FLOOD RISK MANAGEMENT STUDY FOR THU DUC CITY

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1. Introduction

Thu Duc City is a municipality under the administration of Ho Chi Minh City (HCMC). The city was founded by the Standing Committee of the National Assembly in Dec 2020, and is comprised of Districts 2, 9, and Thu Duc District of HCMC. The city covers 211.56 km2 and the population is 1,013,795 inhabitants. With the establishment of Thu Duc City, it is envisioned that HCMC will be able to better contribute to national economic growth and boost the development in Southern Key Economic Zone. The City has engaged Sasaki to prepare its spatial masterplan, which is mostly completed and expected to be approved by end of 2022.

The joint HCMC – WBG working group (HWG) was initiated at the beginning of December 2021 and was formally launched on 23 March 2022. Its objective is to put in place a structured system of engagement with Ho Chi Minh City (HCMC) that includes a broad range and depth of expertise that the World Bank Group (WBG) has to offer. For the Thu Duc City technical group, WBG has provided support in the following four areas including Review of Thu Duc Masterplan for 2022-2026 and beyond, Analysis and development of policies and investment strategies for key sectors to inform the Thu Duc City Masterplan, Support to the development of options for financial planning and budgeting and Expansion of the support model to the broader HCMC masterplan. As a newly established city within Ho Chi Minh City, Thu Duc City will need substantial investment in infrastructure to achieve its goal of becoming a financial and innovation hub, and a sustainable green city. The City would like WBG to conduct evidence-based analysis on key sectors such as flood risk management and green urban mobility as inputs to the masterplan for better informed decision making for strategic investments.

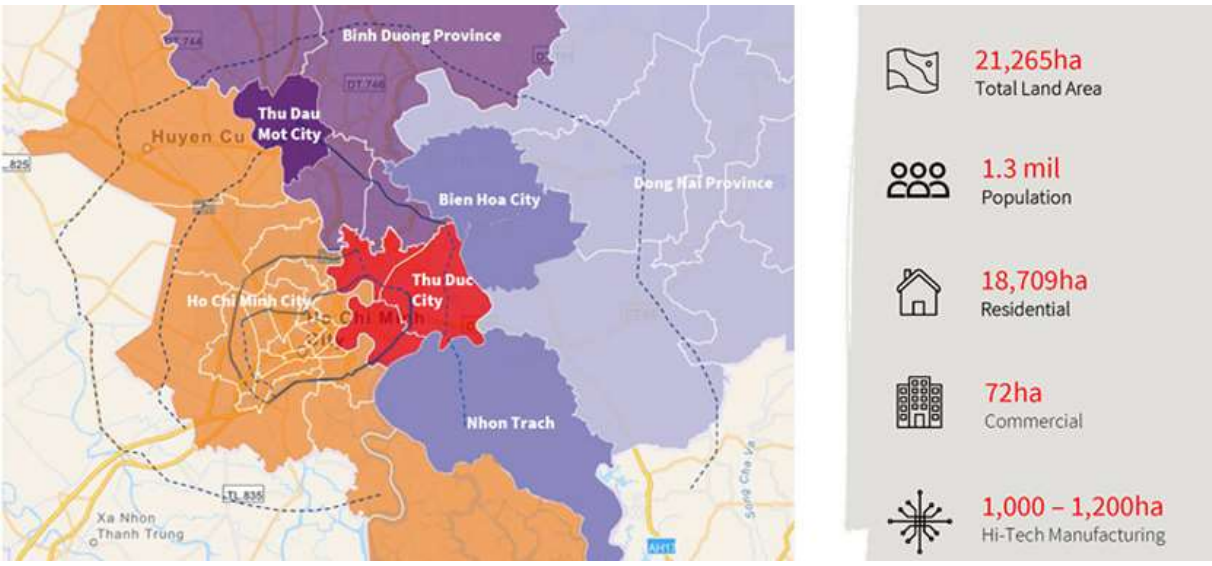


Figure 1 Map showing the newly formed Thu Duc City, a "city within a city" combining three districts of Ho Chi Minh City

This is a summary of the Flood risk study for the Thu Duc city in which approaches and methods is briefly presented in chapter 2; Flood risk management (FRM) analysis in chapter 3; chapter 4 present potential solutions for flood risk mitigation in Northern and Southern sub regions of the city; recommendations on action prioritization in chapter 5 including non-structural and structural investment actions.

2. Approaches and Methods

2.1 Approaches

Flood risk management: The way flood risks develop and can be influenced is presented in the following figure 2. An essential element in this scheme is the distinction between the flood **hazard** and the flood **risk**. The flood hazard refers to the occurrence of floods (depth, duration, flow velocity and frequency) as such, while the risk refers to the damage that is potentially caused by the flood hazard. The figure 2 indicates that the natural hazards (meteorological and sea level) lead stepwise to the eventual flood damage. For each step measures can be identified that aim at the reduction of the ultimate flood damage.

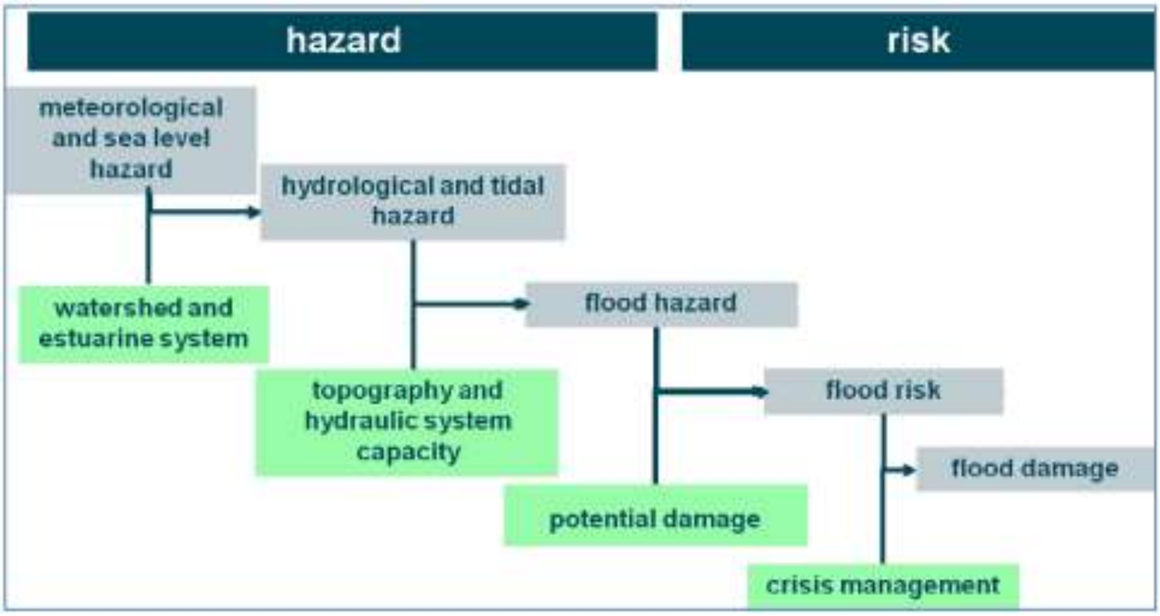


Figure 2 The development of Flood Risk

The integrated management of flood risk is often presented as a combination of the following three components: 1. Flood mitigation, aiming at the reduction of the flood hazard; 2. Flood protection, aiming at the reduction of the vulnerability (or exposure) of people and assets against the damaging impacts of flooding; and 3. Resilience enhancement. This refers to the ability of a system, community or society to cope with the damaging impacts of floods.

Drainage basin identification: Although there are several specific rainwater drainage basins in the Thu Duc city that can be identified in the later stages of planning, in the strategic recommendation based on elevation and river network maps, Thu Duc city needs to be divided into 2 sub-regions for flood study including northeast (NE) and southeast (SE) sub-region as defined in drainage master plan, 2001 (plan 752). Flooding causes and inundation situations in these two sub-regions are different as results of the high elevation, sloping terrain in the north and low lying, relatively flat, with densely canals in the south. Regional drainage basins should be identified with NE and SE and separated by Rach Chiec- Rach Trau Trau channel (see figure 2)

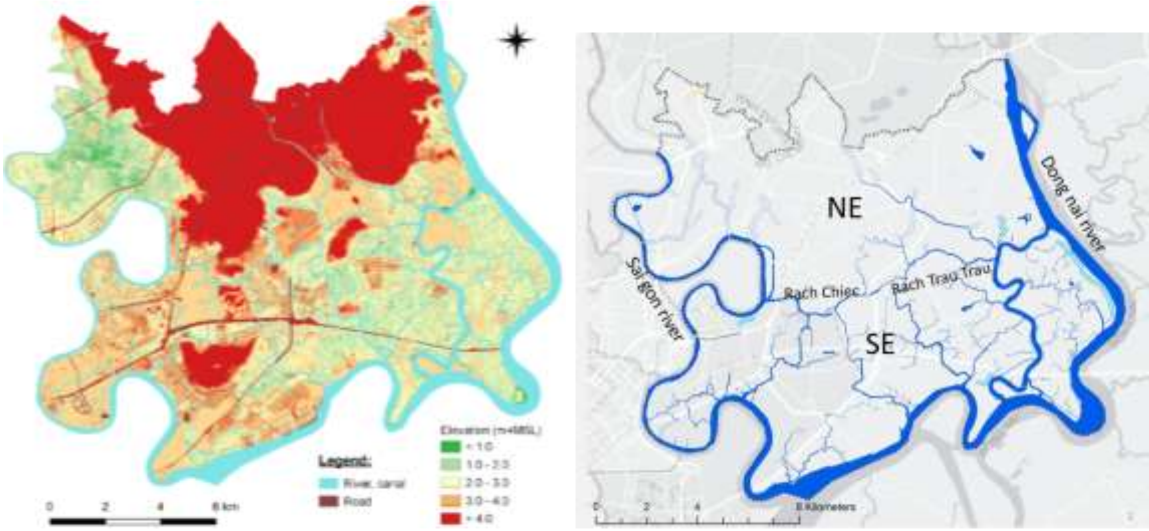


Figure 3 Regional drainage basin identification, Jica plan 2001

In the northern area, existing urban areas located right at the lower of the slope are affected by the flow due to rainwater from highland of the basin with high velocity which are flooded very quickly after 30-45 minutes of rain. The overflow on the street is very dangerous for traveling people on the streets (see figure 4, 5). According to the “Source-Pathway-Receptor” model, solving the flooding problem in the low elevation urban areas is not only trying to increase the drainage infrastructural capacity, but also to reduce peak flow at source and pathway locations.

Figure 4 Flooding in Thu Duc market (left) and Do Xuan Hop street (right), 21/5/2021

Figure 5 Overflowing on To Ngoc Van street (left) and Vo Van Ngan street (right)

Most of the southern area of Rach Chiec and Trau Trau canal is flat and low-lying plain, mainly influenced by water levels on the Dong Nai and Saigon rivers, including floods from upstream and fluctuations of tides downstream impacts. However, the advantage of the southern area of Thu Duc is that the natural canal system is also the potential for the development of water ecological friendly urbans. Therefore, solving the flooding problem in this area should be integrated in the spatial planning with urban development in a sustainable, adapting to CC direction.

The vulnerability to flooding is governed by the city' topography as mentioned above; climate change can lead to more extreme rainfall and to higher extreme water levels in the rivers. Due to natural and manmade causes, the land surface also subsides, thus giving a more unfavorable condition for drainage and flooding.

2.2 Methods

<u>The Source – Pathway – Receptor model</u> can be used to analyze flood flow and impacts then to recommend appropriate solution(s) for flood risk mitigation. This model is useful for flood management on the NE sub region of the Thu Duc city. The model allows to propose Sustainable Urban Drainage System (SUDs) and Green infrastructures (GI) solutions in flood management of the city.

Flood Hazard and Risk modelling:

<u>Flood hazard models:</u> The modelling platform applied in this project, includes the combination of 4 models:

- Hydrological model (NAM) for Dong Nai river basin
- 1D hydraulic model (MIKE 11) for Dong Nai river basin
- Urban storm water drainage model (MIKE Urban) for Thu Duc City
- 2D hydraulic model (MIKE 21) for the flood plain in Thu Duc City

The *hydrological - hydraulic model for Dong Nai river basin* simulates the conditions in the river and estuary system surrounding Thu Duc City and to which the city is draining its excess flood waters. The model provides the downstream boundary conditions for the urban storm drainage model of Thu Duc City in current and future climatic conditions.

The *urban storm water drainage model and 2D hydraulic model for Thu Duc City* is the main modelling tool for investigating the flood hazards in the project area. The model simulates the urban drainage system behaviour and the flood inundation in the urban area under a range of conditions. Flood mitigation measures like introduction of pumps and flood storage areas can be included in the model schematisation to assess their effectiveness.

Flood Risk model: The flood inundation extent and depth have been translated into flood damage and flood risk maps with help of the **Global Flood Risk Tool** developed by Royal HaskoningDHV. Flood risk maps indicating the flood damage for cases with flood exceedance probabilities of respectively 10% (1/10 year) and 1% (1/100 year) are produced and Expected Annual Damage (EAD) in Thu Duc City are estimated.

3. Flood risk analysis

To gain a better understanding of the flood hazard and flood risk in Thu Duc City, flood hazard maps and flood risk maps of the current and future climate situations have been produced.

Flood risk assessments support decision makers in prioritising flood risk reduction investments. If the chance of a flood event is small, and the impact to assets and citizens is minor, the flood risk is considered low and generally does not require an intervention or investment. On the contrary, the chance of a flood event is high and the impact is large, the flood risk will be high, and it requires attention.

The flood hazard and flood risk maps prepared for Thu Duc City indicate where the highest and lowest impacts can be expected for the current climate situation in 2022 as well as the future climate situation in 2050 (including expected climate change and sea level rise).

Flood risk is often estimated as the sum of direct and indirect damages, and in addition indication of the number of affected (vulnerable) population is given. Within this flood risk assessment, a first ballpark number is presented for direct damages only. Direct damages account for damage to properties and assets (tangible damage to buildings, roads, bridges, power stations, and other infrastructure). This damage number can be used to make a first comparison to the potential costs of mitigation measures reducing flood risk. Indirect damages, describing the negative effects on economic activity (e.g. disruptions to logistics, downtime of businesses), is generally a multitude of the estimated direct damages, but generally within the same order of magnitude. It is recommended to quantify the indirect damages and number of affected populations in next studies to create a complete overview of the flood risk in Thu Duc City and its potential for flood risk reduction through mitigation measures.

The potential flood inundation and related flood risk given the **current[1] and future land use[2] with current and future climate conditions** are discussed in this section. These conditions provide the reference – the baseline – for the analyses that consider future climatic conditions and various flood risk management interventions.

Below is the summary of the risk assessment results for Thu Duc city. Details can be found in Annex 1.

3.1. Flood hazards

The flood maps with the maximum flood inundation extent and depth for cases with flood exceedance probabilities of respectively 10% (1/10 year; a flood event with a 10-year return period) and 1% (1/100 year; a flood event with a 100-year return period) in both the current and future land use and climate scenarios are provided in figure 6 and 7. The total area in Thu Duc City that is inundated with a flood depth over 0.30 m is provided in **Error! Reference source not found.**Table 1.

[1] The current land use plan adopted by HCMC at HCM CPC's Decision 5759/QD-UBND dated November 12, 2012

[2] The future land use plan that is currently formulated in the draft Spatial Master Plan of Thu Duc city developed by Sasaki

For any flood condition, widespread inundation is observed throughout Thu Duc City. In the sloping high elevation areas (North) of Thu Duc City, flooding is more local around the water courses and some larger inundated areas in the northeast. In the low elevation areas, flooding is also observed throughout the area with very serious large-scale inundation in the less developed northwest and southeast. With extreme condition (1/100 year flood), a total of inundated area with over 30cm is estimated at 5,858 ha, counting for 31% of the total Thu Duc city area. But in the same flood frequency with the future land use plan and climate change in 2050, the total of inundated area is estimated at 6,880 ha, counting for 37% of Thu Duc City. In a more attention manner, the total inundated area with a depth of more than 1m could increase twice from the current to future and use and climate scenarios (from 733 ha, counting for 3.9% of Thu Duc city to 1,595 ha, counting for 8.3% of Thu Duc city).

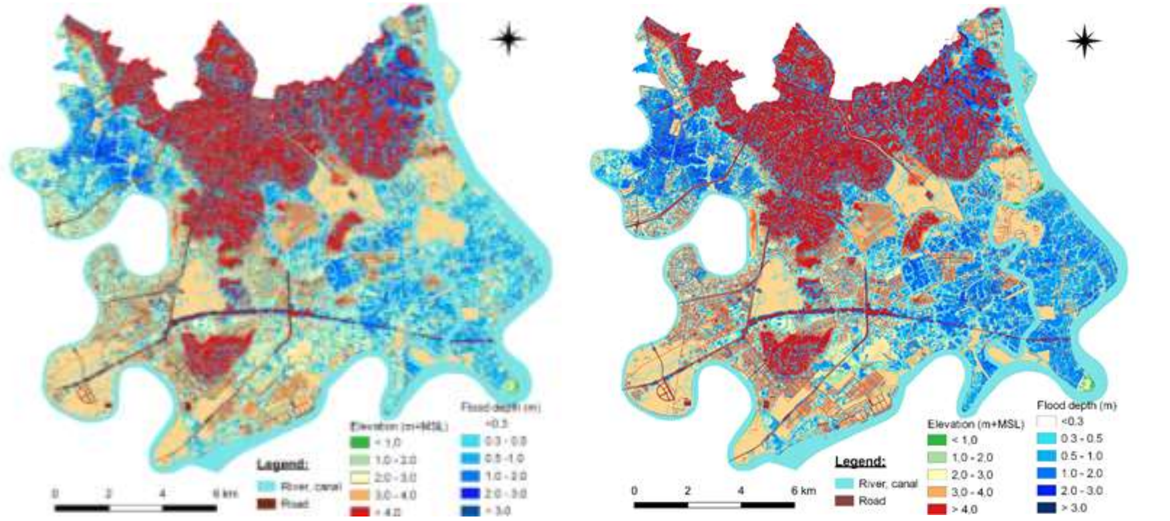


Figure 6 Maximum flood inundation maps of flood exceedance probability of 10% (left) and 1% (right) for current scenario

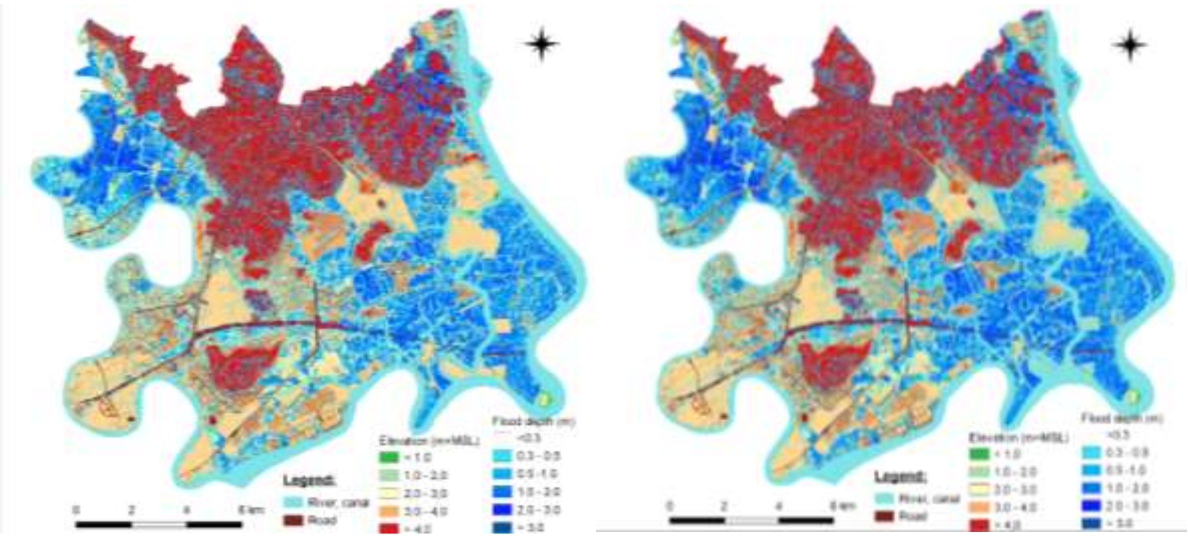


Figure 7 Maximum flood inundation maps of flood exceedance probability of 10% (left) and 1% (right) for future scenario in 2050

3.2. Estimated flood damage and risk

The flood inundation extent and depth have been translated into flood damage and flood risk maps with help of the Global Flood Risk Tool from Royal. Flood risk maps indicating the flood damage for cases with flood exceedance probabilities of respectively 10% (1/10 year) and 1% (1/100 year) are presented in figure 8 and 9 and the total estimated flood damage and expected annual risk in Thu Duc City are provided in Table 1.

Most damage occurs in the higher elevation in the north, in the northwest and in the southwest parts of the city. Here, higher value properties are inundated and damaged. With the future scenarios, the total flood damage during a simulated flood event with an exceedance probability of 1% is estimated at US$521 million, which is an increase of 36% compared to the current conditions (US$ 382 million). In other numbers, the annual damage increases from US$53 million to US$84 million between the current and future scenarios.

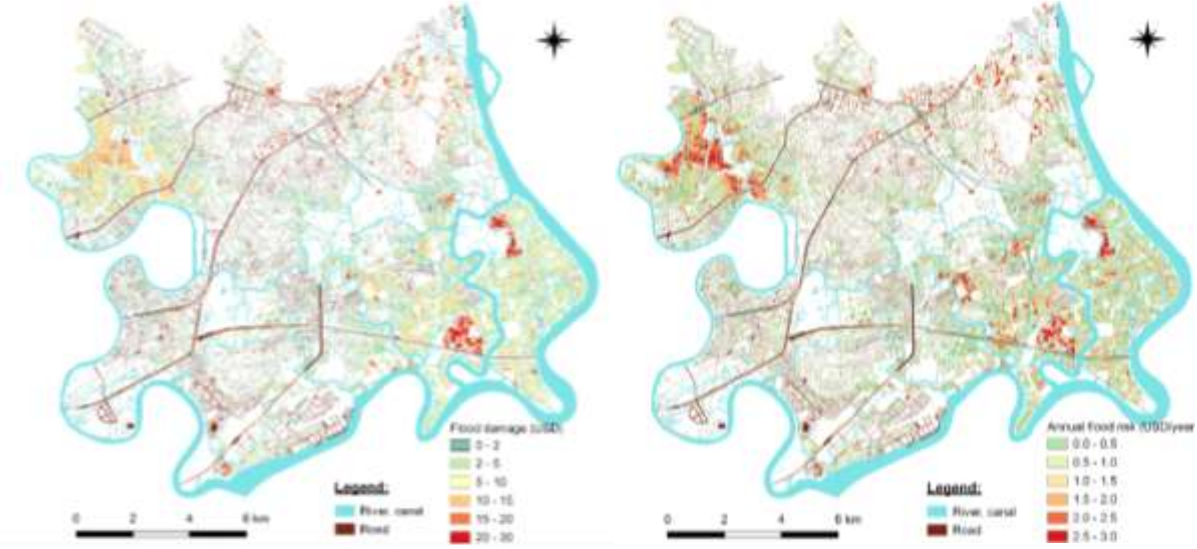


Figure 8 Flood damage for flood exceedance probability of 1% (left) and mean annual flood risk (right) in current land use plan and climate

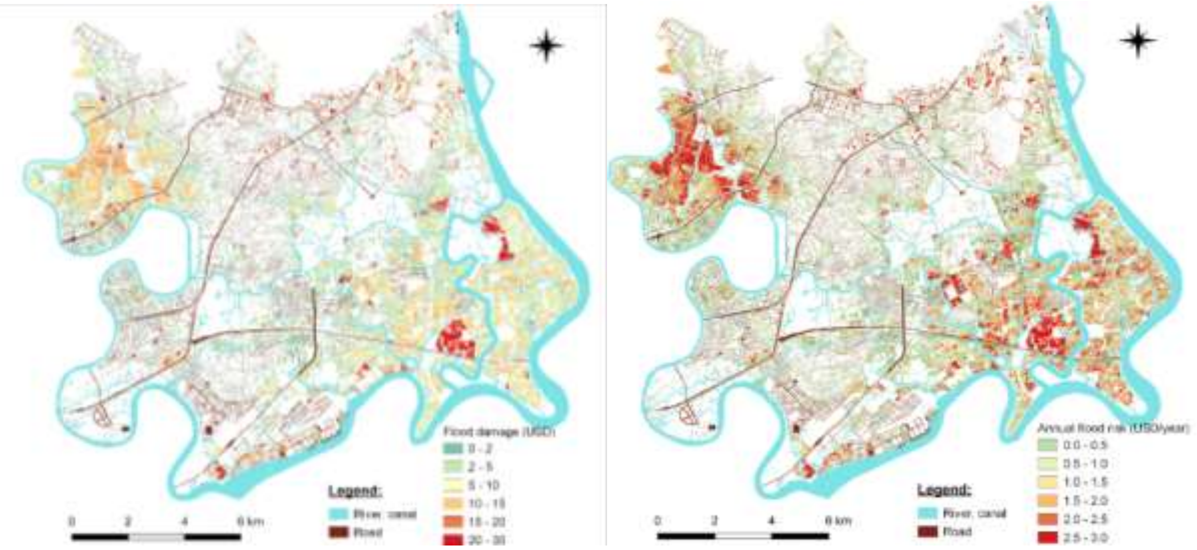


Figure 9 Flood damage for flood exceedance probability of 1% (left) and mean annual flood risk (right) in future land use plan and climate

Table 1 Inundated area of Thu Duc city in current (2020) and future (2050) scenarios

Case	**Current climate (2020)**			**Future climate (2050)**		
Return period	*5 yr*	*10 yr*	*100 yr*	*5 yr*	*10 yr*	*100 yr*
Total inundated area (ha)	2,487	4,730	5,858	3,875	6,334	6,880
Total inundated area (% of Thu Duc City)	13%	25%	31%	21%	34%	37%
Total flood damage (MUS$)	139	268	382	264	442	521
Mean annual damage (MUS$)	53			84		

4. Flood risk mitigation solutions

The sustainable development of the city therefore requires a systematic adoption and implementation of flood-sensitive spatial planning and associated adaptive flood risk management. Creating flood-safety on both the shorter and the longer term will facilitate the realization of the ambitious development potential of Thu Duc City: the economic center of HCMC and Viet Nam located in an attractive and green urban environment that offers a high quality of life.

4.1. Principles:

Given the sensitivity of Thu Duc city development to the water, a flood risk management concept and approach is recommended to support the future flood-safety of Thu Duc City.

Multi-layer flood safety approach: A comprehensive flood risk management strategy aims to reduce the flood hazards as well as the flood exposure and vulnerability of infrastructure and the population. The various types of interventions that jointly comprise a multi-layer flood safety approach are illustrated in Figure 10.

Figure 10 Multi-layer flood safety approach

The flood management components focused on 'delay' and 'store' are integrated with the flood-sensitive spatial planning layer discussed hereafter. A flood protection system generally requires substantial investment in flood management infrastructure. The safety level should be based on a careful analysis of the cost-benefit of infrastructure investments and the potential social impacts of flooding. In high value urban areas like parts of Thu Duc City, the protection against large-scale flooding from the rivers often assumed a flooding probability of less than once per 100 years. Damage caused by smaller scale and shallower flooding resulting from direct rainfall on the urban area is generally accepted with a higher frequency of at least once per 5 years because the impacts are much smaller.

The flood protection system – the prevention layer – cannot guarantee a 100% flood safe environment due to cost considerations. This means that smaller or larger flood inundations may happen. In order to reduce the impact of these flood inundations several non-structural measures are generally taken (‘planning layer’). The main measures are generally spatial planning and building codes. Through spatial planning, areas that are less vulnerable could be allocated to more frequent flooding to protect areas with a higher exposure and/or vulnerability. This could mean for example that green space and less vulnerable areas (parks, sports fields, agricultural areas) are designed to flood to protect business districts, residential areas and (critical) infrastructure. In areas with a relatively high flood risk, building codes should be adopted to reduce the impact of potential flooding.

The ‘emergency response layer’ aims to reduce flood hazards and impacts of flooding at the onset of, during and in the aftermath of flood events. This is required during extreme events or in case of failure of the flood protection system. This layer includes measures like impact-based flood early warning, preparation of emergency management plans, improved operational management, enhanced public awareness, and effective flood insurance mechanisms.

The flood-sensitive urban development of Thu Duc City requires main investments in the ‘protection layer’ and ‘spatial planning layer’. Creating an effective ‘emergency response layer’ – although of key importance – requires a much lower level of investment.

Multi-level urban planning: Flooding in Thu Duc City is caused by high river levels, direct rainfall on the urban area or a combination of both in a way that exceeds the various flood protection levels discussed earlier. To mitigate or at least minimize the impacts of potential flood inundation, the urban area has to be planned and designed in a flood sensitive manner.

Flood sensitive urban planning and design accommodates for retention and/or temporary storage of excess flood waters in way the economic damage and social impacts are minimal. This requires a systematic urban planning at different scales: the city, neighbourhoods and street scales. Multi-functional urban design and blue-green flood management measures play a key role in such planning approach. When successfully implemented, not only the flood safety but also the attractiveness and liveability of the urban environment will generally substantially increase. Figure 11 explores the development of multi-functional water storage and zoning requires a view on the vertical perspectives of the area as well, and results in an elevation-based spatial plan.

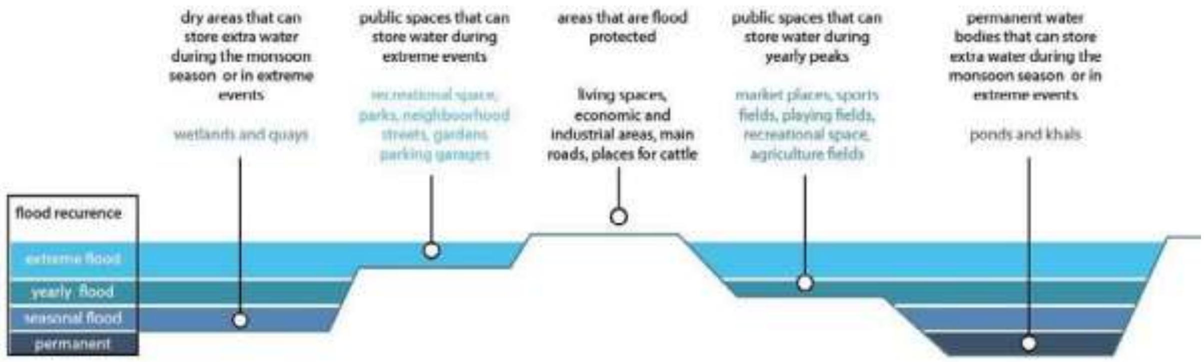


Figure 11 Example of elevation-based spatial planning for South Asia in which zoning is linked to the probability of flooding and the potential for flood risk reduction (CDR International, HaskoningDHV, Defacto, Neelen & Schuurmans, Wageningen University & Research, 2019)

Nature-based flood management measures: Flood management in an urban environment traditionally focuses on the urban drainage system consisting of 'grey' infrastructure: a combination of drainage pipes and canals, sluice gates and pumps, and embankments and dikes. A sole focus on this 'grey' urban drainage infrastructure results in a very substantial investments when the need for flood risk reduction in a rapidly developing urban area like Thu Duc City, is growing. Nature-based solutions (NBS) is an umbrella term referring to "actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al. 2016.). Robust system-based approaches effectively anticipate the natural and socio-economic variability and trends in wider sense. They include nature-based solutions but could have a more infrastructural character. Thu Duc City should therefore aim to adopt nature-based flood risk management solutions to be able to anticipate to uncertain future trends in climate change and socio-economic development. They can complement gray infrastructure. Nature-based solutions provide multiple benefits to cities and address different societal challenges. This includes reducing disaster risk and building climate resilience, restoration of biodiversity, creating opportunities for recreation, improving human health, and supporting community well-being and livelihoods. In many cases, integration of NBS has proven to be cost-effective.

As mentioned in approaches chapter, the Thu Duc city is divided into 2 sub-regions for flood study including northeast and southeast sub-region as defined in drainage master plan, 2001 (plan 752). Since flooding causes and inundation mechanisms in these two sub-regions are different as results of the high elevation, sloping terrain in the north and low lying, relatively flat, with densely canals in the south flood risk mitigation solutions must be also different.

4.1 Approach for flood risk mitigation in the Northern sub region (NE, JICA plan)

In the northern areas, existing urban areas located right at the lower of the slope affected by the flow due to rain from highland of the basin with high velocity which are flooded very quickly after 30-45 minutes of rain. The overflow on the street is very dangerous for traveling people on the streets. According to the Source-Pathway-Receptor model, solving the flooding problem in this low elevation urban areas is not only trying to increase the drainage infrastructural capacity, but also to reduce peak flow at source and pathway locations. Which means to create stormwater storages in the high area to delay the water going down with high velocity to the drainage system in the low-lying area in the south. This will help to reduce the pressure of the drainage system in the low-lying area that reduces cost of construction. Combined solutions could be considered as below:

- Detention measures with green infrastructural application on high and slopping land to reduce peak flow discharged to downstream areas;
- In lower area with low elevation, the land can be protected by polder system locally or opened with wetland models;

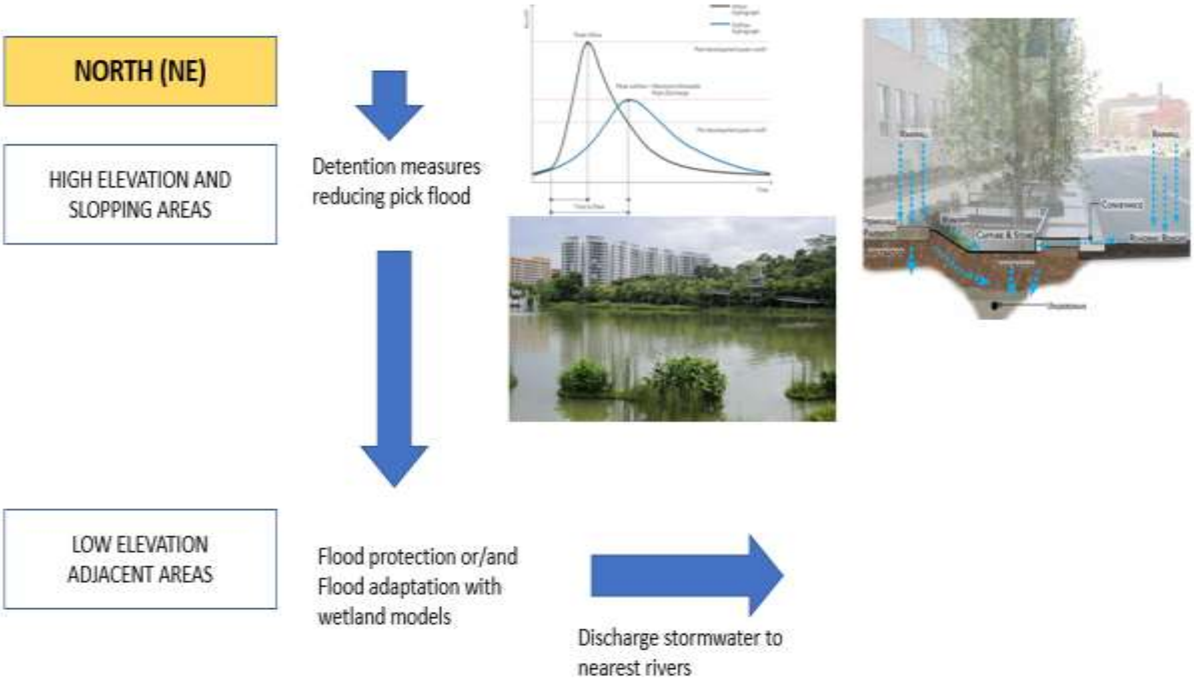


Figure 12 Recommended combined solutions for the NE area.

Figure 13 Examples of GI: detention pond (left) and water absorbing landscape (right)

4.2 Approach for flood risk mitigation in the Southern sub region (SE, JICA plan)

The southern areas of Rach Chiec and Trau Trau canal have low elevation, mainly influenced by water levels on the Dong Nai and Saigon rivers, including floods from upstream and fluctuations of tides downstream impacts. Maximum design water levels on the rivers have been defined based on hydro- hydraulic simulations with potential floods of the basins. Flow discharges from Tri An hydropower plant as well as Dau Tieng irrigation storage reservoir operations must be considered in combination with high water levels during spring tides.

Traditional solution for river flood control is a polder infrastructural system including embankment in combination with sluice gates and pumps. Water levels inside of the ring dykes can be controlled within tidal fluctuations by opening and closing sluice gates during ebb tide and flood tide periods respectively that can protect land from high river water levels and create a storage volume for storm water retention before that can be discharged to the rivers during low water level period; during extreme rain, pumping will be added to control water levels not exceed accepted levels. Following polder approach, “large polder” or “small polder” options could be analyzed and selected.

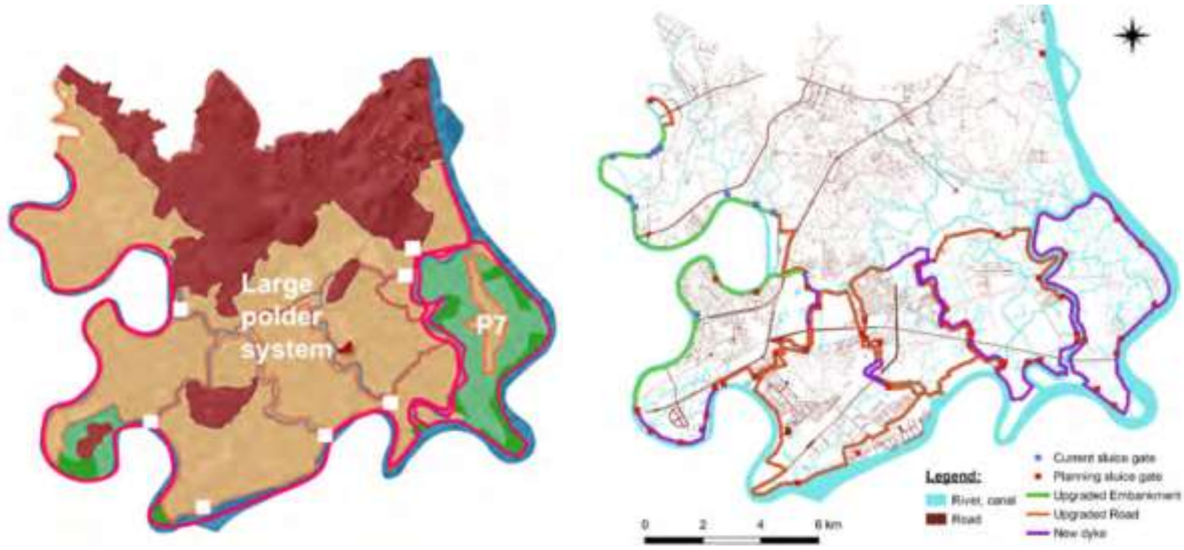


Figure 14 Layouts of large polder (left) and small polder (right) options

Partly polder and adaptive urban option: In general, the polder approach has some limitations, such as:

- Closing sluice gates during high water levels can limit navigation capacity of the river/ canal network; some time the system closed could make negative impacts on water environment due to water blocked;
- Inside dyke system residential activities and infrastructures can get risk due to any failures of system operations or dyke breaking.
- On the one hand budget required for polder infrastructural constructions, on the other hand cost for land leveling up to certain elevation (+2.00 to +2.50m) required also; it will be costly.

Protecting lowlands from river flooding can encourage unexpected formation of densely populated urban areas instead of the opportunity to form cities that are friendly to water and nature. Therefore, an alternative of combining polder and natural development could be considered for reduction of flood risk in the south area of the Rach Chiec - Trau Trau canals. A combined solution in which poldering structures can be installed to protect existing densely urban areas locally, and adaptive urban with residential, commercial areas on land leveling above maximum river water in combination with some eco-wetlands is recommended**.**

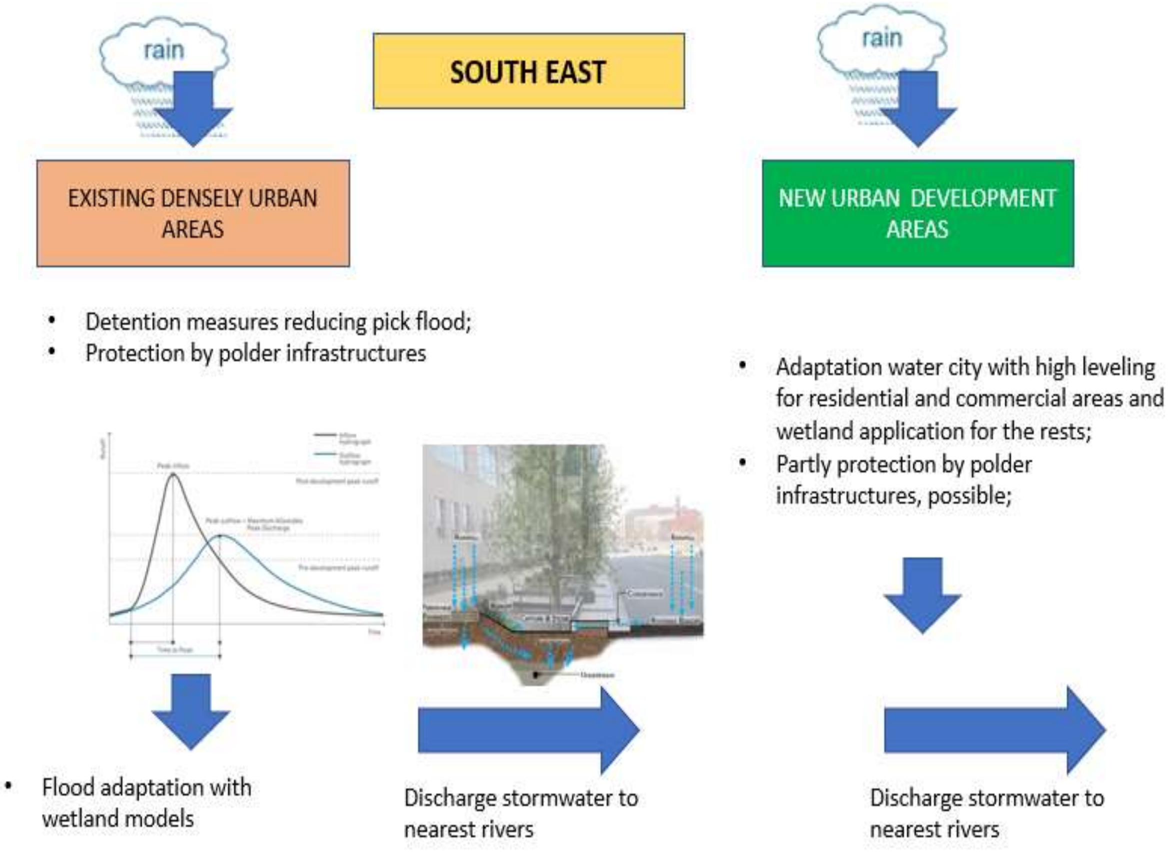


Figure 15 Recommended combined solutions for the SE area.

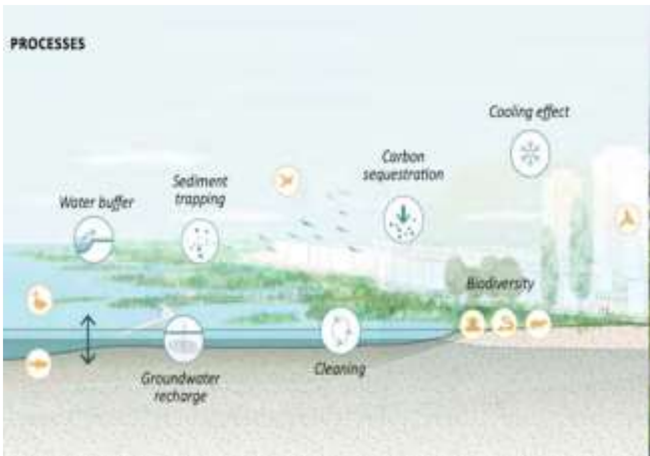


Figure 16 Example of an urban and wetland combination model.

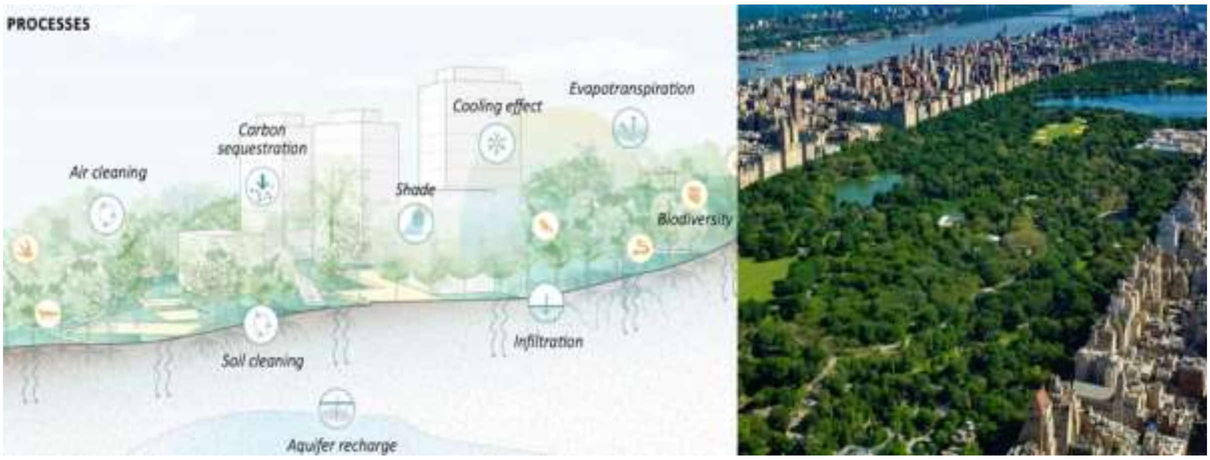


Figure 17 Example of an urban forest model.

4.3 Overarching long-term measures

Using the principles described above, an overarching conceptual approach for long-term flood risk management in Thu Duc is recommended as illustrated in Figure 14 to ensure the most cost-effective and robustness of a flood resilient urban planning and development. While the upper area with a steep slope should maximize the rainwater storage and infiltration to delay the water going down to the lower area as long as possible. The middle area with less steep should maximize the rainwater storage and drainage capacity, and improve the resilience of the infrastructures. The plain area should be a combination of the flood protection and discharge system, and nature-based solutions to improve the adaptive urban development, and attractiveness and quality of life in the urban area. On top of these specific recommended approaches for each of the different areas of Thu Duc city, an effective coordination and implementation policy for integrated urban planning, flood risk operational management, flood forecasting and early warning, resilient infrastructure O&M and public awareness should also be established.

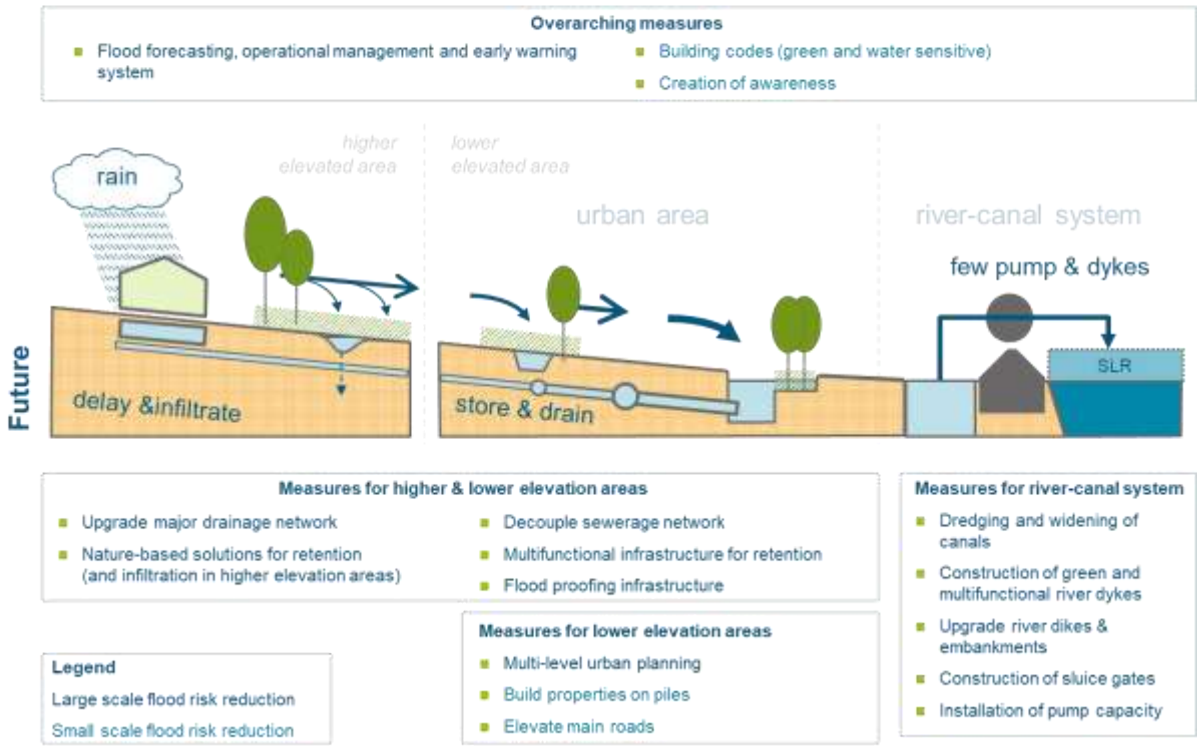


Figure 18. Recommended overarching approach for future suitable flood risk management in Thu Duc city

4.3 Possible FRM interventions in Thu Duc city

An intensive analysis on the efficiency of various possible interventions to reduce the flood risk in Thu Duc city has been carried out, considering the impacts of reducing flood risk and damage, cost of construction and minimization of the negative environmental and socio-economic impacts (e.g. the need for relocation of people and enterprises and provide additional social, environmental, or economic benefits).

Four following intervention options are considered in the analysis to improve the flood risk reduction system in Thu Duc city:

- Option1: Business as usual – improving the current approach
- Option 2: Optimizing the current polders – systematic introduction of pumping
- Option 3: City-wide integrated flood management – large polders with sluice gates
- Option 4: City-wide integrated flood management – large polders with pumps

Summaries of flood hazard and risk simulations for the three flood risk mitigation options are presented in the Table 2 below. It is noted that inundated areas in option without polder are existing lowland urbans that could be protected by local polders or leveled transition. A qualitative comparison of the three potential solutions for the south of the city is summarized in Table 3. Details of the analysis on flood risk and cost-benefit for each of the considered intervention options are provided in Annex 2.

Table 2 Simulated flood area and flood damage in various options with current and future scenarios

Case	Current climate (2020)			Future climate (2050)		
Return period	5 yr	10 yr	100 yr	5 yr	10 yr	100 yr
Total inundated area (ha)						
Without polder	2,487	4,730	5,858	3,875	6,334	6,880
Small polders	909	3,958	4,591	1,674	4,546	5,085
Large polders	362	3,566	4,110	840	3,967	4,799
Total inundated area (% of Thu Duc City)						
Without polder	13%	25%	31%	21%	34%	37%
Small polders	5%	21%	24%	9%	24%	27%
Large polders	2%	19%	22%	4%	21%	26%
Total flood damage (MUSD)						
Without polder	139	268	382	264	442	521
Small polders	46	210	263	95	261	314
Large polders	17	184	224	41	214	279
Annual flood damage (MUSD)						
Without polder	53			84		
Small polders	37			47		
Large polders	31			38		
Difference with without polder (ha)						
Small polders	-1,578	-771	-1,266	-2,201	-1,788	-1,795
Large polders	-2,125	-1,163	-1,748	-3,034	-2,367	-2,081
Difference with without polder (MUSD of damage)						
Small polders	-93	-57	-119	-170	-181	-207
Large polders	-122	-83	-158	-224	-228	-241

Table 3 Qualitative comparisons of potential solutions

Criteria	Partly polder & Adaptive urbans	Large polder option	Small polder option
Technical issues			

Protect urban from river floods	+ Urban infrastructures and buildings are located on leveled land with design flood levels	+ Operation of sluice gates in combination with ring dyke embankment can protect land from river floods;	+ Operation of sluice gates in combination with ring dyke embankment can protect land from river floods;
Drainage storm water	+++ Depending on drainage system design and implementation;	++ Depending on drainage system design and implementation; Early close of the gates can create available space for water retention;	+ Depending on drainage system design and implementation; Early close of the gates can create available space for water retention;
Environmental impacts	**0** Open system for navigation, water exchanges;	**--** Large area will be closed by sluice gates and embankments/ navigation will be limited; water blocked some time	**-** Smaller areas will be closed by sluice gates and embankments/ navigation will be limited; water blocked some time
Cost	**--** Smaller cost for some polder infrastructures, Cost for land leveling up to +2.50m	**--** Cost for large polder infrastructures; Cost for land leveling up to +2.00m	**--** Cost for small polder infrastructures; Cost for land leveling up to +2.00m
Operation	**0** Not required	**--** Complicated and costly	**--** Complicated and costly
Opportunity for water/ nature friendly urban	**+**	**0**	**0**

Possible application of the nature-based solutions in Thu Duc city: The flood drainage from the urban areas into the surrounding water courses under gravity, is hampered by the tidal movement. The outflow from the sluice gates is driven by the water level difference between the water levels in the urban area and the water levels in the surrounding water courses: larger canals and rivers. Drainage can generally only take place at lower tidal water levels. While no drainage is possible during higher tides, excess flood waters have to be stored in the urban system. This requires sufficient open-water areas with high enough embankments and potentially areas that can be inundated during higher flood levels without causing damage. Maintaining sufficient open-water area and alternative space for water is essential for a future-proof and well-functioning urban drainage system like required in Thu Duc City.

When urban development progresses, the essential 'space for water' generally gradually diminishes, which raises the flood hazards without mitigating measures. Regaining 'space for water' once an urban area is fully built up, is very expensive and requires re-allocation of land use and sometimes relocation. Moreover, using nature-based solutions can help to reduce cost for flood risk management while enhancing the attraction and living environment of the urban area. Part of Thu Duc City are already densely populated and open water space has seriously decreased. Utilizing the existing wetland and linear park opportunities should be seriously considered for the future development of Thu Duc city.

The total areas in Thu Duc City is 18,761 ha of which at mean sea level (MSL) 781 ha (4.2%) is open water. With higher water levels, the open-water areas increases to 1,227 at 1.0 m above MSL. There are however large differences in the city. More densely populated areas in the west (P1, P2, P3 and P4 – see figure on the right for coding), have open-water areas of 1.8 to 3.6%. Still relative undeveloped areas in the southeast (P5, P6 and P7) have much largely open-water ratios of respectively 6.6 to 10.7%. The challenge is to maintain sufficient space for water in the areas that are still being developed, and create substantially more space for water in areas that have already progressed much further in their urban development.

Table 4 Estimated current open-water areas in different parts of Thu Duc City

		Total area	Open water area (ha)			Open water area (%)		
		(ha)	at 0.0 m+MSL	at 0.5 m+MSL	at 1.0 m+MSL	at 0.0 m+MSL	at 0.5 m+MSL	at 1.0 m+MSL
Sub-areas (polders)	P1	2,736	61	119	145	2.2%	4.3%	5.3%
	P2	6,708	149	182	219	2.2%	2.7%	3.3%
	P3	2,000	72	90	98	3.6%	4.5%	4.9%
	P4	2,277	40	54	89	1.8%	2.4%	3.9%
	P5	1,279	85	95	120	6.6%	7.4%	9.3%
	P6	1,976	211	231	311	10.7%	11.7%	15.7%
	P7	1,785	163	207	246	9.1%	11.6%	13.8%
	P2-P6	14,240	557	651	837	3.9%	4.6%	5.9%
	Total	**18,761**	**781**	**977**	**1,227**	**4.2%**	**5.2%**	**6.5%**
Large polder (P2-6, C2-8)	P2-P6	14,240	714	808	994	5.0%	5.7%	7.0%
	P1	2,736	61	119	145	2.2%	4.3%	5.3%
	P7	1,785	163	207	246	9.1%	11.6%	13.8%
	Total	**18,761**	**938**	**1,134**	**1,384**	**5.0%**	**6.0%**	**7.4%**

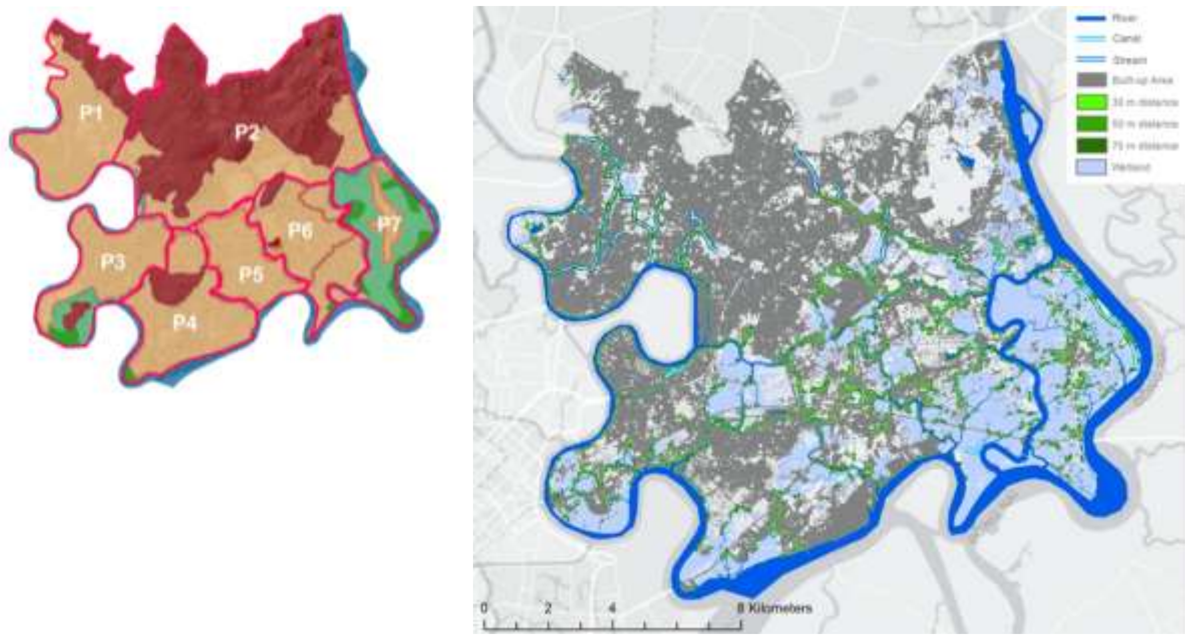


Figure 19 Potential for flood storage in urban area

5. Action Prioritization

5.1 Introduction

Thu Duc City is envisioned to become HCMC's technology, finance and service leader. At the same time the city is situated between two important rivers, the Saigon River and Dong Nai River, as well as adjacent to Dong Nai and Binh Duong; it is a strategic location that will create momentum for future development and requires strategic recommendations regarding flood management. In previous chapters, strategic recommendations for adapting Thu Duc City to flood risk in the future have been developed and they have been translated into measures.

In this Chapter, a preliminary roadmap for prioritization of the proposed structural and non-structural flood risk management measures is developed towards effective flood risk management in Thu Duc City. This roadmap is inspired by the principles of adaptive planning[3] and addresses the sequence of implementation of the measures considering uncertainties related to climate change.

5.2 General principles of an adaptive roadmap

In the previous chapter, oriented solutions are presented for Northern and Southern sub regions of the city. The said solutions consist of structural, non-structural, no-regret measures as well as nature-based solutions.

This roadmap is inspired by the general principles of adaptive planning under climate change uncertainties. In investment strategies where uncertainty is important, adaptation (or strategic) pathways help to understand, schedule, and develop optimal combinations of measures to meet the future long-term goal. The roadmap considers that doing nothing about flood risk

[3] Defining the solution space to accelerate climate change adaptation, Marjolijn Haasnoot, Robbert Biesbroek, Judy Lawrence, Veruska Muccione, Robert Lempert, Bruce Glavovic, 2020

reduction is not an option for Thu Duc City, as was seen in the flood risk assessment. The development of adaptive pathways for flood management in Thu Duc City requires preparing a series of detailed steps and assessments.

The preliminary adaptive roadmap is developed considering:

- Robust and flexible measures that perform well over a wide range of different future scenarios;
- Prioritisation of low-regret measures; these are measures that contribute to the long-term goals of flood protection, but that can be implemented now without too many uncertainties about their effectiveness in the future; and
- Measures that will be necessary for the long-term goals but that can be postponed.
- Phasing of implementation and understanding of interlinkages between the measures is crucial.

Phasing of measures: Scheduling measures and developing optimal combinations of measures should solve the issues of today, consider the long-term goal, and from there, back cast towards the present. By doing so, a preferred strategy can be selected which includes both short- and medium-term measures, keeping a long-term vision in mind. To adapt in the coming decades, the landscape and community will likely require a phased transformation that combines reinforcement, rehabilitation, improvements, as well as new construction. For instance, river embankments are to be constructed in the near future with a lower crest level than what is predicted considering the climate change and sea level rise scenario. In time with sea level rise, the height is required to be increased which can be done by raising the crest. What is important now, is that the additional space required for the expansion in the future is allocated now (in the urban master plan).

Interlinkages of measures: Some measures can be implemented stand-alone as they individually serve different components of the flood risk reduction scheme. Some measures are interlinked and their effectiveness depends on implementation of the other. For example, both water retention/storage measures as well as construction of drainage sluices significantly reduce flood risk, however the overall effectiveness of the system depends on the connection between the retention areas to the sluices as well as the drainage capacity of the sluices and canals. Decoupling of the sewerage system to avoid polluted water in the open/public retention areas is important as well. Other measures are seen as complementary and part of a larger system that aims to contribute to overall flood risk reduction, for instance introduction of green and water sensitive building codes have a smaller scale contribution to flood reduction and may accompany the larger scale infrastructure for retention.

5.3 Action Prioritization

Following the principles as described in the previous section, measures are grouped in two categories:

1) Short term solutions

   The short-term measures are low-regret measures and selected by keeping the long-term goals in mind (i.e. looking into the future and back cast towards the present). These serve as a basis for realization of the overall vision of a flood sensitive urban development of Thu Duc City.

2) Medium to long term solutions

   Following the short-term measures, the medium to long term measures that are adaptive and elaborate more on city-wide solutions.

Within the potential short-term measures, a prioritization is made and the measures are further grouped into potential investment packages considering their interlinkages and considering the system as a whole.

5.3.1 Non-structural actions

Priority non-structural actions include:

1. Selecting FRM policy for the Thu Duc city then integrating selected FRM solutions into the city spatial master planning including developing nature-friendly urbans that are highly adaptive to CC impacts;
2. Detailed planning of separate flood control solutions for the North and South areas of Rach Chiec - Trau Trau, which defines appropriate drainage design criterion for the high elevation and sloping area in the north;
3. Research and propose green infrastructure solutions to reduce peak flow from high and sloping land in the north of the city for reducing pressure on the drainage system in Thu Duc market, Vo Van Ngan, Kha Van Can streets, etc.,
4. Studying flood adaptive urban models those are suitable to specific conditions of sub-areas in the south (P1,2, 3, 4, 5, 6, 7); then issuing specifications of urban planning and implementation for specific areas to manage urbanization including private urban developers;
5. Development and deployment of a Flood Risk Management Information System as an integrated urban management tool; This activity can be integrated with the FRMIS deployment project of the whole HCMC.
6. Building a spatial database with sharing platform of Thu Duc city; this activity can be integrated with sharing database building activities of the whole city;

5.3.2 Structural investment actions

Priority structural actions include:

1. Building retention areas on high land areas in the north, along sloping pathway to reduce peak flowing to the flood prone at Thu Duc market, Vo Van Ngan, etc.,
2. Upgrading and new installing drainage infrastructural systems;
3. Preparing an investment project for flood mitigation and environmental improvement at location of Tam Phu, Go Dua (P1), referring Urban Forest model (see figure 15); this item could be integrated with DOC project proposals;
4. Preparing investment projects for MTIP 2026-2030;

First three actions could be combined for formation of one or two investment projects, that should be discussed in following steps;

6. Conclusions

The existing flood hazards and risks are high throughout Thu Duc City. Hotspot are observed in the areas in the southwest and northeast that are currently less developed and have seen no or limited land filling. But also throughout other parts of the city, flooding risks are very substantial due to, mainly, insufficient drainage capacity. With rapid urban development together with climate change, the future flood risk will rapidly increase if measures are not not taken.

A forward looking planning approach with respect to flood risk management will be essential to ensure that the future city provides a water secure and attractive living and working environment. 'New' areas in Thu Duc City, planned for development, still offer many possibilities to maintain space for (flood) waters. These areas need to be protected at the desired locations through the urban master planning and design concepts such as 'water sensitive cities' and multi-level urban planning. Suggestions have been made in this report towards measures and design methods that are applicable for these areas.

Since the spatial master planning of Thu Duc new city is an opportunity to form a creative, nature-friendly city which can adapt well to the impact of CC, the selection and integration of an appropriate flood risk management strategy is critical at this time. To manage the extreme rainfall events that occur in the climate in Thu Duc City, creating sufficient water retention and storage is important. Water storage provides buffering capacity when the discharge capacity of the urban drainage system cannot keep up with the peak floods from extreme rainfall.

Risk mitigation measures need to be suitable for the northern and southern areas of the city (separated by Rach Chiec - Trau Trau). Priority should be given to green infrastructure solutions including retention pond, water absorbing landscape on northern high sloping land to reduce pressure in flood area of Thu Duc market, Vo Van Ngan street, etc.. Construction of polder system infrastructures including embankments, tidal sluices, pumping stations should be carefully considered; first of all, such systems should be built only for existing densely urban areas located on irreplaceable low land; the remaining areas should be leaved for opportunities of developing nature/water-friendly urban areas. The participation of private urban developers should be managed by the criteria identified in the master plan. In addition, developing an operational flood early warning system, introducing flood resilient building codes and creating awareness amongst citizens are non-structural measures proposed as part of the initial investment package.

The urban drainage system for a high value city like Thu Duc will need to be functioning using a design standard of 1/5yr to 1/10yr. This means that still regular, but acceptable, flooding will take place, especially in case the maintenance of the urban drainage system is inadequate. Therefore, the street profiles and the surrounding urban area should be designed to accommodate this urban flooding without significant damage up to a design storm of 1/50yr. This means for example appropriate design of street profiles, reservation of sufficient open water area to buffer floods, systematic creation of urban flood retention and storage (blue-green measures) and protection of critical infrastructure to ensure service continuity.

To protect against flooding directly from the river, a design standard should be applied and a recommendation of 1/100yr is considered as a minimum with a suggested gradual upgrade in the coming decades to 1/1,000yr. Worldwide, similar low lying urban areas apply similar protection levels. Direct floods from the river have not been investigated at large within this assessment. It is recommended to determine the potential reduction of extreme water levels in the river through optimisation of reservoir operations and other measures – this would be a regional assessment that not only concerns Thu Duc City but also wider Ho Chi Minh City.

Financing methods of the flood management approach will have to be further explored. Financing can origin from the public as well as the private sector through public private partnerships (PPP). The existing legal setting is to be considered given the current law that requires land-filling by private developers to mitigate floods, but also the support for potential PPP structures. The transition allowing for a more collective (and cost-effective) solution in the future is important and should be considered in the further study.

Annex 1: Flood Hazard and Flood Risk Assessment

A1.1 Method

Using the flood hazards as input, prepared through the hydraulic modelling, flood risks can be quantified. The damage associated to flood inundation can be systematically quantified by combining flood hazard conditions (e.g. inundation depth and duration) with the land use and population in affected areas (exposure) and their vulnerability. Flood risk reduction can be achieved by reducing flood hazards, exposure and/or vulnerability.

Structural flood mitigation measures (like improvement of open and closed drainage conduits, tidal sluice gates, pumping stations, land filling and flood storage) focus on reducing the flood hazards. Non-structural measures like flood sensitive spatial planning, early warning and insurance focus on reducing the exposure and vulnerability. In reality, a comibation of structural and non-structural interventions will be required to effectively reduce flood risks in an urban environment like Thu Duc City.

The project approach is illustrated in the process diagram below.

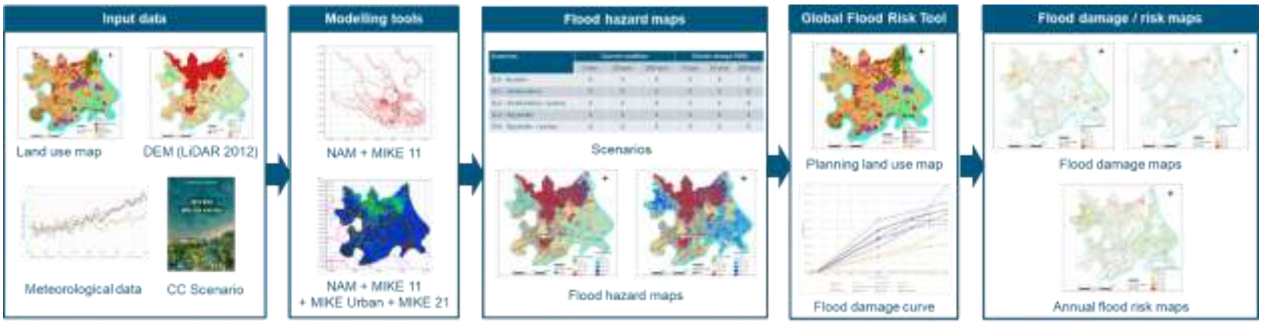


Figure 0-1 Approach diagram of flood risk analysis

A1.2 Key assumptions and data

Land use
The flood hazards and risk have only been analysed for the urban development that has been planned in the draft master plan prepared by consulting joint venture of Sasaki, EnCity and VIUP (Planning consultant). Measures have been identified to reduce the current and future flood risks for this planning within acceptable limits. The planned land use is provided below.

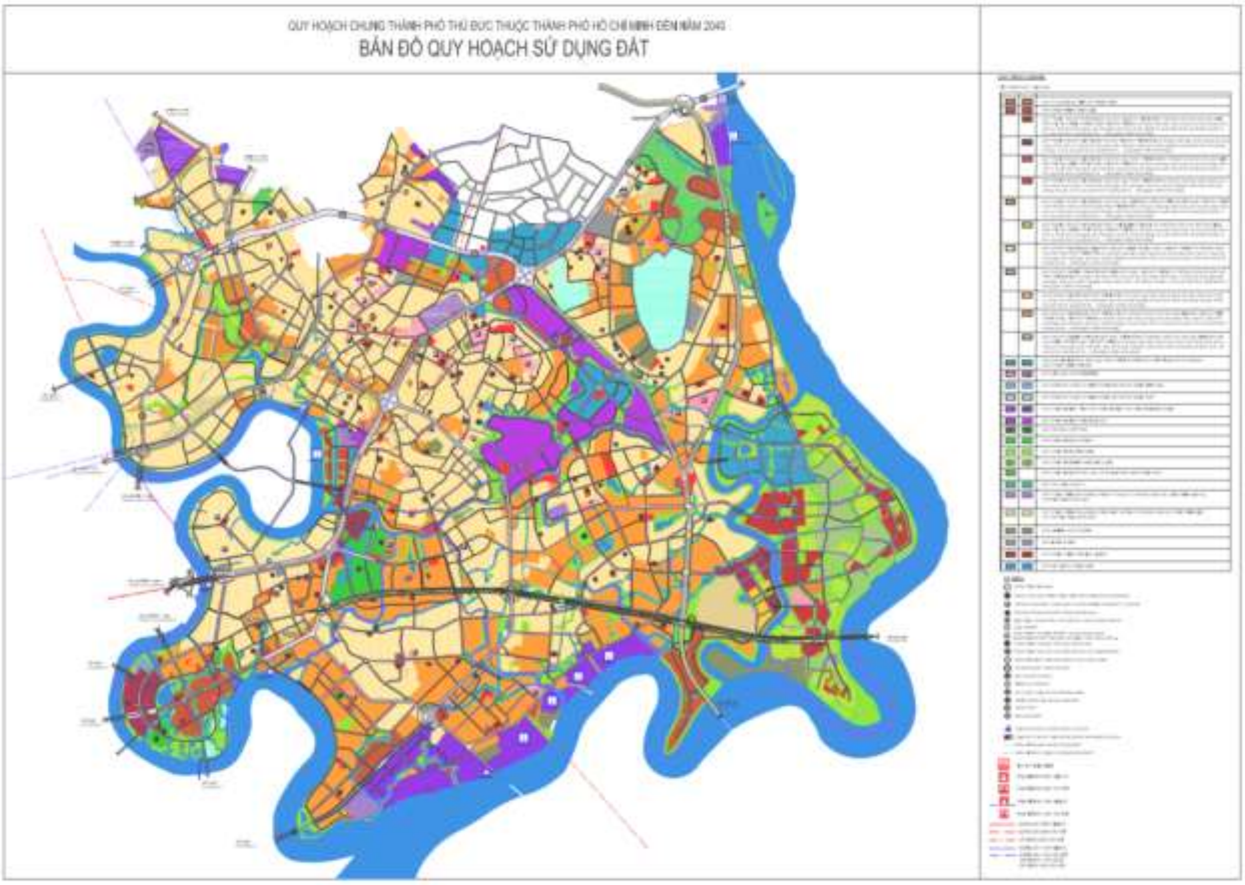


Figure 0-2 Planning land use map for Thu Duc City

No alternative land use scenarios have been at this stage except when directly related to flooding management, like reserving space for flood storage.

Design conditions

The flood hazard and risk conditions in Thu Duc City have been derived for design conditions with return periods of 5, 10 and 100 years (exceedance probabilities of respectively 20%, 10% and 1%). Considering these conditions, model boundaries will be applied with similar return periods which assumes that the boundary conditions are statistically dependent. This is in reality not fully true and means that the simulations to a degree overestimate the actual flooding conditions for the simulated return periods.

The following model boundary conditions are considered:

- Hydrological model (NAM) + 1D hydraulic model (MIKE 11)
  - Daily rainfall in the rural area and 3-hour rainfall in HCMC
  - Inflow at upstream model boundaries
  - Tidal boundary
- Urban storm water drainage model (MIKE Urban) + 2D hydraulic model (MIKE 21)
  - 3-hour rainfall in model domain
  - Tidal boundary computed with MIKE 11 model

The design condition caused high river and tidal canal conditions are more stringent. A minimum design condition in Viet Nam is a flood condition with 10 year return period. Given the high economic value of Thu Duc City and the dense population, design conditions with a minimum return period of 100 years seem more appropriate.

Climate change
The design conditions will be analysed for the current climate and with climate change in 2050. Climate change in 2050 is specified as follows:

- Increase of rainfall intensity by 27%;
- Sea level rise of 28 cm.

A1.3 Assessing the flood hazards

A1.3.1 Hydrological – hydraulic model setup

The modelling platform applied in this project, includes the combination of 4 models:

1. Hydrological model (NAM) for Dong Nai river basin
2. 1D hydraulic model (MIKE 11) for Dong Nai river basin
3. Urban storm water drainage model (MIKE Urban) for Thu Duc City
4. 2D hydraulic model (MIKE 21) for the flood plain in Thu Duc City

The *hydrological - hydraulic model for Dong Nai river basin* simulates the conditions in the river and estuary system surrounding Thu Duc City and to which the city is draining its excess flood waters. The model provides the downstream boundary condtions for the urban storm drainage model of Thu Duc City in current and future climatic conditions.

The *urban storm water drainage model and 2D hydraulic model for Thu Duc City* is the main modelling tool for investigating the flood hazards in the project area. The model simulates the urban drainage system behaviour and the flood inundation in the urban area under a range of conditions. Flood mitigation measures like introduction of pumps and flood storage areas can be included in the model schematisation to assess their effectiveness.

Hydrological model (NAM) for Dong Nai river basin
This model is used to simulate the rainfall – runoff regime in the basin. The model uses the data from 16 rainfall stations including: Can Dang, Loc Ninh, Phuoc Long, Tay Ninh, Dau Tieng, Phuoc Hoa, Dong Phu, Ta Lai, Go Dau, Tan Son Hoa, Bien Hoa, Tri An, Long Thanh – Xuan Loc, Moc Hoa, Tan An, Vung Tau. The runoff flow from subbasin will feed as side inflows of the river and canals into the hydraulic model.

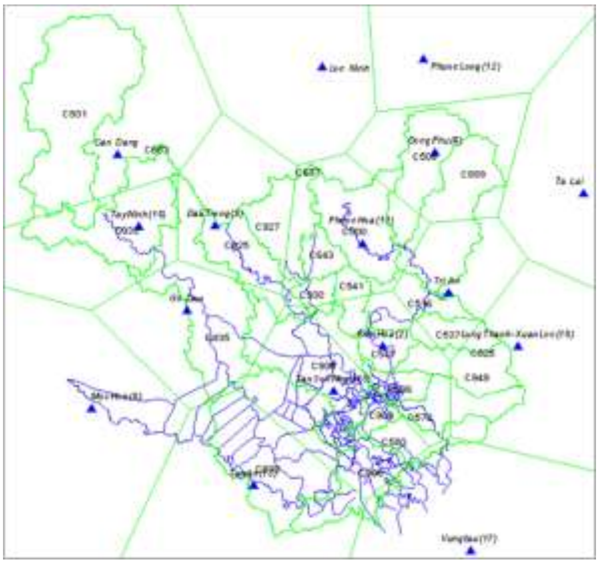


Figure 0-3 Thiessen polygon network of NAM model

1D hydraulic model (MIKE 11) for Dong Nai river basin

The hydraulic model of the Dong Nai river basin has been developed using MIKE 11. The geographic coverage of this model is illustrated in Figure 0-4.

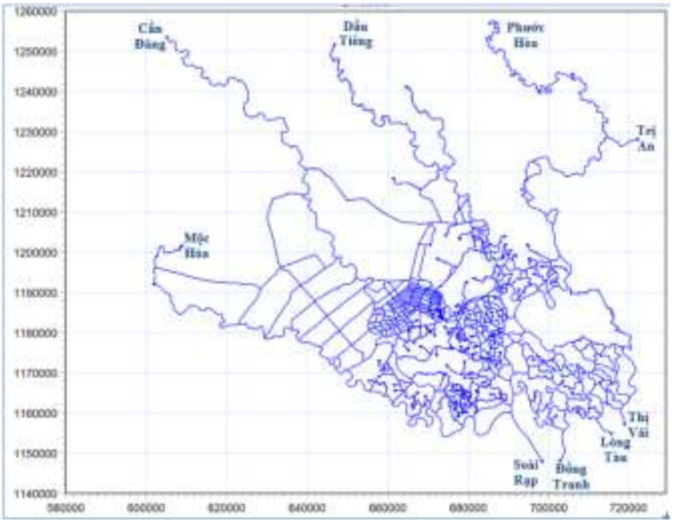


Figure 0-4 Domain of 1D hydraulic MIKE 11 model for Dong Nai river basin

The model domain includes of the following river branches: Dong Nai, Sai Gon, Vam Co, Nha Be, Soai Rap and the main canals in the lower basin. The upsboundaries are located at Tri An, Dau Tieng, and Phuoc Hoa reservoirs, and at Can Dang and Moc Hoa hydrological stations. The downstream model boundary is located at the East Sea.

No updates have been applied to this model for the purpose of this project.

Urban storm water drainage model (MIKE Urban)

The urban storm water drainage model for Thu Duc City has been developed using MIKE Urban.

The model includes all main drainage pipes with diameters higher than 600 mm with total length of 145km, manholes, and outlets to the tidal river system with the installed control structures (flap gates).

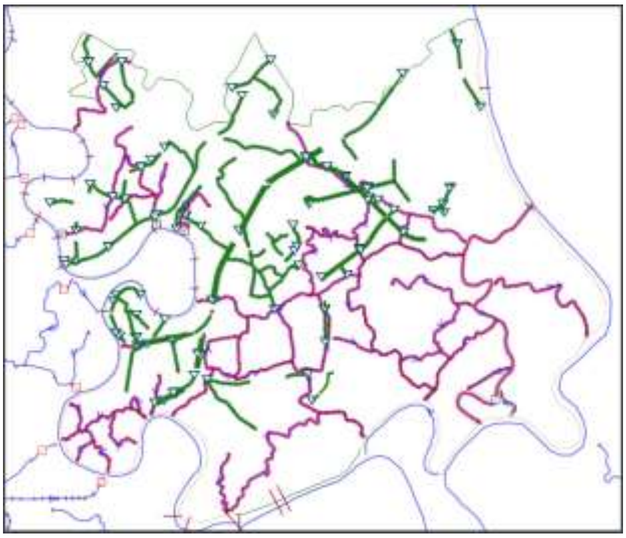


Figure 0-5 Urban storm water drainage model (MIKE Urban) for Thu Duc City

2D hydraulic model (MIKE 21) for the flood plains in Thu Duc City

2D hydraulic model (MIKE 21) was setup for the flood plains and potential inundation areas in Thu Duc City. The entire study area is divided into 130,776 grid cells, the terrain elevations are calculated based on the digital terrain model (DEM) measured by LiDAR survey in 2012. When assessing the flood sensitivity of the proposed urban planning for Thu Duc City, the DEM included in the model will be corrected to erflect the anticipated land filling in the current and planned future built up areas in Thu Duc City.

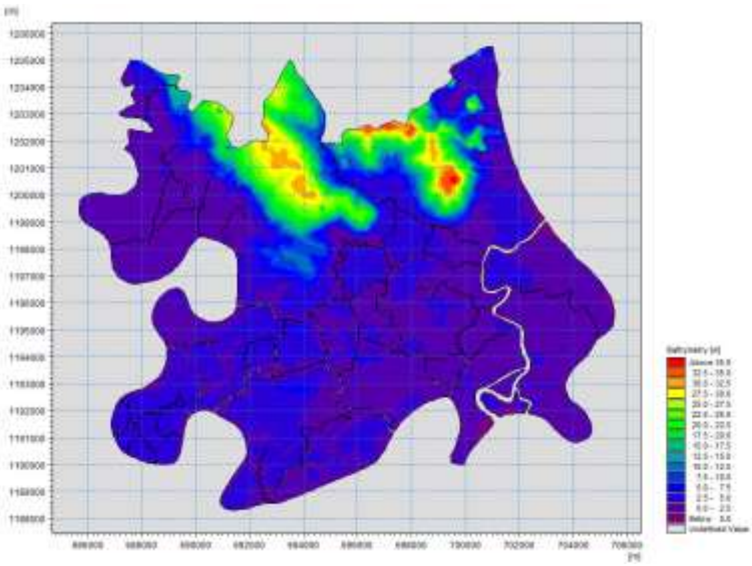


Figure 0-6 MIKE 21 model for the flood plains in Thu Duc City

Coupling of 1D and 2D models (MIKE Flood)

Four models (NAM, MIKE 11, MIKE Urban and MIKE 21) are coupled for the simulation of flood hazard in Thu Duc city. The rainfall – runoff (NAM model) will flow through floodplains (MIKE 21) to the manholes and drainage pipes (MIKE Urban) or rivers/canals (MIKE 11). During the high tide, however, there may be reverted flows from rivers/canals to drainage pipes and floodplains. The result of the coupling models is shown in the Figure 0-7

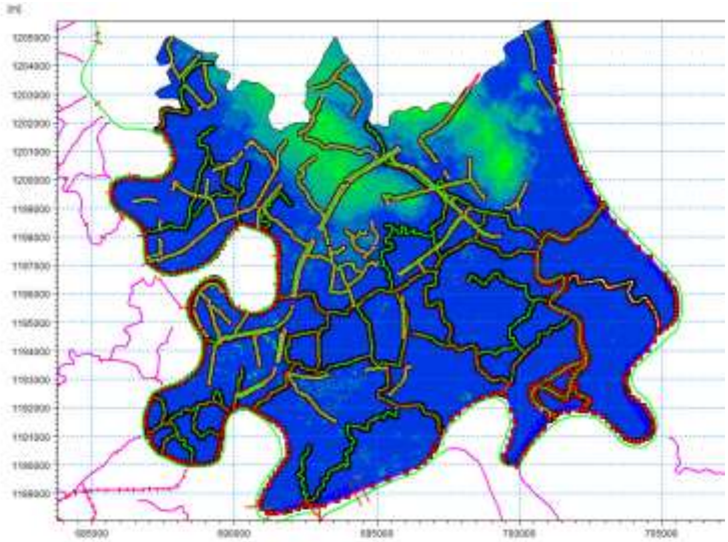


Figure 0-7 Coupling of 1D and 2D models (MIKE Flood)

A1.3.2 Input data

Geographic data

Geographic data consists of river/canal cross section data for the hydraulic model and Digital elevation model (DEM) for the calculation of flood storage cells and flood map production. The characteristics of geographic data are as below:

- River/canal cross section data: collected from various projects related to flood protection in Ho Chi Minh City and other surveys, studies in the area.
- Digital elevation model (DEM) for the Ho Chi Minh City is collected from former HCMC Steering Centre for Flood Control, originated from MONRE. This DEM with a high resolution 5x5 m, acquired through a LIDAR survey in 2012. The DEM plays a very important role in flood storage calculation and flood mapping.

Model boundaries

The model boundaries consist of rainfall, upstream water level and discharge conditions and downstream (tide) water levels:

- Upstream boundaries: outflows of Tri An, Dau Tieng, Phuoc Hoa reservoirs, discharge at Can Dang station and water level at Moc Hoa station.
- Downstream boundary: water level at Soai Rap river mouth, calculated following a derived correlation with the observed water level data at Vung Tau station. The correlation function for the water level at Vung Tau and Soai Rap was developed by Southern Institute of Water Resources Research in the study for hydraulic calculation for flood control works in Ho Chi Minh City in Planning 1547 as below. This correlation was developed based on the observed data at two stations in 23-26 March, 2008 with data interval of 15 minutes (Figure 0-8)

$$H_{Soai\ Rap} = H_{Vung\ Tau} \times 1.0646 + 25.833 \text{ (cm)}$$

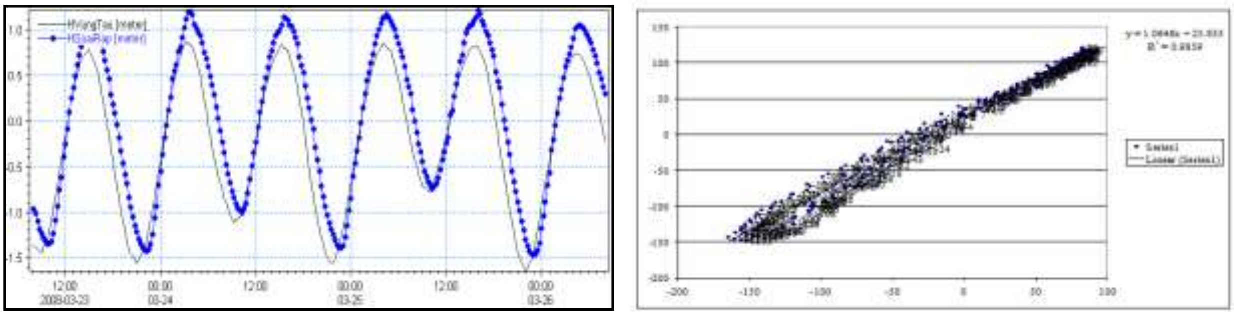


Figure 0-8 Observed water level data at Vung Tau and Soai Rap (left) and their correlation (right) (Source: SIWRR)

Rainfall data

The rainfall data calculated for Dong Nai river basin are daily rainfall data for the rural area and hourly rainfall data for the Ho Chi Minh City area. The hourly data is collected at Tan Son Hoa station which located near Thu Duc City.

Table 0-1 Calculated frequencies of daily rainfall (unit: mm)

Station name	Frequencies of daily rainfall (P %)										
	0.01	0.10	0.20	0.3	0.5	1	1.5	2	3	5	10
Biên Hoà	297.3	244.8	229.0	217.6	208.1	192.3	183.0	176.4	167.1	155.2	138.8
Bình Chánh	336.1	270.3	250.5	236.2	224.3	204.4	192.7	184.4	172.7	157.8	137.2
Cần Đăng	281.1	231.5	216.6	205.8	196.8	181.9	173.1	166.8	158.0	146.8	131.3
Củ Chi	280.1	231.9	217.4	206.9	198.2	183.6	175.1	169.0	160.4	149.5	134.4
Dầu Tiếng	342.5	278.9	259.8	245.9	234.4	215.2	203.9	195.9	184.6	170.2	150.3
Đồng Phú	446.9	358.9	332.3	313.2	297.2	270.6	255.0	243.9	228.2	208.3	180.8
Gò Dầu	256.0	210.3	196.6	186.6	178.4	164.6	156.5	150.7	142.6	132.3	118.0
Hóc Môn	267.6	219.8	205.5	195.1	186.4	172.0	163.6	157.5	149.0	138.2	123.3
Lộc Ninh	364.9	295.4	274.5	259.4	246.8	225.8	213.5	204.8	192.4	176.7	155.0

Station name	Frequencies of daily rainfall (P %)										
	0.01	0.10	0.20	0.3	0.5	1	1.5	2	3	5	10
Long Thành	348.1	282.4	262.6	248.3	236.4	216.5	204.9	196.6	184.9	170.0	149.5
Mạc Đỉnh Chi	303.1	250.9	235.2	223.9	214.4	198.7	189.4	182.9	173.6	161.8	145.5
Mộc Hoá	370.5	298.4	276.7	261.0	248.0	226.2	213.4	204.4	191.5	175.2	152.7
Nhà bè	304.7	247.1	229.8	217.3	206.9	189.5	179.3	172.1	161.8	148.8	130.8
Phước Hoà	455.9	365.0	337.6	317.8	301.4	273.9	257.8	246.3	230.1	209.5	181.1
Phước Long	409.8	334.4	311.7	295.3	281.7	258.9	245.5	236.0	222.6	205.5	182.0
Tà Lài	374.4	306.2	285.7	270.8	258.5	237.9	225.8	217.2	205.0	189.6	168.3
Tân An	489.6	385.6	354.3	331.7	312.9	281.5	263.0	249.9	231.4	207.9	175.4
Tân Sơn Hoà	263.6	220.1	207.1	197.6	189.8	176.6	168.9	163.5	155.7	145.9	132.3
Tây Ninh	307.6	254.0	237.8	226.2	216.5	200.3	190.8	184.0	174.5	162.3	145.6
Trị An	214.7	184.1	174.9	168.3	162.8	153.5	148.1	144.3	138.8	131.9	122.3
Vũng Tàu	414.2	333.1	308.7	291.0	276.3	251.8	237.5	227.2	212.8	194.4	169.1

Rainfall series with 15-minute observations in Tan Son Hoa station were used to calculate the rainfall-frequency for 15, 30, 45, 60, 120 and 180-minutes (see in Table 0-2). The design 3-hour rainfall was prepared as in Table 0-3, pick time intervals include the rainfall intensity corresponding to the frequencies for the shorter duration such as 45-minute, 1-hour, 2-hour rainfall.

Table 0-2 Calculated frequencies of hourly rainfall at Tan Son Hoa station(unit: mm)

Rainfall duration	Frequencies of daily rainfall (P %)					
	0.2	0.5	1	2	5	10
15 minutes	98.8	90.0	83.1	76.2	66.7	59.1

Rainfall duration	Frequencies of daily rainfall (P %)					
	0.2	0.5	1	2	5	10
30 minutes	110.0	104.5	100.5	96.3	90.1	84.8
45 minutes	127.0	120.4	115.3	109.8	102.0	95.4
60 minutes	152.0	142.0	134.1	126.0	114.6	105.3
120 minutes	174.7	162.3	152.6	142.6	128.5	117.0
180 minutes	195.2	177.7	164.4	151.1	133.26	119.5

Table 0-3 Distribution of rainfall in the duration of 3 hours (unit: mm)

Frequency P%	Duration (minutes)											
	0-15	15-30	30-45	45-60	60-75	75-90	90-105	105-120	120-135	135-150	150-165	165-180
0.2%	3.0	14.3	33.4	50.2	66.7	22.1	4.0	0.7	0.2	0.2	0.2	0.3
1%	2.5	12.0	28.2	42.2	56.2	18.6	3.4	0.6	0.1	0.1	0.1	0.3
5%	2.0	9.7	22.8	34.2	45.5	15.1	2.7	0.5	0.1	0.1	0.1	0.2
10%	1.8	8.7	20.5	30.7	40.8	13.5	2.5	0.4	0.1	0.1	0.1	0.2
50%	1.3	6.1	14.3	21.5	28.5	9.5	1.7	0.3	0.1	0.1	0.1	0.1

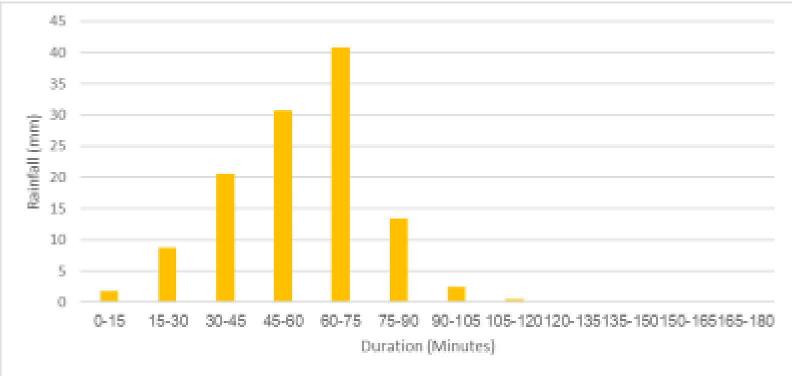


Figure 0-9 Design 3-hour rainfall intensity with frequency of 10%

Discharge data

There are three important reservoirs (Tri An, Dau Tieng, Phuoc Hoa) that strongly impact the hydraulic regime in Dong Nai Lower Basin. The selection of discharge boundaries at these reservoirs is important for the calculation of flood in Ho Chi Minh City. The design spillway outflows of these reservoirs are high but the actual operation outflows are quite low compared to the design outflows. For example, based on the observed data from 1980 to date, the maximum outflow of Tri An is 3910 m^3/s in 1982 which is quite different with the design spillway outfow of 21000 m^3/s (P=0.1%). Therefore, in this study, we suggest to use the discharge boundaries of these reservoirs based on the study of Southern Institute of Water Resources Planning in the master plan for flood protection in Ho Chi Minh City (Plan 1547 or MARD Plan), see Table 0-4.

Table 0-4 Flood release frequencies of upstream reservoirs (unit: m^3/s)

Frequency	Tri An		Dau Tieng		Phuoc Hoa	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
0.2%	10256.6	7755.7	3697.4	1982.6	4815.5	4778.6
0.5%	8628.8	6439.3	3150.0	1660.5	4135.9	4093.9
1%	7622.9	5662.4	2778.0	1398.4	3285.6	3261.0

Frequency	Tri An		Dau Tieng		Phuoc Hoa	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
5%	4483.2	3052.9	1775.0	741.1	1748.8	1740.2
10%	3356.4	2147.8	1381.0	513.3	1223.4	1206.0
20%	2443.0	1502.5	1014.0	333.1	854.3	828.1

The discharge frequency at Can Dang station is calculated based on observed data, see Table 0-5.

Table 0-5 Discharge frequency of Can Dang station (unit: m^3/s)

Station name	Frequencies of discharge (P %)										
	0.01	0.10	0.20	0.3	0.5	1	1.5	2	3	5	10
Cần Đăng	266	215	200	189	180	164	155	149	140	128	112

Water level data

From the hourly time series of water level data of all stations in the region, the statistical method is applied to determine the maximum water level of all stations corresponding to the design frequency. The observed maximum water levels are presented in Table 0-6. Thu Duc City is near the Phu An Station with a frequency of maximum water level of 10% and 1% is 1.68 m and 1.87 m+MSL, respectively.

Table 0-6 Maximum water level corresponding to design frequency at hydrological stations (Unit: m MSL)

Station name	Maximum water level corresponds to design frequency							
	0.2%	0.5%	1%	1.5%	2%	3%	5%	10%
Nha Be	1.97	1.91	1.87	1.84	1.82	1.79	1.75	1.69
Phu An	1.98	1.92	1.87	1.84	1.82	1.79	1.75	1.68
Vung Tau	1.61	1.59	1.57	1.56	1.55	1.54	1.52	1.49
Moc Hoa	4.1	3.85	3.64	3.52	3.43	3.29	3.11	2.84

Control structures

The control structures are simulated in the model including:

- Culverts have been built and operated such as Nhieu Loc – Thi Nghe sluice gates, the sluice gates and culverts on the right-bank and left-bank of the Saigon River.
- The sluice gates are being built in the Trung Nam Project or will be built according to the Plan 1547 such as: Ben Nghe, Tan Thuan, Phu Xuan, Muong Chuoi, Cay Kho, Phu Dinh, Ba Buom, Cau Kinh and Vam Thuat.

Climate change and sea level rise

Climate change and sea level rise scenarios for Viet Nam were released by the Ministry of Natural Resources and Environment for the first time in 2009 and updated in 2016 and in 2020 following the roadmap defined in the National Strategy on Climate Change. The update provided the latest information on the trends of climate change and sea level rise, as well as climate change and sea level rise scenarios for Viet Nam in the 21st century. RCP8.5 scenario is recommend to use for the planning.

According to the RCP8.5 scenario, the rainfall will tend to increase in the rainy season about 27% in 2050. RCP 8.5 also indicate that sea water level increasing in 2050 on East coast is 28 cm.

Table 0-7 Changes in autumn rainfall (%) when compared with baseline period (%)[4]

No.	Province, City	RCP 4.5 scenario		RCP 8.5 scenario	
		2046-2065	2080-2099	2046-2065	2080-2099
49	Ho Chi Minh	23.1 (-0.6 ÷ 47.3)	20.7 (6.0 ÷ 32.6)	27.0 (13.4 ÷ 40.3)	38.3 (16.1 ÷ 63.0)

[4] Climate change scenario, MONRE 2020

Table 0-8 Sea level rise scenarios based on the RCP8.5 scenario (cm)

Regions	21st century timeline							
	2030	2040	2050	2060	2070	2080	2090	2100
Mui Ke Ga – Mui Ca Mau	14 (10÷18)	20 (14÷27)	28 (19÷37)	32 (21 ÷ 46)	41 (27 ÷ 59)	51 (33 ÷ 73)	61 (41 ÷ 88)	73 (48 ÷ 105)

A1.3.3 Model calibration and validation

Calibration and validation indicator commonly used in hydrological and hydraulic modelling is Nash-Sutcliffe. With X_t^{Obs} being the observations, and X_t^{Sim} being the simulation results (both for time step t=1...n) and $\bar{X}^{Obs}$ being the average of the observations, the Nash-Sutcliffe coefficient is defined as:

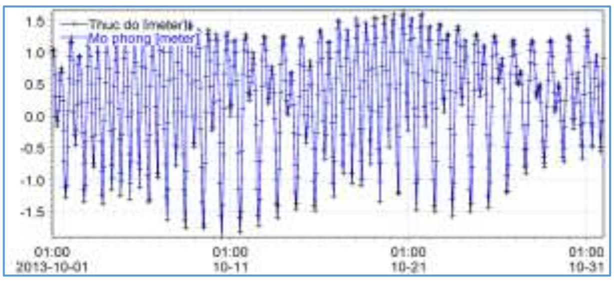
$$NS = 1 - \frac{\sum_{k=1}^{n}\left(X_k^{Sim} - X_k^{Obs}\right)^2}{\sum_{k=1}^{n}\left(X_k^{Obs} - \bar{X}^{Obs}\right)^2}$$

The Nash-Sutcliffe coefficient can be less or equal to 1. A value close to 1 is good. Negative values mean that the average value of the observations is a better predictor than the model used; using the average values of the observations as the simulated values time series corresponds with a NASH value of 0.0. The Nash-Sutcliffe indicator punishes mismatches (or time shifts) of peak values.

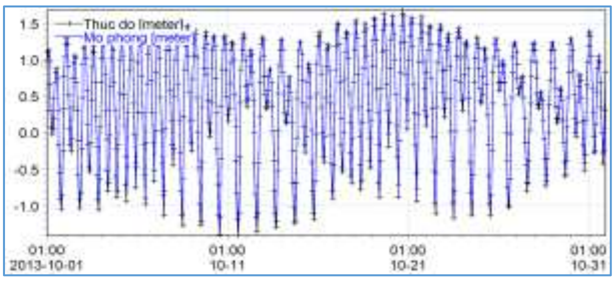
The quality of model calibration and validation is evaluated based on NASH as below:

- Excellent: 0.75 < NASH ≤ 1.00
- Good: 0.65 < NASH ≤ 0.75
- Average: 0.50 < NASH ≤ 0.65
- Fair: NASH ≤ 0.50

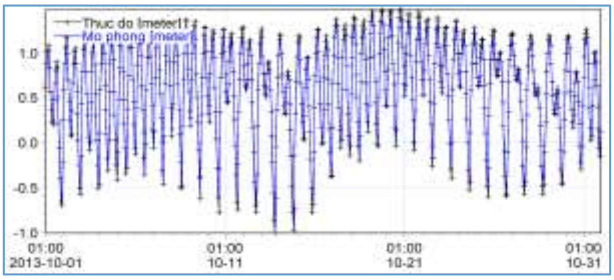
The 1D hydraulic model was used in the master plan for flood protection in Ho Chi Minh City and it was calibrated with observed discharge and water level data at 22 locations measused in 02 – 08 Jun, 2009. It is also calibrated in the spring tide in Oct 2013 and is validated in the spring tide in Sep 2019.



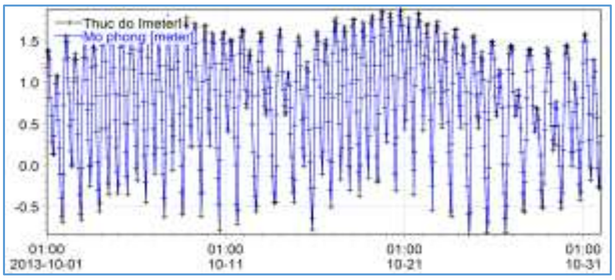
Water level at Nha Be station



Water level at Phu An station

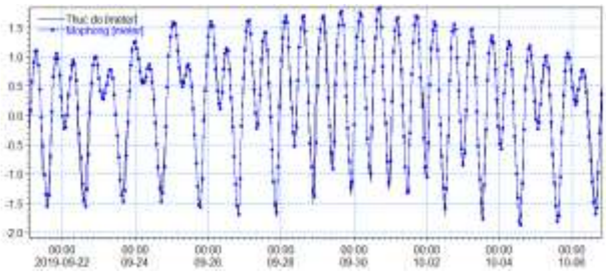


Water level at Thu Dau Mot station

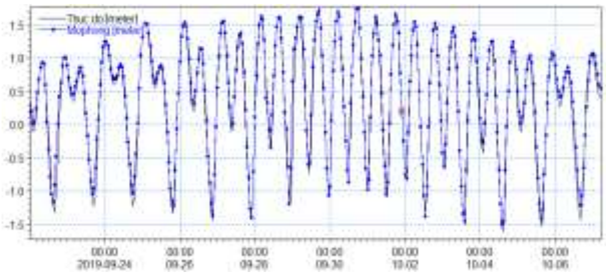


Water level at Bien Hoa station

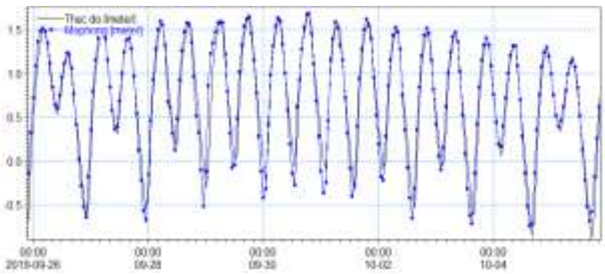
Figure 0-10 Comparison of simulated and observed water level in Oct 2013



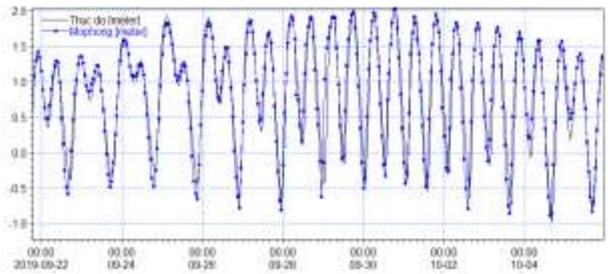
Water level at Nha Be station



Water level at Phu An station



Water level at Thu Dau Mot station



Water level at Bien Hoa station

Figure 0-11 Comparison of simulated and observed water level in Sep 2019

Table 0-9 NASH results of model calibration and validation

Station	Calibration Oct 2013	Validation Sep 2019
Nhà Bè	0,94	0,97
Phú An	0,95	0,96
Thủ Dầu Một	0,92	0,92
Biên Hòa	0,93	0,94

The model calibration and validation results indicate a very good performance of the model, with NASH coefficient from 0.92 to 0.97. The simulated water level has the same phase as the observed data. The simulated results showed high accuracy at the peaks and have slightly difference at the feet. In general, this model is reliable and sufficiently accurate during flood conditions to evaluate the river flood hazard for Thu Duc City.

A1.4 Assesing the flood risks

The flood hazard maps provide information on where flooding occurs, do not provide insights in whether the impact of flooding is small or large. Therefore, we has been made of our in-house Global Flood Risk Tool (GFRT) that contains numerous flood damage functions for urban areas in Vietnam. The GFRT is Royal HaskoningDHV's cloud-based platform that facilitates the supports systematic and comprehensive analtyses of flood exposure and risk. It is also supports the deveklopment and evaluation of flood risk mitigation measures and related investments. With help of the GFRT, flood damages and risk can be quantified for all or part of project area.

The flood hazard inundation maps generated with flood hazard models for various return periods flood frequencies are uswed as input to the GFRT. Economic damage is then computed by projecting the flood inundation maps on the available land use and systematically deriving the flood damage by using damage curves. Considering the annual expected flood risk allows to scope reasonable investments (basic cost-benefit analysis) and draw preliminary conclusions on feasibility of potential structural measures.

The GFRT is used as an online digital shell with a visually attractive user interface in which the hazard assessments, damage curves, exposure data and costs for measures are combined. An example of a hazard map, land use map and damage map developed for flood risk assessments for the harbour of Rotterdam in The Netherlands are shown in the figure below.

Figure 0-12 Example application of GFRT for harbour of Rotterdam in the Netherlands

Annex 2: City-wide flood management directions

A2.1 City-wide flood management

Several options to improving the city-wide flood management system in the lower elevation area of the city will be investigated hereafter. These options are:

1. Business as usual – improving the current approach
2. Optimizing the current polders – systematic introduction of pumping
3. City-wide integrated flood management – large polders with sluice gates
4. City-wide integrated flood management – large polders with pumps

The four investigated options and their flood risk reduction performance are discussed in the subsequent sections hereafter.

Overview of scenario calculations
The scenarios simulated for the flood model are summarized in Table 0-10. Scenarios for the flood risk analysis include flood return periods of 5 years, 10 years and 100 years in the current condition and climate change condition for a) the baseline situation (6 scenarios) and b) structural scenarios (24 scenarios).

Table 0-10 List of flood hazard scenarios

Scenario name	Current condition			Climate change 2050		
	RP 5 (20%)	RP10 (10%)	RP100 (1%)	RP 5 (20%)	RP10 (10%)	RP100 (1%)
Baseline	Y	Y	Y	Y	Y	Y
Small polders	Y	Y	Y	Y	Y	Y
Small polders with pumps	Y	Y	Y	Y	Y	Y
Large polder	Y	Y	Y	Y	Y	Y
Large polders with pumps	Y	Y	Y	Y	Y	Y

A2.1.1 Business as usual – improving the current approach

Main features
This option follows the flood management plan development developed by MARD plan (decision no. 1547). The MARD plan assumes that the city will be subdivided in 7 smaller polder areas leaving the main drainage canals that are intersecting the urban in open connection with the surrounding rivers. Sluice gates will be built in the water courses that are entering the urban areas in each of the smaller polders. The sluice gates will allow the discharge of excess flood waters and sewerage during lower tides, and will protect the city against potential flooding due to higher tidal water levels. The smaller polders will need to be protected by embankments against flooding due to high water levels in the rivers. Figure 0-13 shows the distribution in separate polder areas and the required construction of sluice gates and embankment or dikes.

For an adequate functioning of the urban flood management system, creating or maintaining sufficient open-water or space for water is essential (~10%). This needs to be explicitly included in the urban land use planning. With sea level rise and land subsidence the discharge capacity of the sluice gates will rapidly decrease in the coming decades. This means that the space reservation for open water and (green) flood storage need to anticipate to the long-term trends in relative sea levels rise, and look forward to 2100.

The following main interventions will be required:

- Sluice gates: construction of 47 new sluice gates
- Dikes/embankments: upgrade 80.1 km of existing dikes/embankments and construction of 51.1 km of new dikes/embankments
- Space of water: reverting of 829 ha of existing built areas to flood storage space. Please note the this estimate is tentative and needs to be further verified.

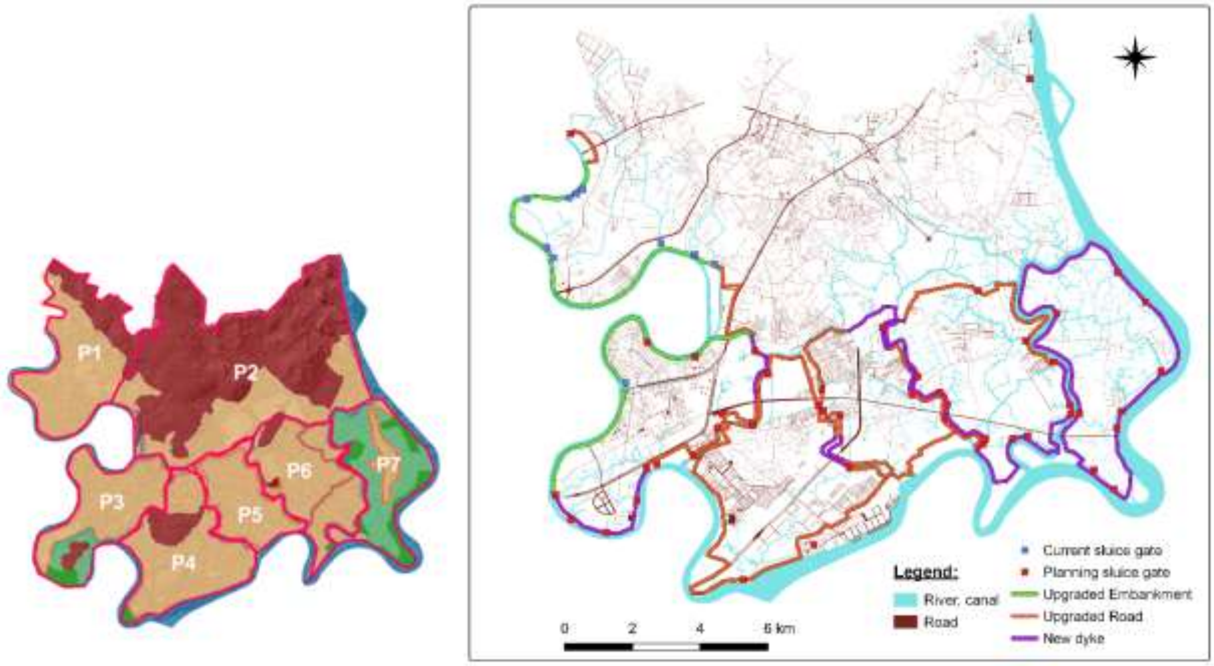


Figure 0-13 Distribution of Thu Duc City into small polders (left) and location of flood managegement infrastructure (right)

Flood hazards

The potential reduction of the flood inundation and related flood risk of the case with small polders that are drained via sluice gates assuming the *future* land use and under the *current (2020)* and *future (2050)* climate conditions are discussed hereafter.

Maps with the maximum flood inundation extent and depth for cases with flood exceedance probabilities of respectively 10% (1/10yr) and 1% (1/100yr) are provided in Figure 0-14. The total area in Thu Duc City that is inundated with a flood depth over 0.30m is provided in Table 0-11.

- *Current climate (2020)*

  Under the 1 in 10yr flooding conditions, still widespread inundation is observed throughout Thu Duc City. The total area that is inundated with a depth over 0.30m during a simulated flood event with an exceedance probability of 10% is estimated at 3,958 ha (21% of Thu

Duc). This is a reduction of 771 ha (16%) compared to the baseline. About 483 ha (2.6% of Thu Duc) is inundated with a depth of over 1m.

Under more extreme conditions (1/100yr flooding conditions), the total area inundated over 0.30m is 4,591 ha (24% of Thu Duc). This is a reduction of 1,266 ha (22%) compared to the baseline.

- *Future climate (2050)*

  The inundated area will increase with climate change due to an increase in rainfall intensities and sea level rise. The total area that is inundated with a depth over 0.30m during a simulated flood event with an exceedance probability of 10% is estimated at 4,546 ha (24% of Thu Duc). This is a reduction of 1,788 ha (28%) compared to the baseline. About 647 ha (3.4% of Thu Duc) is inundated with a depth of over 1m.

  Under more extreme conditions (1/100yr flooding conditions), the total area inundated over 0.30m is 5,085 ha (27% of Thu Duc). This is a reduction of 1,795 ha (26%) compared to the baseline.

Flood damage and risk

Maps with the mean annual flood damage for this case are provided in Figure 0-15. The associated mean annual flood risk in Thu Duc City is provided in Table 0-12.

- *Current climate (2020)*

  The total flood damage during a simulated flood event with an exceedance probability of 10% is estimated at 210 MUSD, which is a reduction of 57 MUSD (21%) compared to the baseline. In case of more extreme flooding conditions (1/100yr), the flood damage is estimated at 263 MUSD, which is a reduction of 119 MUSD (31%) compared to the baseline.

  The mean total annual flood damage is estimated at 37 MUSD/yr, which is a reduction of 17 MUSD/yr (31%) compared to the baseline. The map with the distribution of the mean annual damage over the city shows that damage occurs widespread over the area with hotspots in the northwest and southeast parts.

- *Future climate (2050)*

  With climate change, the mean annual damage clearly aggravates. The total flood damage during a simulated flood event with an exceedance probability of 10% is estimated at 261 MUSD, which is a reduction of 181 MUSD (41%) compared to the baseline. In case of more extreme flooding conditions (1/100yr), the flood damage is estimated at 314 MUSD, which is a reduction of 207 MUSD (40%) compared to the baseline.

  The mean total annual flood damage is estimated at 47 MUSD/yr, which is a reduction of 37 MUSD/yr (44%) compared to the baseline. The added value of the proposed risk reduction measures is substantially increasing with climate change.

Table 0-11 Area inundated with a flood depth over 0.30m. All cases. Current (2020) and future (2050) climate

Case	Current climate (2020)			Future climate (2050)		
Return period	*5 yr*	*10 yr*	*100 yr*	*5 yr*	*10 yr*	*100 yr*
Total inundated area (ha)						
Baseline	2,487	4,730	5,858	3,875	6,334	6,880
Small polders (sluice gates)	909	3,958	4,591	1,674	4,546	5,085
Small polder (pumped)	158	3,495	3,696	315	3,422	4,172
Large polders (sluice gates)	362	3,566	4,110	840	3,967	4,799
Large polders (pumps)	137	2,949	3,475	312	3,274	3,672
Total inundated area (% of Thu Duc City)						
Baseline	13%	25%	31%	21%	34%	37%
Small polders (sluice gates)	5%	21%	24%	9%	24%	27%
Small polder (pumped)	1%	19%	20%	2%	18%	22%
Large polders (sluice gates)	2%	19%	22%	4%	21%	26%
Large polders (pumps)	1%	16%	19%	2%	17%	20%
Difference with baseline (ha)						
Small polders (sluice gates)	-1,578	-771	-1,266	-2,201	-1,788	-1,795
Small polder (pumped)	-2,329	-1,234	-2,162	-3,560	-2,912	-2,708
Large polders (sluice gates)	-2,125	-1,163	-1,748	-3,034	-2,367	-2,081
Large polders (pumps)	-2,351	-1,780	-2,382	-3,563	-3,060	-3,208
Difference with baseline (%)						

Case	Current climate (2020)			Future climate (2050)		
Return period	***5 yr***	***10 yr***	***100 yr***	***5 yr***	***10 yr***	***100 yr***
Small polders (sluice gates)	-63%	-16%	-22%	-57%	-28%	-26%
Small polder (pumped)	-94%	-26%	-37%	-92%	-46%	-39%
Large polders (sluice gates)	-85%	-25%	-30%	-78%	-37%	-30%
Large polders (pumps)	-95%	-38%	-41%	-92%	-48%	-47%

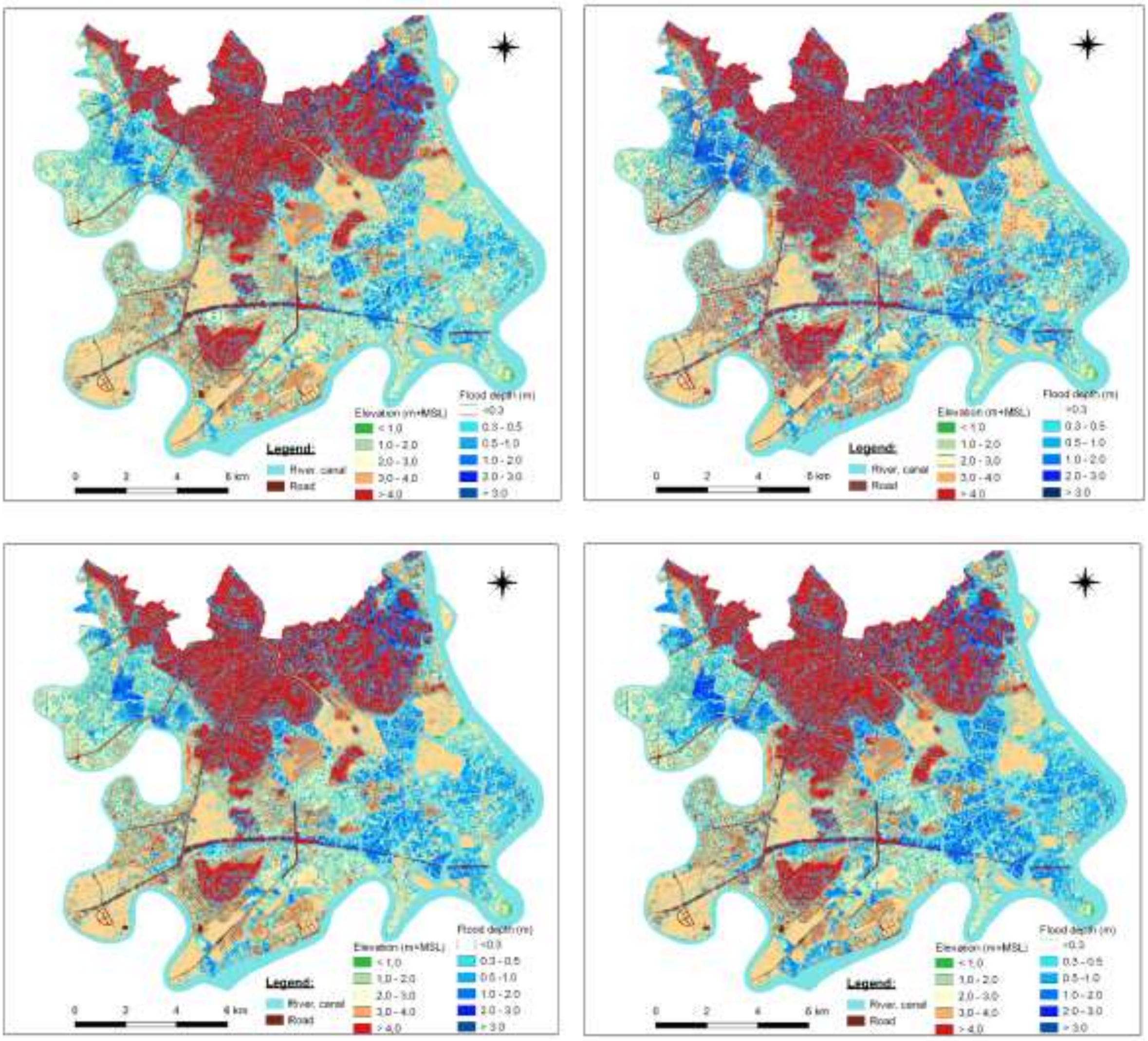


Figure 0-14 Maximum flood inundation map for cases with flood exceedance probability of 10% (left) and 1% (right). Case: small polders with sluice gates. Current climate 2020 (top) and future climate 2050 (bottom).

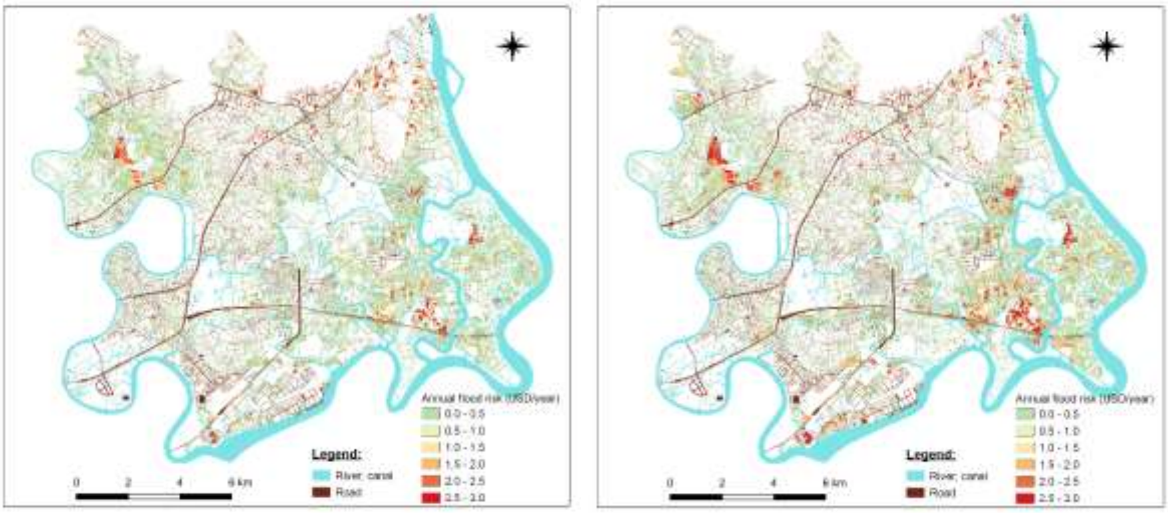


Figure 0-15 Mean annual flood risk (USD/yr). Case: small polders with sluice gates. Current climate 2020 (left) and future climate 2050 (right)

Table 0-12 Flood damage and risk in MUSD. All cases. Current (2020) and future (2050) climate

Case	Current climate (2020)				Future climate (2050)			
Return period	***5 yr***	***10 yr***	***100 yr***	***Mean annual***	***5 yr***	***10 yr***	***100 yr***	***Mean annual***
Total flood damage (MUSD)								
Baseline	139	268	382	53	264	442	521	84
Small polders (sluice gates)	46	210	263	37	95	261	314	47
Small polder (pumped)	7	177	192	28	14	174	225	30
Large polders (sluice gates)	17	184	224	31	41	214	279	38
Large polders (pumps)	5	147	182	24	14	165	191	27
Difference with baseline (ha)								
Small polders (sluice gates)	-93	-57	-119	-17	-170	-181	-207	-37
Small polder (pumped)	-132	-90	-190	-26	-251	-268	-296	-54
Large polders (sluice gates)	-122	-83	-158	-23	-224	-228	-241	-46
Large polders (pumps)	-134	-121	-200	-29	-251	-277	-330	-57
Difference with baseline (%)								
Small polders (sluice gates)	-67%	-21%	-31%	-31%	-64%	-41%	-40%	-44%
Small polder (pumped)	-95%	-34%	-50%	-48%	-95%	-61%	-57%	-65%
Large polders (sluice gates)	-88%	-31%	-41%	-43%	-85%	-52%	-46%	-55%
Large polders (pumps)	-96%	-45%	-52%	-55%	-95%	-63%	-63%	-68%

A2.1.2 Optimizing the current polders – systematic introduction of pumping

Main features
This option is similar as discussed in 0, but the pumping stations will be constructed next to the sluice gates. The pumping stations faciltate discharge of exces flood waters while the tidal levels in the rivers and main canals are too high to release water under gravity. Figure 0-13 shows the distribution in separate polder areas and the locations of the sluice gates where now also pumps will be installed. The embankments or dikes constriuction will be similar as in the previous option.

The water storage requirement is somewhat smaller than in case only sluice gates are installed. For an adequate functioning of the urban flood management system, creating or maintaining sufficient open-water or space for water is still essential (~6%). This space reservation needs to be explicitly included in the urban land use planning. The space reservation for open water and (green) flood storage need to anticipate to the long-term trends in climate change and look forward to 2100.

The following main interventions will be required:

- Pumping stations: construction of 32 new pumping stations with a total capacity of 249 m^3/s.
- Dikes/embankments: upgrade 80 km of existing dikes/embankments and construction of 31 km of new dikes/embankments
- Space of water: reverting of 272 ha of existing built areas to flood storage space. Please note the this estimate is tentative and needs to be further verified.

Flood hazards
The potential reduction of the flood inundation and related flood risk of the case with small polders that are drained via pumping stations assuming the *future* land use and under the *current (2020)* and *future (2050)* climate conditions are discussed hereafter.

Maps with the maximum flood inundation extent and depth for cases with flood exceedance probabilities of respectively 10% (1/10yr) and 1% (1/100yr) are provided in Figure 0-16. The total area in Thu Duc City that is inundated with a flood depth over 0.30m is provided in Table 0-11.

- *Current climate (2020)*

  Under the 1 in 10yr flooding conditions, still widespread inundation is observed throughout Thu Duc City. The total area that is inundated with a depth over 0.30m during a simulated flood event with an exceedance probability of 10% is estimated at 3,495 ha (19% of Thu Duc). This is a reduction of 1,234 ha (26%) compared to the baseline. About 394 ha (2.1% of Thu Duc) is inundated with a depth of over 1m.

  Under more extreme conditions (1/100yr flooding conditions), the total area inundated over 0.30m is 3,696 ha (20% of Thu Duc). This is a reduction of 2,162 ha (37%) compared to the baseline.

- *Future climate (2050)*

  The inundated area will increase with climate change due to an increase in rainfall intensities and sea level rise. The total area that is inundated with a depth over 0.30m during a simulated flood event with an exceedance probability of 10% is estimated at 3,422 ha (18% of Thu Duc). This is a reduction of 2,912 ha (46%) compared to the baseline. About 474 ha (2.5% of Thu Duc) is inundated with a depth of over 1m.

Under more extreme conditions (1/100yr flooding conditions), the total area inundated over 0.30m is 4,172 ha (22% of Thu Duc). This is a reduction of 2,708 ha (39%) compared to the baseline.

- *Replacing the sluice gates by pumping stations*

  Replacing the sluice gates by pumping stations, largely removes the effect of the tidal movement on the drainage capacity of the small polders. With this measure, the areas that inundate with a depth over 0.30m during rain storms with a probability of exceedance of 10% and 1% will reduce by respectively 463 ha (12%) and 896 ha (20%) in the current climate. With the assuming climate change in 2050, the reduction of the inundated areas will provide a similar relative flood hazard reduction: respectively 687 ha (15%) and 913 ha (18%).

Flood damage and risk

Maps with the mean annual flood damage for this case are provided in Figure 0-17. The associated mean annual flood risk in Thu Duc City is provided in Table 0-12.

- *Current climate (2020)*

  The total flood damage during a simulated flood event with an exceedance probability of 10% is estimated at 177 MUSD, which is a reduction of 90 MUSD (34%) compared to the baseline. In case of more extreme flooding conditions (1/100yr), the flood damage is estimated at 192 MUSD, which is a reduction of 190 MUSD (50%) compared to the baseline.

  The mean total annual flood damage is estimated at 28 MUSD/yr, which is a reduction of 26 MUSD/yr (48%) compared to the baseline. The map with the distribution of the mean annual damage over the city shows that damage occurs widespread over the area with the hotspots reduced to mainly the northwest part.

- *Future climate (2050)*

  The total flood damage during a simulated flood event with an exceedance probability of 10% is estimated at 174 MUSD, which is a reduction of 268 MUSD (61%) compared to the baseline. In case of more extreme flooding conditions (1/100yr), the flood damage is estimated at 225 MUSD, which is a reduction of 296 MUSD (57%) compared to the baseline.

  The mean total annual flood damage is estimated at 30 MUSD/yr, which is a reduction of 54 MUSD/yr (65%) compared to the baseline. The added value of the proposed risk reduction measures is substantially increasing with climate change.

- *Replacing the sluice gates by pumping stations*

  By replacing the sluice gates by pumping stations, the mean annual flood risk will reduce by respectively 9 MUSD/yr (24%) in the current climate, and by 17 MUSD/yr (37%) assuming climate change in 2050.

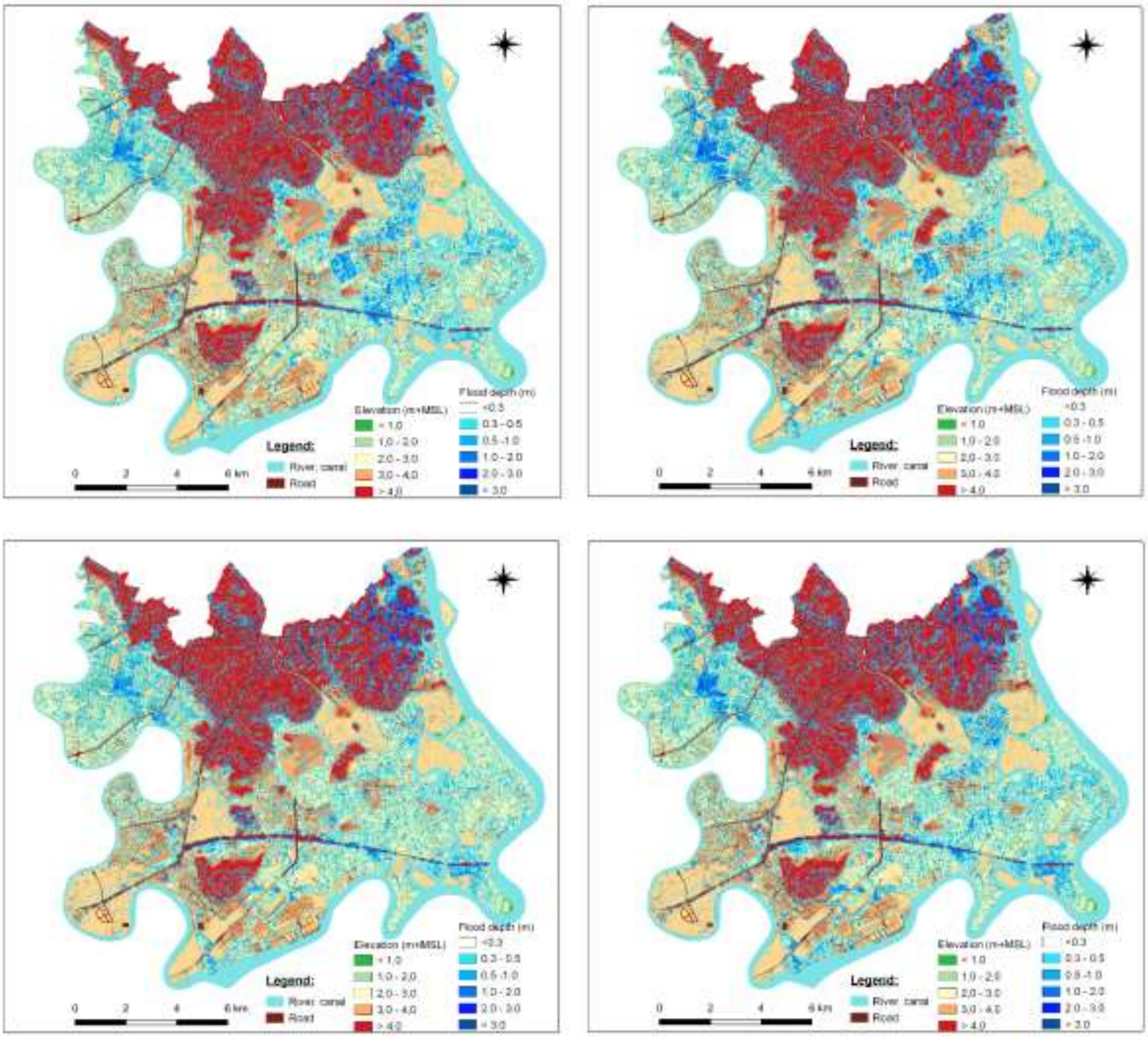


Figure 0-16 Maximum flood inundation map for cases with flood exceedance probability of 10% (left) and 1% (right). Case: small polders with pumping stations. Current climate 2020 (top) and future climate 2050 (bottom).

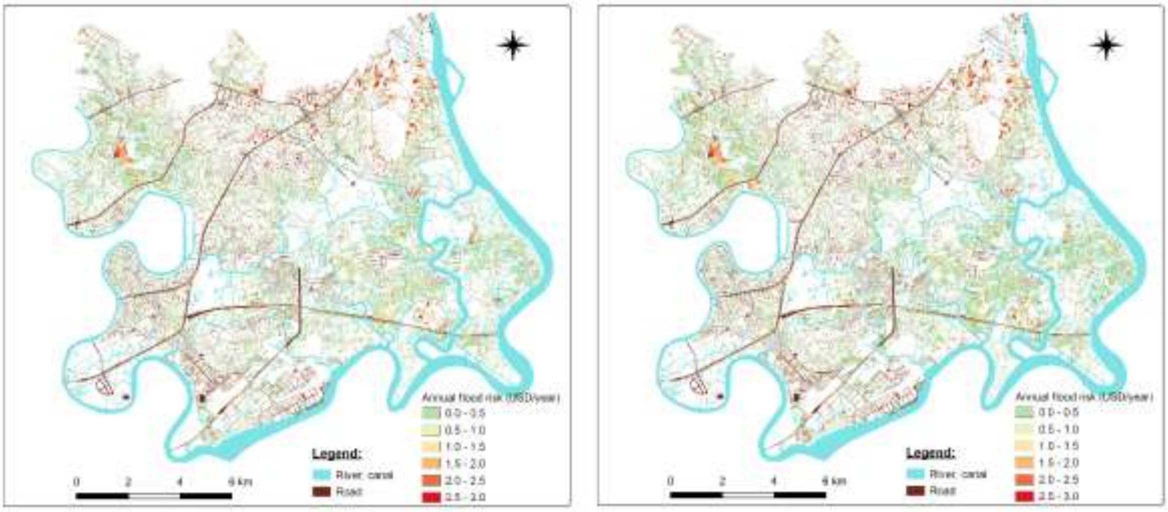


Figure 0-17 Mean annual flood risk (USD/yr). Case: small polders with pumping stations. Current climate 2020 (left) and future climate 2050 (right)

A2.1.3 City-wide integrated flood management – large polders with sluice gates

Main features
Instead of 7 smaller polder areas, a number of the polders could be included in a larger polder. This creates a truly city-wide flood management system with substantially more open-water surface because the larger canals that intersect the city, now become part of the polder. This reduces the required pumping capacity and directly increases the flood resilience. The length of the flood defence that protect against flooding from the river becomes much shorter. Also the number of sluice gates or pumping stations that drain the city becomes substantially lower. The main canals will now be partially closed which affects navigation and the incremental development of the flood management system is more difficult.

Sluice gates will be built in the smaller and larger water courses that discharge into rivers surrounding the urban area. The sluice gates will allow the discharge of excess flood waters and sewerage during lower tides, and will protect the city against potential flooding due to higher tidal water levels. The polders will need to be protected by embankments against flooding due to high water levels in the rivers. Figure 0-18 shows the distribution in separate polder areas and the required construction of sluice gates and embankment or dikes.

For an adequate functioning of the urban flood management system, creating or maintaining sufficient open-water or space for water is essential (~10%). Because part of the main canals are included in the large polder, the additionally required flood storage is less than in the case of smaller polders. The space for flood storage needs to be explicitly included in the urban land use planning. With sea level rise and land subsidence the discharge capacity of the sluice gates will rapidly decrease in the coming decades. This means that the space reservation for open water and (green) flood storage need to anticipate to the long-term trends in relative sea levels rise, and look forward to 2100.

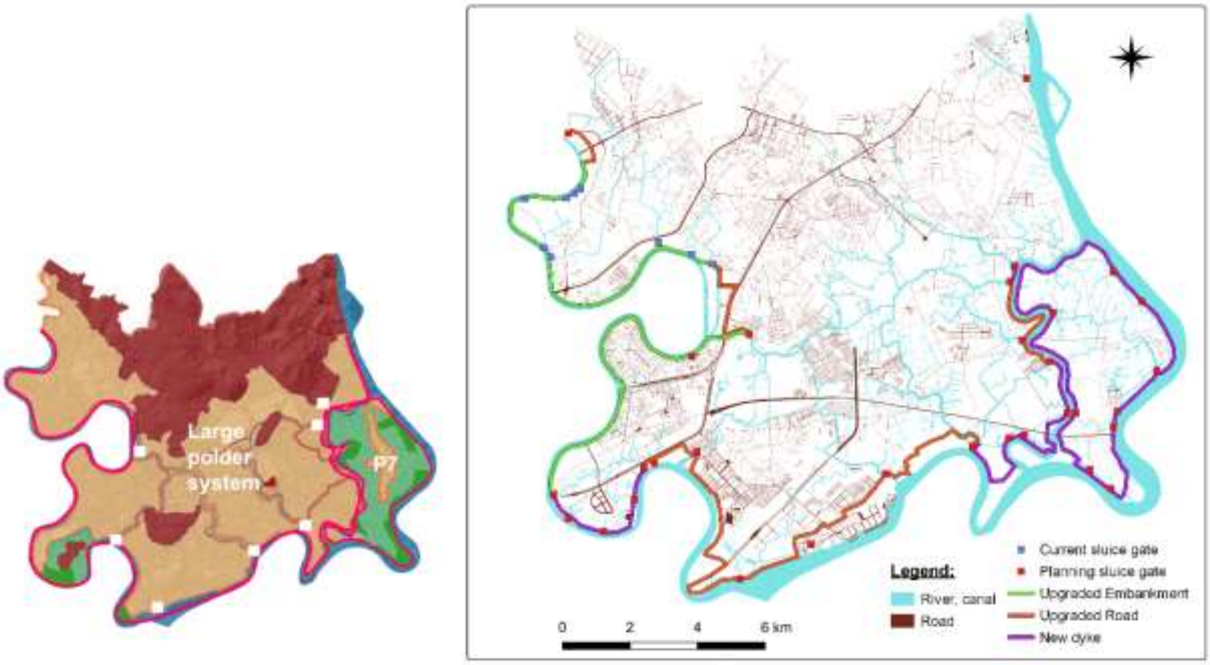


Figure 0-18 Distribution of Thu Duc City into large and small polder (left), and location of flood managegement infrastructure (right)

The following main interventions will be required:

- Sluice gates: construction of 31 new sluice gates of which 7 are larger and located in the main canals intersecting the city
- Dikes/embankments: upgrade 52.7 km of existing dikes/embankments and construction of 35.9 km of new dikes/embankments
- Space of water: reverting of 559 ha of existing built areas to flood storage space. Please note the this estimate is tentative and needs to be further verified.

Flood hazards

The potential reduction of the flood inundation and related flood risk of the case with a large polder that is drained via sluice gates assuming the *future* land use and under the *current (2020)* and *future (2050)* climate conditions are discussed hereafter.

Maps with the maximum flood inundation extent and depth for cases with flood exceedance probabilities of respectively 10% (1/10yr) and 1% (1/100yr) are provided in Figure 0-19. The total area in Thu Duc City that is inundated with a flood depth over 0.30m is provided in Table 0-11.

- *Current climate (2020)*

  The total area that is inundated with a depth over 0.30m during a simulated flood event with an exceedance probability of 10% is estimated at 3,566 ha (19% of Thu Duc). This is a reduction of 1,163 ha (25%) compared to the baseline. About 422 ha (2.2% of Thu Duc) is inundated with a depth of over 1m.

  Under more extreme conditions (1/100yr flooding conditions), the total area inundated over 0.30m is 4,110 ha (22% of Thu Duc). This is a reduction of 1,748 ha (30%) compared to the baseline.

- *Future climate (2050)*

  The total area that is inundated with a depth over 0.30m during a simulated flood event with an exceedance probability of 10% is estimated at 3,967 ha (21% of Thu Duc). This is a reduction of 2,367 ha (37%) compared to the baseline. About 520 ha (2.8% of Thu Duc) is inundated with a depth of over 1m.

  Under more extreme conditions (1/100yr flooding conditions), the total area inundated over 0.30m is 4,799 ha (26% of Thu Duc). This is a reduction of 2,081 ha (30%) compared to the baseline.

Flood damage and risk
Maps with the mean annual flood damage for this case are provided in Figure 0-20. The associated mean annual flood risk in Thu Duc City is provided in Table 0-12.

- *Current climate (2020)*

  The total flood damage during a simulated flood event with an exceedance probability of 10% is estimated at 184 MUSD, which is a reduction of 83 MUSD (31%) compared to the baseline. In case of more extreme flooding conditions (1/100yr), the flood damage is estimated at 224 MUSD, which is a reduction of 158 MUSD (41%) compared to the baseline.

  The mean total annual flood damage is estimated at 31 MUSD/yr, which is a reduction of 23 MUSD/yr (43%) compared to the baseline.

- *Future climate (2050)*

  The total flood damage during a simulated flood event with an exceedance probability of 10% is estimated at 214 MUSD, which is a reduction of 228 MUSD (52%) compared to the baseline. In case of more extreme flooding conditions (1/100yr), the flood damage is estimated at 279 MUSD, which is a reduction of 241 MUSD (46%) compared to the baseline.

  The mean total annual flood damage is estimated at 38 MUSD/yr, which is a reduction of 46 MUSD/yr (55%) compared to the baseline. The added value of the proposed risk reduction measures is substantially increasing with climate change.

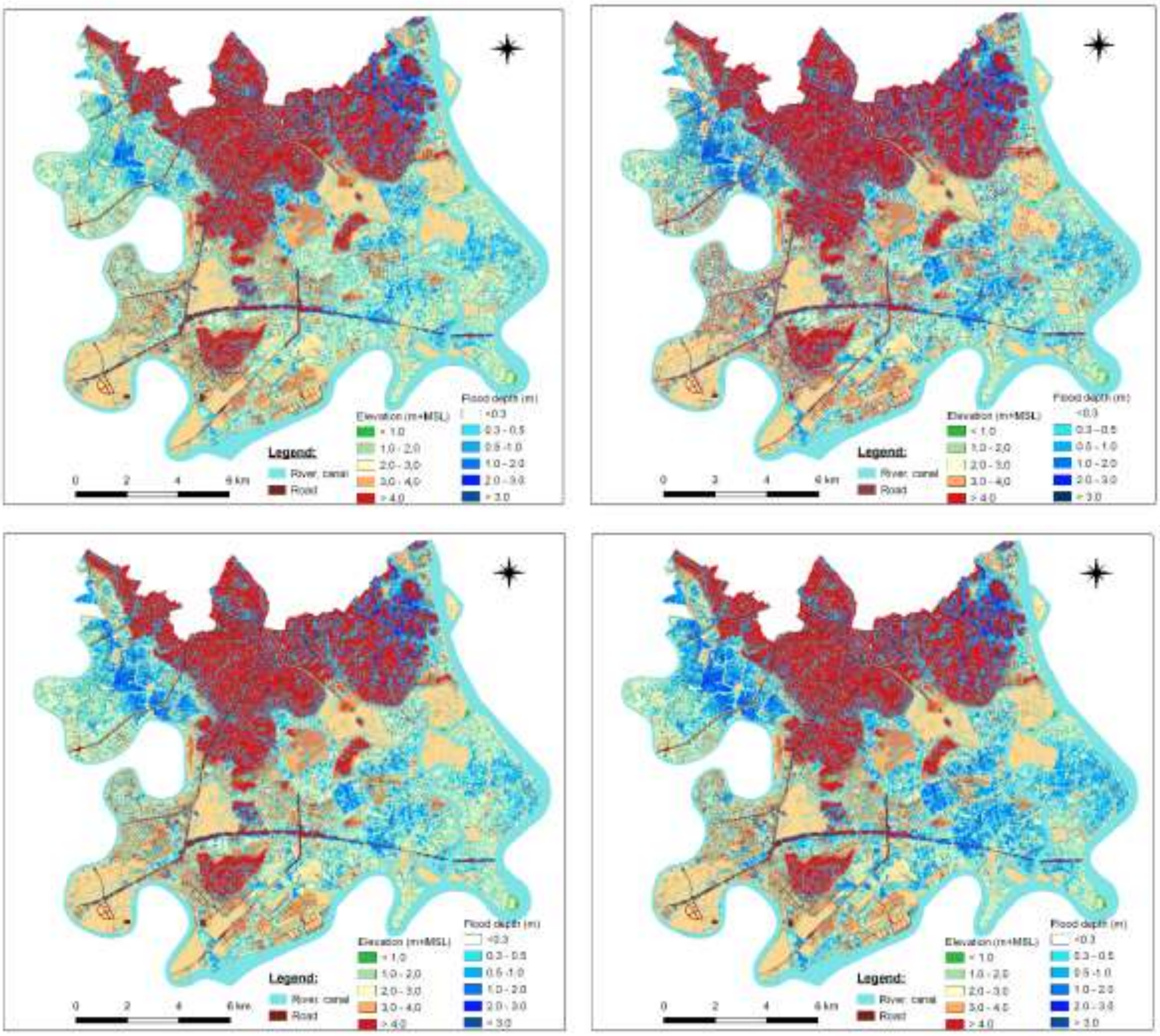


Figure 0-19 Maximum flood inundation map for cases with flood exceedance probability of 10% (left) and 1% (right). Case: large polder with sluice gates. Current climate 2020 (top) and future climate 2050 (bottom).

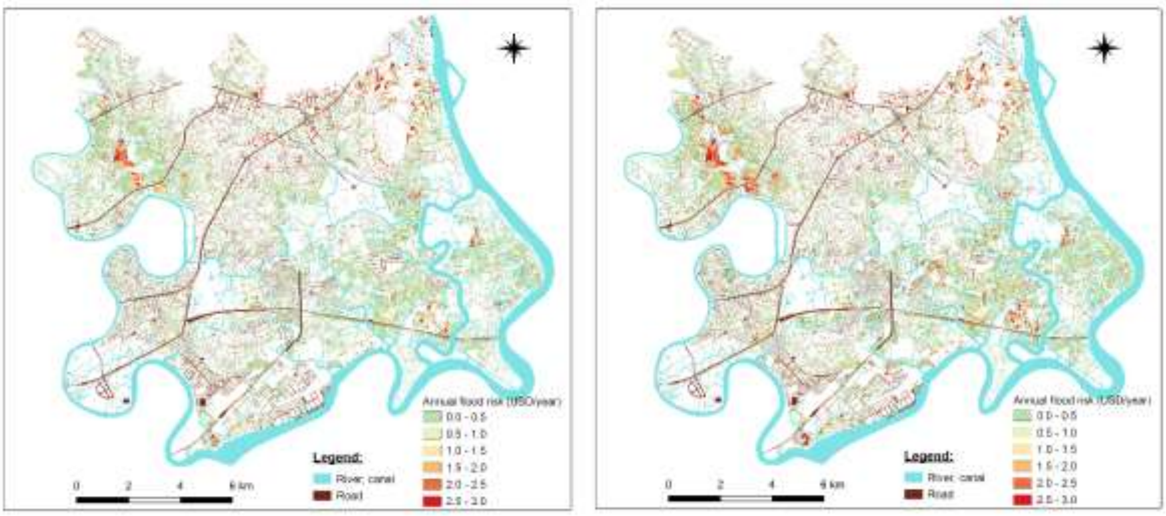


Figure 0-20 Mean annual flood risk (USD/yr). Case: large polder with sluice gates. Current climate 2020 (left) and future climate 2050 (right)

A2.1.4 City-wide integrated flood management – large polders with pumps

Main features
This option is similar as discussed in 0, but the pumping stations will be constructed next to the sluice gates. The pumping stations faciltate discharge of excess flood waters while the tidal levels in the rivers and main canals are too high to release water under gravity. Figure 0-18 shows the distribution in separate polder areas and the locations of the sluice gates where now also pumps will be installed. The embankments or dikes constriuction will be similar as in the previous option.

The water storage requirement is somewhat smaller than in case only sluice gates are installed. For an adequate functioning of the urban flood management system, creating or maintaining sufficient open-water or space for water is still essential (~6%). This space reservation needs to be explicitly included in the urban land use planning but is almost negligent in this option. The space reservation for open water and (green) flood storage need to anticipate to the long-term trends in climate change and look forward to 2100.

The following main interventions will be required:

- Pumping stations: construction of 21 new pumping stations with a total capacity of 146 m^3/s.
- Dikes/embankments: upgrade 52.7 km of existing dikes/embankments and construction of 35.9 km of new dikes/embankments
- Space of water: reverting of 19 ha of existing built areas to flood storage space. Please note the this estimate is tentative and needs to be further verified.

Flood hazards
The potential reduction of the flood inundation and related flood risk of the case with a large polder that is drained via pumping stations assuming the *future* land use and under the *current (2020)* and *future (2050)* climate conditions are discussed hereafter.

Maps with the maximum flood inundation extent and depth for cases with flood exceedance probabilities of respectively 10% (1/10yr) and 1% (1/100yr) are provided in Figure 0-16. The total area in Thu Duc City that is inundated with a flood depth over 0.30m is provided in Table 0-11.

- *Current climate (2020)*

  The total area that is inundated with a depth over 0.30m during a simulated flood event with an exceedance probability of 10% is estimated at 2,949 ha (16% of Thu Duc). This is a reduction of 1,780 ha (38%) compared to the baseline. About 338 ha (1.8% of Thu Duc) is inundated with a depth of over 1m.

  Under more extreme conditions (1/100yr flooding conditions), the total area inundated over 0.30m is 3,475 ha (19% of Thu Duc). This is a reduction of 2,382 ha (41%) compared to the baseline.

- *Future climate (2050)*

  The total area that is inundated with a depth over 0.30m during a simulated flood event with an exceedance probability of 10% is estimated at 3,274 ha (17% of Thu Duc). This is a reduction of 3,060 ha (48%) compared to the baseline. About 368 ha (2.0% of Thu Duc) is inundated with a depth of over 1m.

Under more extreme conditions (1/100yr flooding conditions), the total area inundated over 0.30m is 3,672 ha (20% of Thu Duc). This is a reduction of 3,208 ha (47%) compared to the baseline.

- *Replacing the sluice gates by pumping stations*

  Replacing the sluice gates by pumping stations, largely removes the effect of the tidal movement on the drainage capcity of the small polders. With this measure, the areas that inundate with a depth over 0.30m during rain storms with a probability of exceedance of 10% and 1% will reduce by respectively 617 ha (17%) and 634 ha (15%) in the current climate. With the assuming climate change in 2050, the reduction of the inundated areas will provide a similar relative flood hazard reduction: respectively 693 ha (17%) and 1,127 ha (23%).

Flood damage and risk
Maps with the mean annual flood damage for this case are provided in Figure 0-17. The associated mean annual flood risk in Thu Duc City is provided in Table 0-12.

- *Current climate (2020)*

  The total flood damage during a simulated flood event with an exceedance probability of 10% is estimated at 147 MUSD, which is a reduction of 121 MUSD (45%) compared to the baseline. In case of more extreme flooding conditions (1/100yr), the flood damage is estimated at 182 MUSD, which is a reduction of 200 MUSD (52%) compared to the baseline.

  The mean total annual flood damage is estimated at 24 MUSD/yr, which is a reduction of 29 MUSD/yr (55%) compared to the baseline.

- *Future climate (2050)*

  The total flood damage during a simulated flood event with an exceedance probability of 10% is estimated at 165 MUSD, which is a reduction of 277 MUSD (63%) compared to the baseline. In case of more extreme flooding conditions (1/100yr), the flood damage is estimated at 191 MUSD, which is a reduction of 330 MUSD (63%) compared to the baseline.

  The mean total annual flood damage is estimated at 27 MUSD/yr, which is a reduction of 57 MUSD/yr (68%) compared to the baseline. The added value of the proposed risk reduction measures is substantially increasing with climate change.

- *Replacing the sluice gates by pumping stations*

  By replacing the sluice gates by pumping stations, the mean annual flood risk will reduce by respectively 6 MUSD/yr (21%) in the current climate, and by 89 MUSD/yr (32%) assuming climate change in 2050. Especially with progressing climate change, the transition from draining with sluice gates to pumping stations will substantially reduce the mean annual flood damage.

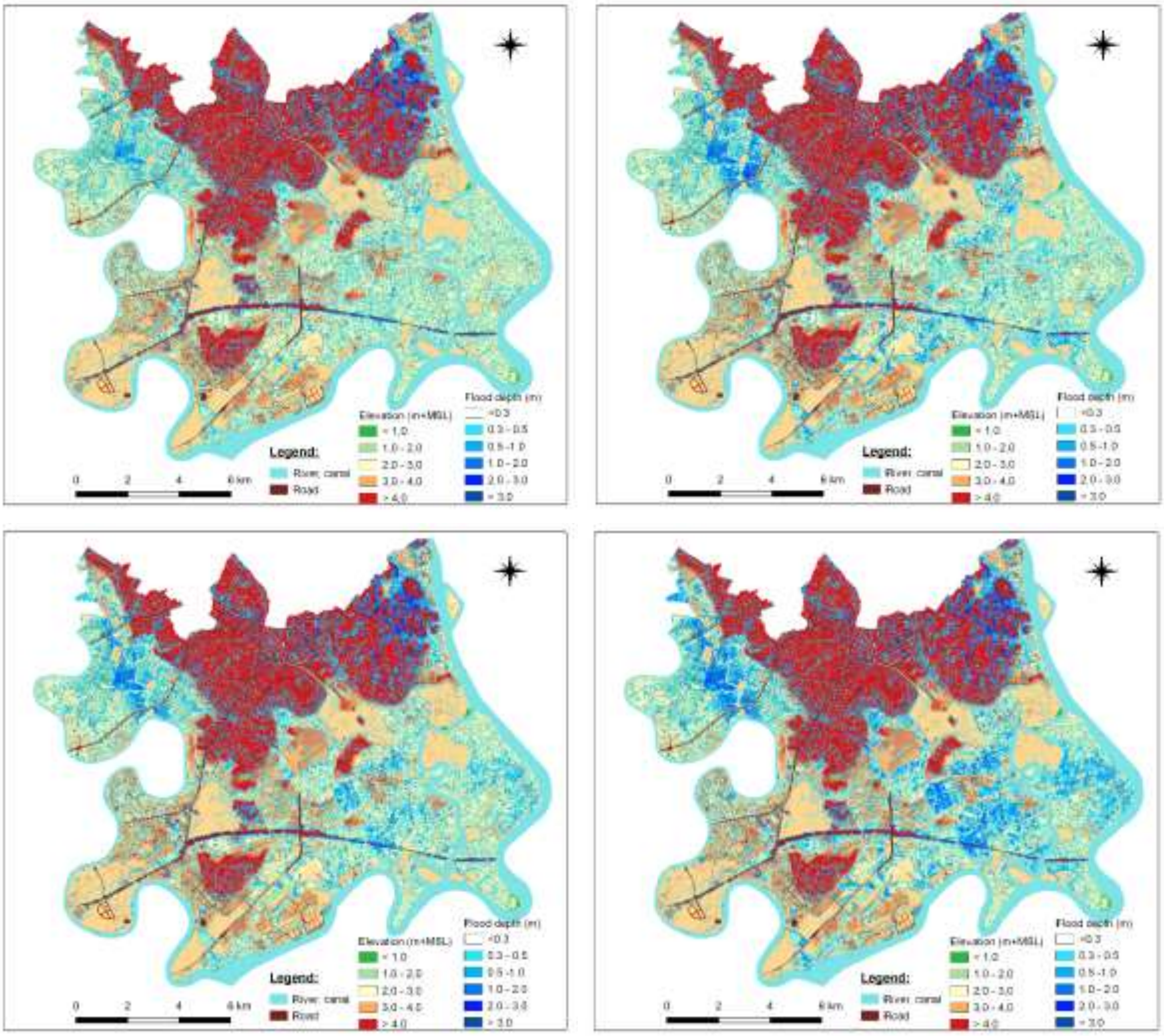


Figure 0-21 Maximum flood inundation map for cases with flood exceedance probability of 10% (left) and 1% (right). Case: large polder with pumping stations. Current climate 2020 (top) and future climate 2050 (bottom).

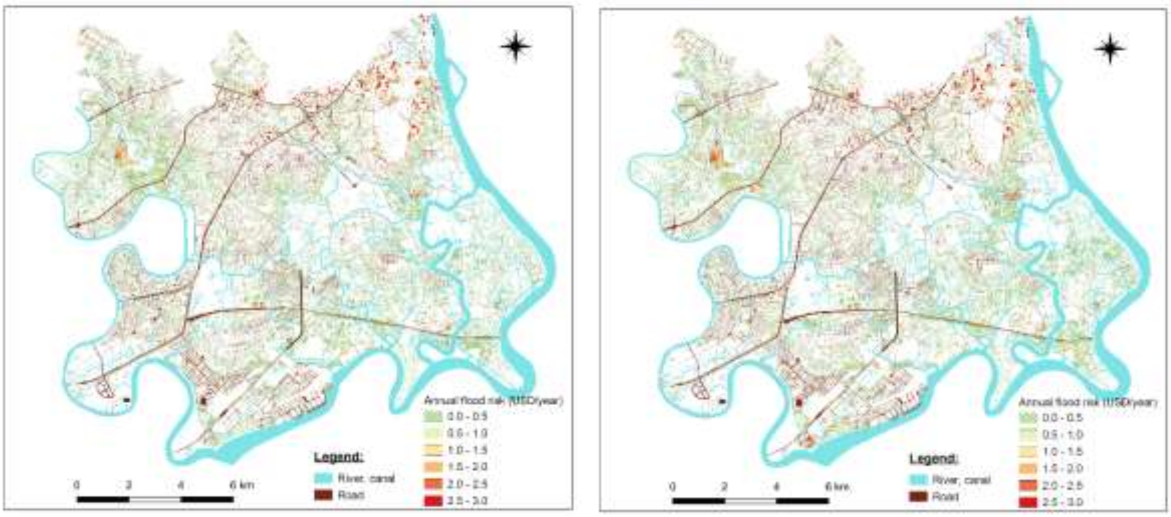


Figure 0-22 Mean annual flood risk (USD/yr). Case: large polder with pumping stations. Current climate 2020 (left) and future climate 2050 (right)

A2.2 Comparison city-wide flood management directions

A concise, qualitative, multi-criteria assessment (MCA) is presented on the next page, with the objective to provide an initial overview of the potential benefits and drawbacks of the options in consideration. The MCA considers the sustainability of proposed measures by minimizing the need for maintenance, and the practicality of their implementation (i.e. likelihood of successful implementation), and aim to minimise negative environmental and socio-economic impacts (e.g. the need for relocation of people and enterprises and provide additional social, environmental, or economic benefits).

A2.3 Combining measures

In the current situation, smaller polder systems are in place that discharge excess flood waters via sluice gates and a very limited number of pumping stations. In the previous section several options have been discussed for improving the city-wide flood management system. This analysis shows that on the somewhat longer term, the development of a large polder system operated with pumping stations adjacent to sluice gates is preferable for coping with relative sea level rise and the space requirements for of urban development. Besides implementing an adequate urban drainage system with sufficient flood storage in the new development areas, the following developments in the city-wide flood management system are advised:

- Initiate the development of the large polder with sluice gates but anticipate to the implementation of pumping stations in the coming 10 years
- Upgrade and construct an adequate dike system for the large polder system option
- Improve the current sluice gate and associated embankment systems that protect the lowest and most vulnerable areas. This will faciltate to optimal use of the open-water area in the large polder for flood storage without the risk of flooding of parts of the urban area

The preliminary adaptive roadmap discussed in Chapter **Error! Reference source not found.** discusses the path towards the implementation of the flood risk management system in more detail.

Criteria	Small polders	Small polders with pumps	Large polders without pumps	Large polders with pumps
Technical	0/+	0	+	+
Technical performance and future	+	++	+	+++
	Based on the hydraulic assessment and flood risk assessment, the large polders with pumps has the largest flood risk reduction. The small polders with pumps performs better than the small polders without pumps and the large polder without pumps.			
Constructability / construction complexity	++	+	+	0
	Known construction methods in Vietnam. Relatively small structures.	Known construction methods in Vietnam, however, pumps and gates have to be combined. Relatively small structures.	Several larger sluice gates that are more challenging to construct (building in wet environment).	Several larger sluice gates that are more challenging to construct (building in wet environment). Pumps and gates have to be combined.
Operations & Maintenance complexity	0	--	0	-
	Many structures require attention and frequent maintenance. The maintenance is relatively easy.	Many medium sized pumps (>30) are prone to failure, require attention and frequent maintenance.	Few structures require somewhat more attention and frequent maintenance. The maintenance is	Several smaller to medium sized pumps (<30) are prone to failure, require attention

Criteria		Small polders	Small polders with pumps	Large polders without pumps	Large polders with pumps
				relatively easy but could be costly.	and frequent maintenance.
	Climate resilience & adaptability (flexibility and expandability)	0		++	
		The smaller polders without pumps could be expanded into smaller polders with pumps to reduce flood risk in the future. However, the required pumping capacity is higher than the larger polders. And, the smaller polders require a lot of gates and dykes inside the city that cannot easily be upgraded.		The larger polders without pumps could be expanded into larger polders with pumps to reduce flood risk in the future. Water in the larger polder can be more easily managed and the concept has fewer gates and pumps which allows for easier upgrading following to the climate changes in the future.	
Environment		0		0	
		The smaller polders without pumps and with pumps have similar effects on the environment. The gates of the smaller polders will only close if heavy rain in combination with high tide is		The larger polders without pumps and with pumps have similar effects on the environment. The gates of the large polders will only close if heavy rain in combination with high tide is	

Criteria		Small polders	Small polders with pumps	Large polders without pumps	Large polders with pumps
		forecasted. Therefore, the system remains operating in a similar way as it is currently doing for most of the time. Therefore, the environmental impacts are minor. Whether the effects of changes in the tide water system are positive or negative will require further assessment. Compared to the large polder, the smaller polders will create a smaller water environment in the individual polders, and leave the river-canal system to be fully part of the larger river system.		forecasted. Therefore, the system remains operating in a similar way as it is currently doing for most of the time. Therefore, the environmental impacts are minor. Whether the effects of changes in the tide water system are positive or negative will require further assessment.	
	Ecological and landscape development	0		0	
	Underground and groundwater	0		0	
	Sediments / morphology	0		0	
	Biodiversity	0		0	
	Water quality	-		-	
		At present, sewerage water is combined with stormwater, and is discharged directly into the river-canal system. Closing off temporarily to prevent flooding, will accumulate at present untreated wastewater. We advocate for decoupling the stormwater drainage system from the sewerage system over time. This will allow to retain water in the city in green-blue retention areas. Overall, decoupling the two systems and			

Criteria	Small polders	Small polders with pumps	Large polders without pumps	Large polders with pumps
	treatment of sewerage water will improve the water quality overall (and the water quality scoring in the future would be positive).			
Socio-economic	0	+	0/+	+
	The smaller polders without pumps and with pumps have similar effects on the environment.		The larger polders without pumps and with pumps have similar effects on the environment.	
Relocation of existing properties, businesses and citizens	--		-	
	Total length of waterfront to be upgraded or built, and the number of gates to be constructed, is in total larger than the large polders, and therefore the smaller polders score worse.			
Flood impacts to livelihoods and economy (benefits)	+	++	+	++
	Based on the hydraulic assessment and flood risk assessment, the large polders with pumps has the largest flood risk reduction. The small polders with pumps performs better than the small polders without pumps and the large polder without pumps. Urban areas that are protected from flooding generally experience an increase in land value, improved community health and allow for further economic growth.			
Quality of life the city (excl. flood impacts)	++	++	++	++
	The smaller and polders introduce several blue-green areas that are multi-purpose and provide space for recreation and access to nature.			
Navigation	0		-	
	Some transport over water takes over the canals between the individual polders. By realising larger polder systems, some of these waterways will be blocked. This could be prevented by providing shiplocks, however, these are often costly and their financial feasibility will have to be investigated,			

Criteria		Small polders	Small polders with pumps	Large polders without pumps	Large polders with pumps
		starting by an assessment on the existing economic value of these shipping routes as well as considering whether these port locations are to remain within the (largely residential and commercial) areas of the Thu Duc City. Shiplocks generally do result in longer shipping times. In case of the small polders, it is expected that existing transport over water can continue without any hinder.			
Expenditure		-	---	-	--
	Capital Expenditure (CAPEX)	USD 0.33 billion	USD 0.47 billion	USD 0.29 billion	USD 0.38 billion
	Operational Expenditure (OPEX)	--	---	-	--

Legend

+++	high positive impact
++	medium positive impact
+	positive impact
0	no impact
-	negative impact
--	medium negative impact
---	severe negative impact

Summary	Small polders	Small polders with pumps	Large polders without pumps	Large polders with pumps
Technical	0/+	0	+	+
Environment	0		0	
Socio-economic	0	+	0/+	+
Expenditure	-	---	-	--

Legend

+++	high positive impact
++	medium positive impact
+	positive impact
0	no impact
-	negative impact
--	medium negative impact
---	severe negative impact

Annex 3: Investment packages

A3.1 Investment package (1): Drainage improvement

Upgrading of the current urban drainage system to be able to cope with the current (already increasing) floods as well as future expected floods is considered an urgent and low regret measure. This measure is considered irrespectively of the chosen city-wide flood management direction discussed in Appendix 0. It could be combined with creation of flood retention in order to delay the outflow and thereby reduce the peak flows. Green/blue solutions for storage could be combined to optimize the design loads of the network.

Based and the flood risk assessment, possible interventions measures and consultations with the Main Stakeholders, measures in the system are narrowed down as presented in Table 0-13. The distinguished areas presented earlier have been followed here.

Table 0-13 Overview of measures, areas and timing of implementation

Measures and areas	Timing
Thu Duc City wide	
Upgrade major drainage network	Since this will have significant impact, include in first investment package in Polders 1, 2 and 3
Decouple sewerage network (e.g. interceptors for existing areas, separated system for newly developed areas)	Since this will have significant impact, include in first investment package in Polders 1, 2 and 3
Flood forecasting, operational management and early warning system	Can be done in paralel with implementation of first investment package.
Building codes (green and water sensitive)	One of the first things to be done in order to take full benefit
Higher elevated areas	
NBS for retention & infiltration	Can be included in next investment package
Retention in street profile, parking areas, water squares etc.	Where possible, integrate in first investment package
Green buildings with storage	Can be included in next investment package
Urban areas	
Dredge canals (and widen)	Since this will have significant impact, include in first investment package
Optimise canal embankments	Since this will have significant impact, include in first investment package
NBS for retention &	Can be included in next investment package
Green corridors for extreme floods	Can be included in next investment package
Create awareness	One of the first things to be done in order to take full benefit
Public recreation for retention	Can be included in next investment package
Elevate roads for evacuation pathways	To be further investigated
Build properties on piles (P7)	To be further investigated
River-canal system	
Construct sluice gates	Since it has a significant impact include in first investment package
Construct multi-functional river dyke (combine with roads)	Proposed to include in next investment package
Upgrade/construct (green) river embankments	These are proposed to include in the first investment package
Install pump capacity	Proposed to include in next investment package

For the river-canal system, locations are identified in Figure 0-23 and are based on the findings of the flood risk assessment.

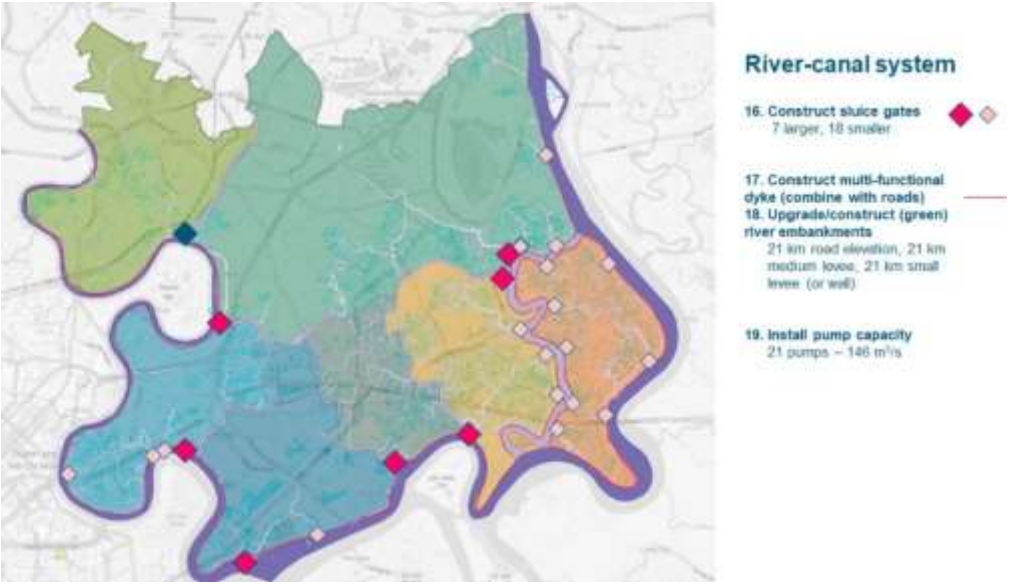


Figure 0-23 Locations of proposed measures in river-canal system

As mentioned, the MTIP has already identified measures and this planning relates to various projects and initiatives for Polders 1, 2 and 3 varying from buildings, education, health control and projects aiming at water management. For the latter, projects are divided into drainage (including sewer improvements), embankments and dredging. The table below presents said water management projects which are planned for the next 5 years. It is noted that these projects have been approved by Thu Duc City's People Committee in 2021. There is some overlap between embankments and dredging since there are in some occasions identified as a combined projects; for now this has been assumed being acceptable.

Few projects planned in MTIP are related green parks and creation of retention areas and they have been left out since the first investment package deals with drainage infrastructure only. When detailing the plans in next stages of the preparation, these green parks and retention areas, amongst others, can be revisited and assessed to which extend they can be integrated in the overall urban planning. The relevant MTIP projects are presented in Table 0-14,

Table 0-14 Relevant MTIP projects for flood mitigation Thu Duc City

Polder	Currency	MTIP projects planned 2021 - 2025			Totals
		Drainage	Embankments	Dredging	
1	Million VND	247,577		52,072	299,649
	Million USD	10.65		2.24	12.89
2	Million VND	26,049	88,351	69,219	183,619
	Million USD	1.12	3.80	2.98	7.90
3	Million VND	170,216	4,310,566	5,194,533	9,675,315
	Million USD	7.32	185.40	223.42	416.14
			Totals	Million VND	10,158,583
1 USD =	23,250	VND		Million USD	436.93

Since Polders 1, 2 and 3 are most densely populated and are exposed to drainage problems and waterlogging it make sense to first invest in the areas of said polders (see also the earlier presented risk maps of these areas). From a concept of controlling the water in upstream areas once pluvial water enters the system, this also makes sense. Since the MTIP has already been prepared with a certain level of detail including locations of the measures and cost estimates, it stands to reason to take the MTIP as guidance in defining the first investment package. The project components presented in the MTIP as show in the table here above have been supplemented with the measures presented in table in Table 0-14,

Outline cost estimate first investment package and phasing
An outline cost estimate for the first investment package is shown in Table 0-15. As said, for the drainage infrastructure, cost estimates prepared for MTIP have been used at this stage; other cost estimates are based on Consultant’s engineering judgement.

Table 0-15 Ouline cost estimate for first investment package

Cost item		Outline cost estimate in Million USD
Capital cost		
Construction and rehabilitation of embankments		200.00
Drainage and sewerage works		30.00
Dredging of canals		225.00
Sluice gates		50.00
Project management and consultancy cost		
Project management and consultancy cost		10.00
Flood forecasting, operational management and early warning system		5.00
Feasibility studies, detailed design, tendering and supervision		25.00
Sub-total		545.00
Contingencies	10%	54.50
Taxes	15%	81.75
Total		**681.25**

It is assumed that cost for environmental mitigating measures and cost associated with social safeguarding are included in afore mentioned outline cost estimates.

The implementation including preparations would typically take some 5 years after decisions have been taken.

A3.2 Investment package (2): Nature based solutions for retention

The projected (and already observed) impacts that climate change imposes to Thu Duc City (Chapter **Error! Reference source not found.**), marks the urgency to shift from the traditional protective design approaches to solutions which essentially embed natural processes. A Nature-based approach recognizes and responds to the changing climate by enclosing resilience in natural systems and infrastructure.

Nature-based solutions can be used to create urban flood retention and storage, and thus optimize the required capacity of the urban drainage system which is proposed in the previous section – Investment Package (1). The proposal of nature-based flood retention for Thu Duc focuses in the following two principles:

- Treating waterways and waterbodies as part of a network of larger systems and landscapes;
- Maintentaing all existing green spaces as well as reserving additional space where required.

The following sub-measures related to nature-based retention are considered relevant:

- *Green/ blue spine*: Thu Duc is surrounded by three rivers of approximately 192 km, streams of 15 km of and almost 8 km of canals. Along these waterbodies and where sufficient land area is/ can be made available, green areas can be developed in the form of wetlands. The wetlands can store rainwater in extreme yearly events and support the ecosystem. In addition, during normal conditions parts of these green areas could be used for recreational purposes. Connections between the water bodies should be maintained in such way that
- *Buffer zones*: Along the major rivers surrounding Thu Duc, blue buffer zones can be developed that create capacity to hold stormwater surpuses. During periods of excess (as well as shortage) of water, the buffer zones can be used for water management and controlling the city's water level. This measure is very relevant for the low areas of Thu Duc that can only drain at lower tidal water levels to the surrounding water courses. Subsequently, green/ blue buffer zones can contribute in drainage of excess water and be used as an alternative to pumping and drainage systems.
- *Green parks:* Within the Thu Duc city, existing areas which are not directly connected to the main watercourses should also be preserved. Such green areas could be used as extreme rainfall retention areas and can be either connected to canals/ rivers that can can carry the load or (on a larger time scale comparing to extreme rainfall) can be used as a sponge for infiltration.
- *Community retention ponds*: The urban pond parks can be deep and store large quantities of water that are infiltrated into the groundwater, or drained. This way that have a maximal capacity to store rainwater.

Potential locations for implementation of nature-based retention measures are preliminarily identified (Table 0-16 and Figure 0-24) and the results of the flood risk assessment (Chapter **Error! Reference source not found.**) as well as the World Bank (2022) "Presentation on

Nature Based Solution in Thu Duc City” are used as a basis. For each measure, the cost is also estimated following preliminary methodologies as explained in Table 0-16, which is for now assumed being acceptable.

Table 0-16 Preliminary identified locations for nature-based soltutions and cost estimate

Nature-based solutions	Potential locations	Preliminary cost estimate methodology
Green/ blue spine	The World Bank (2022) "Presentation on Nature Based Solution in Thu Duc City" has made an assessment on extents of beautification of all the green areas along the rivers in proximity of existing built up areas. Thereafter, four potential locations for liner parks are proposed, however they are located on the south west where future flood risk appears to be relatively low/ negligible. In terms of urgency, in the north west, even though available space appears to be more scarce, there could be pontial for green/ blue spine development to mitigate the large flood risk. Furthermore, the large canal on the south east (Song Tac) as well as the smaller canals surrounding the Long Truong area could be considered and space could be reseved already, as expected rapid development of Thu Duc indicates that this area will be developed in the near future (See Figure 0-24)	The cost estimates from World Bank (2022) "Presentation on Nature Based Solution in Thu Duc City" World Bank (2022) is used as a basis. It is suggested that this cost should be increased to account for: Preservation/ beautification of green areas along rivers that are currently not bulit up (but they are envisaged to be); Land acquisition costs in some areas that deal with a high flood risk. On the other hand, not all green areas around rivers require greening and development of recreational facilitites, thus part of the the World Bank (2022) estimated cost could be reduced. Balancing the two aforementioned components would lead to a cost of the same order of magnitude as included in the World Bank (2022) estimates ~ 320 million USD (See table for breakdown).
Buffer zones	Buffer zones are applicable to the low areas of Thu Duc and where there is a combination of high flood risk and available green areas/ aquaculture areas along the rivers/ canals. Two potential locations are preliminarily identified (See Figure 0-24).	Construction of buffer zones involve dredging activities, construction costs (including ring dike) as well as land acquisition costs. With the basis of the preliminary identified locations' geometries and unit rates from

		literature, a cost of approximately 175 million USD is estimated.
Green parks	Where current green spaces are located, specifically on the noth west and and south east.	Land acquisition cost minimal as it refers to existing green spaces. Some costs could be considered for beautification, however a more thorough assessment is needed.
Retention pond	Where existing green spaces and flood risk is high, specifically on the noth west and and south east. The size of the pond can be considered as 5-10% of the drainage area. A total of 10 retention ponds have been considered with an area of 10,000 m2 each and depth of 3 m. Potential locations for these ponds are not allocated in the map at this stage.	Construction of retention ponds imply

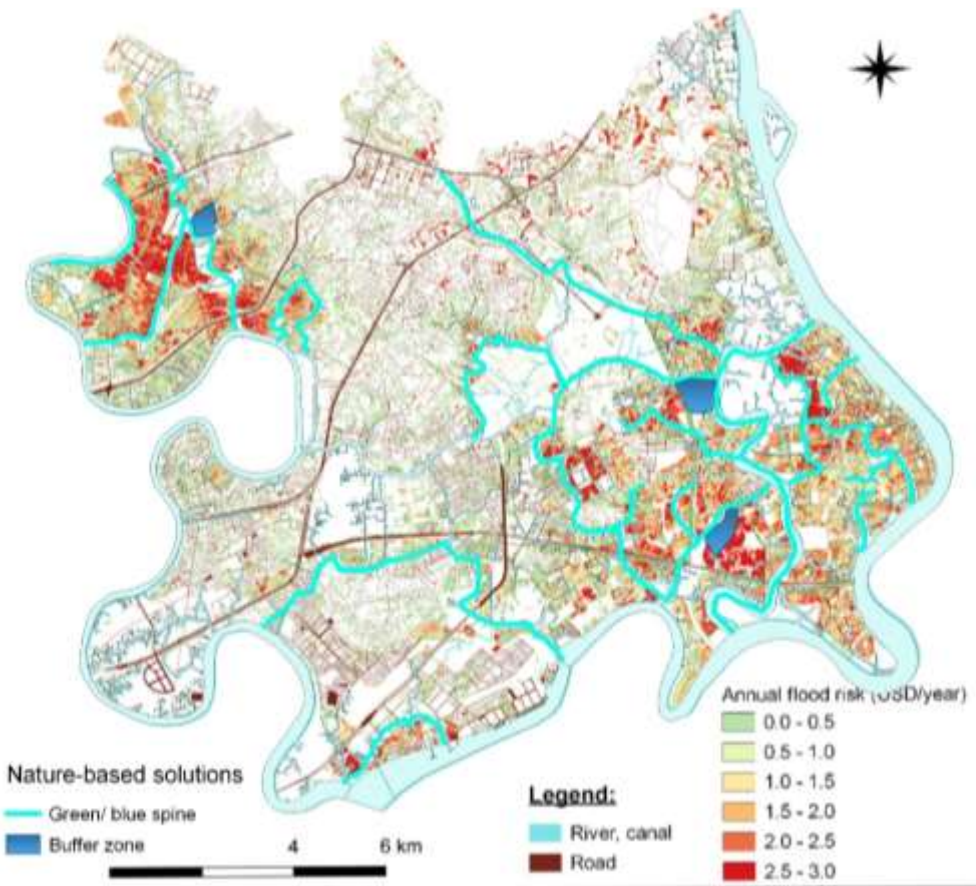


Figure 0-24 Preliminary proposal for nature-based solutions for retention (green/ blue spine and buffer zone)

Table 0-17 Nature based solutions for retention: preliminary cost estimate breakdown for capital cost

Item	Currency	Unit	Unit rate	Source	Units	Preliminary capital cost estimate
Green/ blue spine						
Greening and recreational facilities	USD	km	1,623,622	Average from WB (2022) NBS Thu Duc presentation	120	194,834,697
Land acquisition	USD	m^2	250	Average of the maximum government price for urban/ peripheral areas in Ho Chi Minh City (2009)	500,000	125,000,000
					Sum (USD)	319,834,697
Buffer zone						
Dredging	USD	m^3	2		5,650,000	11,300,000
Construction cost for inland wetland	USD	m^2	2	WB (2022) NBS Thu Duc presentation	1,130,000	2,712,000
Construction of small ring dike	USD	m	2,600		7,500	19,500,000
Land acquisition (assumed for 50% of the buffer zone area)	USD	m^2	250	Average of the maximum government price for urban/ peripheral areas in Ho Chi Minh City (2009)	565,000	141,250,000

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					Sum (USD)	174,762,000
Retention pond						
Dredging (3 m depth)	USD	m^3	2		300,000	600,000
Detention pond construction	USD	m^2	60	WB (2022) NBS Thu Duc presentation	100,000	6,000,000
Infiltration trenches	USD	m^2	75	WB (2022) NBS Thu Duc presentation	100,000	7,500,000
Land acquisition	USD	m^2	250	Average of the maximum government price for urban/ peripheral areas in Ho	100,000	25,000,000
					Sum (USD)	39,100,000
					Total (USD)	**533,696,697**