Europe, Africa, the Middle East and Asia. In 1999 he started working as coordinator for Integrated Coastal Zone Management in the World Bank financed Cyclone Hazard Mitigation Project in Andhra Pradesh, India. This assignment laid the basis for his PhD work, which he started working on in 2006. Furthermore he was involved in ICZM projects for Cyprus, Vietnam, Bangladesh, the Netherlands and Suriname.

A selection of publications

Peer reviewed articles:

Marchand, M., J. Buurman, A. Pribadi, A. Kurniawan (2009). Damage and casualties modelling as part of a vulnerability assessment for tsunami hazards: a case study from Aceh, Indonesia. *J. Flood Risk Management* Vol. 2 pp. 120-131.

Nicholls, R., F. Hoozemans and M. Marchand (1999). Increasing flood risk and wetland losses due to global sea-level rise: regional and global analyses. In: *Global Environmental Change*. Vol. 9, suppl. Issue 1999, pp. S69-S87. Pergamon.

Marchand, M., E.C.L. Marteijn and P. Bakonyi (1995): Policy Analysis as a tool for habitat restoration: a case study of a Danube River Floodplain, Hungary. *Water Sci. Technol.* 31/8, pp. 179-186.

Marchand, M. (1987). The productivity of African floodplains. In: *Int. J. of Environmental Studies*. Vol. 29 (1987), pp. 201-211, New York.

Marchand, M. and W.T. de Groot (1986). Divergent principles of rural planning; a case study on impoldering. In: *Int. J. of Environmental Studies*, Vol. 27 (1986); pp. 31-43, New York.

Books, book chapters and proceedings:

Monteiro, P.M.S. and M. Marchand (2009). Catchment2Coast - A systems approach to coupled river-coastal ecosystem science and management. *Deltares Select Series*, vol. 2. IOS Press.

Winchester, P., M. Marchand and E. Penning-Rowsell (2006). Promoting sustainable resilience in coastal Andhra Pradesh. Chapter in book '*Managing Coastal Vulnerability*', L. McFadden, R. Nicholls and E. Penning-Rowsell (Editors), Elsevier.

Marchand, M., K. Heynert, H. van der Most and W. E. Penning (Eds.) (2003). *Dealing with flood risks. Proceedings of a seminar on the regional implications of modern flood management*. Delft Hydraulics Select Series 1/2003. Delft University Press (DUP Science). Delft.

Marchand, M. (1988). Wetland Management: a shared responsibility. In: *UNEP: Drylands, Wetlands, Croplands: Turning Liabilities into Assets. Exchange of Environmental Experience Series - Book Two*. Nairobi.

Conference papers:

Marchand, M., K.M. de Bruijn, M.J.P. Mens, J.H. Slinger, M.E. Cuppen, J. Krywkow and A. van der Veen (2008). Flood risk management: experiences from the Schelde Estuary. *Proc. Int. Conference FLOODrisk 2008*, 30 September – 2 October, Oxford.

Marchand, M. (2008). Differential vulnerability in coastal communities: evidences and lessons learned from two deltas. *Proc. Conference Flood Recovery, Innovation and Response*, London, 2 & 3 July 2008. (Ed. D. Proverbs, C.A. Brebbia and E. Penning-Rowsell, WIT Press, Southampton). pp. 283-293.

Bari, M.F., M. Marchand and A.T.M.H. Zobeyer (2005). Alternative approaches of assessing environmental flows in selected rivers of Bangladesh. Paper presented at the Int. Conf. Modelling Tools for Environment and Resources Management, Asian Institute of Technology, Bangkok, 6-10 June 2005.

Marchand, M., W. E. Penning and K. Meijer (2002). Environmental Flow Requirements as an Aid for Integrated Management. *Proceedings of the 4th International Ecohydraulics Symposium*, 3-8 March 2002, Cape Town.

Marchand, M. and B. van der Valk (2001). Integrated Coastal Zone Management in Andhra Pradesh. Paper presented at the TROPMET 2001 conference, 6-9 February 2001, Mumbai (India).

Marchand, M. (1994). The Art of Habitat Rehabilitation. *Proceedings 1st International Symposium on Habitat Hydraulics*. Trondheim, Norway, 18-20 August 1994.

Baarse, G., M. Marchand and F. Hoozemans (1993). *How to Account for Impacts of Climate Change in Integrated Coastal Zone Management. Concepts and Tools for Approach and Analysis*. Prepared for the World Coast Conference 1993 (Intern. Conf. on Coastal Zone Management, Noordwijk, The Netherlands, 1-5 November 1993). Resource Analysis/Delft Hydraulics.

Marchand, M. and R. Misdorp (1991). *Adaptive strategies to accelerated sea level rise and their impacts on coastal ecosystems: a global assessment and a case study from Egypt*. Paper presented at the Symposium on Impacts of Climate change on Ecosystems and Species (December 2-6, 1991) Amersfoort, The Netherlands.

Marchand, M. and H.A. Udo de Haes (eds.) (1991). Wetlands. A selection of the papers presented at the International Conference 'The People's Role in Wetland Management', Leiden, the Netherlands, 5-8 June 1989. Special issue of *Landscape and Urban Planning*, Vol. 20 (1991).

Marchand, M. and W.T. de Groot (1988). *Wetland values and functions: a systematic classification*. Paper presented at the Intern. Symp. on Hydrology of Wetlands in Semi-arid and Arid Regions, Seville, Spain, 9-13 May 1988.

De Groot, W.T. and M. Marchand. *Kafue Flats, Zambia: floodplain planning on a crossroads.* Paper Intern. Symp. Polders of the World, Lelystad, Oct. 1982.

Other journals:

Klijn, F. and M. Marchand (2000). Veerkracht: een nieuw doel voor het waterbeheer? In: *Landschap* 17(1) pp. 31-44.

Drijver, C.A. and. Marchand (1986). Taming the Floods: environmental aspects of floodplain development in Africa. *Nature and resources*, Vol. XXII, No. 4, Oct-Dec. 1986, UNESCO, Paris.

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