Implementation of a Decision Theoretical Framework
A Case Study of the Red River Delta in Vietnam

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Abstract

We describe an application and implementation of a decision framework developed for selection of flood management strategies. It concerns developing countries in particular. The framework is developed to provide policy support and advice about water governance to meet demands at national, local, and river basin levels and can be of assistance as a tool for hazard management. The components in this framework are a simulation module interlinked with a decision module. The tool helps to analyse complex decisions that contain large degrees of uncertainty and number of interconnections.

Introduction

The vulnerability of developing countries increase as natural disasters, e.g. floods, become more frequent and intense, cf. (Munich-Re 1998). Damages are increasing, mainly as a result of the increasing concentration of population and assets in high risk zones as well as detrimental land-use practices (Loster 1999). Climate change may be a factor influencing future flood losses and this situation will probably become even more alarming in the future (IPCC 2001).

Currently, the cost of catastrophes in the developing world are mostly borne by the victims and governments, but considering the increasing numbers of disasters the financial cost will become unbearable and further entrench poverty and inequality.

For a government to decide on which flood coping strategy to choose is difficult. Several aspects need to be considered. Catastrophe simulation tools can help policy-makers who need to deal with complex flood management policymaking entailing the solution of problems involving many uncertainties and stochastic variables. Flood management aims at reducing loss of life, disruption and damage caused by floods. Complex decision making for river basin management involves technical, environmental, social, and economical aspects.

When events occur frequently and are not severe, it is not very difficult to estimate risk exposure and losses. In such cases, insurance premiums can be calculated based on a rich source of historical data (Buhlmann 1970; Daykin et al. 1994; Ekenberg et al. 1995). Catastrophes are, however, relatively rare events. There is not enough data to predict possible catastrophic losses in every particular location. Furthermore, catastrophes produce highly correlated losses which depend on the patterns of catastrophes, coverage at different locations, mitigation measures, insurance, etc. (Ermolieva 1997). Simulation is a possible solution to the complexity problem, using historical data and correlations of variables. Using a combination of historical data about hazardous events such as probabilities and simulated events as well as a policy strategy, it is possible to evaluate the damage and estimate the economic consequences of a particular hazard strategy.

The Case Study

The Red River Basin in Vietnam has a catchment area of 169,000 km^2, of which 86,000 km^2 is situated within Vietnam's borders, 81,240 km^2 in China and 1,100 km^2 in Laos (Sweco-Groner and Delft-Hydraulics 2005; SWECO WL 2005a). Dykes form the primary defence against flood disasters. The condition of these dykes and the ability to maintain them in the social and economic climate is important. Maintenance costs for the dykes are high in the region. Many sections lie below the normal flood level, requiring large efforts in the flood season to protect them against collapse. There are also multi-purpose upstream reservoirs. Normally, these reservoirs act as water reservation bodies for hydroelectric plants, but in the flood season their priority is to serve as flood-control measures (ADRC 2005). A strategy using only structural measures is not a realistic option since the cost for maintenance is constantly rising and losses increasing due to more dense population in land areas protected by the dykes. However, it seems that many consider further measures of dyke rehabilitation to be economically and socially justifiable (Benson 1998). Already in 1995, the government realised that more funding must be allocated to non-structural measures in order to cope with the economic situation of rising costs for maintenance and post-disaster liabilities (World Bank 1995). There are several strategies for coping, incorporated into development plans for the basin, such as forecasting, warning systems, and other preparedness actions (UNDP 1998; UNDP 2002).

Long-term effects of risk reduction measures are difficult to evaluate, nevertheless such measures are often considered to be more beneficial than post-disaster liabilities and structural measures (Green et al. 2000; Hansson 2004).

A Flood Management Tool

There is a vast number of catastrophe simulation models, see, e.g., (Aon-Holdings 2002; Benz 2004). However, they are usually limited in several aspects. Disadvantages include lack of cross-disciplinary data, such as environmental, financial, and social data in the same model. Furthermore, individual stakeholders are seldom taken into consideration. Most current models use an analytical approach, without simulations, where the risk is calculated. Moreover, catastrophe simulation tools often provide decision makers with general data with no decision analytical support. But in reality, flood management involves aspects from a multitude of disciplines and stakeholders. Therefore, we developed a model combining a stakeholder analysis with cross-disciplinary data as well as decision making facilities, see Figure 1.

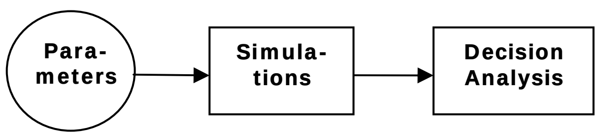

Figure 1. Combined simulation and analysis tool

The simulation approach seems to be the most suitable one for evaluating different flood failure scenarios. For instance, in the present version of the model, nine different possible scenarios are used, simulated 10,000 times over a period of ten years. Damage is calculated for each period. The number of possible scenarios makes the problem quite complex and not really suited for a more analytical treatment. Moreover, stochastic variables make the decision situation even more complex.

In the present model, the focus has been on including the most important groups of stakeholders: the government, property-owners, insurance companies, NGOs, and donor agencies. By implementing an integration with a decision tool, a large number of uncertainties can be dealt with, and imprecise values and probabilities can be used; stakeholders can assess the result and investigate the importance of certain perspectives and important variables. Various kinds of sensitivity analyses can also be made. The model has been developed to deal with several stakeholders' outcomes that can be managed on a per consequence basis.

The present framework enables the stakeholder to simulate property loss, level of compensation, different insurance settings, donations, and depths concerning different types of flood events (i.e. probabilities and magnitudes). Taking into consideration the overall impreciseness in the situation the framework enables the decision-maker to access the result and investigate long term effects. For the evaluation of the options, aggregated data from the simulations have been used, automatically fed into the decision module following the flow in Figure 1.

Parameters

The following aspects have been parameterised together with real data for property value, damage rate, dyke failure reparation cost, maintenance cost, poverty rate, etc.

- *Warning systems and education*: If the government decides to implement such measures, there are thresholds, and if the amount of funding exceeds a threshold, it is assumed that the measure reduces damages by 5 percent. When inhabitants in a region are educated they can protect their property, for instance, by building houses on stilts. If warned at an early stage, they can escape and save livestock prior to a flood occurring. However, it is common in developing countries for warnings not to reach the inhabitants in time due to lack of modern media, such as phone and TV (UN 2005). Moreover, if inhabitants in a region lack knowledge on how to act when a warning reaches them, the measure is ineffective.
- *Maintenance of levee sections*: Maintenance costs differ for each location based on the length of the levee. If the amount of funding for maintenance is below a certain threshold value, then probabilities for a flood failure is assumed to increase by 10 percent. If maintenance costs are above a higher threshold then probabilities for dyke failure and overtopping is reduced by 10 percent. The probabilities for the threshold limits are retrieved from (SWECO/WL 2005b).
- The variable *borrowing* is added to the model; it is updated each year and can include interest and instalments. This value reduces the governmental funds each year.
- For each location and for each strategy, if a failure occurs, *cost for reparation of levee* is set, both for overtopping and for piping. This cost reduces the wealth of the government after a flood. No costs for insurance, labour, or risk profit are included in these figures, and only the basic cost is represented.
- If there have been *two or more floods* within a time period, a variable can be set which reduces, by this factor, the governmental compensation to property owners who experienced losses. At the end of the time period the settings return to normal compensation level. The same possibilities are applied for the variable *borrowing*. At the end of the time period the settings return to normal compensation level.
- For each location, and for each flood scenario, there can be *expected donations* (development aid) from one or more donor agencies. The donations are added to the government's wealth.

As an example the wealth transformation function of the government Gov is demonstrated in Equation 1. The wealth W is transformed over time t and is reduced by flood compensation G_i paid to the property owners i, where x is the policy parameter deciding the compensation level. n represents the number of property-owners in the region that are compensated.

Equation 1. Governmental wealth transformation function used in the simulation model

$$W^{Gov}(t,x,\omega) = W^{Gov}(t-1,x,\omega) - E(t,x) - M(t,x) - \sum_{i=1}^{n} G_i(t,x,\omega) + \sum_{i=1}^{n} T_i(t,x,\omega) + I(t,x)$$

The size of the compensation also depends on the severity of the flood, decided by ω. *E* corresponds to expenditures for the government, which can include flood-related expenditures such as contributions to a flood fund. *M* represents costs for flood mitigation and the costs for maintenance of structural flood mitigation measures. *M* can also be a function of renaturalisation costs such as reforestation of a specific area, relocation of inhabitants, warning systems, or similar. *T* represents income for the government in the form of tax received. Finally, *I* represents possible additional income for the government, which can include domestic and international aid/donations and income from potential loans. If the government borrows funding, *E* can also include payments to loan agencies. Furthermore, if an international perspective is introduced and several governments are sharing the compensation and maintenance cost, function 1 can be extended accordingly.

Equation 1 is used in the simulation model and updated each year. Similar equations exist for each stakeholder. In order for a policy strategy to be completely evaluated, all stakeholders' views must be taken into account, with varying importance weights. Striving for a Pareto optimal solution for the stakeholders affected by the policy, we use a weighted goal function. Different preferences and weights can be assigned to individual stakeholders as well as to groups.

A weighted goal function of the stakeholders could then be defined as follows:

Equation 2. Weighted goal function used in the decision tool

$$G(x,\omega) = \alpha\sum_{i=1}^{n_1}\alpha_i W^{Ind}(x,\omega) + \beta\sum_{i=1}^{n_2}\beta_i W^{Gov}(x,\omega) + \gamma\sum_{i=1}^{n_3}\gamma_i W^{Ins}(x,\omega) + \delta\sum_{i=1}^{n_4}\delta_i W^{Ngo}(x,\omega)$$

G represents the goal itself and n_1, n_2, n_3, and n_4 are the number of stakeholders in each group. W^{Ind} represents the individual stakeholders, W^{Gov} represents the governmental stakeholder, W^{Ins} represents the insurers, and finally, W^{Ngo} represents the NGOs in the region. Weights are assigned to each group of stakeholders and also to each specific stakeholder. α, β, γ, and δ are the weights which play the same role as in standard welfare analysis, i.e. where *i* represents the specific stakeholder for each group. The purpose of the goal function is to make it possible to use weights in order to control and analyse the impact of the importance of both the individuals and different groups of stakeholders. The goal function of all the stakeholders has multi-objective tradeoffs. We first have to optimise the goal for each single stakeholder in all groups. Each group is then evaluated with the restrictions of weights and goal functions. $G(x,\omega)$ can then be evaluated in several ways, e.g. with respect to maximum and minimum values. The approach intended for this framework is that the decision-maker will be able to analyse the situation by considering various sets of weights and understanding how they affect the strategy decision situation.

Settings

In earlier versions of the model and simulations, we have shown that the model is successful when comparing and evaluating strategies using different insurance schemes and government compensation settings (Brouwers et al. 2002; Hansson 2002; Brouwers et al. 2004). In this paper, we present an implementation of the extended framework for flood management strategies.

For the simulations we have used four possible locations for floods in the Bac Hung Hai irrigation and drainage system, see Figure 2. Real data on flood probabilities and flood damages is gathered on location, and statistics are retrieved from local authorities (SWECO/WL 2005b).

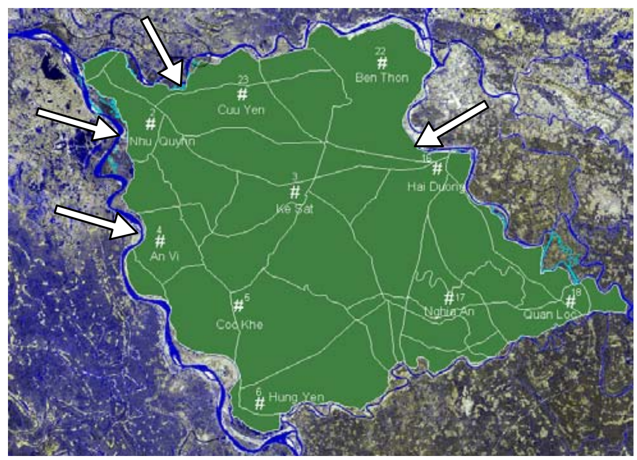

Figure 2. Failure locations in the polder, figure from (SWECO/WL 2005b)

We simulate nine different flood scenarios; corresponding to the magnitude (return-period) of a 100-year flood. Four scenarios concern levee piping at the four different locations, four concern overtopping, and finally one contains no event.

Locations and probabilities

1) Song Hong, Red River, protected by 64-80 km levee. Probability for overtopping is 4.7% and for piping 2,6%.
2) Song Hong 2, Red River, 80-120 km levee. Probability for overtopping is 4.2% and for piping 31%.
3) Sound Duong, Duong River, 0-45 km levee. Probability for overtopping is 0.49% and for piping 0.1%.
4) Song Thai Binh, at the Thai Binh River, 0-15 km levee. Probability for overtopping is 4.29%, and for piping 44%.

Table 1 shows data from a typical village in the polder. Each type of house has a property value and suffers a certain percent of damages, that is, property value reduction, in case of a failure. Each house is linked to a specific location. Damages are reduced by a certain percentage of property value if enough funds are given to warning systems and education. We have used this data for each of the four different locations where levee failures occur. The total population number in the polder is 2.8 million, for the experiments we include 11,200 which can be affected by a flood. Given a new situation or location, the data can be easily altered w.r.t. values, specific locations, number of houses, a.s.o.

Table 1. Different types of houses in and values per location
Data retrieved from (IMECH/NIAPP 2005).

Type of house	Value 10^6 VND	Number of houses	Damage rate
Villa	560	14	10 %
House with concrete frame	263	56	15 %
House with concrete roof	134	812	15 %
House with tiled roof	42	1,624	20 %
Thatched cottage	7	294	60 %

Analysis of Strategies

We have analysed three feasible flood coping strategies.

- *Strategy 1*: Government compensation in combination with structural measures
- *Strategy 2*: More non-structural pre-mitigation measures (education and warning systems)
- *Strategy 3*: The use of a catastrophe fund

What differ in strategies 1 and 2 are the new variables and functions concerning non-structural measures – warning systems and education in combination with a higher maintenance level of the existing levee. Strategies 1 and 2 use the same settings for government compensation in case of a flood, insurance rate, and level of compensation from the insurer. Today, the use of insurance is close to non-existent in the region. Therefore, insurance rate and compensation are set low. Premiums for a bundled insurance are paid to the insurance company each year, at a certain percentage of property value where a percentage of the bundled insurance is set specifically to flood loss compensation. For the initial analysis of the strategies the poverty rate as been set to 30 % (GSO 2005).

Furthermore, the cost of borrowing money and/or receiving funds from donors is different for the strategies. In Strategy 2 donations are given from agencies and NGOs, different amounts depending on failure scenario, while none is given for Strategy 1. In Strategy 1, the amount of funding borrowed is assumed to be 40% higher compared to Strategy 2. If two or more failures occur within a time period, it decreases the compensation. In Strategy 2 it is assumed to decrease by 30% less than in Strategy 1. The costs for reparations caused by overtopping and piping are currently the same for all strategies. In Strategy 3 we use different settings to illustrate different possible coping strategies where we use a mandatory fee for all property owners, which go to a catastrophe fund. If an event occurs, the government compensates the property owners. No donations or aid is given in this strategy. Maintenance costs reach the upper threshold and the probabilities for a failure are decreased, but no funds are provided for warning measures or education.

Estimations are calculated with regard to the strategies and the occurrence of floods. The results from the simulations are automatically transferred into the decision module where a decision tree is automatically generated. It takes interval values and criteria into consideration, and uses qualitative comparisons to see the effects of ranking stakeholders against each other.

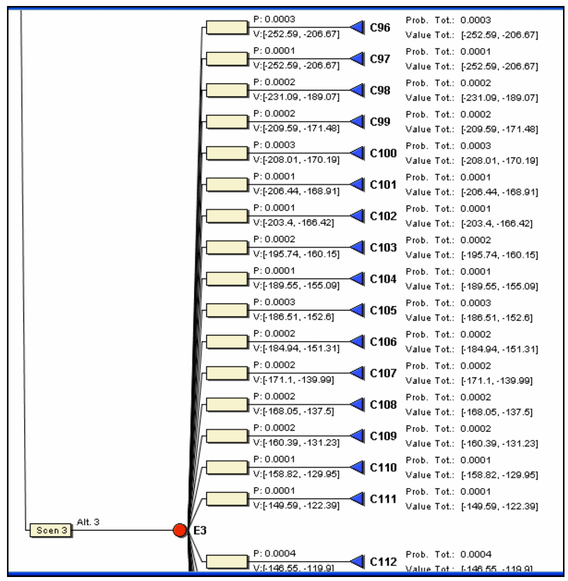

Figure 3. Last level of a decision tree

Stakeholders

There are several groups of stakeholders in the model, viz. the government, the NGO's, the insurance companies, and the property owners. The importance of each stakeholder group is represented by a weight in the model. The weights of the stakeholders are modelled at the last level of a decision tree, see Figure 3 showing the result from a governmental perspective concerning Strategy 3. There is no need to enter fixed numbers for the weights, only intervals or comparisons between weights are required.

The weights add up to 1 for each of the probability nodes at the next-to-last level. The effects of manipulating the weights and how they can then be easily analysed are further demonstrated in (Ekenberg et al. 2003).

Strategies are called alternatives in the tool ("Alt"). The overall view from the property owners' perspective, see Figure 4 (left), shows that the outcome of Strategy 2

(“Alt2”) and Strategy 1 are somewhat close and that Strategy 3 is the least preferable. One of the reasons is that a mandatory fee to a catastrophe fund is introduced in this strategy. The figure shows an overview of the range of the alternatives’ expected values.

For the aggregated loss for all property owners in the polder per simulation round (over a time period of 10 years, using Strategy 2), the largest deficit was –2,760,700 USD recorded with a probability of 1%. By implementing Strategy 1, the property owners experience similar losses but with slightly less probability. The largest deficit recorded using this strategy was –5,402,900 USD with 1% probability. More funding is allocated by the government to pre-mitigation strategies which reduce losses. The aggregated loss for the property owner is different for each location, depending on the number of failures. For location 4, the worst case balance for the aggregated property owners using Strategy 1 is –3,220,100 USD, compared to –2,075,000 USD for location 3.

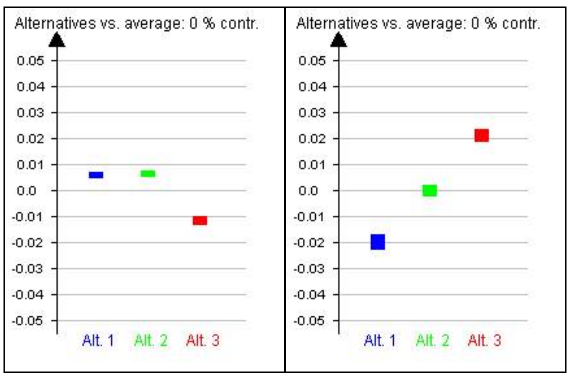

Figure 4. To the left: Cardinal ranking from the property owners’ perspective. To the right: Cardinal ranking from the governmental perspective.

In Figure 4 (left) and the following figures, the y-axis scale is normalized to [0, 1] with 0 representing the worst and 1 the best possible outcome. Even if compensation is similar for Strategy 1 and 2, the losses are less, since more funds are given to education and warning. Interestingly, Strategy 2 is preferable to Strategy 1 for both the property owner and the government, see also Figure 4 (right). This can give a hint to the decision maker regarding issues of fairness and equity. However, the amounts of losses in the different strategies are of course an important aspect to take into consideration, which can influence the decision. In the decision module, limits can be set to exclude unacceptable consequences, from different stakeholders’ perspectives. By imposing limits, we can point out alternatives that are totally unacceptable.

The result for Strategy 3 vs. the other two strategies for the government is, with these settings, the opposite, see Figure 4 (right). Strategy 3 is to prefer since a steady income is beneficial and property owners can be compensated without major losses. However, the government does suffer losses and experiences several negative simulation time periods. The probability for the largest deficit within this strategy –1,960,800 USD is 0.1%. The largest deficit for the government using Strategy 2 is –7,330,000 USD with the same probability.

An evaluation setting equal stakeholder weights and comparing the results is shown in Figure 5 (left). This gives a view of the policy selection situation when all stakeholders are considered equally important. The strategy “Catastrophe fund” is to prefer, however the loss is almost equal to the deficit, and it can be discussed if the deficit may be too large to be acceptable.

However, from earlier stakeholder interviews (Ekenberg et al. 2003) it was clear that the financial balance of the government was considered more important than the wealth of the property owners followed by the balance of the insurers. It is difficult to state precisely how “more important” should be interpreted. But in this framework, there is no need for such fixed values. All that is required is to make comparisons of the weights. Thus, we have stated that the balance of the government is the most important followed by the property owners and finally the insurance agents, see Figure 5 (right). In this Figure we see that Strategy 3 is clearly to prefer and Strategy 2 is slightly preferable compared to Strategy 1. The result from Figure 5 (right) is similar to results from Figure 4 (right). The difference is that in Figure 4 (right) only the government is considered. In Figure 5 (right), we consider all three stakeholder groups and use comparative importance preferences consistent with the stakeholder interviews. Thus, all stakeholders are taken into consideration with varying degree of importance consistent with agreed statements of importance.

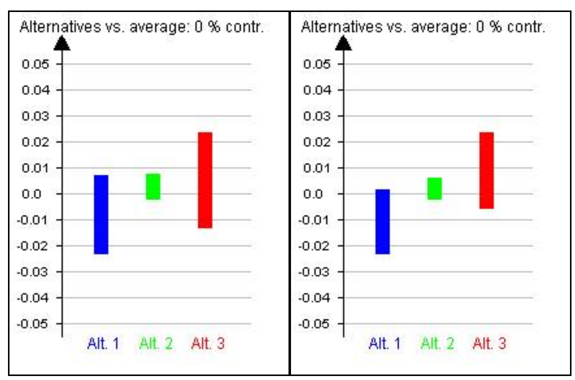

Figure 5. To the left: Cardinal ranking, weights of stakeholders is set equal. To the right: Cardinal ranking, weights of stakeholders is set as indicated by the interviews.

Concluding Remarks

We have developed a framework for multi-stakeholder, multi-criteria flood management policy evaluation. This paper presents the results from an application of the framework using real data from the Red River Delta in Vietnam. We have analysed strategies for dealing with this complex and interdisciplinary issue. The results from the investigation demonstrate that, for the particular Bac Hung Hai area, if the government’s financial balance is set to be more important than the property owner and the insurer, a reasonable choice of strategy is Strategy 3, that is, the use of a catastrophe fund. It also indicates that Strategy 2, the use of more non structural pre mitigation measures, is preferable for both property owners and the government, which leads to the conclusion that in this case study non-structural pre-mitigation measures are in fact financially preferable to structural measures. In more general terms, the case study demonstrates that it is possible to use a combined simulation and evaluation framework for the investigation of flood management policies. It is feasible to investigate the effects of different policy options and make sensitivity analyses based on different views of stakeholder importance in order to gain a better understanding of the possible outcomes of policies prior to making the actual decisions, thus making it a decision support tool for stakeholders and policy makers.

Acknowledgements

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