Chapter 17
Urban Water Management Under Uncertainty: A System Dynamic Approach

Nguyen Hieu Trung, Nguyen Hong Duc, Nguyen Thanh Loc, Dinh Diep Anh Tuan, Lam Van Thinh, and Kim Lavane

Abstract Urban water management (UWM) is a complex task with a number of constraints especially in developing cities. Rapid population growth, inadequate water infrastructure, and inefficiency in water management policies have led to increased pressure on the city's water supply and drainage systems. These challenges, however, remain uncertain in terms of both temporal scale and magnitude of change, such as climate change and sea level rise. A city needs an appropriate framework to support not only short-term adaptation activities but also long-term strategies to enhance its resilience to these uncertainties. Therefore, system dynamics—methodologies to frame, understand, and discuss complex issues and problems—is a suitable approach for such complex UWM issues. The purpose of this chapter is to share our experiences in applying a system dynamics approach in Can Tho City, Vietnam. The study went through several steps that involved identifying key stakeholders and tools to support decision making, recognizing exogenous uncertainties and potential measures with their effectiveness indicators, building models to support decision making in present and future scenarios related to the UWM, and engaging stakeholders during the study approach to ensure the complex model results were well taken up and used for their future decisions. Throughout the case study, the system dynamics approach shows its capacity in supporting the city's policy makers and managers in dealing with such interdisciplinary and complex issues.

Keywords Urban water management · System dynamic · Robust decision support · Stakeholder engagement · Flood · Water pollution · Scenario analysis · Climate change · Sea level rise

Nguyen Hieu Trung (✉)
College of the Environment and Natural Resources, Can Tho University, Can Tho, Vietnam

Research Institute for Climate Change, Can Tho University, Can Tho, Vietnam
e-mail: nhtrung@ctu.edu.vn

Nguyen Hong Duc · Nguyen Thanh Loc · Lam Van Thinh · Kim Lavane
College of the Environment and Natural Resources, Can Tho University, Can Tho, Vietnam

Dinh Diep Anh Tuan
Research Institute for Climate Change, Can Tho University, Can Tho, Vietnam

M. A. Stewart, P. A. Coclanis (eds.), *Water and Power*, Advances in Global Change Research 64, https://doi.org/10.1007/978-3-319-90400-9_17

17.1 Introduction

Can Tho City is one of the five major cities in Vietnam that is located in the at the center of the Vietnamese Mekong Delta, an area where water is central to everyday life and underpins the local economy, including agriculture, aquaculture, transport, and tourism. With a population of 1.25 million inhabitants in 2014, population growth rate of 9.7%, and about 52% of the population living in urban districts, the city's clean water requirements for household use, services, and manufacture are currently under pressure due to rapid urbanization, increase in upstream water uses, climate change, and sea level rise (World Bank 2014; CSIRO 2012). Moreover, limited investments in water supply and sanitation infrastructure and improper maintenance, especially in areas of rural-urban interface (Neumann et al. 2013), have led to surface water pollution, causing a significant decline in groundwater storage and quality (Moglia et al. 2012). In addition, land subsidence has been estimated and observed at a rate of 1–2.5 cm/year (Ramalho 2017; Erban et al. 2014) due to overexploitation of ground water.

The major challenges for urban water management (UWM) in Can Tho City include not only a lack of infrastructure, management institutions, and financial resources, as mentioned above, but also uncertainty in future socioeconomic development and changes in natural conditions both on a temporal scale and on a magnitude scale associated with global, regional, and national developments. Therefore, this study applied a system-dynamic approach to frame, understand, and discuss complex issues and problems so that it could inform the stakeholders and decision makers in Can Tho City of effective measures to control inundation and water quality and, as a result, to reduce the impacts of uncertainty factors.

The study was implemented for 18 months (from June 2015 to December 2016) in Ninh Kieu District, Can Tho City. Ninh Kieu District is the most developed and most important district in the city, with a population of 209,274 people and an area of 29.22 km^2. With rapid socioeconomic development, this district is the representative case in the city for an increasing population and urbanization under the threat of flooding in the rainy season, lacking water supply in the dry season, and issues related to water pollution.

17.2 Study Approach

The study was conducted based on a comprehensive and community engaging framework, the Robust Decision Support (RDS) framework developed by RAND Corporation. In this framework, the following six steps have been performed.

1. Identify key stakeholders and available tools
2. Define urban water challenges and potential solutions
3. Understand the perception of local community on water demands and their view on future water issues

4. Project the future socioeconomic scenarios
5. Evaluate the effectiveness of the proposed inundation and pollution control measures
6. Inform stakeholders on key findings and consult them for suitable inundation and pollution control measures

17.2.1 Step 1: Identify Key Stakeholders and Available Tools

In step 1, we reviewed existing literature and organized meetings with key informers and experts to identify key stakeholders and tools to support the decision-making process for UWM planning.

17.2.2 Step 2: Define Urban Water Challenges and Potential Solutions

For step 2, a stakeholder consultation workshop was organized (Fig. 17.1) to discuss the case study's water challenges and potential solutions. The stakeholder mapping method (Mitchell et al. 1997) was used to reconfirm the key stakeholder list from

Fig. 17.1 Stakeholder consultation workshop to discuss water challenges and potential solutions

step 1 and to identify the level of the stakeholders' influence/power and interest on issues relating to the clean water scarcity in the city. Participants were local city department leaders, business leaders, community groups, and experts. The participants discussed in groups

- to recognize exogenous uncertainties (X) both in socioeconomic and in natural changes,
- to propose potential inundation and pollution control measures (levers, L),
- to define indicators to measure the measures' effectiveness (M), and
- to delineate the relationships (R) among X, L, and M.

17.2.3 Step 3: Understand the Perception of Local Community on Water Demands and Their View on Future Water Issues

To understand the perception of local community on water demands and their view on future water issues, we interviewed 200 households in the study area (Fig. 17.2). The survey asked about the water demands, water uses, water saving practices, and especially, how gender played a role in these practices.

Fig. 17.2 Household survey to understand the perception of local community on water demands and their view on future water issues

17.2.4 Step 4: Project the Future Socioeconomic Scenarios

The projected scenarios were defined based on different time scales (present and future) and the city's socioeconomic scenarios (population growth rate, economic development plans, and water demands). VENSIM, a system dynamic model developed by Ventana System Inc., was used to estimate the total volume and quality of waste water releasing from major waste water sources of the study area (domestic, markets, hospitals, and offices) according to the projected socioeconomic scenarios. Because of the limited time and budget, this study projected only the level of chemical oxygen demand (COD).

The socioeconomic scenarios were defined based on the population and economic growth, such as the current growth rate (growth rate during 2004–2014), the target growth rate according to Decision on Socioeconomic Development Plan of Can Tho City to 2020 and Vision to 2030 by Prime Minister in 2013, and a faster growth rate scenario (target growth rate +10%).

17.2.5 Step 5: Evaluate the Effectiveness of the Proposed Inundation and Pollution Control Measures

An existing storm water management model (SWMM) (Rossman 2015) developed for Ninh Kieu District by Huong and Pathirana (2013) was updated with newest data of drainage network (Fig. 17.3). The model's inputs were waste water source discharges and COD resulting from the VENSIM model (step 4), rainfall and tide data (including climate change scenarios in year 2030 according to Van et al. 2012), reservoir and permeable area (according to the current and the proposed measures), and the socioeconomic development scenarios in step 4.

The outputs of the SWMM model were the projected inundation level, volume, and duration and the COD concentration in the water drainage network for each inundation and pollution control measure. Two groups of measures were water uses (saving water) and wastewater treatment (decentralized or centralized).

Key findings from these models were presented at a follow-up workshop with local decision makers to assess the model's utility and to get feedback on how to fine-tune the RDS framework.

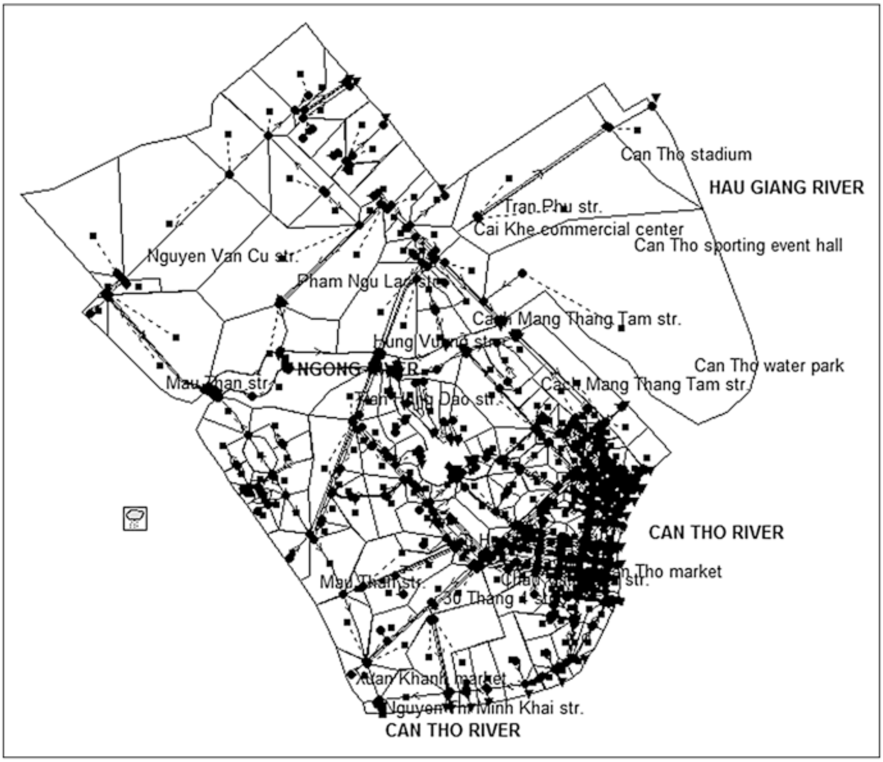


Fig. 17.3 Water drainage network in the storm water management model (SWMM) model (Updated from Huong and Pathirana 2013)

17.2.6 Step 6: Inform Stakeholders on Key Findings and Consult Them for Suitable Inundation and Pollution Control Measures

After the models and scenarios were modified according to the stakeholder's recommendations in the follow-up workshop, we organized the last workshop to inform them of the key findings from the models and to consult them about the suitable inundation and pollution control measures for current and future scenarios (Fig. 17.4). To help the stakeholders take up the key information more easily, the effectiveness/robustness indicators of the measures were visualized in color-ranking tables, with darker red meaning less robustness (negative to no effective) and darker green meaning more robustness (positive to very effective). Concerning investment cost for the proposed measures, due to data limitations levels of investment costs were provided in qualitative ranking forms (very low, low, medium, high, and very high).

Fig. 17.4 Final stakeholder consultation workshop to propose short-term and long-term inundation and pollution control measures

17.3 Results and Discussion

17.3.1 Key Stakeholders and Their Roles in UWM

Stakeholders with high interest in and high influence on UWM were People's Committee (PC), People's Council (PCO), the Department of Construction, the Climate Change Coordinating Office, and the Department of Natural Resources and Environment. These stakeholders were the highest governmental management departments or offices of the city that directly manage issues related to UWM. Among them, PC and PCO were considered to have the highest interest and power, as they are the final decision makers. Other stakeholders appeared to have slightly lower interest and power. However, they still played a significant role as they were major consultants for PC and PCO.

Stakeholders with high interest in and medium influence on UWM were the Department of Planning and Investment; the Centre of Fresh Water and Sanitization, which belongs to the Department of Agriculture and Rural Development; Can Tho Water Supply—Sewerage Joint Stock Company (WSSC); and Industrial Project Management Boards. The Department of Planning and Investment was engaged in assessing and issuing the investment of the UWM projects based on the feedback from the direct UWM-related departments, such as the Department of Construction and the Department of Natural Resources and Environment. WSSC was responsible for urban water supply and drainage, the Centre of Fresh Water and Sanitization was responsible for rural water supply, and the Industrial Project Management Boards managed the use of water and the waste water in the city's industrial zones.

Stakeholders with medium interest and medium influence were the Department of Transportation, the Department of Information and Communications, the Department of Health, ODA Project Management Units, Can Tho City Institute for Socio-economic Development Studies, regional universities, and research institutes. These stakeholders were occasionally asked for feedback for the UWM projects but were not directly engaged in decision-making procedures.

Stakeholders with high interest but low influence were local community, companies, factories, and enterprises. They were daily water users and released significant amounts of wastewater to the environment. However, they were informed of the UWM projects only when these were about to be implemented, rather than having direct channels to engage in the planning, designing, and decision making of the projects.

This stakeholder analysis was based on information obtained from the first stakeholder consultation workshop organized in August 2015 (step 2). Some roles of stakeholders may have changed according to new institutional arrangements.

At the household level, results from household surveys (step 3) also confirmed that the local communities had very high interest in UWM since their livelihoods were based mainly on surface water and pipe water supplied by Can Tho WSSC. Water was used daily mainly for cooking, washing, and sanitation. Water uses for business, manufacture, and services accounted for 24.88% of the surveyed households. These enterprises were mainly small restaurants, coffee shops, car washing stores, bottled water production stores, and so on. In the rainy season, a few households used rainwater for gardening, yard washing, and toilet flushing.

Local communities somehow had less influence on the quality of the supplied water. Over 40% of the interviewees reported that there were occasionally problems related to tap water quality, such as pungent and chlorine smell, or yellow and muddy water. They thought that these problems were probably due to washing water tanks in the WSSC, water disinfection, and repairing water pipes.

The household survey, however, noted that it was the households that were highly influential in changing the domestic water demand: 68% of the interviewees responded that their household water demand increased because of hotter weather, more family members, and more demands for washing machines, showering, and so forth, and they were well aware that they needed to save water. Over 70% of households were applying some water saving actions in daily activities, especially in the dry season. A majority of people were knowledgeable of water saving, and the average of potential monthly saved water per person was 0.6 m^3 (around 20 l/day).

The surveys also found that women had higher interest and understanding of water-related issues. More women than men attended community meetings related to water or environmental issues. They also played a higher role in decision making on water usage for households and small businesses. Moreover, since they were the ones to directly pay the bill, they mostly applied water-saving actions in the family (Fig. 17.5).

17.3.2 Urban Water Challenges and Potential Solutions

In the first stakeholder consultation workshop (step 2), the participants also discussed the possible exogenous uncertainties (X), proposed potential inundation and pollution control measures (levers, L), defining indicators to measure the measures' effectiveness (M), and delineating relationships (R) among X, L, and M.

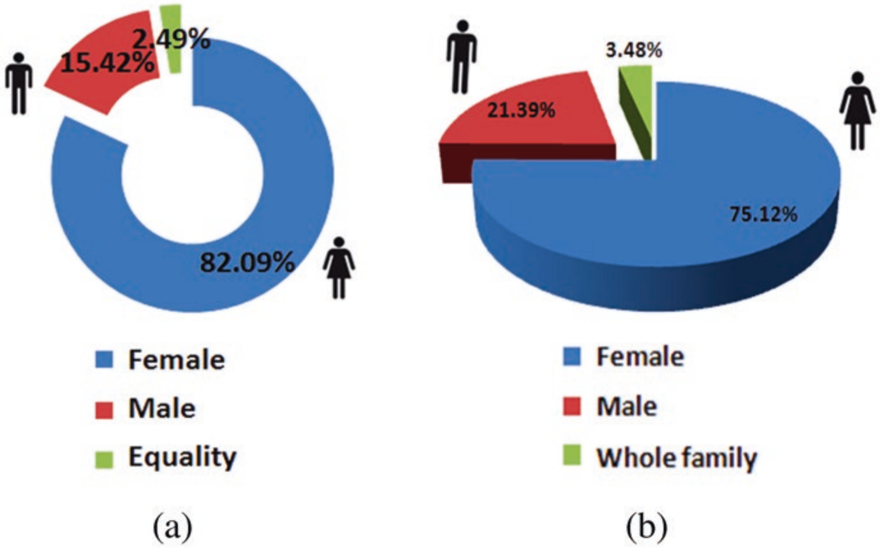


Fig. 17.5 Household's water demands (**a**) and water-use decisions (**b**) by gender

The group discussion shared the same opinions on the key uncertainties (X), their trends, and the degree of uncertainty. The exogenous uncertainty factors X were divided into socioeconomic and nature environment factors.

As for socioeconomics, water demands of the city would increase and be highly uncertain due to the unpredictable migratory increases, together with the uncertainty in urbanization and industrialization growth.

As for the natural environment, the most uncertainty comes from the impacts of climate change. Climate change would cause abnormal floods because of extreme rainfall in the rainy season, not only in Can Tho but also in the whole Mekong River basin. In the dry season, the dropping of water discharge from the Mekong River and local rainfall would increase the risk of seawater intrusion, and combined with a lack of proper waste management, this would increase water pollution. When water is salty and polluted, more uncontrolled groundwater extraction would lead to more land subsidence and, as a consequence, increase inundation in the city. Since saline intrusion is projected to be not too serious for the city in the near future, two main water issues that the city should be now aware of are inundation and water pollution.

The workshop also identified potential measures to reduce inundation and water pollution (levers, L). Two types of measures were identified: structural and non-structural measures. After group discussions and plenary discussion, stakeholders selected the following measures for further evaluation of their effectiveness to reduce inundation and pollution:

- Structural measures (L_s): increasing permeable area (L_s1), upgrading retention reservoirs (L_s2), and upgrading drainage system (L_s3)

Table 17.1 Metrics to evaluate the effectiveness of the proposed measures

Indicators	Metrics (M)
Water demand	Domestic use: current: 130 l/person/day
	Target development: 180 l/person/day
	Fast development: 220 l/person/day
	Saving: 90 l/person/day
Water quality: chemical oxygen demand concentration	Domestic use water standard (TCVN 02–01)
	Drinking water standard (QCVN 01/2009-BYT)
	Surface water for ecology (TCVN 08/2008)
	Percentage of clean water accessed in urban area (100%)
Inundation: inundation points, volume, duration, and level	Point, volume (m^3), duration (min), and height (m), to be defined based on baseline data

- Nonstructural measures (L_n): encouraging water saving (L_n1) and household septic tanks waste water treatment (L_n2)

To evaluate the effectiveness of the measures, stakeholders recommended measures' performance and thresholds (M), as displayed in Table 17.1. Based on the socioeconomic development scenarios, water demand levels were estimated accordingly. At the current economic development, the domestic water demand is 130 l/person/day, while in higher economic development, this level would increase to 180–220 l/person/day. The responses from the household survey showed that if water saving measures are applied, domestic water demand can dropped to 90 l/person/day.

Figure 17.6 shows the relationship diagram (R) drawn by stakeholders during the workshop. This diagram defines the cause and effect relationships among the uncertainty factors X, proposed measures L, and metrics M to evaluate the achievement of L. This exercise was a very efficient approach to help stakeholders visualize the UWM problems and well reflect stakeholder perceptions of the issues discussed. Moreover, such diagrams resulting from stakeholder discussions will help modelers know users' expectations for the outputs (M) and so take into account more realistic and sufficient data and parameters (X) and define better scenarios (X and L) to address stakeholder concerns.

17.3.3 The Impacts of Socioeconomic Development on Total Waste Water Discharge and Quality

The relationship R defined by stakeholders was transferred into a system dynamic model (Fig. 17.7). The model allows users to change parameters according to the socioeconomic scenarios. Three scenarios were analyzed to project socioeconomic development:

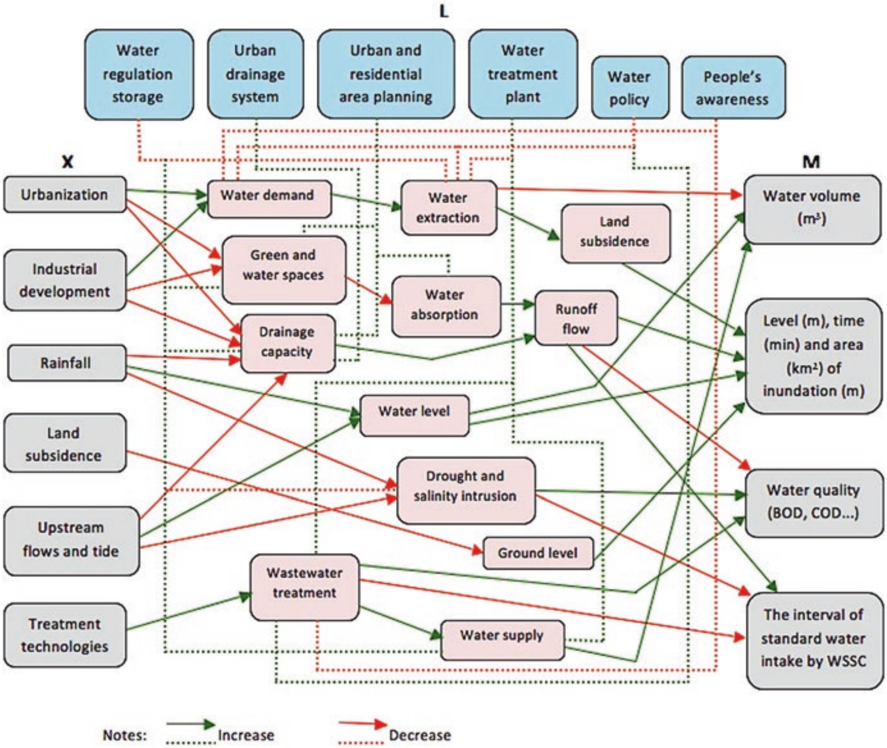


Fig. 17.6 Relationship diagram (R) drawn by stakeholders during step 2 defining the cause and effect relationships among the uncertainty factors X, measures L, and metrics M to evaluate the achievement of L. Continuous lines from X show the consequences of X to the city's water-related problems (pink boxes); dotted lines from L to pink boxes show which problems L will impact. Green lines represent increases; red lines represent decreases

- Baseline scenario X_e0: Current growth rate (based scenario)
- Target scenario X_e1: Target growth rate
- Fast growth scenario X_e2: Faster growth rate

In the baseline scenario, X_e0, Can Tho City's population will increase at the current rate (Fig. 17.8). In the target scenario X_e1 and fast growth scenario X_e2, the population growth rate was projected to increase 9.7% in the 2030s according to the projection in the Decision on Socioeconomic Development Plan of Can Tho City to 2020 and Vision to 2030 by Prime Minister in 2013.

In baseline scenario X_e0, the gross domestic product (GDP) of the city increases with the same rate as the previous period (2004–2013 increased about 14,5%/year and income per person was about $5630 in 2013). In the target scenario X_e1, the city's GDP is projected to increase 15% per year and income per person in 2030 would achieve $14,200. In the fast growth scenario X_e3, the GDP would increase an additional 10% higher than the target scenario.

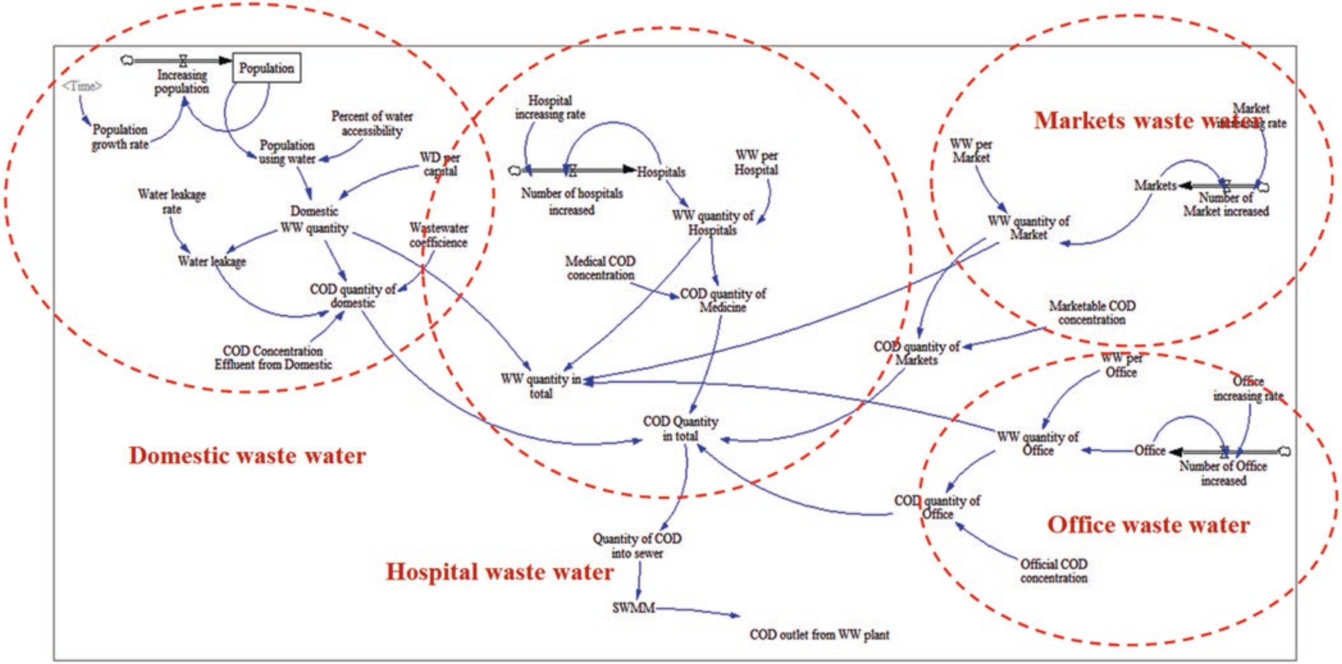
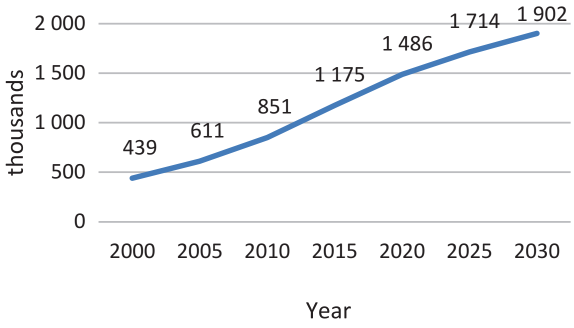


Fig. 17.7 The VENSIM model to project water quality and quantity in different socioeconomic and scenarios

Fig. 17.8 Projection of Can Tho City's population at current rate



Besides projecting the wastewater volume and the quality of water that flows into the drainage water system, the model was used to estimate the effectiveness of nonstructural measures such as saving water (L_n1) and treatment of wastewater at the household level (L_n2).

Figure 17.9 presents changes in the quantity of wastewater and COD load into the drainage network in different socioeconomic scenarios (X_e0, X_e1, and X_e2) and the impacts of nonstructural measures (L_n1, L_n2) in each socioeconomic scenario from 2015 to 2030. The model results suggest that socioeconomic development rates will impact strongly the total volume of wastewater and the pollution sources. Up to 2030, in the baseline scenario (X_e0), the total volume of waste water will increase sharply, from around 6.5 million m^3/year in 2015 to about 8 million m^3/year in 2030, and COD load into the environment will increase from around 1.45 million kg in 2015 to almost 2 million kg in 2030. Compared to the baseline scenario X_e0, waste water volume and COD load of the target scenario X_e1 in 2030 will increase significantly: around 28% and 20%, respectively. For the fast development scenario X_e2, the increase of waste water quantity and COD load will be 50% and 38%, respectively.

17.3.4 *The Efficiency of the Measures to Reduce Inundation and Pollution*

Figure 17.9 shows that in the baseline scenario, if waste water is treated at the household level by simple techniques such as septic tanks ($X_e0 \cdot L_n2$), compared to the baseline scenario, in 2030 the total COD load can be reduced by nearly 30%, even though the total volume remains the same. In the target development scenario, household water saving ($X_e1 \cdot L_n1$) will be significantly reduced in both the volume of waste water and COD load: 33% and 24%, respectively. Similarly, for the fast development scenario ($X_e2 \cdot L_n1$), household water saving will reduce the amount of wastewater by 54% and the COD load by 42%.

To evaluate the impacts of the structural measures, we used the SWMM model. We took three structural measures into account, as agreed in the second stakeholder consultation workshop (step 6): increasing 1% permeable area (L_s1) by upgrading

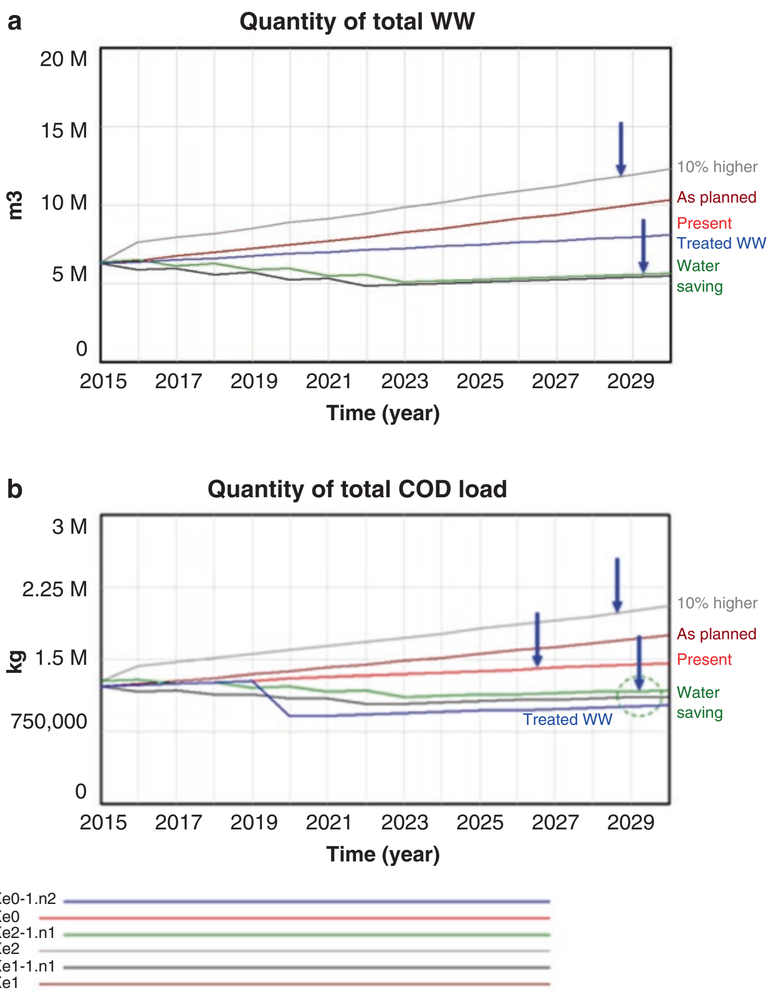


Fig. 17.9 The changes in waste water (WW) quantity (**a**) and chemical oxygen demand (COD) load (**b**) under different scenarios as indicated by the key below: X_e0, current growth rate (base scenario); X_e1, target growth rate; X_e2, target growth rate +10%; $X_e0{\cdot}L_n2$, X_e0 + household septic tanks; $X_e1{\cdot}L_n1$, X_e1 + water saving; Xe2·Ln1: Xe2 + water saving

the sidewalk area, upgrading the retention lake (L_s2), and upgrading one pipeline in the drainage system at a flooding hotspot (area from 30/4 street to Hoa Binh street) (L_s3). To compare their effectiveness, we used “no action” as a baseline measure (L_s0). The model analyzed a number of scenarios—combinations of socioeconomic scenarios (X_e) and climate change and sea level rise scenarios X_n0 (current rainfall and water level) and X_n1 (projected rainfall and water level in 2030)—but in this chapter we show only some scenarios to demonstrate model results and their implications for UWM.

Population as 2015 & Socio-economic growth as 2015					
Metrics (M)		Levers (L)			
		L_s0	L_s1	L_s2	L_s3
Flooding	*Point*	311	0%	3.54%	0.96%
	Volume (m^3)	634,948	1.19%	4.98%	4.85%
	Time (hour)	1.75	0.57%	0%	100%
	Level (m)	0.41	0%	0%	100%
Water quality	*COD concentration (mg/l)*	206	0%	0%	38.35%
Investment & maintenance level			**VL**	**M**	**VH**

Robust 0% 100%
Not Robust 0% -100%

Fig. 17.10 Robustness of the structural measures in the baseline scenario. For definitions of levers, see text. *VL* very low, *M* medium, *VH* very high

Projected population in 2030s & Socio-economic growth as 2015													
Metrics (M)		Levers (L)											
		L_s0	L_s1	L_s2	L_s3	L_n1	L_n2	$L_s1.L_n1$	$L_s2.L_n1$	$L_s3.L_n1$	$L_s1.L_n2$	$L_s2.L_n2$	$L_s3.L_n2$
Flooding	*Point*	326.0	0.6%	3.4%	0.3%	0.3%	0.0%	0.3%	4.3%	1.8%	0.6%	3.4%	0.9%
	Volume (m^3)	1270603.0	0.6%	9.1%	5.9%	25.5%	0.0%	26.1%	30.9%	30.7%	0.6%	9.1%	5.9%
	Time (hour)	8.7	0.2%	11.5%	97.0%	55.3%	0.0%	55.5%	58.7%	97.1%	0.2%	11.5%	97.2%
	Level (m)	0.5	0.0%	2.1%	89.4%	4.3%	0.0%	6.4%	4.3%	89.4%	0.0%	2.1%	89.4%
Water quality	*COD concentration (mg/l)*	148.0	-1.4%	0.0%	14.2%	-18.2%	39.9%	-17.6%	-18.2%	5.4%	40.5%	41.2%	53.4%
Investment & maintenance level			**VL**	**M**	**VH**	**VL**	**VL**	**VL**	**M**	**VH**	**VL**	**M**	**VH**

Robust 0% 100%
Not Robust 0% -100%

Fig. 17.11 Robustness of the proposed measures in 2030 for the socioeconomic baseline scenario and climate change and sea level rise scenario ($X_e0{\cdot}X_n1$). For definitions of levers, see text. *VL* very low, *M* medium, *VH* very high

Figure 17.10 shows the effectiveness of the proposed structural measures in 2015 for the baseline scenario $X_e0{\cdot}X_n0$. For stakeholders' reference, the investment and maintenance levels were relatively compared. Compared to the baseline measure L_s0, with the current population increasing the permeable area measure by 1% (L_s1) was slightly robust. However, this measure would be more robust if more permeable areas were allocated in the future. In addition, considering its low investment cost, this solution can be more efficient. Upgrading the retention lake (L_s2) is more robust because it will reduce both the number of inundation points and flood volume. Upgrading the water drainage pipeline (L_s3) is highly robust. However, investment and implementation costs for this measure are very high.

Figure 17.11 presents the robustness of structural and nonstructural measures in 2030 for the socioeconomic baseline scenario and climate change and sea level rise scenario ($X_e0{\cdot}X_n1$). At the lowest investment and implementation costs, increasing permeable area by 1% combined with household wastewater treatment ($L_s1{\cdot}L_n2$) has average robustness. At medium investment and implementation costs, the high-

Projected population in 2030s & Socio-economic growth 10% faster than the city planned										
Metrics (M)		Levers (L)								
		L_s0	L_s1	L_s2	L_s3	L_n1	$L_s1.L_n1$	$L_s2.L_n1$	$L_s3.L_n1$
Flooding	Point	337	0.0%	3.9%	0.3%	3.3%	3.9%	6.8%	4.5%
	Volume (m^3)	1,986,618	0.4%	11.1%	6.9%	49.7%	50.1%	53.5%	50.3%
	Time (hour)	8.90	1.1%	11.2%	97.0%	27.4%	27.5%	38.8%	97.1%
	Level (m)	0.51	0.0%	2.0%	88.2%	9.8%	9.8%	9.8%	88.2%
Water quality	COD conc.(mg/l)	126	-0.8%	-3.2%	13.5%	-34.9%	-34.9%	-34.1%	-9.5%
Investment & maintenance level			VL	M	VH	VL	VL	M	VH

Robust 0% 100%
Not Robust 0% -100%

Fig. 17.12 Robustness of the proposed measures in 2030 for the fast development scenario and climate change and sea level rise scenario ($X_e2{\cdot}X_n1$). For definitions of levers, see text. *VL* very low, *M* medium, *VH* very high

est robustness measure is the combination of upgrading the retention lake and household waste water treatment ($L_s2{\cdot}L_n2$). At very high investment and implementation costs, the highest robustness measure is the combination of upgrading the drainage system and household water saving ($L_s3{\cdot}L_n2$).

Figure 17.12 shows the robustness of the proposed measures in 2030 as in the fast development scenario and climate change and sea level rise scenario ($X_e2{\cdot}X_n1$). In this scenario, only the very high investment and implementation costs will be effective in both inundation and pollution reduction (upgrading drainage system, L_s3). The other measures only be effective will in reduction of inundation. It should be noted that in this study we analyzed only household water treatment as a measure to reduce pollution. Therefore, in 2030, under the pressure of fast socioeconomic development and climate change, more robust solutions for wastewater treatment should be considered (e.g., centralized wastewater treatment).

17.3.5 Stakeholders' Priority on the Proposed Measures

In the final stakeholder consultation workshop (step 6), we presented the color-ranking tables shown in Figs. 17.10, 17.11, and 17.12 and asked them to select the measures that they thought were suitable for short-term (current) and long-term (2030) implementation. For the current situation, stakeholders proposed the combined measure of increasing permeable area, upgrading the retention lake, and household water saving. They explained that this combined measure was simple to implement and not so expensive for investment and implementation. For long-term solutions, based on information provided from the models, stakeholders proposed the combination of upgrading the retention lake, upgrading the drainage system, and household wastewater treatment. However, since this combined measure required high cost and household wastewater treatment required more technical support and monitoring to ensure treatment quality, they agreed that pilot projects needed to be carried out. In addition, the stakeholders recommended more research be conducted to evaluate the other wastewater treatment measures such as semicentralized or centralized wastewater treatment.

17.4 Conclusion

This study shows that the Robust Decision Support (RDS) framework is a comprehensive, logical, and reliable framework. Applying this framework provides a full understanding and visualizes an overview of the issues during the decision-making process. Visualizing the complex model's results with simple color-ranking tables enabled the decision makers to come up with optimal solutions for particular situations (scenarios); therefore, it helps reduce individual and fragmented decision making. The participative nature of the framework would ensure social and political acceptance of the project's outcomes.

However, when the RDS framework was applied, we faced the following challenges. (a) Modeling socioeconomic issues and nature environment issues was complex and time-consuming, and it required a large amount of qualitative data (especially for model calibration and validation). (b) Even though model results were simplified into color-ranking tables, when there were so many scenarios to examine, the many tables provided might cause confusion for stakeholders. (c) The study was interdisciplinary, but it was not always easy to form a complete interdisciplinary research team.

Acknowledgments This study was funded by the Sustainable Mekong Research Network (SUMERNET)—Stockholm Environment Institute (SEI) Asia. We would like to express our gratitude to Dr. Eric Kemp-Benedict, Dr. Chayanis Krittasudthacheewa, Dr. Chu Thai Hoanh, Ms. Ha Nguyen, and Mr. Agus Nugroho from SEI for providing us with great technical and logistic support during the study implementation. We thank our colleagues from the Can Tho City Climate Change Coordination Office, especially Mr. Ky Quang Vinh and Ms. Chau Thi Kim Thoa, for their great assistance in data collection and their close collaboration in ensuring stakeholder engagement during the study implementation. We also would like to thank the staff from the city's departments and offices, researchers from Can Tho University, and local research institutes for their informative discussions in the consultation workshops. Last but not least, we acknowledge the interviewees in Ninh Kieu District for the valuable information they provided during the household survey.

References

CSIRO. (2012). *Planning for sustainable urban water systems in adapting to a changing climate – a case study in Can Tho City, Vietnam*. In: M. Nguyen et al. (Eds.), CSIRO.

Erban, L. E., Gorelick, S. M., & Zebker, H. A. (2014). Groundwater extraction, land subsidence, and sea-level rise in the Mekong Delta, Vietnam. *Environmental Research Letters, 9*(8), 84010 Available at: http://stacks.iop.org/1748-9326/9/i=8/a=084010?key=crossref.b639ea338e342899358515e74a86f960.

Huong, H. T. L., & Pathirana, A. (2013). Urbanization and climate change impacts on future urban flooding in Can Tho city, Vietnam. *Hydrology and Earth System Sciences, 17*(1), 379–394.

Mitchell, R. K., Agle, B. R., & Wood, D. J. (1997). Toward a theory of stakeholder identification and salience: Defining the principle of who and what really counts. *The Academy of Management Review*, *22*(4), 853. Available at: http://www.jstor.org/stable/259247?origin=crossref. Accessed 1 Sept 2017.

Moglia, M. et al. (2012). Application of the water needs index: Can Tho City, Mekong Delta, Vietnam. *Journal of Hydrology*, *468–469*, 203–212. Available at: http://www.sciencedirect.com/science/article/pii/S0022169412007159. Accessed 8 Oct 2014.

Neumann, L. E., et al. (2013). Water use, sanitation and health in a fragmented urban water system: Case study and household survey. *Urban Water Journal, 11*(3), 1–13.

Prime Minister. (2013). *Quyết định 1533/QĐ-TTg năm 2013 quy hoạch tổng thể phát triển kinh tế xã hội Cần Thơ 2020*. Available at: https://thuvienphapluat.vn/van-ban/Thuong-mai/Quyet-dinh-1533-QD-TTg-nam-2013-quy-hoach-tong-the-phat-trien-kinh-te-xa-hoi-Can-Tho-2020-205926.aspx. Accessed 2 Sept 2017.

Ramalho, E. C. (2017). Pore water pressures and slope stability impacts of 25 years of groundwater extraction on subsidence in the Mekong delta, Vietnam. *Environmental Research Letters, 9*. http://iopscience.iop.org/article/10.1088/1748-9326/9/8/084010/meta

Rossman, L. A. (2015). *Storm water management model user's manual*, Available at: http://www.epa.gov/water-research/storm-water-management-model-swmm

Van, P. D. T. et al. (2012). A study of the climate change impacts on fluvial flood propagation in the Vietnamese Mekong Delta. *Hydrology and Earth System Sciences*, *16*(12), 4637–4649. Available at: http://www.hydrol-earth-syst-sci.net/16/4637/2012/. Accessed June 13, 2013.

World Bank. (2014). *Can Tho, Vietnam: Enhancing urban resilience*. Washington, DC: Work Bank Group.