International Conference on Flood Resilience:
Experiences in Asia and Europe
5-7 September 2013, Exeter, United Kingdom

ON THE FLOOD AND INUNDATION MANAGEMENT OF HO CHI MINH CITY, VIET NAM

Ruben Dahm[1*], Ferdinand Diermanse[1], Ho Long Phi[2,3]

[1] Deltares, The Netherlands; [2] Centre of Water Management and Climate Change (WACC), Viet Nam; [3] Viet Nam National University (VNU-HCMC), Viet Nam
[*] *Rotterdamseweg 185, P.O. Box 177, 2600 MH, Delft, The Netherlands; Tel: +31 (0)88 335 8012; E-mail: ruben.dahm@deltares.nl*

ABSTRACT

This paper explores the application of a probabilistic modelling framework to assess multiple strategies to increase long-term flood resilience of an urbanised system. The probabilistic nature of the framework enables the quantification of annual expected damage for combinations of strategies, different measures, and scenarios like climate change, land subsidence and urbanisation. We demonstrate the framework for Ho Chi Minh City, Viet Nam, which ranks among the top ten cities in the world in terms of exposed population affected by climate change. A preferred strategy was identified to increase the city's flood resilience. The case study shows that the framework is capable of quantifying the impact of strategies to increase flood resilience, with specific added value for deltaic areas, where multiple flood forcing factors interact.

KEYWORDS
Climate change; flood hazard management; probabilistic analysis; urban flooding.

1. INTRODUCTION

Resilience to flooding has gained increasing attention over the last decade. In 2004, Walker *et al.* defined social-ecological resilience and in recent years the concept of resilience is increasingly applied to cities and urban drainage management (Gersonius, 2008; Djordjević *et al.;* 2011, Shah and Ranghieri, 2012). Djordjević *et al.* (2011) restated resilience equal to resisting, recovering, reflecting and responding, hence incorporating a required and beneficial component of learning from the past. Shah and Ranghieri (2012) applied the concept of resilience specifically to cities: "A resilient city is one that is able to cope with disaster and climate impacts now and in the future, thereby limiting the magnitude and severity of those impacts." According to Shah and Ranghieri (2012) cities can assess, manage and limit the risks of potential disasters and climate change impact to construct long-term resilience by: i) understanding the level of exposure and sensitivity to a given set of impacts, ii) developing policies and effective programs to reduce impacts, and iii) identifying resources to promote investments that will limit vulnerabilities and enhance adaptive capacity.

As recently as 2007, the World Bank listed Viet Nam within the top five of countries potentially most affected by climate change in a comparative study for eighty-four coastal developing countries (Dagupta, 2008). Projections suggest that there will be an increase in frequency and intensity of tropical storms, thus affecting storm surge on already rising sea levels (WWAP, 2012). Furthermore, according to Nicholls *et al.* (2008) Ho Chi Minh City (HCMC) ranks among the top ten cities world wide in terms of exposed population affected by climate change. As Viet Nam's economic centre, HCMC accounts for 23% of national gross domestic product and 20% of foreign direct investments (ADB, 2010). Consequently, increasing HCMC's flood resilience is eminent. Frequent flooding hampers the fast urban and economic development of HCMC which functions as a key growth centre in the southern part of Vietnam. The Asian Development Bank described four major reasons for HCMC's vulnerability (ADB, 2010). The first apparent reason is that a large part of the land cover has an elevation between 0 and 1 m+MSL (40-45%) and 15-20% has an elevation between 1 and 2 m+MSL, while tide levels near HCMC's main district frequently rise to 1.5 m+MSL. Secondly, due to the attractive economy for migrants, HCMC's population numbers will increase (currently 6.3 million). Furthermore, local spatial planning and changing land use increases vulnerability through decreased infiltration, localized flooding and land subsidence induced by groundwater abstraction. Finally, climatic conditions and flood hazards are already severe and expected to intensify. Understanding the causes for HCMC's vulnerability and the level of exposure to any set of impacts contributes to constructing policies and measures that will lead to long-term urban flood resilience.

Flood prevention has been one of the biggest preoccupations of HCMC authorities in recent years. Therefore, the HCMC People Committee, the executive arm of the centrally governed city, identified the need for an integrated approach for flood and inundation management in HCMC. This approach had to be based on existing sectorial master plans and ongoing projects as well as existing national and local strategies, like facing the impact of climate change on sea levels and precipitation. Therefore, the HCMC People Committee initiated the HCMC Flood and Inundation Management project (HCMC-FIM). Long-term objectives of the study were to contribute to alleviating the flooding and inundation problems of HCMC by i) proposing an integrated approach for flood and inundation management, and ii) strengthening technical and management capabilities of HCMC Steering Centre of the Urban Flood Control Program and relevant Vietnamese agencies.

This paper describes the framework that was developed in the HCMC-FIM project to understand the causes and consequences of flood processes and to asses the impact of flood risk mitigating strategies. The purpose of this framework was to contribute to the policy discussion for long-term resilient urban flood management and its application to HCMC.

2. STUDY AREA

Ho Chi Minh City is located in the basin of the Saigon, Vam Co and Dong Nai rivers, which has a total area of about 2,100 km^2. A cascade of dam reservoirs strongly influences the flow conditions upstream along the Saigon and Dong Nai rivers. The most downstream located reservoirs are the Dau Tieng, Phuoc Hoa and Tri An reservoirs (see Figure 1). The Saigon river flows through the city centre, the Dong Nai and Vam Co are the eastern and western boundaries of the city's water system. Due to its central location, the Saigon river is generally responsible for the flood hazards affecting HCMC the most. High flows on the Vam Co occur in the flood season of the Mekong delta, when Mekong flood waters reach the Vam Co river through canals and over land. The Soai Rap and Dinh Ba estuaries are the main river mouths downstream of the city. These branches connect the city water system with the South China Sea and are crucial gateways for the HCMC harbour. The highest rainfall intensities and river discharges are observed in the period June-December, whereas highest tides are observed in the period September-January.

The area is confronted with flood events on a regular basis. Floods in HCMC are caused by (combinations of) i) high tides in the South China Sea, ii) high intense rainfall on the city, iii) high river discharge due to spilling from the reservoirs after prolonged periods of high rainfall, or iv) diverted flood waters from the Mekong river.

3. MODELLING FRAMEWORK

3.1 Introduction

The main purpose of the HCMC-FIM project was to contribute to alleviating the flooding and inundation problems of HCMC by developing an integrated approach for flood and inundation management. Different strategies of potential flood mitigating measures have been evaluated taking into account several scenarios like climate change and urban development of HCMC. The effectiveness of measures is expressed in terms of risk reduction. This involves the estimation and linkage of flood hazards (probability of flooding) and flood vulnerability (extent of damage that can result from flooding). Sections 3.2-3.4 describe the main aspects related to the flood hazard assessment, section 3.5 describes the damage assessment.

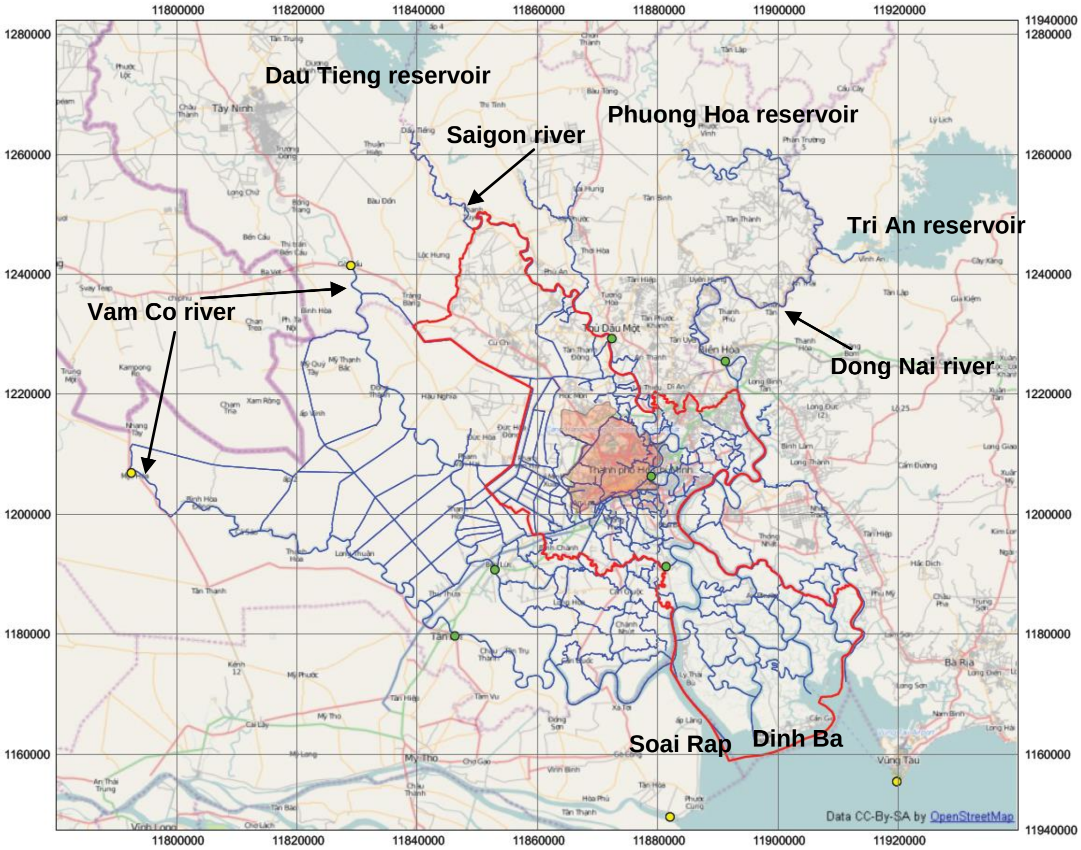

Figure 1. Study area. The red line shows the outline of HCMC province, and HCMC centre is marked as red transparent. The blue lines represent the schematized river and canal system; Green dots represent the water level stations; yellow dots show relevant gauge stations.

3.2 Probabilistic model set up

For a quantitative flood risk and hazard assessment, probabilities of flood extents in the project area are required. Ideally, these probabilities are 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 project area. The best alternative is to execute a probabilistic analysis in which potential flood events are identified and probabilities and hazards of these events are quantified. The principal approach is to define the range of potential (extreme) events that may cause floods and then to subsequently i) simulate these events with a hydrodynamic model to obtain the inundation depths in the project area and ii) derive the probability of occurrence of each event.

The basic elements of the HCMC case are presented in Figure 2. The bell-shaped curves on the left represent the relevant statistical features (see section 3.3) of the forcing factors like discharge, rainfall and sea level. The hydrodynamic model (see section 3.4) translates combinations of realisations of the forcing factors (events) into flood hazards, i.e. water levels in the river system and inundation depths in the flood plains. The probabilistic computations have been executed for different strategies (measures) and scenarios. These scenarios were characterised by combinations of climate change, urban development, mitigating measures and land subsidence. By changing relevant parameters in the hydrodynamic model or adjusting statistical features these scenarios were modelled. The probabilistic computations were executed separately for each month in the year in order to take the seasonal variations in climatologic and hydraulic conditions into account. A wide variety of probabilistic computation methods is available to compute the probabilities (see, e.g., Melchers, 2002). In this project numerical integration was used.

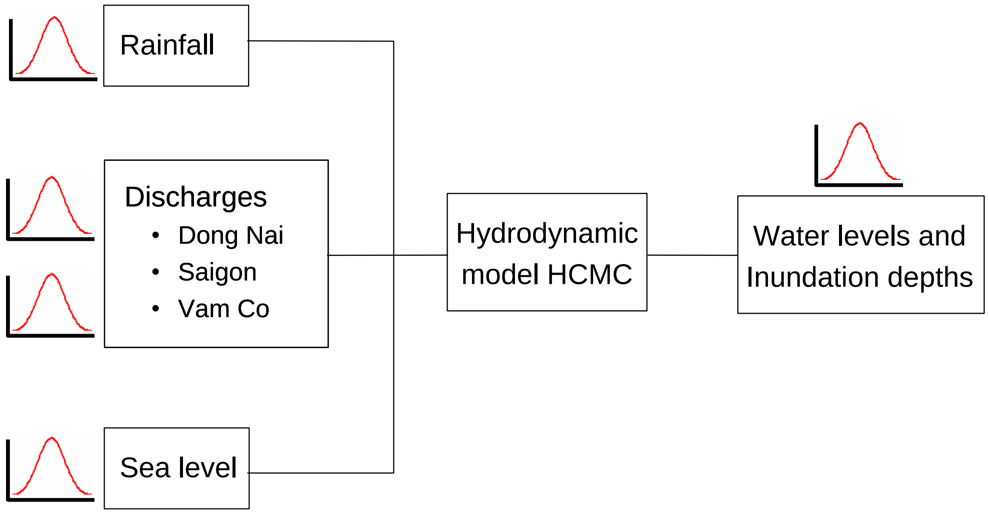

Figure 2. Schematic view of the probabilistic computation for one principal time step.

3.3 Statistical analysis of flood forcing factors

As stated in section 2, HCMC is regularly confronted with flood hazards as a result of (combinations of) high tides, high river discharges and intense rainfall on the city. For each of these flood forcing factors two types of statistics have been prepared as input for the probabilistic model.

- Statistics of extremes: return periods (expressed in years) and associated intensities, water levels or discharges. These relations are derived from observed annual maxima or all peaks over a user defined threshold.
- Statistics of all other possible realisations of the variable under consideration. These are derived from “counting” the number of occurrences.

Note that also statistics of low values like zero precipitation are required. Even though zero precipitation will not lead to flooding, it still may occur in combination with (extremely) high sea levels and as such be part of a flood event. These statistics have been derived for each month in the year separately to take the seasonal variations in climatologic and hydraulic conditions into account. For rainfall and sea level, the available observation series showed significant trends. Therefore, the series were corrected for these trends (“detrending”) before the above described statistics were derived. The observed trends also formed the basis for the definition of future climate scenarios (see section 4).

The sea level time series were tested on the hypothesis of homogeneity. Four statistical tests were applied (see, e.g., Diermanse *et al.* (2010) for an explanation of these tests), Pearson t-test, Spearman’s rank correlation test, Mann-Kendall test and Wilcoxon-Mann-Whitney test. The homogeneity hypothesis was rejected for all tests around the 0.1% level. In other words: the trends were statistically significant. Precipitation trend analysis was executed on three-hourly rainfall events, which are considered to be representative for the typical extreme rainfall events in HCMC. The tests were done for “two-sided” tails, so both positive and negative trends could be detected. For the period of 1961-2007 the P-values are in the order of 5%-10%. This means there is likely to be a trend with a physical cause, but this could not be proven ‘beyond doubt’. A stronger indication of a positive trend in rainfall extremes was obtained by counting the number of events with over 100 mm rainfall in three hours, as observed at the rain gauge located at HCMC airport. In the last decade, this type of event has occurred more than twice as much as in any of the five preceding decades. Even though the existence of a trend line cannot be confirmed with sufficient statistical confidence, it was considered reasonable to apply a trend of 4.6 mm/decade in transforming the observed non-stationary series of annual maximum rainfall into a stationary series.

3.4 Hydrodynamic modelling

A 1D hydrological / hydrodynamic model has been developed for the system of estuaries, rivers and canals around HCMC consisting of the Be, Dong Nai, Saigon, Nha Be, Soai Rap and Vam Co rivers and a selection of its tributaries and canals. This model was developed in the SOBEK modelling suite (Stelling and Duinmeijer, (2003); www.deltaressystems.com). The most important upstream boundary conditions are provided by reservoir spilling. At four downstream locations, water levels have been imposed as boundary conditions. However, measured water levels at these or nearby locations are only available from two field surveys, lasting four days and one month respectively. For all other periods, model boundary conditions were based on regression functions, derived from measured water levels at gauge station Vam Kenh, where sea levels have been monitored for decades. The rainfall runoff process has been schematised with the NAM (Nedbør-Afstrømnings Model) model and parameter values have been provided based on local, Vietnamese expert judgement and maps. Flood hazards maps have been derived from river water levels by the Flood Mapping Module as a part of Delft-FEWS (Werner *et al.*, 2013).

The goodness-of-fit criterion for calibration and validation of the hydraulic model was based on the average of positive differences between measured and simulated water levels (APD), the absolute value of the average of negative differences between measured and simulated water levels (AND) and the standard deviations of the differences. In view of the expected model applications, the main focus of the calibration has been on the correct representation of the peak values. All indicators show root mean square values within the threshold value of 0.1 m for the calibration and validation period, except the AND of the validation (for which the root mean square value was equal to 0.13 m). Therefore, it was concluded that the model has been calibrated successfully for practical applications related to the development of understanding of the system behaviour.

3.5 Potential flood damages

Due to the limited available time it was decided in the HCMC-FIM project to focus only on the direct tangible damages, like damages to buildings, their inventory and roads. Loss of productive land and crop, taking into account paddy, fruit trees and forest, loss of other (grass) land and vehicles was also included as direct tangible damages. Furthermore, the costs of cleaning were taken into account. An extensive field survey was conducted for “representative” districts in the city. Based on the surveys, potential damages per m^2 were estimated for different land use types. These estimated potential damages were adjusted according to GDP projections for Viet Nam for the different time horizons assessed in this project (ADB, 2010). Furthermore, it was estimated from expert opinion what the maximum amount of damage to the assets would be given a certain water level. Potential damages were subsequently estimated and related to scenarios of inundation maps. This resulted in a set of damage functions describing the relation between inundation depth and direct damage for each of the categories described above. Total damages were subsequently derived from the combination of i) surface area of inundated area, ii) corresponding inundation depths from the flood hazard analysis, iii) land use maps, and iv) the damage functions. Flood hazard maps and associated damages were derived for a range of return periods. The expected annual damage (EAD) was subsequently computed as follows:

$$\mathrm{EAD} = \int_0^\infty D(f)\,df \tag{1}$$

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 P, i.e.: f = 1/P.

4. STRATEGIES AND SCENARIOS

We assessed the impact of different flood management strategies on their potential contribution to reduce the flooding in HCMC and increase its resilience. These strategies primarily increase the threshold capacity of the system. Although De Graaf *et al.* (2007) described this as a threshold against variability, we approach this in a broader setting. The modelling framework encompassed scenarios on climate variability, climate change, land subsidence and spatial planning. Three strategies and a reference case were assessed:

1. Reference situation;
2. MARD Plan;
3. MARD Plan *Variant*; and
4. Soai Rap barrier.

The MARD Plan, as originally presented in 2008, envisages the protection of the city centre of HCMC and upstream urban and rural areas (MARD, 2008) with 170 km of dykes and twelve tidal barriers. Drainage will be facilitated by approximately seventy small sluices and culverts through the proposed main dyke structure. The third strategy, the MARD Plan *Variant*, differs from the original MARD-plan in three ways. It i) provides additional protection from the northwest, preventing uncontrolled inflow, ii) leaves the lowlands south and west from HCMC for storage of tidal river water, and iii) allows peak floods from the Saigon river to be retained north and west of the HCMC urban area. The fourth strategy, the Soai Rap barrier, aims at the reduction of the tidal hazard in the HCMC area. The barrier is located in the Soai Rap river just downstream of the Vam Co confluence, as suggested by Ho Chi Minh University of Industry.

These strategies have been tested for different scenarios of climate change: 0.3 m sea level rise by the year 2050 and a 0.75 m increase by the end of the 21st century (MONRE, 2009); 10% and 20% increase in rainfall intensity in the years 2050 and 2100 respectively. Subsequently, the strategies have been tested on a land fill scenario were the elevation of newly developed urban areas is to be filled up to 2 m+MSL. This land fill scenario was based on the HCMC regional and urban master plans for 2025, which deals with the expected population growth of HCMC (HCMC People's Committee, 2010). Furthermore, land subsidence based on spatially distributed predictions for the period 2005-2025 and 2005-2050 has been assessed. These scenarios have been combined in the overall analysis. The impacts of the strategies on the water levels in the river system in and around HCMC have been assessed for four time horizons: 2010, 2025, 2050 and 2100.

5. RESULTS AND DISCUSSION

The flood hazard and damage assesment provided insights in the ratio of costs (investment and maintanance) versus benefits (damage reduction) for the three proposed strategies. The MARD plan *Variant* has the lowest costs of the three strategies and has equal or higher economical benefits. Other criteria have been considered as well in the HCMC-FIM project. For this purpose a multi-criteria analysis was executed to support the comparison of strategies for sound flood and inundation management in HCMC. This multi-criteria analysis assessed three different sets of criteria: technical criteria, support criteria, and financial-economic criteria. The technical criteria included the assessment of the hydraulic performance of each strategy, and an assessment of (i) *flexibility;* the extent in which its implementation can be phased, while obtaining flood risk reduction and allows for adjustments in the course of the implementation, (ii) *environmental impacts* on, among others, valuable terrestrial and aquatic ecosystems, biodiversity, water quality and salt intrusion, and (iii) *robustness*; the extent in which the strategy is sensitive for (and can cope with) uncertainties related to climate change, land subsidence and urban development was reviewed. The weighing of the importance of each set of criteria is a matter of political decision making aimed at a well-considered decision on the integrated flood management strategy for the HCMC area. Therefore, the weigh factors were given by the authorities of HCMC represented during two workshops.

The MARD Plan and the MARD Plan *Variant* were largely comparable with respect to the technical and support criteria, whereas the Soai Rap strategy performed significantly worse. The MARD Plan and MARD Plan *Variant* strategies also scored best in stakeholder support for various reasons, apparently the secured and clear benefits in terms of inundation protection had strong appeal. The results for the MARD Plan and MARD Plan *Variant* were also rather similar when uncertainties regarding the criteria were taken into account. The biggest difference between these two strategies was observed with respect to the cost-benefit criterion, which leads to the recommendation to opt for the MARD plan *Variant*.

The proposed strategy also implies a mainstreaming factor that discourages 'normal' development in HCMC's lowland. The original MARD's dyke system to protect most flood prone areas may nurture overconfidence of both decision maker and community, creating a risk transfer to the future. This could be considered as an additional disadvantage of the original MARD plan and, hence, an advantage of the MARD plan *Variant*.

6. CONCLUSIONS

The probabilistic framework for flood hazard and flood risk assessment was successfully applied for the development and assessment of purpose of flood management strategies for Ho Chi Minh City. The probabilistic nature of the framework enabled the quantification of the annual expected damage for combinations of strategies and scenarios. The various strategies and development scenarios were implemented in the hydrodynamic model, which is the core of the framework. As such, investment costs of mitigating measures could be compared with expected annual reductions in damages. Based on the cost-benefit analysis, a preferred strategy was identified to increase flood resilience in the face of climate change, land subsidence and urbanisation. We demonstrated the framework for the Ho Chi Minh City case; however it can be applied virtually anywhere. The framework has specific added value for deltaic areas, where multiple flood forcing factors interact.

7. ACKNOWLEDGEMENTS

We thank the governments of Viet Nam and The Netherlands for funding the 'Ho Chi Minh City Flood and Inundation Management' project. Furthermore, we thank the consultants of Royal HaskoningDHV, Haarlem Hydraulics and Deltares for their valuable input in the project. Finally, we thank Marjolein Mens for her valuable comments on earlier versions of this paper.

8. REFERENCES

Asian Development Bank, (2010). *Ho Chi Minh City Adaptation to Climate Change*. Manilla, Phillipines.

Dasgupta S., B. Laplante, C. Meisner, D. Wheeler, and J. Yan. (2007). *The Impact of Sea Level Rise on Developing Countries: A Comparative Analysis*. Washington, DC: World Bank.

De Graaf, R.E., F.H.M. van de Ven, and N.C. van de Giesen (2007), Alternative water management options to reduce vulnerability for climate change in the Netherlands. *Natural Hazards* DOI 10.1007/s11069-007-9184-4.

Diermanse, F.L.M., J.C.J. Kwadijk, J.V.L. Beckers and J.I. Crebas. (2010). Statistical trend analysis of annual maximum discharges of the Rhine and Meuse rivers. In: *Climate Change and Hydrological Risk session at the British Hydrological Society*, International Symposium 2010, Newcastle, UK.

Djordević, S., D. Butler, P. Gourbesville, O. Mark, E. Pasche. (2011). New policies to deal with climate change and other drives impacting on resilience to flooding in urban areas: the CORFU approach. *Environmental Science & Policy*, Vol. 14 (2011), pp. 864-873.

Gersonius, B. (2008). Can resilience support integrated approaches to urban drainage management? In: *11th International Conference on Urban Drainage*, Edinburgh, Scotland.

HCMC People's Committee. (2010). *Decision on the adjustment of the HCMC master plan up to 2025.* Ho Chi Minh City, Viet Nam.

Melchers, R.E. (2002). *Structural reliability analysis and prediction*, John Wiley and sons, ISBN0471983241

Nicholls, R.J. et al. (2008). Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates, *OECD Environment Working Papers, No. 1*, OECD Publishing. doi:10.1787/011766488208

MARD (2008). *Water resources planning of flood and inundation management in Ho Chi Minh City*. Report Ministry of Agriculture and Rural Development, Viet Nam.

MONRE (2009).*Climate Change, Sea Level Rise in Viet Nam.* Report Ministry of Natural Resources and Environment, Viet Nam.

Shah, F. and Ranghieri, F. (2012). *A Workbook on Planning for Urban Resilience in the Face of Disasters. Adapting experiences from Vietnam's cities to other cities*. Washington, DC: World Bank

Stelling G.S. and S.P.A. Duinmeijer. (2003): A staggered conservative scheme for every Froude number in rap-idly varied shallow water flows. *International journal for numerical methods in fluids*, Vol. 43 (2003), 12, pp. 1329-1354.

Walker, B., C.S. Holling, S.R. Carpenter, and A. Kinzig. (2004). Resilience, adaptability and transformability in social–ecological systems. *Ecology and Society,* 9 (2): 5.

Werner, M., Schellekens, J., Gijsbers, P., van Dijk, M., van den Akker, O., Heynert, K. (2013). The Delft-FEWS flow forecasting system. *Environmental Modelling and Software* http://dx.doi.org/10.1016/j.envsoft.2012.07.010.

WWAP (World Water Assessment Programme). 2012. *The United Nations World Water Development Report 4: Managing Water underUncertainty and Risk*. Paris, UNESCO.