Robust Cost-Benefit Analysis to Assess Urban Flood Risk Management: A Case Study on Ho Chi Minh City

Ruben DAHM1*, Frits DIRKS2, Jarit VAN DE VISCH2, Ferdinand DIERMANSE1, Marjolein MENS1, Long Phi HO3,4

1Deltares, The Netherlands
2Royal HaskoningDHV, The Netherlands
3Centre of Water Management and Climate Change (WACC), Vietnam
4Viet Nam National University (VNU-HCMC), Vietnam

*Corresponding author
Email: ruben.dahm@deltares.nl

ABSTRACT
Ho Chi Minh City (HCMC), a fast-growing city located in the lowlands of South Vietnam, experienced record high flood levels in recent years. As HCMC accounts for 23% of the national GDP, increasing HCMC’s level of protection against flooding is of vital importance. Many flood risk mitigation strategies have been proposed to protect HCMC. This paper describes a cost-benefit analysis of a selection of these strategies, including a probabilistic risk analysis and a robustness analysis. Probabilistic modelling has been applied in addition to regular hydraulic modelling to provide reliable flood maps of HCMC and to provide input for the flood risk estimation. In the cost-benefit analysis, flood risk reduction is considered as the main benefit of the strategy investment. To test the robustness of a flood risk mitigation strategy, a sensitivity analysis has been carried out to obtain insight into the impact of a number of uncertainties on the outcome of the CBA. With this HCMC case, we demonstrate a successful application of a framework for robust CBA in urban flood risk management taking into account future uncertainty ranging from climate change, sea level rise and land subsidence to investment costs, phasing of the investment and macroeconomic growth.

KEYWORDS
Urban flood risk management, depth-damage function, cost-benefit analysis, robustness

INTRODUCTION
In recent years Ho Chi Minh City (HCMC), a fast-growing city located in the lowlands of South Vietnam, experienced record high flood levels. These events were extensively reported in local newspapers, e.g. Tuoi Tre News (2013) and Saigon GP (2011), and showcase the flood risk HCMC is facing today and might be facing in the (long term) future. Hallegatte et al. (2013) ranked Ho Chi Minh City within the top five of coastal cities world-wide with the highest relative risk (annual average losses in percentage of gross domestic product (GDP)) for a 100 year exposure to floods. The World Bank stated that HCMC is in the top five of cities in East Asia most at risk to floods, both in terms of mortality and economic loss (Brecht et al. 2013). According to the Asian Development Bank, HCMC accounts for 23% of national GDP and 20% of foreign direct investments of Viet Nam (ADB, 2010). Consequently, increasing HCMC’s level of protection against flooding is of vital importance. HCMC’s floods are caused by (combinations of) high tides in the Saigon and Dong Nai rivers, high intensity rainfall on the city exceeding the capacity of the local drainage system, high river discharge due to spilling from the Dau Tieng and Tri An reservoirs after prolonged periods of high rainfall, and/or diverted flood waters from the Mekong river. Figure 1 shows the study area. HCMC’s People Committee acknowledged the need to reduce its cities flood...
risk. It implemented several infrastructural projects, e.g. the upgrading of Nhieu Loc-Thi Nghe canal, and initiated an integrated assessment of the flood and inundation management of the city. This assessment was carried out within the HCMC-FIM project.

The People Committee opted for the assessment of three large structural mitigation strategies to tackle the city’s (future) flood risk. Mitigation measures are aimed to reduce the likelihood of potential consequences of floods. As Sayers et al. (2012) described, ‘infrastructural choices made today will persist for several decades if not centuries, so taking a longer term, strategic view when planning infrastructure investment is critical to making the right choice.’ Likewise, Willems et al. (2013) stated that measures should be robust and able to cope with a variety of future changes. Recognizing uncertainties related to future conditions, e.g. climate and socio-economic change, is therefore key to the assessment of the strategies and for facilitating a robust decision.

Mens et al. (2011) distinguished system robustness from decision robustness. A decision is considered robust when it performs well under a range of conditions (Lempert et al., 2003), and a system is considered robust when it can remain functioning under a range of disturbances (Mens et al., 2011). Mens et al. (2011) considered both concepts complementary as they are relevant at a different moment in the decision-making process. System robustness may help to identify strategies and measures, while decision robustness may contribute to prioritize between identified measures and to plan their implementation in time. As HCMC’s People Committee already identified several strategies, the HCMC-FIM project focussed on decision robustness. Consequently, we analysed costs and benefits of selected strategies for a range of possible future developments in climate and economy.

In this paper, we present a framework for robust cost-benefit analysis of flood risk mitigating strategies, exemplified by results from the HCMC-FIM project.

Figure 1. The study area. The blue lines show the most important rivers and grade 1 canals. The red line indicates the HCMC province boundary.

GENERAL APPROACH

The assessment of several structural flood risk mitigation strategies to provide HCMC with a flood protection system that is able to cope with (future) flood risk, we carried out the following components:

i. Selection of strategies using the ‘Faster and Better’ approach,
ii. Hydraulic and probabilistic modelling of the selected strategies to provide sound flood maps for chosen return periods,

iii. Robust cost-benefit analysis (CBA) using macro-scale variables and damage surveys.

In this paper we briefly address the first and second component and focus on the third component. The results of these three components provided input for a Multi-Criteria Analysis (MCA) to select the most feasible strategy.

‘Faster and Better’: Three flood risk mitigation strategies

In cooperation with the Steering Center for Flood Control of HCMC a selection of the most promising and feasible structural flood risk mitigation strategies was made, following a rapid decision making approach. This method is based on the ‘Faster and Better’ approach as implemented by the Dutch Ministry of Transport, Public Works and Water Management for improved, more effective, and faster decision making in complex infrastructure projects (De Vries et al. 2013).

Three strategies were selected and analysed as possible structural measures for the main flood protection system of the greater HCMC area (highlighted in Figure 2):

i. The MARD plan, as designed in 2008 and approved by the Prime Minister by decision 1547, consisting of 172 km of dikes, and 12 tidal gates to protect the city west of the Saigon river.

ii. The MARD plan variant focussing on a much smaller protection area for the city west of the Saigon river. In addition, part of the protection system is to coincide with a planned third ring-road providing cost savings.

iii. The Soai Rap tidal barrier (Nguyen, 2010) consisting of a partial closure of the Soai Rap river downstream of the confluence with the Vam Co river.

Figure 2. HCMC’s structural flood risk mitigation strategies

Probabilistic modelling

For quantitative flood risk assessment, flood probabilities are necessary and ideally derived directly from available observations. However, this is generally not possible because the record of observation is too short to have witnessed all potential flood events and records are only available for a limited number of locations in the study area. In that case, a probabilistic analysis is required which takes the possible events that lead to flooding and their probabilities of occurrence into account. In practice, often this approach is replaced by a more straightforward one based on design events and/or worst-case scenarios. However, these methods do not fully account for all types of flood events and for this reason may result in
unreliable flood hazard estimates. To assure sound flood probabilities in the robust CBA, we defined a range of potential (extreme) events that may cause floods in the greater HCMC area. Subsequently, we simulated these events with a hydraulic model and derived the probability of occurrence of each event. These probabilistic computations have been executed for different flood risk mitigation strategies and scenarios (i.e. combinations of climate change, sea level rise, spatial planning, and land subsidence) for different reference years and seasonal variations in climatologic and hydraulic conditions were taken into account. This resulted in over 2,000 hydraulic simulations (i.e. as input for the probabilistic analysis) for each flood risk mitigation strategy; see Dahm et al. (2013). The flood hazard maps as used in a CBA are the result of the probabilistic analyses and computed for multiple return periods.

Cost-benefit analysis
We applied a CBA to assess the costs of each flood risk mitigation strategy and its benefits. The costs for implementation of the strategies are weighed and balanced with the benefits, the reduced flood risks. Implementing flood risk mitigating strategies will decrease the flood risks, thereby giving benefits by means of avoided costs of damage due to flooding (i.e. decreasing expected annual flood damage). As advised by Penning-Rowsell et al. (2010) we focussed on direct, tangible costs only. The CBA derived the input for the costs from the hydraulic structures analysis. The hydraulic and probabilistic analysis provided the information to assess the benefits of the flood risk mitigation strategies. In the CBA, this information is combined with the value of tangible damage due to higher water levels in case of flooding before and after implementation of the flood risk mitigation strategies.

The approach for determining the benefits of reduced flood risks can be summarized as:

i. Socio-economic analysis of the project area to enable calculating the value of buildings and inventory, transport and agriculture per square metre. In line with international literature on flood damage assessment, the depreciated value of the assets, excluding taxes, has been applied as the value of installed assets;

ii. Flood hazard analysis to determine inundation depths. The inundation depth has been determined for five return periods: 0.1, 1, 10, 100 and 1000 years. For each return period, the maximum flood depths, \( h(x,y) \), as a function of spatial coordinates \( x \) and \( y \) are known.

iii. Calculation of the damage function by combining (i) the value of land use per square metre in the project area; and (ii) the maximum damage for a given inundation depth;

iv. Loss probability curve development to calculate the expected annual damage. This represents the average damage in any year throughout the project period, for all expected types of flood events. It has been calculated under the assumption that: (i) for the frequency \( f > 10 \) (per year) the damage is assumed to be equal to 0; (ii) for the frequency \( f < 0.001 \) (per year), the damage is assumed to be equal to a frequency of 0.001 (per year); (iii) for all other frequencies, the damage is estimated from log-linear interpolation between the five frequencies. The expected annual damage (EAD) was subsequently computed as follows:

\[
\text{EAD} = \int_{0}^{\infty} D(f) df
\]

In which \( D(f) \) is the damage, \( D \), as a function of the frequency of exceedance, \( f \). The frequency of exceedance is the reciprocal of the return period \( T \), i.e.: \( f = 1/T \).
To analyse the robustness of the proposed structural urban flood risk management strategies, the CBA was carried out for a range of scenarios. Each scenario represents a plausible future and is a combination of the following five macro-scale variables:

i. Investment: optimistic, base and pessimistic cost level;
ii. Phasing of the investment in time: start immediately versus postpone;
iii. Flood hazard: non-corrected versus corrected;
iv. Flood damage: high estimate, base (medium) estimate and low estimate;

In total, this yielded 36 estimates per strategy of the economic criteria Net Present Value of cash flows (NPV) as a percentage of the NPV in the base case. The base case is the scenario where the investment is postponed as long as possible, using non-corrected water levels, high estimate damage values, base cost estimate and a base macro-economic growth estimate.

i. Investment
Three variations for cost variation of the structural measures design reviews were included:

i. Optimistic estimate: similar to the original cost estimates in the MARD plan,
ii. Base (medium) estimate: optimistic estimate plus 15-50%,
iii. Pessimistic estimate: base estimate plus 15-50%.

ii. Phasing
Phasing investments has an impact on the outcome because of the time-related value of money. To identify whether early investment and finalizing as soon as possible (starting in 2013), or late investment (postponing investments but assuring that the strategy is operational by 2025) is preferable, these two phasing options have been included in the CBA.

iii. Flood hazard
The hydraulic modelling and probabilistic analysis provided hazard maps. These results are combined with land use data for damage estimation. To include model uncertainty in the CBA, we derived hazard maps for two sets of model results: the hydraulic model results based on the calibrated and validated model and, based on probabilistic analysis, a corrected set of model results for improved agreement with the observed extreme value statistics.

iv. Flood damage
Next to using international references on flood damage assessment (e.g. MRC 2009), we carried out household and business surveys to establish the current (depreciated) value of the installed assets per square metre in order to allow for a spatial assessment of flood damage reduction. The survey provided detailed information to determine a depth-damage function (DDF) representative to the greater HCMC area then, e.g. the application of a population-scaled GDP DDF as presented by Winsemius et al. (2013). The DDF is shown in Figure 3. Three flood damage values were applied to take survey uncertainty into account: (i) a high damage value estimate being based on the surveys; (ii) a medium (base) damage value estimate half the high damage value; and (iii) a low damage value estimate as a quarter of the damage value derived from the surveys.

v. Macroeconomic growth
To forecast future (depreciated) value per square metre, we used macroeconomic indicators, e.g. the anticipated annual change in the GDP as forecasted by the Asian Development Bank (2009) was used to forecast the value of the inventory. The forecast of the damage to vehicles is based on the growth of the number of vehicles according to HCMC’s master plan (HCMC PC, 2007). The forecasted value of residential areas and planned areas changes based on the
assumption that due to economic growth equipment and inventory will increase. The value to rebuild or repair buildings and roads affected by the flood is assumed not to change. As the number of buildings and metres road is assumed to increase due to economic growth, the total value of land use for roads and residential areas does increase. To include the uncertainty related to changes in the macro economy, all forecasted figures were varied with a lower growth estimate of 50% of the forecasted growth percentage and a lowest growth estimate of 25% of the forecasted growth percentage.

To include the uncertainty related to changes in the macro economy, all forecasted figures were varied with a lower growth estimate of 50% of the forecasted growth percentage and a lowest growth estimate of 25% of the forecasted growth percentage.

Figure 3. Depth-damage functions based on survey data

Analysing decision robustness
A strategy is considered robust when it performs well under a large range of scenarios. In this study, the performance is measured by the relative NPV. Robustness can then be assessed by selecting the scenario in which the impact on the NPV results is largest (i.e. most negative difference) and assessing the Internal Rate of Return (IRR) and CB-ratio for that scenario. The strategy with the highest scores is considered the most robust one.

RESULTS AND DISCUSSION
Table 1 shows the results of the robustness analysis for the three flood risk mitigation strategies. In comparison to the base case, the NPV shows the largest negative difference in the scenario where the plan is finalized as soon as possible, with low flood damage estimates and a pessimistic macroeconomic growth estimate. This worst-case combination of macro-scale variables was combined with a pessimistic cost estimate for the calculation of IRR and CB-ratio. Table 2 summarizes these results. We found that the economic criteria for all three strategies remain positive under this most pessimistic scenario. This means that all strategies can be justified from an economic point of view, but the ‘MARD Plan Variant’ strategy rendered the best cost-benefit ratio. Because this strategy had a positive CB-ratio in all scenarios, it is likely that this flood risk mitigation strategy will have a positive effect on HCMC’s society at large regardless of how the future develops.

Future studies might explore how the chosen strategy can be optimized, by exploring the scenarios under which the strategy performs worst. Additional measures could then be added to the strategy to increase the performance under these particular conditions. This requires an iterative process with decision makers and other stakeholders.
Table 1. Differences in NPV (%) with base case (represented by ‘0’ value) due to uncertainty in macroeconomic growth estimates (optimistic, base and pessimistic), phasing (postpone or finalize as soon as possible) and water levels (non-corrected versus corrected), using high (H), medium (M) and low (L) flood damage estimates.

<table>
<thead>
<tr>
<th></th>
<th>Non-corrected water levels</th>
<th>Corrected water levels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Postpone investment</td>
<td>Finalizing plans asap</td>
</tr>
<tr>
<td>------------------------------</td>
<td>------------------</td>
<td>------------------</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>M</td>
</tr>
<tr>
<td>Soai Rap</td>
<td>2</td>
<td>-51</td>
</tr>
<tr>
<td>MARD Plan</td>
<td>3</td>
<td>-51</td>
</tr>
<tr>
<td>MARD Plan Variant</td>
<td>2</td>
<td>-50</td>
</tr>
<tr>
<td>Optimistic estimate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soai Rap</td>
<td>0</td>
<td>-53</td>
</tr>
<tr>
<td>MARD Plan</td>
<td>0</td>
<td>-53</td>
</tr>
<tr>
<td>MARD Plan Variant</td>
<td>0</td>
<td>-51</td>
</tr>
<tr>
<td>Base estimate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soai Rap</td>
<td>-3</td>
<td>-56</td>
</tr>
<tr>
<td>MARD Plan</td>
<td>-3</td>
<td>-54</td>
</tr>
<tr>
<td>MARD Plan Variant</td>
<td>-2</td>
<td>-52</td>
</tr>
<tr>
<td>Pessimistic estimate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soai Rap</td>
<td>-3</td>
<td>-56</td>
</tr>
<tr>
<td>MARD Plan</td>
<td>-3</td>
<td>-54</td>
</tr>
<tr>
<td>MARD Plan Variant</td>
<td>-2</td>
<td>-52</td>
</tr>
</tbody>
</table>

Table 2. IRR and CB-ratio.

<table>
<thead>
<tr>
<th></th>
<th>Base estimate</th>
<th>Pessimistic estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IRR (%)</td>
<td>CB-ratio</td>
</tr>
<tr>
<td>Soai Rap</td>
<td>10</td>
<td>1:3</td>
</tr>
<tr>
<td>MARD Plan</td>
<td>10</td>
<td>1:4</td>
</tr>
<tr>
<td>MARD Plan Variant</td>
<td>16</td>
<td>1:7</td>
</tr>
</tbody>
</table>

We have shown that the use of depth-damage functions, based on actual field survey results, proved to be instrumental for the risk-based analysis. The survey provided valuable basic data to construct DDF’s. However, only flood depth is used, whereas flow velocity, flood duration and flood water quality may also be aggravating factors. Furthermore, our damage estimation did not include indirect and intangible damages, as this type of damage data was not collected within this study. Kind (2013) provides a method to carry out a social cost-benefit analysis including intangible damages. When analysing alternative strategies and/or optimizing the selected strategy, this social cost-benefit method should be considered.

CONCLUSIONS

This paper presents a framework to perform a robust cost-benefit analysis as part of a broader assessment of flood risk mitigation strategies. Based on the application on HCMC, we conclude the following about the framework:

i. The probabilistic analysis, in addition to the regular hydraulic modelling, provides essential input for analysing flood risk reduction,

ii. The use of depth-damage functions, based on actual field survey results, proved to be very instrumental for the risk-based analysis,

iii. The robustness analysis carried out by adopting different scenarios provided valuable insight into how the strategies performs under a range of future conditions.
The HCMC-FIM project used the results of the robust CBA as input to a Multi-Criteria Analysis, which included non-economic (i.e. technical and hydraulic impacts, environmental impacts, social impacts and stakeholder support) on top of the economic aspects which followed from the CBA. As such, the most feasible strategy could be selected and advised upon to the HCMC People Committee.

With this HCMC case, we demonstrated a successful application of a framework for robust CBA in urban flood risk management taking into account future uncertainty ranging from climate change, sea level rise, and land subsidence to investment costs, phasing of the investment and macroeconomic growth.

ACKNOWLEDGEMENTS
The research described in this paper is supported by the governments of Viet Nam and The Netherlands by funding the 'Ho Chi Minh City Flood and Inundation Management' project. We would like to thank the Steering Center for Urban Flood Control (SCFC) for the valuable cooperation in the research and for providing the survey results.

REFERENCES