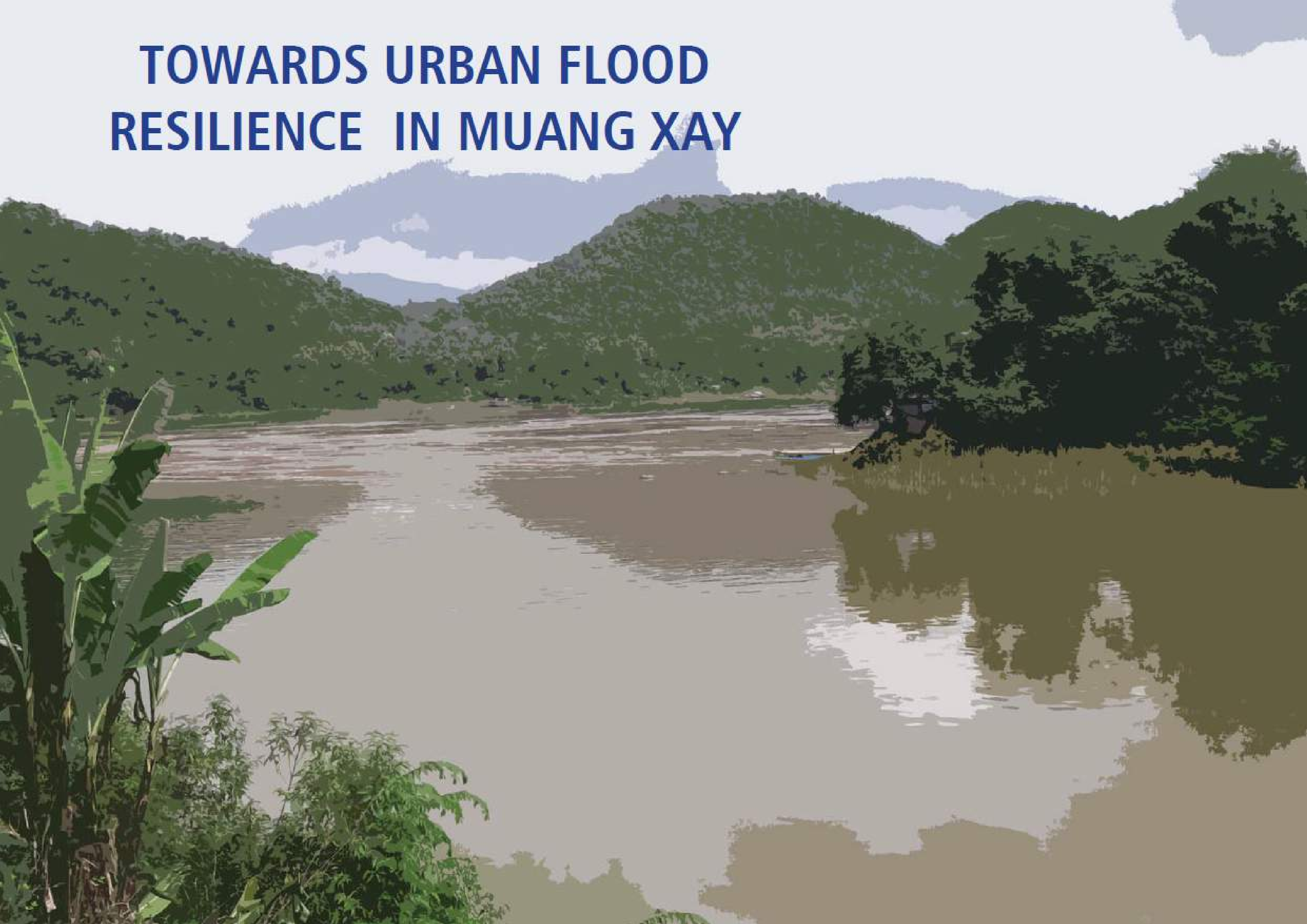
TOWARDS URBAN FLOOD RESILIENCE IN MUANG XAY



TOWARDS URBAN FLOOD RESILIENCE IN MUANG XAY

FLOOD RISK MANAGEMENT AND INVESTMENT PRIORITIES FOR URBAN PLANNING AND DESIGN

1818 H Street NW Washington DC 20433
Telephone: 202-473-1000
Internet: www.worldbank.org

Project Team

World Bank

Henrike Brecht
Senior Infrastructure Specialist
Dzung Huy Nguyen
Senior Disaster Risk Management Specialist
Zuzana Stanton-Geddes
Disaster Risk Management Specialist
Adi Verwey
Senior Flood Risk Management Consultant

Deltares

The Netherlands
Hans Gehrels PhD
Senior Flood Risk Specialist (Team Leader)
Ruben Dahm MSc
Senior Flood Risk Modeler/Hydrologist
Didrik Meijer MSc
Senior Flood Risk Modeler/Hydrologist
Govert Verhoeven MSc
Senior Flood Risk Modeler/Hydrologist
Ferdinand Diermanse PhD
Flood hazard assessment specialist
Laurens Bouwer PhD
Risk management specialist
Dennis Wagenaar MSc
Damage calculation specialist
Elba Stefania Valenzuela Velazquez MSc
Junior researcher/ Graphic Design

Singapore
Mr. Marinus Vis MSc
Environmental Impact Specialist

Earth Systems

Lao PDR
Mr. Chris Smithies MSc
In-Country Coordinator
Ms. Amphone Vongvixay PhD
Senior Hydraulic Engineer
Mr. Somzay Champathangkham MSc
Senior Flood Risk Modeler/Hydrologist
Sengthong Vongsakid MSc
Senior Disaster Risk Management Specialist
Mr. Bounmy Chayavong MSc
GIS and Database Specialist
Ms. Sengkeo Thongvanna
Project Administrator

Australia
Mr. John Ward PhD
Economist
Mr. Nigel Murphy MSc
Social Impact Specialist
Mr. David Dettrick PhD
Reviewer/Senior Flood Risk Modeler/Hydrologist

adpc

Thailand
Mr. Anisur Rahman MSc
Senior Urban Planner (international)w
Mr. Thanongdeth Insixiengmay MSc
Senior Disaster Risk Management Specialist

Vientiane Geomatic Services

Lao PDR
Mr. Paul Simcock MSc
Data acquisition and ground survey specialist

Involved stakeholders and Institutions

Ministry of Public Works and Transport (MPWT)
Department of Inland Waterway Transport
Public Work and Transport Institute
Department of Housing and Urban Planning
Project Officer
Department of Public Works and Transport of Oudomxay Province
Waterway Sector
Road Management Sector
Housing and Urban Planning Sector
Railway Management Sector
Planning and Cooperation Sector
Department of Finance (DOF)
Department of Public Health (DOH)
Department of Education and Sport (DOE)
Department of Post and Telecommunication (DPT)
Department of Planning and Investment (DPI)
Department of Labour and Social Welfare (DLSW)
Department of Agriculture and Forestry (DAFO)
Department of Information, Culture and Tourism (DICT)
Lao Water Supply Office, Oudomxay Branch (Nampapa)
Urban Development Administration Authority of Xay District (UDAA)
Lao Woman's Union Office of Province (LWU)
Military Headquarter

Executive Summary

Lao PDR is regularly impacted by flooding which causes widespread damage to infrastructure and impacts livelihoods. Between 1991 and 2013, on average, 200,000 people per year were affected by floods, which along with droughts pose a serious threat to wellbeing and socio-economic development in the country. Muang Xay, the capital of Oudomxay Province in northern Lao PDR, has been impacted by a number of large flood events, most recently in August 2017, which have caused widespread damage to infrastructure, loss of life and impacted on local livelihoods.

Planning for the implementation of infrastructural and non-structural flood control measures is necessary to prevent further loss of life and assets from future flood events in Muang Xay. The population is growing at approximately 3% per annum with high population density in the inner urban areas of the city. Flood zones are yet to be adequately identified and accounted for in urban planning processes and much of the city's critical infrastructure identified in the study is vulnerable to flooding. Limited enforcement of building and zoning regulations often results in uncontrolled development that may exacerbate future flooding effects.

To address these challenges, the World Bank, with support from the Global Facility for Disaster Reduction and Recovery (GFDRR), provided technical assistance to the Government of Lao PDR (GoL) to improve the understanding of the underlying disaster risks and help identify opportunities for investing in integrated urban flood risk management. The findings of this technical assistance support the GoL in preparation and implementation of planned investments in Muang Xay, the capital of Oudomxay Province under the Lao PDR Southeast Asia Disaster Risk Management (SADRM) Project, with financing by the World Bank. This project foresees a combination of proposed structural and non-structural investments for Muang Xay to support integrated flood risk management amounting to ~14 million US$.

As part of World Bank's technical assistance, a study was conducted by Deltares, Earth Systems, Asian Disaster Preparedness Centre and Vientiane Geomatic Services, assessing investments proposed by the GoL from different perspectives, including disaster risk, benefit-cost analysis (BCA), social and environmental impact, and urban planning and design. Stakeholder consultations were conducted in the form of several workshops and numerous interviews.

Flood risk assessment

Flood risk was assessed for the city of Muang Xay, and the reduction of flood risk was evaluated for a number of infrastructural design options. A hydrological and hydraulic simulation model was constructed based on the available data of the region. The limited availability of data posed considerable limitations on the modelling of flood risk. In general, there is a lack of data on hourly rainfall, multiple rainfall stations, stage discharge relations, and specifics on the reservoir and reservoir operation. River flooding appeared to be the dominant process in the recent flood events.

Flood hazard was modelled and the associated damage was assessed in terms of risk. The expected annual damage (EAD) calculated for the current situation without any flood risk management interventions in place amounts to ~11 million US$ per year over the entire area. The EAD is highest in the western part of Muang Xay near the convolution of the three rivers, with values of over 150,000 USD/year/ha in the area with population densities of over 15,000 people/km2. EAD values for the eastern part of town are generally lower than 100,000 USD/year/ha.

A number of infrastructural investments as proposed by the GoL were assessed in terms of the level of risk reduction that could potentially be achieved, both individually and combined. The analysis showed that GoL proposed interventions can provide varying levels of flood risk reduction with most of the significant reductions potentially experienced during floods with lower return periods (2-,5- and 10- years). Some measures were seen as highly effective (river improvements, dikes, meander shortcut) while others are not so effective (river parks, flap gates) in reducing flood risk at the spatial scale of the river catchment in which Muang Xay is situated. The study shows that a significant flood risk reduction can be achieved with the implementation of the package of interventions as proposed by the GoL. The results show that a reduction of expected annual damage and the number of people that is affected by the flood risk of ~50% when all proposed interventions are combined.

As a next step in the analysis, in order to further reduce flood risk, the design of the most promising infrastructural interventions was further optimized. The optimized design show that flood risk can be substantially further reduced in the urban area of Muang Xay. When implementing a combination of river improvements, a meander shortcut and dike works, a flood with a return time of 20 years can be prevented in the urban area of Muang Xay and the associated damage (EAD) reduces with ~8.3 M USD per year (~77%).

Apart from the interventions that were proposed by the GoL, the potential effect of additional reservoirs or retention areas in the Nam Kor catchment and the Nam Mao catchment has been explored. Simulation results show that reservoirs potentially have a large effect in reducing the flood hazard because maximum river discharges are greatly reduced. When all design options, including the reservoirs, are combined into one intervention package, the model results show that the flood risk for Muang Xay almost completely reduces to zero, with the associated damage (EAD) being reduced with 99%. This includes all return times up to 100 years. It has to be stressed, however, that the current conclusions are based on very limited local and open data. Uncertainty is therefore substantial and should be reduced before more detailed design is possible.

Benefit-cost analysis

A benefit-cost analysis (BCA) was conducted considering combinations of structural and non-structural measures against the Project budget of approximately US$12.1M. Nine different investment options were further assessed by multi-criteria analysis (MCA) incorporating the BCA rankings with EAD, budget exceedance, alignment with community preferences and environmental and social ratings. Package 8 (reservoirs only) has the highest composite score largely due to its high BCA and the fact that it comes in US$3M under budget. Package 6 (Extended river improvement + Park 2 + Nam Kor shortcut investment) is the next highest ranked package with Package 9 (all options combined) the lowest ranked package, mainly due to the extent of budget exceedance.

It is recommended that Package 4 (original GOL proposal + Nam Kor shortcut) is developed within this project potentially resulting in annual EAD reduction of almost 50% compared to the base case. It is further recommended that extended river bank protection / river improvement works could be implemented in the medium term and the development of two reservoirs is considered for the longer term. Initial modeling indicates that the combination of the above measures could provide up to 98.7% annual reduction in EAD for a 1 in 100-year flood event.

Social and environment impact

The proposed investments were subjected to a site based environmental and social screening exercise and an environmental risk assessment. Key potential environmental and social impacts from development of infrastructural flood mitigation measures include localised dust, noise and sedimentation during the construction phase, conversion of non-critical riparian habitats, downstream impacts due to changed flow regimes and the potential requirement for some resettlement. Although a number of World Bank Safeguards may be potentially triggered by the project, it is expected that environmental and social impacts from the proposed investments can be managed and mitigated to an acceptable level by application of environmental and social safeguards during the detailed design and construction phases of the project. There is currently a lack of flood mitigation infrastructure in place within Muang Xay. DRM laws and planning processes are being institutionalised at the national level but are yet to be implemented locally. Current risk management practices are largely reactive and limited resources to respond to flood events often leaves local citizens exposed while hampering socio-economic development.

Experience from past projects shows that complementing structural investments with the implementation of non-structural measures is critical to project success. A key focus of the next phase of the project will be to provide technical assistance to GOL planning bodies in order to integrate disaster risk management (DRM) and environmental management aspects into current urban planning processes. Significant opportunities are also present for the introduction of low cost, locally appropriate flood mitigation measures to complement the proposed structural investments such as retrofitting flood mitigation equipment to existing in-stream infrastructure. During consultations, villagers expressed the desire to become more resilient through implementation of community based DRM, flood data collection and early warning systems. Villagers also requested participation in the design, construction and maintenance of flood mitigation infrastructure including community led blue-green measures.

Urban planning

In order to support the development of a Strategic Integrated Urban Design and Flood Risk Management Plan for Muang Xay City, a set of guidelines was developed. Regarding Institutional strengthening the implementation of a three-step planning framework for future urban development is vital. This framework should include a structured plan, urban area plan and detailed/ action area plan, at the same time it needs to be flexible and allow for periodic review, classified land use zoning options and risk-sensitive land use planning options. Institutions such as PTRI and DHUP should be trained on resilient infrastructure design and construction.

Actions to support flood resilience include the adoption of blue-green measures. Blue infrastructure refers to wetlands, ponds and wet detention basins; whereas green infrastructure includes recreation grounds, gardens, parks and green roofs. The implementation of flood hazard mapping exercises, as well as, the implementation of programs within communities and schools will help in the promotion of flood hazard awareness.

In conclusion

The results of this study show that flood risk in Muang Xay can almost completely be reduced to zero. These findings, however, are based on very limited local and open data. We therefore recommend to further elaborate and detail the design options that were considered in the present study.

It is believed that the implementation of the above recommendations will improve planning and coordination for urban planning and disaster risk management, increased flood resilience among local communities, a reduction in the threats posed by flood events for existing and planned infrastructure and positive outcomes for environmental and social management.

Content

List of Acronyms

ADB	Financed Urban Infrastructure
asl	Above Sea Level
BCA	Benefit Cost Analysis
BCR	Benefit Cost Ratio
CCA	Climate Change Adaptation
Desinventar	UN's Disaster Information Management System
DHUP	Department of Housing and Urban Planning
DICT	Department of Information Culture and Tourism
DOW	Department of Waterways
EAD	Expected Annual Damage
ESMF	Environmental and Social Management Framework
GoL	Government of Lao PDR
GFDRR	Global Facility for Disaster Reduction and Recovery
HOT	Humanitarian Open Street Map Team
IDCRM	United Nations Integrated Disaster and Climate Risk Management Project in Lao Pdr
IFM	Integrated Flood Management
IFRM	Integrated Flood Risk Management
LaoDI	Lao PDR Disaster Information Database
MCA	Multi-Criteria Analysis
MLSW	Ministry of Labor and Social Welfare
MONRE	Ministry Of Natural Resources and Environment
MPI	Ministry of Planning and Investment
MPWT	Ministry Of Public Works And Transport
NDRMP	National Disaster Risk Management Plan
NPV	Net Present Value
NSEDP	National Social Economic Development Plan
NSPDM	National Strategic Plan on Disaster Management
OB	Optimism Bias
PDPCC	Provincial Disaster Prevention and Control Committee
PONRE	Resource and Environment Office
PTI	Public Works and Transport Institute
r	Discount Rate
SADRM	Lao PDR Southeast Assia Disaster Risk Management
SIUDFRM	Integrated Urban Design and Flood Risk Management
SUDS	Sustainable Drainage Systems
UDAAS	Urban Development Administration Authorities
VDPCC'S	Village Level Disaster Committees

Towards Urban Flood Resilience in Muang Xay

01 INTRODUCTION

Muang Xay, capital of Oudomxay Province in northern Lao PDR, is regularly impacted by large flood events, causing widespread damage to infrastructure and impacting livelihoods. It is estimated that between 1991 and 2013, on average, 200,000 people per year were affected by floods, which along with droughts poses a serious threat to well-being and socio-economic development in the country. Likewise, the frequency and severity of disasters have increased over the years, and most models predict further intensification in the future. This underlines the need to improve disaster risk management (DRM) and climate change adaptation (CCA) in Muang Xay.

Despite recent progress in national level disaster planning and policy development, key challenges regarding integrated flood risk management remain, including (i) weak institutions and regulatory frameworks; (ii) limited meteorological and hydrological forecasting capacity; (iii) insufficient financing for resilient sectoral investments; and (iv) low financial resilience to both recurrent and extreme disasters due to the lack of sustainable and cost-effective financial protection policies and mechanisms. Flood response remains ad-hoc, with limited long-term preparatory action, and DRM in the country awaits comprehensive development.

To cope with these threats, the World Bank, with support from the Global Facility for Disaster Reduction and Recovery (GFDRR) provided technical assistance to the Government of Lao PDR (GoL) to improve the understanding of the underlying disaster risks and help identify opportunities for investing in integrated urban flood risk management. This was done by assessing the proposed investment from a technical, social, environmental and economic perspective. The findings of this technical assistance will support the GoL in preparation and implementation of planned investments in Muang Xay, the capital of Oudomxay Province, under the Lao PDR Southeast Asia Disaster Risk Management Project, financed by the World Bank.

As part of World Bank's 'Lao PDR Southeast Asia Disaster Risk Management Project' an assessment of structural and non-structural interventions was conducted in collaboration with Deltares, Earth Systems, Asian Disaster Preparedness Centre and Vientiane Geomatic Services. The present publication draws on a series of technical reports that were written recently in the framework of the World Bank project.

LAO PDR SOUTHEAST ASIA DISASTER MANAGEMENT PROJECT

With the aim to reduce the impact of floods in Oudomxay, improve early warning systems in a number of provinces, and improve financial protection of the country, the GoL is currently implementing the 'Lao PDR Southeast Asia Disaster Risk Management Project', supported by financing and technical assistance from the World Bank. The project covers two important components:

Component 1: Integrated Urban Flood Risk Management, to strengthen flood resilience in Oudomxay Province. Structural investments will include flood protection infrastructure in Muang Xay, including investments in riverbank protection and embankments, floodgates, weirs, river-side parks, and drainage canals. Infrastructure investments will be complemented with non-structural measures, including strengthening land-zoning, institutional capacity-building on integrated flood disaster risk management, etc.

Component 2: Hydromet Modernization and Disaster Risk Management Systems, intended to improve the delivery of weather, climate and hydrological services and end-to-end early warning systems in Lao PDR with physical investments in Oudomxay and Luangprabang provinces, including capacity building.

ABOUT THIS REPORT

The present report provides technical support to the city of Muang Xay in the assessment of future investments (both infrastructural and non-structural) in urban flood risk management. The ultimate goal of flood risk reduction is the mitigation of risks of damage to people, built infrastructure, agricultural lands, or any other urban or rural assets that directly or indirectly contribute to the economy and livelihoods of people in Muang Xay. Flood risk reduction strategies presented in this report comprise a well-balanced mix of both infrastructural and non-structural measures, on both short and long-term timescales.

In addition, the report provides guidance for developing a strategic integrated urban design and flood risk management plan for Muang Xay. The development of this strategy is an important step towards the use of water and floods as a design parameter for spatial planning, to increase flood risk awareness and to develop practical strategies to cope with flood risk. The preparation of the strategic plan for Muang Xay City takes the following elements into account:

- Reduction of the adverse impact of floods and the likelihood of floods;
- Promotion of sustainable flood risk management;
- Consideration of opportunities to work with natural processes and where possible, design dual-purpose facilities delivering multiple benefits from flood risk management;
- Communication, awareness raising and emergency response

Chapter 2 includes a biophysical and socio-economic profile of the Muang Xay project area, and provides an assessment of the current situation and arrangements for flood risk management and urban planning in Muang Xay City and Oudomxay Province.

Chapter 3 describes the methodology of flood risk assessment for the city of Muang Xay and the surrounding areas, including flood modelling, flood hazard and risk mapping with specification of modelling tools and rainfall-runoff modelling concepts.

Chapter 4 provides a description of the mechanism of flooding in Muang Xay, as well as the relevance of urban planning within the context of integrated flood risk management.

Chapter 5 summarizes the review of priority investments and non-structural measures including urban planning and zoning. It details selected locally appropriate examples of flood risk management and community resilience measures that may be applicable in Muang Xay and other parts of the country.

Chapter 6 evaluates the reduction of flood risk as a result of infrastructural interventions. A number of investment options are considered: river bank protection, dyke construction, river bed improvements, construction of flapgates and riverside parks. In addition, an environmental and social assessment of each of the investments is provided.

Chapter 7 summarizes an economic assessment of priority investments and non-structural measures. The economic model quantifies the costs and benefits of different combinations of structural and non-structural investments and considers the economic and social consequences of each option, in order to identify the best possible combinations of no-regret investments for the city within the current project budget.

The report ends with conclusions and recommendations in Chapter 8 for a Strategic Integrated Urban Design and Flood Risk Management Plan for Muang Xay.

02 MUANG XAY PROFILE

A biophysical and socio-environmental review of Muang Xay was conducted. Information was obtained using a combination of desktop research, consultation and data collection with key stakeholders.

BIOPHYSICAL CONTEXT

Oudomxay Province is located in the northwest of Lao PDR and is bordered by China to the north as well as by five other Lao provinces. The province consists of seven districts and 471 villages and covers an area of 15,370km2. Oudomxay Province is characterised by mountainous terrain and river valleys with elevations ranging from 300m to 1,800m above sea level. Approximately sixty rivers flow through the province, some of which form tributaries to the Mekong River which flows through the southern part of the province. The provincial capital, Muang Xay, is situated in the north-western part of the province and covers an official area of 399km2 although the majority of the population lives within an area of 72.5km2. Muang Xay is situated in the Nam Kor river basin and is surrounded by mountains.

Climate

Oudomxay Province has a tropical monsoon climate. Average annual precipitation (1990-2016) at the Muang Xay Weather Station is 1,833mm. Most of the rainfall (90%) occurs in the wet season months from April to September with the highest peaks in July and August. An analysis of rainfall across Lao PDR between 1995 and 2014 shows that rainfall in Muang Xay has experienced a modest decrease . However, rainfall is projected to increase modestly by 2050 and many climate indicators predict that rainfall will occur in shorter and more intense periods.

Hydrology

Oudomxay province has a wealth of water resources in three primary watersheds, with approximately 66 small and large rivers. The Nam Ko River and its tributaries including the Nam Mao, Nam Hin and Nam Sin pass through Muang Xay. The project area is confined between three mountains, the upper Nam Kor river mountain to the north and the upper Nam Hin river mountain and upper Nam Mao river mountain to the southwest. The elevation of the Nam Kor river bank is approximately 636-640 metres above sea level.

Bioregion around Muang Xay

Oudomxay Province is part of the Northern Indochina Subtropical Moist Forests ecoregion. Approximately 85% of the province consists of upland areas (1,306km2) and 15% of lowland areas (230km2). According to statistics from the District Office of Natural Resources and Environment in Muang Xay, forested land accounted for over 90% of land use in the province with 19.6km2 utilised for agriculture and 23.9km2 for another land cover. Key agricultural and forestry commodities produced in the province include rice, corn, rubber, eucalyptus tree, forest products. Managed forest areas in the province are generally divided into three major categories: conservation forests, production forests, and protection forests.

Biodiversity

There is a wealth of biodiversity in Oudomxay Province. The provincial forests are reported to support tiger, elephant, deer, muntjak deer, bear, boa, turtle, Amyda catelageane, wild boar and many other animals. Plant diversity is also rich with such varieties as agar wood, Phyllanthus Milabilis, hopea, ironwood (Maidengnam), honey orchid, rattan, Debrenaesia hypoleuca, bamboo, mushroom, herbs and other species.

DEMOGRAPHICS

In 2015, the population in Muang Xay Town amounted to 35,289 people, of which 51% are female. According to statistics from the Lao Population and housing Census 2015, Muang Xay has a predominantly young population with 72% of people under the age of 35. Population density in Muang Xay is 58 persons / km2 based on a total village land area of 604km2. However, most of the population is concentrated in an area of approximately 75km2 indicating that the true population density in many areas is likely to be closer to 400 persons/km2.

Muang Xay has more than 14 different ethnic groups, the largest ethnic group (60% of the population) being the Khamu who are a part of the Lao Theung ethnic people's category. The other major ethnic

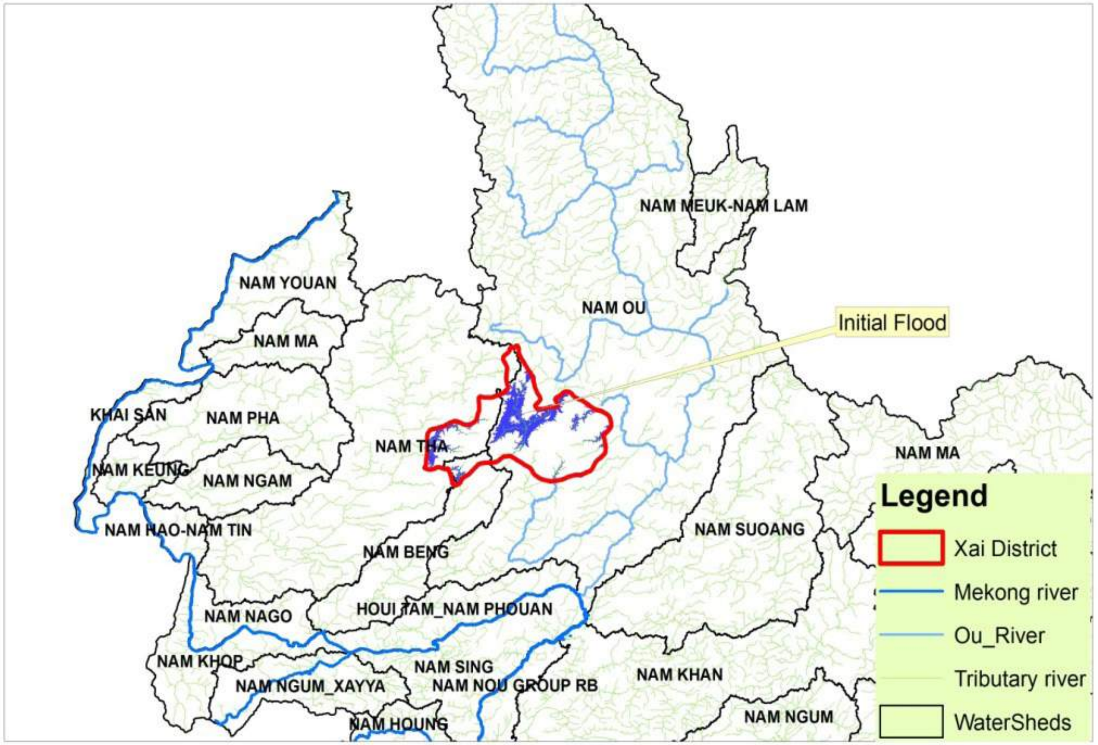


Fig. 2.1 *Map of Muang Xay Town and surrounding terrain. The map shows the main rivers located near Muang Xay city as well as the flood extent of August 2008. (Source: DMH,2017)*

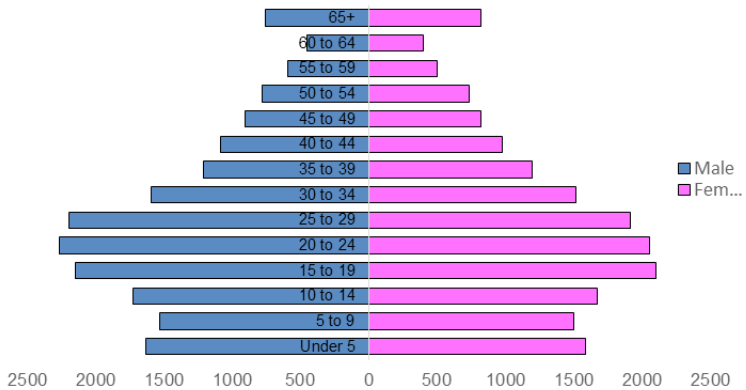


Fig. 2.2 *Age-sex data for Muang Xay 2015 (Source: PHC 2015).*

groups are the Lao Loum and Hmong (Hmong Khao, Hmong Dam and Hmong Lai) which account for approximately 25% and 15% of the population.

Vulnerability to flooding

Vulnerable categories of the population susceptible to suffer harm from flooding include: poor, disabled, elderly, single female-headed households and households with limited land tenure security.

According to the Lao Expenditure and Consumption Survey of 2013, 30% of the population of Oudomxay is considered as poor. It is reported by local authorities that Ban Houaykhoum and Ban Nawan Noi are the poorest villages of the province.

Reports estimate that 0.5% of the population (0.3% of female population) have a disability, which is low compared to the national average of 2.8% for both sexes. Ban Nongmaengda village has the highest number of reported disabilities with 0.7%, of which 0.4% are female. No information is available about the type or level of disability.

Figures from the Population Housing Census 2015, report that 3.8% of the population in the Xay District were over 65 years old and 6% of the population were over 60. The old-age dependency ratio in the Xay District is 6 elderly dependents for every 100 working age people. National average reports a dependency of 7 elderly dependents for every 100 working age people. These ratios are only rough indicators of economic burden, as not all 'working-age' people actually work, while some 'dependents' are actually in the workforce.

The national average for single female-headed households in the urban area according to the Population Housing Census 2015 is 17.8%. All villages consulted in the present study reported figures below the national average ranging from 3.4 % in Ban Houaykhoum to 13.3% in Ban Nawan Noi. In terms of land security, most of the consulted villages reported a very high level of residential land ownership ranging from 95% of households in Ban Thin and Ban Nasao with permanent land titles to 100% in Ban Nawan Noi and Ban Pasak.

INFRASTRUCTURE

Oudomxay is connected to Luang Prabang by National Road 1. The town has an energy supply of 24 hours per day and 21 villages out of 22 villages have access to drinking water supply. The main infrastructure for Muang Xay includes 10 kindergartens, 20 primary schools, 1 lower secondary school, 9 upper secondary schools, 4 vocational schools and 3 colleges. Regarding healthcare the main infrastructure of the city is composed of one provincial hospital, a military hospital, a private hospital, 30 clinics and one health service facility. Muang Xay city has 11 temples including the temple in Ban Thin, Ban Cheng, Ban Nasao Ban Namee, Ban Nalao, Ban Nalae, Ban Bor, Ban Houaykhum, Ban Donekeo, Ban thiew and Phu That Stupa/temple.

LEGISLATIVE FRAMEWORK FOR FLOOD RISK MANAGEMENT AND URBAN PLANNING

Lao legislative and planning frameworks are now in the process of incorporating DRM principles, but this is yet to be institutionalised and implemented on the ground. Urban planning to date in Muang Xay has not considered DRM and suffers from a lack of data to support design hazard levels across the city. An analysis of the legislative framework has been carried out to understand how Muang Xay has been coping with flooding and how urban planning and development could increase or reduce flood risk in the city.

Institutional Arragement

The administrative hierarchy for urban areas in Lao PDR has five levels, the national capital, secondary towns (Luang Prabang, Savannakhet, Thakek, Pakse), provincial capitals, district towns and village units (both individual settlements and villages within urban areas).

At the national level, the Ministry of Public Works and Transport (MPWT) is the key agency in charge of urban planning. Urban development administration authorities (UDAAs) manage and implement the financed urban infrastructure (ADB), whereas the economic planning for urban development is the responsibility of the Ministry of Planning and Investment (MPI).

At a national level, disaster prevention and control is the responsibility of the Ministry of Labour and Social Welfare (MLSW). An overview of the current institutional arrangements for disaster risk management in Lao PDR is shown in Figure 2 3.

Flood risk management

A National Strategic Plan on Disaster Management (NSPDM) was first issued by the MLSW in April 2003 with flood risk reduction as the main focus. The overall aims of the NSPDM are to:

- Safeguard sustainable development and reduce the damage of natural or human-made disasters to community, society and country economy;
- Shift strategy from relief and mitigation after disaster impact to community, society and economy of government organizations to preparedness before disaster strike emphasizing on flood, drought, landslide and fire parallel with continuing to mitigate in post-disaster period;
- Move from government-centered to community-centered approaches in dealing with disaster by building adaptive capacity within communities; and
- Promote sustainable management of the environment and natural resources such as forest, land and water.

The NSPDM outlined goals for 2005, 2010 and 2020. The Draft NDRMP (2016-2020) aims to support resilient development under the 8th National Social Economic Development Plan (2016-2020; 8th NSEDP). The goals set to be achieved by 2020 were formulated as follows:

- To make Lao society safer and minimizing the impact of disaster on people's lifes, national economy, public and private property;
- To assist victims of disaster, helping them to mitigate disaster impacts and quickly recover from disaster shocks;
- To integrate disaster management and prevention into legal and economic frameworks from the village to the national level; and
- To mainstream disaster management concepts and environmental protection within Lao society.

Communication, early warning and evacuation

The responsibility for DRM coordination has moved from the Ministry of Natural Resources and Environment (MONRE) back to the MLSW at the national level but provincial and district level line agencies in Muang Xay are still awaiting formal confirmation of the new arrangements. This delay has hampered the effectiveness of coordination and clear lines of communication for early warning and evacuation efforts among GoL agencies.

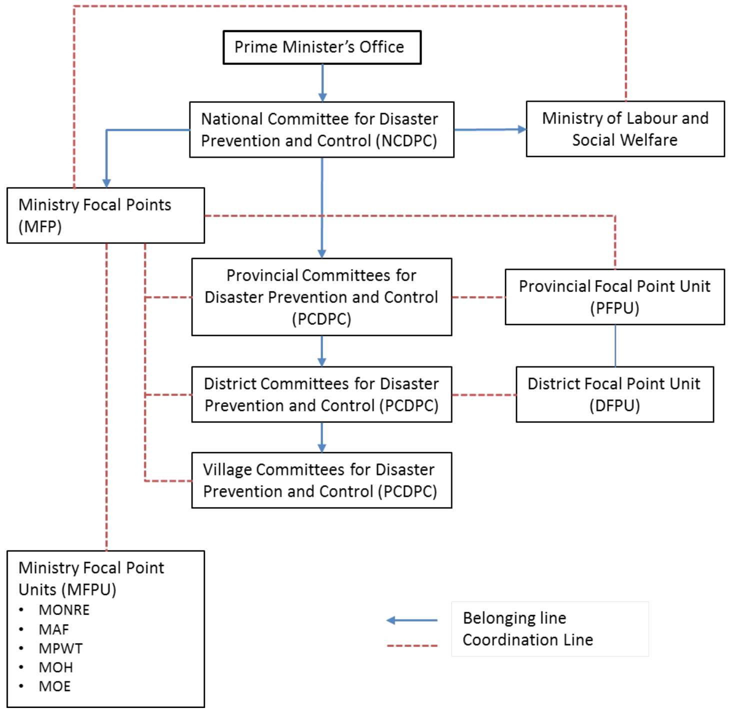


Fig. 2.3 *Overview of the current institutional arrangements for DRM in Lao PDR (Source: Earth Systems 2017)*

Above: *Overview of rivers crossing rural areas in Muang Xay.*

At the start of every wet season, letters are sent to village committees about the need to prepare for flooding. The Resource and Environment Office (PONRE) is responsible for early warning through the Department of Meteorology and they currently broadcast the weather situation through district radio once a week on Tuesdays. Information on upcoming storms that may lead to heavy rain and floods is sent from DMH of MONRE to PONRE in Muang Xay. DONRE then sends notifications to the district and the district sends to the village by fax, phone and official letters. Village committees and schools set up information meetings when river levels rise to initiate flood readiness by safeguarding assets and preparing for evacuation if required. At the beginning of a flood event the Provincial Disaster Prevention and Control Committee (PDPCC) will call villages and relevant GoL agencies. Village committees will then inform villagers by loudspeaker systems and often a volunteer will walk around to inform households in areas of the village too far away from loudspeakers. The most common form of early warning for citizens in Muang Xay is phone contact by relatives upstream to inform that a flood is on the way.

The military is responsible for evacuation efforts during flood events. They conduct disaster emergency response training annually and are able to mobilise quickly to high risk areas during floods. In addition to assisting the population to move to safe areas, the military also assists with asset protection and clean up and recovery efforts after the event.

Operation and maintenance of existing flood management infrastructure

The Department of Waterways (DOW) is responsible for the operation and maintenance of any infrastructure on or in waterways within Muang Xay. The UDAA is responsible for operation and maintenance of urban drainage while the Provincial Public Works and Transport are responsible for major repairs of urban infrastructure.

According to MPWT there is currently no existing flood management infrastructure in Muang Xay. Maintenance of all urban infrastructures is largely reactive due to lack of assigned budgets for ongoing maintenance. Accordingly, many public assets are repaired after damage or drains cleared after blockages have been identified.

03 METHODOLOGY

This section summarizes the methodology of flood risk assessment. The flood modelling, flood hazard and risk mapping methodology are detailed, including the specification of modelling tools and rainfall-runoff modelling concepts.

WORKSHOPS

Decision-making for flood management in Muang Xay occurs at multiple levels involving villagers, vulnerable groups, communities, local authorities and civic bodies. It also involves governments and decision makers from other sectors responsible for related spatial planning decisions.

Aiming to include all the stakeholders in the development of the SIUDFRM for Muang Xay City, a series of structured workshops were carried out in collaboration with the GoL and Muang Xay flood management agencies. The focus of these workshops was to (i) elicit historical flood exposure, consequences (incl. vulnerability), adaptations and management responses; (ii) scope out prevailing flood pressures, proposed structural and non-structural interventions and governance mechanisms; (iii) prioritise stakeholder initiatives and investments that account for levels of impact and uncertainty; (iv) arrange for ongoing participatory processes to report the evaluation of cross-sectoral, structural and non-structural priority actions nominated by participants.

The outputs of the workshops listed the expectations and objectives of flood-affected interests. They also provided the foundation for further multi-criteria analysis, relevant scenario analysis, data requirements for World Bank economic analysis and the ranking of integrated structural and non-structural flood management proposals. Last but not least, the workshop outcomes provided critical baseline data for ongoing monitoring and evaluation of project initiatives and a preliminary assessment of vulnerability.

STAKEHOLDER CONSULTATIONS

Stakeholder consultations focused on semi-structured interviews with key government stakeholders, the Lao Women's Union and village authorities in two flood-affected villages in Muang Xay. Consultations included:

- Semi-structured interviews with NGO's and development organisations and flood-affected villages in Muang Xay;
- Male and female focus groups with 10 flood affected villages;
- Multi-stakeholder focus groups with government, mass organisations and NGO's; and
- Participatory workshops.

DATA COLLECTION

The main focus on data collection was existing data from government and stakeholders. Field investigations were focused on site assessments for the proposed investments and further mapping of critical infrastructure.

The following data was collected for the development of flood maps:

- Location of the main rivers,
- Location and characteristics of the bridges,
- Information about the weir upstream of Nam Mao bridge,
- Cross-sections of ~100 locations (ground survey),
- Transects of flood plains at 5 locations (ground survey),
- Water levels from two newly installed level stations from July 22 2017 onwards,
- Water levels at the Nam Kor bridge 2 of the period 2005-2015,
- Water level measurements at the Nam Mao bridge of the period 2010 and 2016,
- SRTM elevation data, and
- Over 52.000 point height measurements (ground survey).

The Department of PWT Oudomxay took members of the project team to inspect an area of the drainage system that has been planned to be converted into a 4 or 5 cell lagoon treatment system. As well, the project team inspected the identified critical infrastructure of Muang Xay city to determine flood risk susceptibility and the potential for flood impacts on operations during flooding periods.

Above: *Workshop activities and field investigations carried out in Muag Xay city*

HYDROLOGICAL AND HYDRAULIC MODELLING

In the area of Muang Xay, two types of flood mechanisms are considered, pluvial flooding and river flooding. Pluvial flooding occurs when high-intensity local storm events lead to local (urban) flooding due to insufficient drainage capacity or bottlenecks in the urban drainage system. River flooding is caused by heavy rainfall in the upstream catchment, leading to high river discharges and overtopping of rivers.

Hydrological and hydraulic models were developed to calculate the flood hazard imposed upon Muang Xay by the Nam Mao, Nam Hin and Nam Kor rivers. The models consider not only the city itself but the entire river catchment area, as river flooding is the dominant flood mechanism in Muang Xay.

Hydrological model

A hydrological model was constructed to calculate the forcing input for the hydrodynamic modelling. The hydrological model contains data and information on rainfall and evaporation, catchment delineation, land use and soil characteristics to determine the response of the catchment to selected rainfall events.

The Deltares WFlow distributed (grid) rainfall-runoff model was used to simulate the rainfall-runoff processes at the catchment scale. This distributed model was run using available global datasets updated with local information. In this study, the SBM conceptual model embedded in WFlow was used.

The catchment was also modelled with the HBV model of Killingtveit and Sælthun [1995]. By applying two hydrological models, the uncertainties in the hydrological modelling and their impacts on computed flood risks were assessed.

Fig. 3.1 *Overview of Hydrological model. Muang Xay Rivers and streams as applied in WFLOW. The grey dots represent the lateral connections.* *(Source: Deltares, 2017)*

Hydraulic model

The Deltares SOBEK modelling suite is used for the hydraulic modelling of the area . A 1D-2D hydraulic model of the river and the area adjacent to the river was developed in order to calculate river flooding. The 1D model includes the cross sections of the river and all existing infrastructure, such as bridges and weirs. The 2D model includes a detailed representation of ground elevation to get a realistic estimation of the flooded area and the water depths in the city. The 1D and 2D models were combined into a 1D-2D model of the city that includes the principal drainage and a detailed elevation model of the urban areas most vulnerable to flooding. The models were calibrated using available data of historic flood events and by carrying out a sensitivity analysis. Flooding was simulated for return periods of 2, 5, 10, 25, 50 and 100 years.

FLOOD HAZARD ASSESSMENT

The main purpose of hazard assessment is to derive inundation depths for relevant potential flood events for the entire project area. The principal approach is to define the range of potential (synthetic) events that may cause floods and then to subsequently [a] simulate these events with the hydrologic/hydraulic model to obtain the inundation depths in the project area and [b] derive the probability of occurrence of each event. Based on the combined information of [a] and [b], the probabilities of inundation depths in the area can be determined by using an appropriate probabilistic computation technique. These steps were followed for each scenario of infrastructural design options. The following procedure was carried out to compute the overall flood risk:

1. Derive upstream boundary flow conditions for the Nam Hin, Nam Mao and Nam Kor for a range of return periods (2, 5, 10, 20, 50 and 100 years);
2. Simulate the flows with the hydraulic model to derive flood maps for the same set of return periods
3. Compute the total damage for each return period
4. Combine the results of the different return periods to quantify the overall flood risk

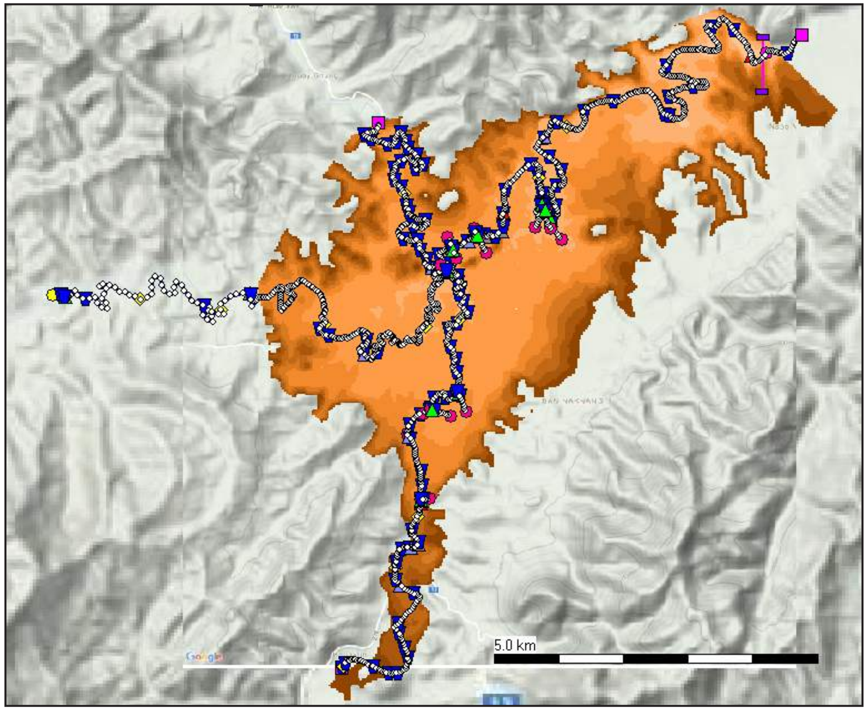


Fig. 3.2 *Overview of 1D2D hydraulic model built in SOBEK.*
(Source: Deltares, 2017)

Derivation of river flow statistics

The hydraulic model of the Nam Kor catchment has several (17) inflows, three of which are the most relevant as they are the upstream boundary flows of the Nam Hin, Nam Mao and Nam Kor rivers. For the risk assessment, it was necessary to derive river flows with return periods of 2, 5, 10, 20, 50 and 100 years. These values were based on statistics of peak flows and flow durations.

The challenge was the fact that these statistics needed to be derived from a limited data set. To derive flow statistics from rainfall data using a hydrological model, the following approach was used:

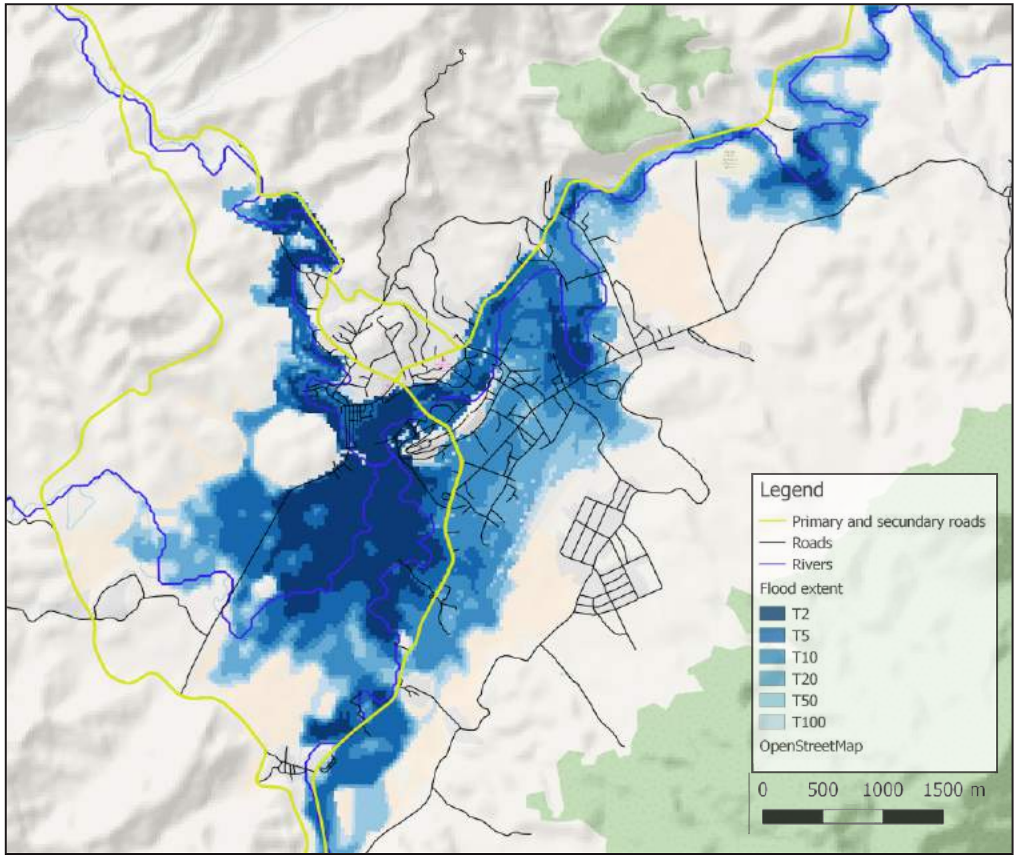


Figure 3.3 *Flood extent for the reference case, flood event of August 2008. (WFLOW; Manning's coefficient, n = 0.045 s/m1/3)*
(Source: Deltares 2017)

1. Simulate the entire period for which rainfall data is available with the hydrological model, resulting in a discharge time series of equal length.
2. Derive discharge statistics from the derived discharge time series.
3. Determine the T-year river flows from the discharge statistics (Time=2, 5, 10, 20, 50, 100 years).

Sensitivity analysis of hazard maps

Hydrological model simulations were carried out with two different models: HBV and WFLOW. The average annual discharge values appeared to be very similar. Due to the limited availability of data to validate the hydrological and hydrodynamic models, several combinations were tested to provide some insight into the impact of model choice. The inflows for 6 return periods derived from both hydrological models (WFLOW and HBV) and both roughness values (n=0.030 s/m1/3 and n=0.045 s/m1/3) of the cross sections in the SOBEK 1D2D flood model were combined.

The model tests for September 2008 and August 2013 events were compared and taken into account for a sensitivity analysis. The results of the WFLOW hydrological model with a roughness value of n=0.045 s/m1/3 showed more accurate results. For this reason, the flood risk assessment and impact analysis of future interventions continued with the WFLOW hydrological model.

Resulting hazard maps

Figure 3.3 shows the combined flood map for the Muang Xay area for the so-called reference case (WFLOW; Manning's coefficient, n = 0.045 s/m1/3). The more frequent flood events like return periods of 2 years and 5 years are in darker blue and less frequent flood events e.g. return periods of 50 years and 100 years are in light blue. The maps for the various return periods will be used as input for the damage model. The damage model then computes damages for a range of return periods. The resulting damages will subsequently be translated to meaningful risk indicators like the expected annual damage (EAD).

3.1 Damage categories and potential damage

Damage category	Potential damage (USD/person)
Residential - Structure	2,717
Residential - Content	906
Non-residential (incl. cars)	1,812

EVALUATION OF FLOOD RISK

For purposes of the present report, risk is defined as the combination of hazard, exposure and vulnerability. The hazard component is the combination of probability and magnitude of natural hazards. Exposure is a measure of the assets and population at risk. Vulnerability is a measure of potential exposure losses (damages and fatalities) if a hazardous event occurs.

Exposure data

Very little exposure data is available for the Muang Xay area. The damage model is therefore based on population data and data about important objects such as schools and temples. Population per village in the Muang Xay area is known. Secondly, a high (12m) resolution global dataset is available indicating which areas contain buildings (Global Urban Footprint). Thirdly, a countrywide population map is available from WorldPop (100m resolution). These three sources of data have been combined to make a population map as input for the damage calculation.

The Global Urban Footprint map was used to filter out places that are empty and ensure that only areas are included in the model with buildings. The local data with village population was then used to scale the global data set population in such a way that the total population in the map within the village corresponds to the known village population.

The construction cost of a house in the area has been estimated by a local contractor to be 48,000 USD for an average house. Based on experiences with more detailed damage models in many other countries (e.g. Sri Lanka, Afghanistan, USA, the Netherlands, Germany, UK and Bangladesh) the value of the building content was estimated to be 1/3 of the building structure. Also based on experiences in other more detailed studies, the non-residential damage (offices, stores, schools, hospitals, cars, roads, etc.) was estimated to be 1/2 of the residential damage. In this way also the non-residential damage was included based on the relationship between building information and population data. The resulting damage categories and their corresponding potential damage per person are shown in Table 3.1.

Vulnerability

Vulnerability functions express a relationship between the water depth and the damage. For this study, these relationships have been based on similar curve functions as created for Sri Lanka (Dias et al., 2017). The damage functions for Sri Lanka are based on expert meetings with construction experts and locals who have experienced floods. The damage function for the non-residential category is a combination of the damage functions for building structure, building content and cars.

It is questionable to what extent these damage functions made for Sri Lanka are applicable to Muang Xay. Several studies have shown that damage calculations are relatively sensitive to the damage functions applied and that transfer of damage functions from one area to another can result in significant inaccuracies (e.g. Jongman et al., 2012; Wagenaar et al., 2014). It is therefore recommended to construct local damage functions for future more detailed studies.

Damage and loss

Conceptually it is important to note the difference between flood damage and flood loss. The term “flood damage” is related to the physical damage of public and private assets such as infrastructure, houses, contents, agricultural losses and vehicles due to contact with flood waters. The term “flood loss” has a much broader meaning and refers to secondary or tertiary losses, as well as intangible losses such as losses to human life and ecological systems.

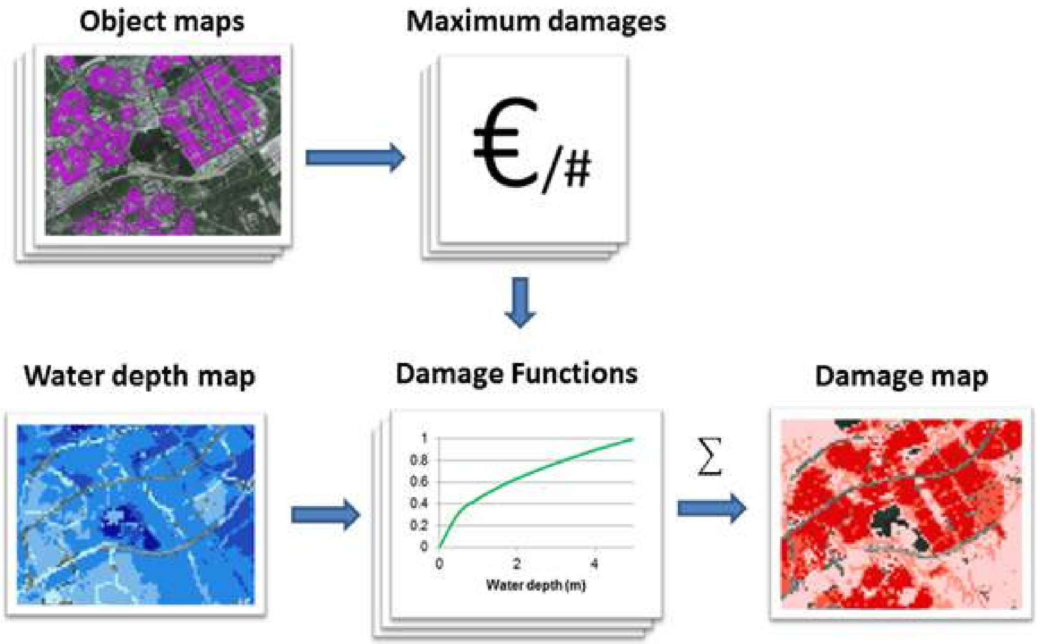


Figure 3.4 *Overview of the damage calculation*
(Source: Deltares 2017)

Flooding is most relevant when it leads to damage. Therefore, flood maps need to be translated into damage maps. In a damage map, data about exposed objects is combined with a flood map and the vulnerability of these exposed objects (damage functions). The exposed objects are separated into a number of different categories of objects (e.g. residential and non-residential) for which damage functions have been created and for which exposure data has been collected. An overview of the damage calculation is shown in Figure 3.4.

The damage calculations were carried out with Delft-FIAT (Flood Impact Assessment Tool). Delft-FIAT is a set of Python scripts that can be applied to set up a damage calculation anywhere. It carries out the damage calculation as shown in figure 5.1 and is completely generic. It makes an overlay between user-specified exposure (objects), flood maps and the vulnerability to flooding (damage functions) of the specific objects.

Risk calculation

Damage calculations were carried out for flood maps at different return periods (2, 5, 10, 20, 50, 100 years). These calculations can be used for the calculation of the expected annual damage (EAD), also known as flood risk. The flood risk is expressed in USD per year and can be shown in the form of a map for a specific situation (e.g. USD/y for each cell of the current situation) or as a total figure for a specific situation (e.g. USD/y for the whole area in the current situation).

The advantage of risk maps or risk figures is that the entire flood assessment can be captured in one map or one figure. This makes it easy to compare the current situation with the situation after future interventions. A second advantage of applying risk maps is that it expresses all flood risk in one monetary value that with some further economic calculations can be compared to the cost of interventions. It is, therefore, an essential input for cost-benefit analyses. Flood risk is calculated based on the following formula:

$$Risk = \int_{0}^{p_{max}} Damage\ (p)dp$$

Where:
Risk = flood risk [USD/y]
p = The flood exceedance probability [1/y]
Damage (p) = The flood damage at different flood probabilities [USD]
p_{max} = The highest probability for which damages are to be expected [1/y]

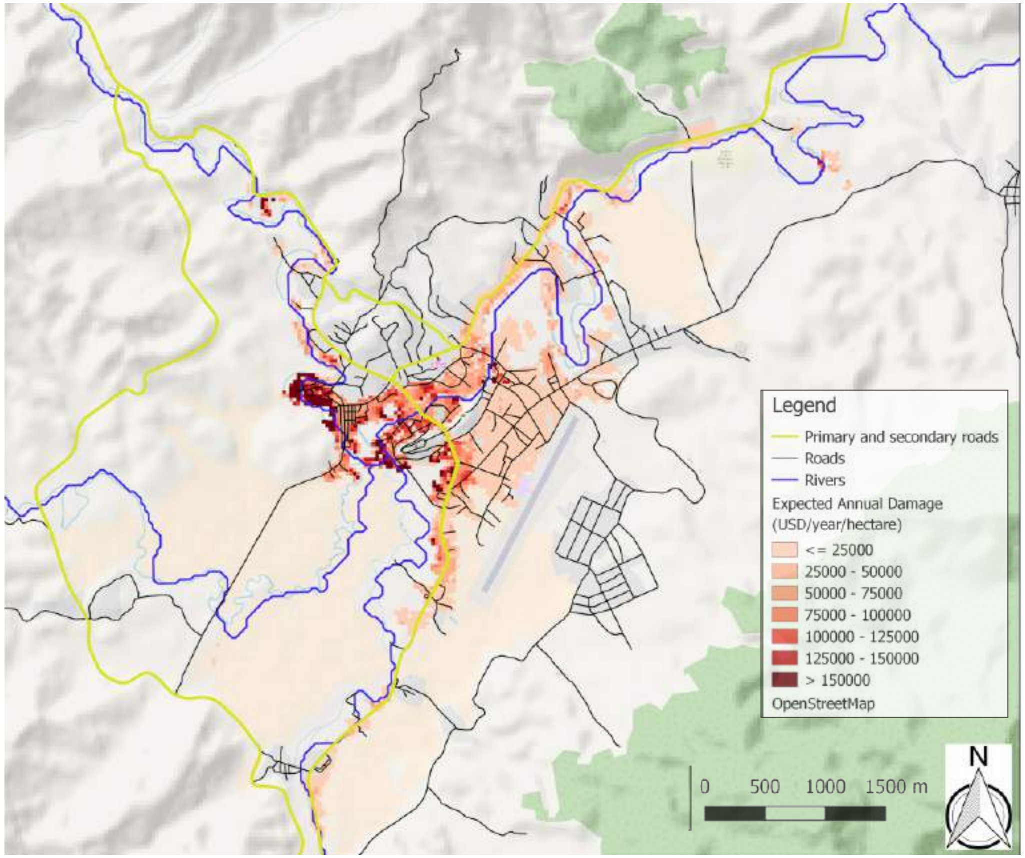


Figure 3.5 *Expected annual damage (USD/ year/ ha) for the reference case, flood event of August 2008*
(Source: Deltares 2017)

The flood risk was calculated using inundation maps, land use, vulnerability curves and values at risk (economic exposure) as input. Inundation maps are available from the flood modelling. Land use, vulnerability curves and maximum damages are available from the assessment of exposure and vulnerability.

Risk assessment for the reference case

Figure 3.5 presents the expected annual damage (EAD) in USD/year/hectare for the reference case (WFLOW; Manning's coefficient, n = 0.045 s/m1/3). The map shows that damage is higher in the western part of the town. The EAD value for the eastern part of the town is generally lower than 100,000 USD/year/ha. The highest damage is noticed in the area with population densities of >15,000 people/km2

04 UNDERSTANDING FLOOD RISK MANAGEMENT

INTRODUCTION TO INTEGRATED FLOOD RISK MANAGEMENT

Integrated flood risk management (IFRM) is defined as the development of strategies towards a culture of preventions through management of flood risk and living with floods. Aiming at maximizing benefits from the use of floodplains while at the same time minimizing losses and damages, the IFRM integrates land and water resources development.

Integrated flood risk management includes five key components:

- Adopting an adequate combination of measures, both structural and non-structural which have to address long-short events;
- Holistic management of the water cycle considering all types of possible floods (i.e, pluvial, river flooding);
- Integration of land and water management;
- Adoption of integrated hazard management approaches;
- Ensuring a participatory approach aiming to reduce vulnerability.

Integrated flood risk management will include the implementation of different types of measures depending on the type of flood. These measures are generally arranged in a cascade which ensures that all the potential types of measures are consciously evaluated. As illustrated in Figure 4.1 the cascade elaborates a number of guiding principles for categories of measures. Additionally, per every type of measure, there is often a corresponding policy and management field. It should be noticed that IFRM makes linkages and agreements between measures and policy development.

The development of a well-balanced strategy for integrated flood risk management should include a proper understanding of the system, not only examining characteristics of past flood events but also looking into future scenarios. This chapter will further describe flooding in Muang Xay and the flood hazard that the development of future infrastructure may pose to the city.

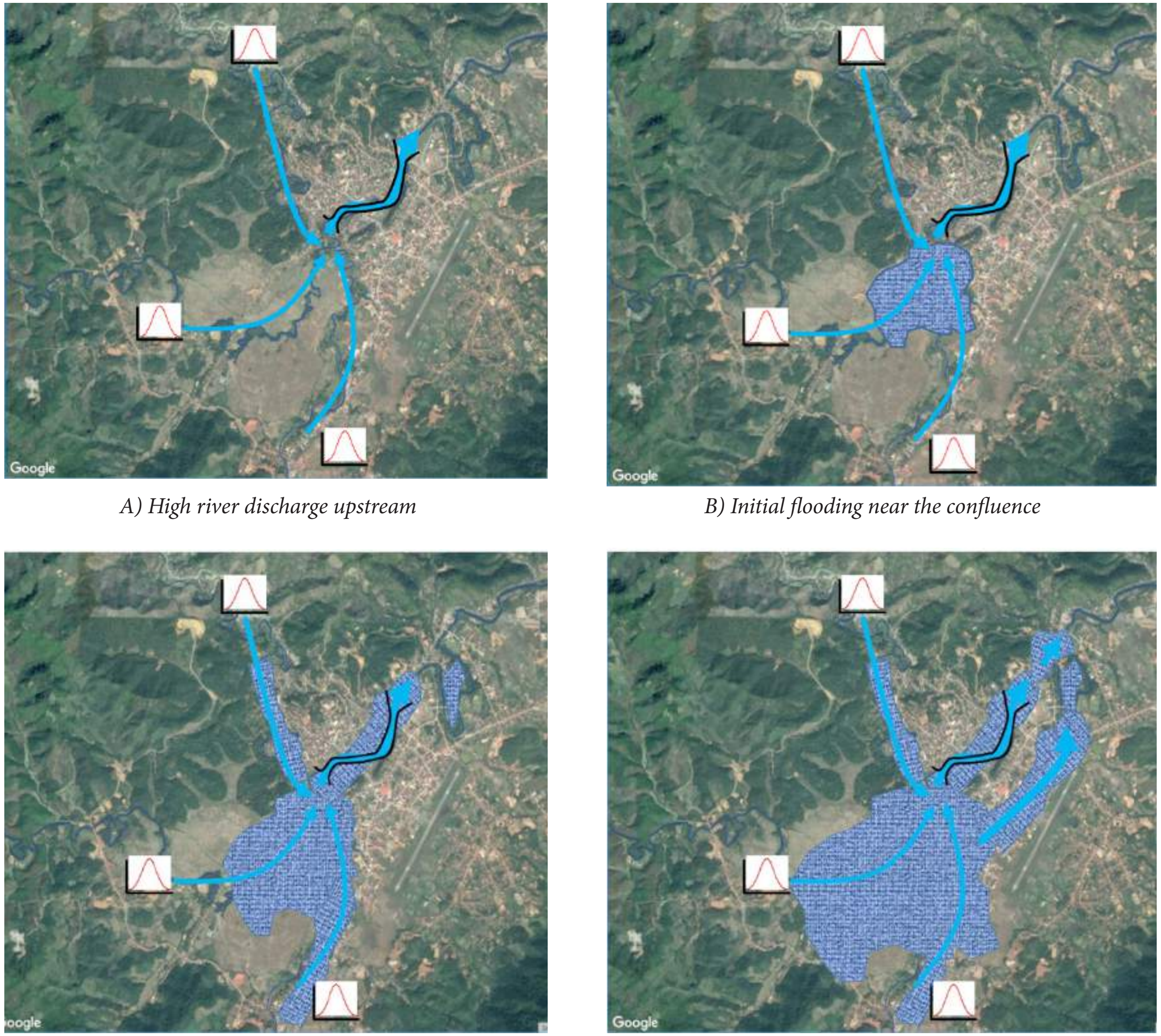
Fig. 4.1 *Cascade with Integrated Flood Risk Management measures and corresponding policy and management field. (Source: WMO, 2007)*

UNDERSTANDING THE MECHANISM OF FLOODING IN MUANG XAY

Two types of flooding have been considered for the area of Muang Xay: **pluvial flooding and river flooding.** Pluvial flooding occurs due to insufficient local drainage capacity or bottlenecks in the urban drainage system, whereas river flooding occurs as a result of high river discharges and overtopping of river banks.

Figure 4.2 schematically demonstrates how flooding takes place in Muang Xay. Simultaneous high flow discharges of the three rivers (Nam Kor, Nam Hin and Nam Mao) come together just upstream of the Muang Xay city centre (Figure 4.2 A). After the confluence, the narrow river profile causes a reduction in the discharge river capacity, increases of water levels and backwater effects (Figure 4.2 B). Prolonged high river discharges subsequently cause flooding alongside the upstream river banks (Figure 4.2 C). In even more extreme flood events river levels upstream of the city centre may rise to such heights that the flooding bypasses the main river parallel to the airport in the direction of the meander downstream of the Nam Kor River (Figure 4.2 D).

Information on past flood events in Muang Xay and Xay District was collected during semi-structured interviews with relevant GoL stakeholders and follow-up data collection with key line agencies. Further information was collected at the village level. A summary of the collected information is summarised below, key lessons show the main cause of flooding is the result of over-flow of the river banks due to sustained rainfall over a preceding period followed by a significant rainfall event.



A) High river discharge upstream

B) Initial flooding near the confluence

C) Flooding along the riverbanks

D) Extrem flooding bypassing the river

Fig. 4.2 *Sequence of flooding events schematically depicted for the Muang Xay area. (Source: Deltares, 2007)*

1985:
The 1985 flood was a flash flood event that occurred after a week of heavy rain, which caused the Nam Kor and Nam Mao Rivers to overflow. The flood event hit Ban Lak 11 at about 3 am on 25th August before reaching Muang Xay at about 5 am. The 1985 flood event is remembered by local residents and GoL officials as the worst flood event in Muang Xay.

1992:
The flash flood event in 1992 occurred due to a landslide. Muang Xay Town was not significantly affected but there was significant damage to the Tad Lak 11 waterfall, a prominent tourism site in Xay District. The flash flood changed the landscape around the waterfall and huts, a shop and a restaurant surrounding the waterfall were destroyed by landslide.

2008:
In August 2008, heavy rain caused the Nam Kor River to flood in Muang Xay at about 3 am in the morning. The water levels in Muang Xay increased slowly during the flood event which lasted about 6 hours. Many upstream villages also contacted downstream villages to warn them of the coming flood and this allowed many communities to respond and move assets to areas safely above the flood peak.

The extent of the September 2008 flood event has been mapped in a post-disaster study. The map was created by the Infrastructure Development Institute in 2009. This event was used to validate the results simulated with the hydraulic model.

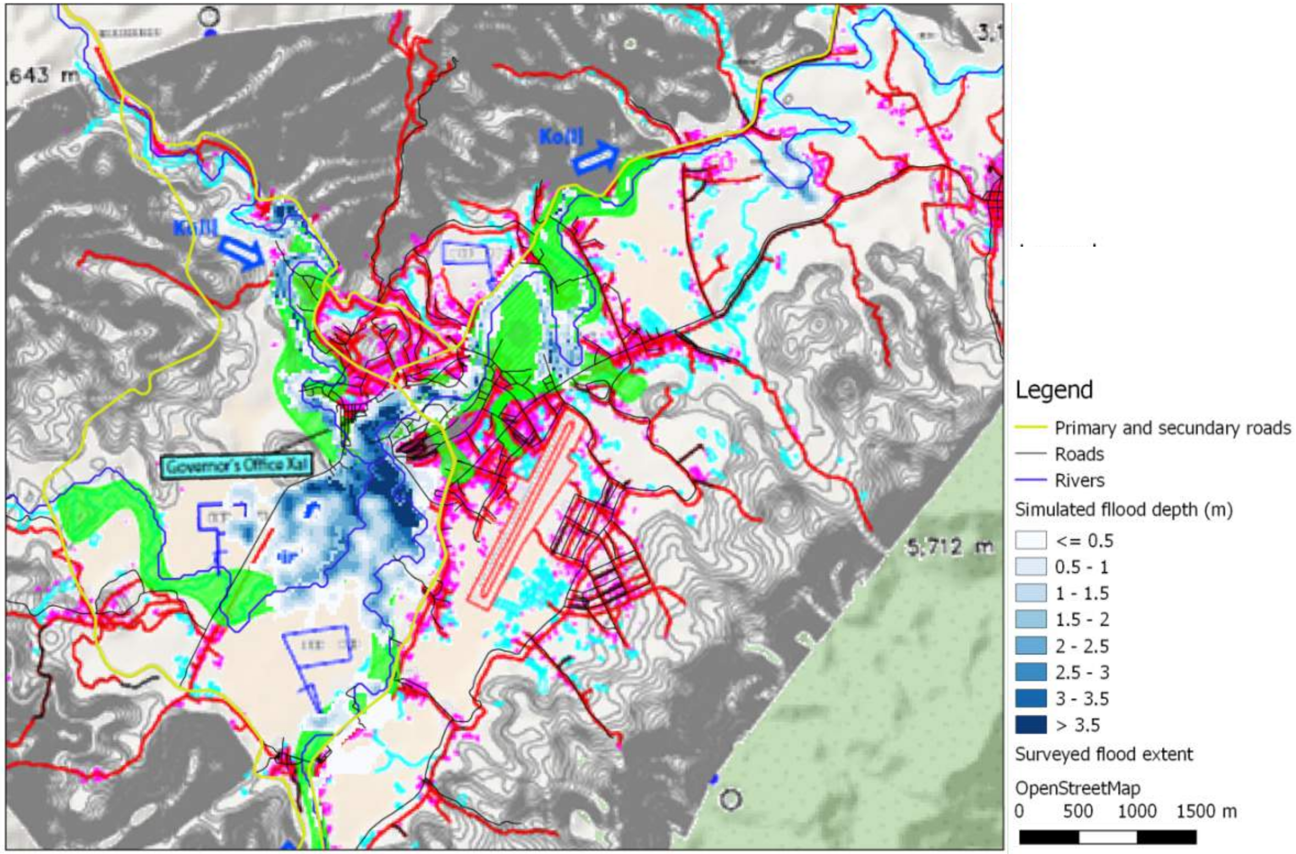


Fig. 4.3 *Overlay of the simulated flood map of the September 2008 event on the surveyed flood extent (green area). The overlay of this simulated flood extent and the survey show a good fit in some parts of the Muang Xay area. However, and as expected in some areas (e.g. near the future river park) there is only a limited fit. Given the available data, the simulation results are considered as acceptable.*

2013:
The 2013 flash flood, occurred as a result of torrential rains on August 20-21 with maximum daily rainfall of 93.6 mm. Seven districts suffered damage to infrastructure, loss of life (17 persons), and loss of agricultural production up to a value of 1,233 million kips (150,000 USD). Flood damage in the provincial capital of Muang Xay was largely caused by inundation from the Nam Kor River.
2016:
According to the provincial flood damage report, twenty-three villages were affected by the flood event between 12th and 15th August 2016. The estimated damage cost for the Nam Mao Pump House was 70,227,850 kip.

2017:
According to the provincial report, rainfall recorded during the 4th and 5th August 2017 measured 132.22 mm. On 5th August, the flood event in Muang Xay lasted between 7 am and 6 pm. Letters were sent out to villages warning of the likelihood of flooding at the start of the wet season but there was no formal warning just prior to the event despite heavy rainfall for the 3 preceding days. Once the flood had started, village loudspeakers urged villagers to move their families and key assets to safety in flood-affected villages. Urban infrastructure, utilities, houses, shops and markets nearby both the Nam Kor and Nam Mao rivers were affected. Xay district had eight affected villages of which five villages were in Muang Xay.

Above: *Overview of flood damages in Muang Xay (Source: Deltares, 2007)*

URBAN PLANNING IN MUANG XAY AND ITS ROLE IN FLOOD MANAGEMENT

Spatial development has rapidly taken place over the last 10 years across the city, especially along the main roads and rivers (Nam Mao and Nam Kor). The construction of new roads, hotels and other infrastructure for hosting the Lao National Games and the upcoming Lao-China railway in the southwestern part of the city have greatly influenced the development of the city. However, some developments are not in line with the city master plan.

The master plan has delineated generalized land-use for the control of urban development. Land use has been sub-divided into 7 classes: urban area, areas surrounding the urban centre, suburb-area, urban expansion area, transport area, agricultural area and forest and nature area. Agriculture and forest use accounts for approximately 66% of the surface (4839 ha). The urban centre and inner urban area account for only 6% of the total area of the city, although urban areas are expected to increase by up to 29% by the end of the planning year 2021. Rapid urban development without appropriate controls will lead to mixed land use (i.e. residential, commercial, civic, and industrial development in the same areas). The railway line through the south-western part of the city is also expected to influence mixed spatial development.

Except for a handful of planned residential areas, almost all housing in the city is characterised by spontaneous or informal development. In spontaneous housing areas, houses are developed on an incremental basis by individual initiatives. One of the major characteristic features of urban residential land use growth is that it follows mainly the access routes and areas of higher elevation, which have comparatively better service facilities. However, due to the presence of largely vacant land within the built-up area, there is still plenty of scope for infilling within the existing urban area.

The Master Plan has not identified any flood zones to be brought under development control for flood hazard mitigation and the current planning guidelines for the city do not indicate plinth level standards in different city areas based on past flood inundation in 1985, 1992, 2008 and 2017.

The most recent flood event in August 2017 raised a number of issues regarding flood risk management and urban planning in Muang Xay. A number of unapproved developments on the waterways may have exacerbated flood damage and flood extent during this event. The case of the Chinese bridge located in Ban Nasao is a clear example of how urban development plays a fundamental role in flood events. The bridge was constructed without consideration of food risk and dwellings were constructed in high-risk flood areas along the Nam Mao River. Additionally, the bridge was constructed without proper approval from the UDAA, and it did not follow any standard. During the flood event of August 2017 the natural flow of the water was interrupted through

Above: *Buildings affected by flood events in Muang Xay city (Source: Deltares, 2017)* the congestion of debris, a situation that contributes to the extent of inundation in the surrounding areas.

During preparation of the current master plan of Muang Xay, flood hazard information in relation to the city was not available and flood hazards were therefore not considered. As a result, it is not mandatory to consider historical flood heights or levels. Moreover, the master plan does not indicate flood-prone or flood risk areas to guide development. This has resulted in many developments in the city within flood-prone areas. The Oudomxay Provincial Hospital was constructed in the year 2005. The flood height of the area where the hospital is located was inundated up to 1.1 meters in depth during 1985 flood . However, the current plinth level of the hospital is 0.5 meter, which is below the height of the flood level in the area within the last 30 years. Moreover, the 20 years return period flood inundation maps (developed under the project) indicate that the hospital location is at high risk (Figure 4.4).

Developing a strategic integrated urban design and flood risk management plan for the city of Muang Xay is an important step towards the use of water and flood management as a design parameter for spatial planning, to increase flood risk awareness and to develop practical strategies to cope with flood risk. The preparation of a strategic plan for Muang Xay will need to take the following elements into account:

- Reduction of the adverse impact of floods and the likelihood of floods;

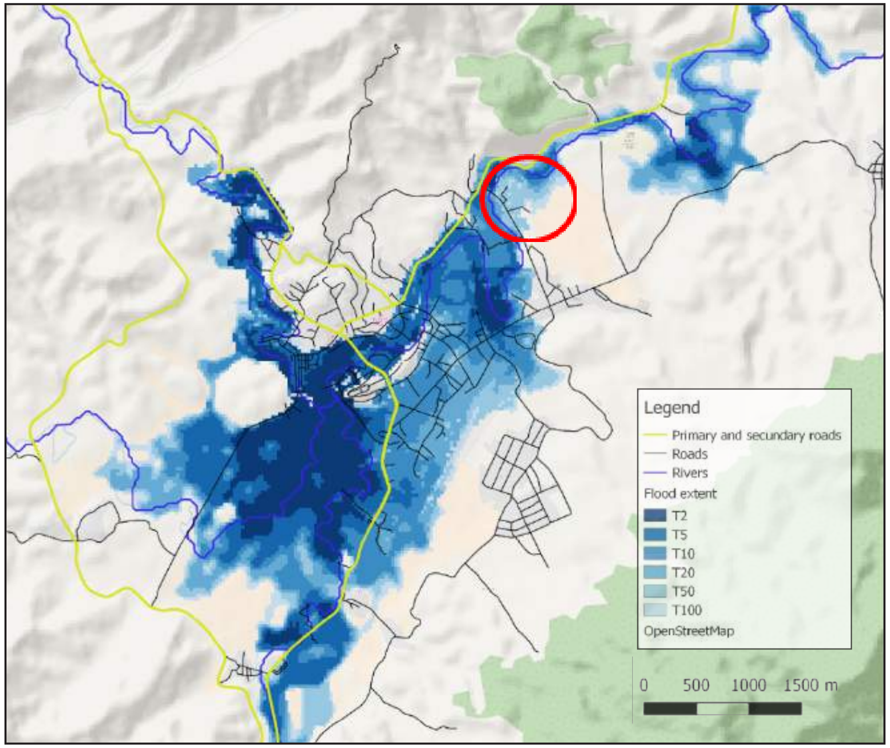


Fig. 4.4 *Flood Extent Map of Different Return Period. Red Circle Area indicates the location of the Oudomxay Provincial Hospital Prone to 20 years return period flood* (Source: Deltares 2017)

- Promotion of sustainable flood risk management measures, addressing all phases of the flood risk management cycle, focusing particularly on damage prevention by avoiding construction of residential, commercial and industrial infrastructure in present and future flood-prone areas or by adapting future developments to the risk of flooding;
- Consideration of opportunities to work with natural processes and where possible, design dual-purpose facilities delivering multiple benefits from flood risk management;
- Communication, awareness raising and emergency response.

Critical infrastructure

Critical infrastructure prone to damage from flooding in Muang Xay includes schools, temples, bridges, hospitals, markets, a power substation, roads and drainage infrastructure. Analysis of the calculated flood risk maps shows that much of the infrastructure is located outside of the inundation areas for events with return times of 2 years and 5 years, but most infrastructure is at risk for events with return times of T = 20, 50 and 100 years. **Schools are most vulnerable to flooding under the 1 in 20 year scenario while the provincial hospital is under threat from a 1 in 50 or a 1 in 100 year event.**

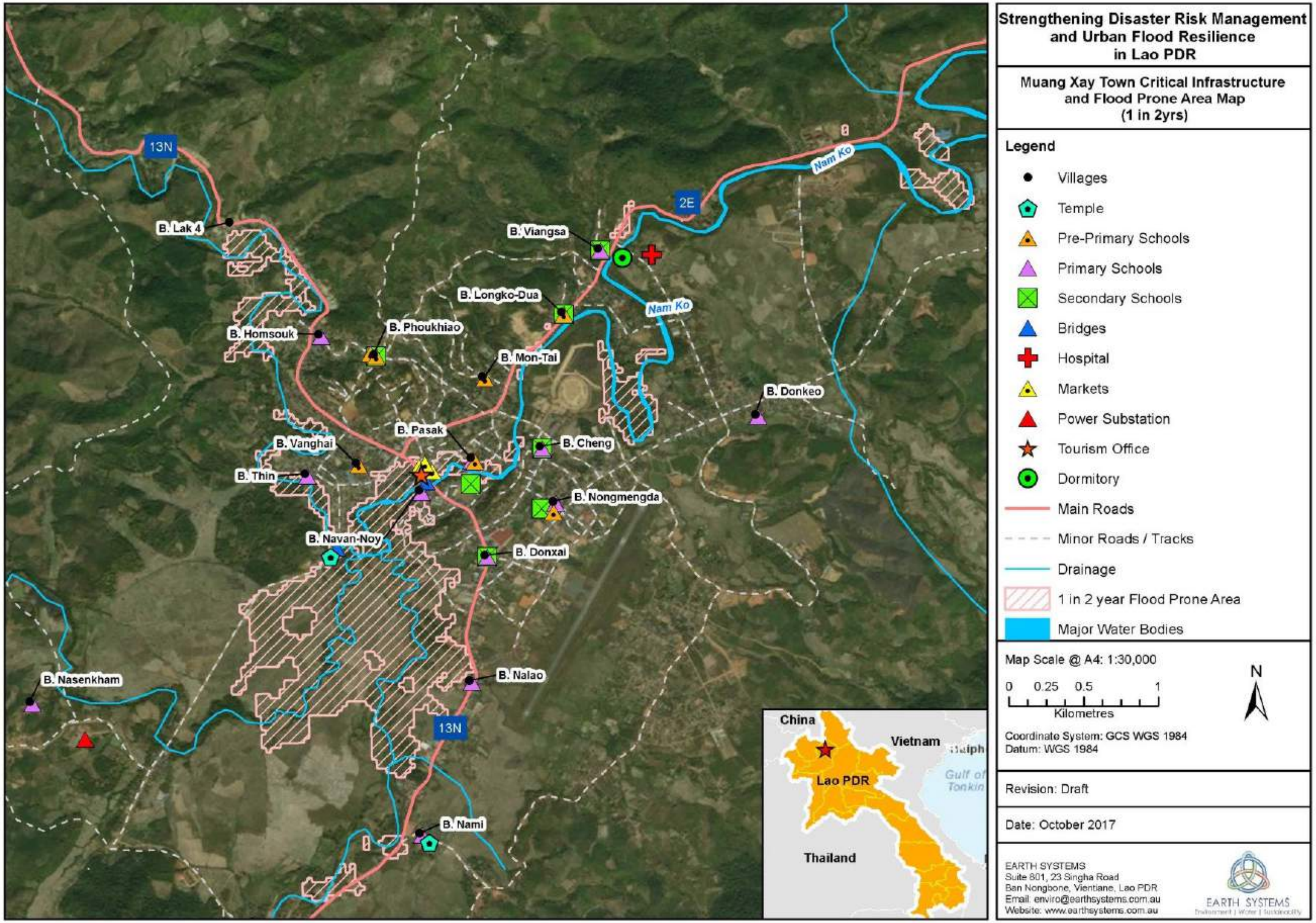


Fig. 4.5 *Critical infrastructure and expected flood prone area for a 1 in 2-year flood event (Source: Earth Systems, 2017)*

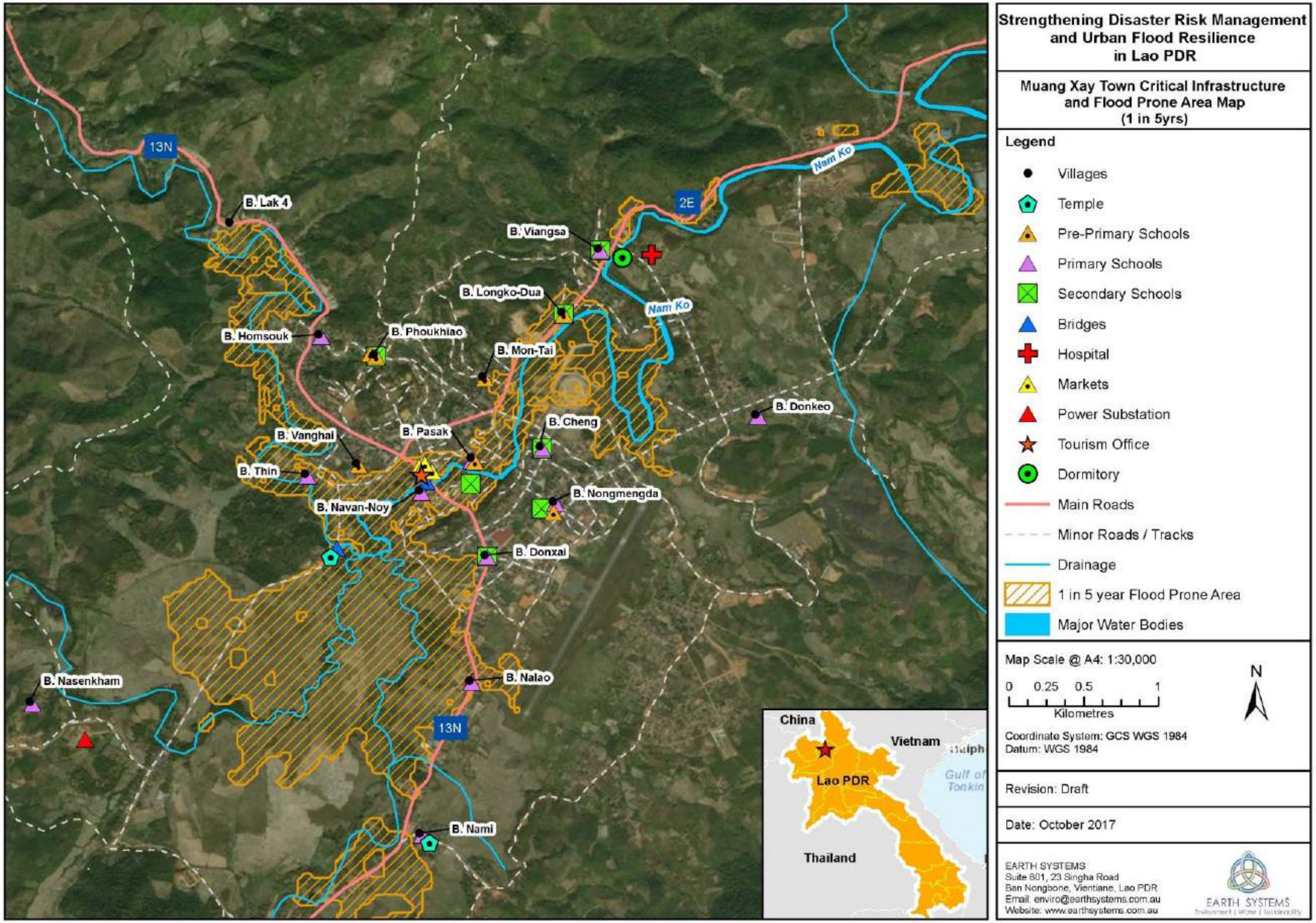


Fig. 4.6 *Critical infrastructure and expected flood prone area for a 1 in 5-year flood event (Source: Earth Systems, 2017)*

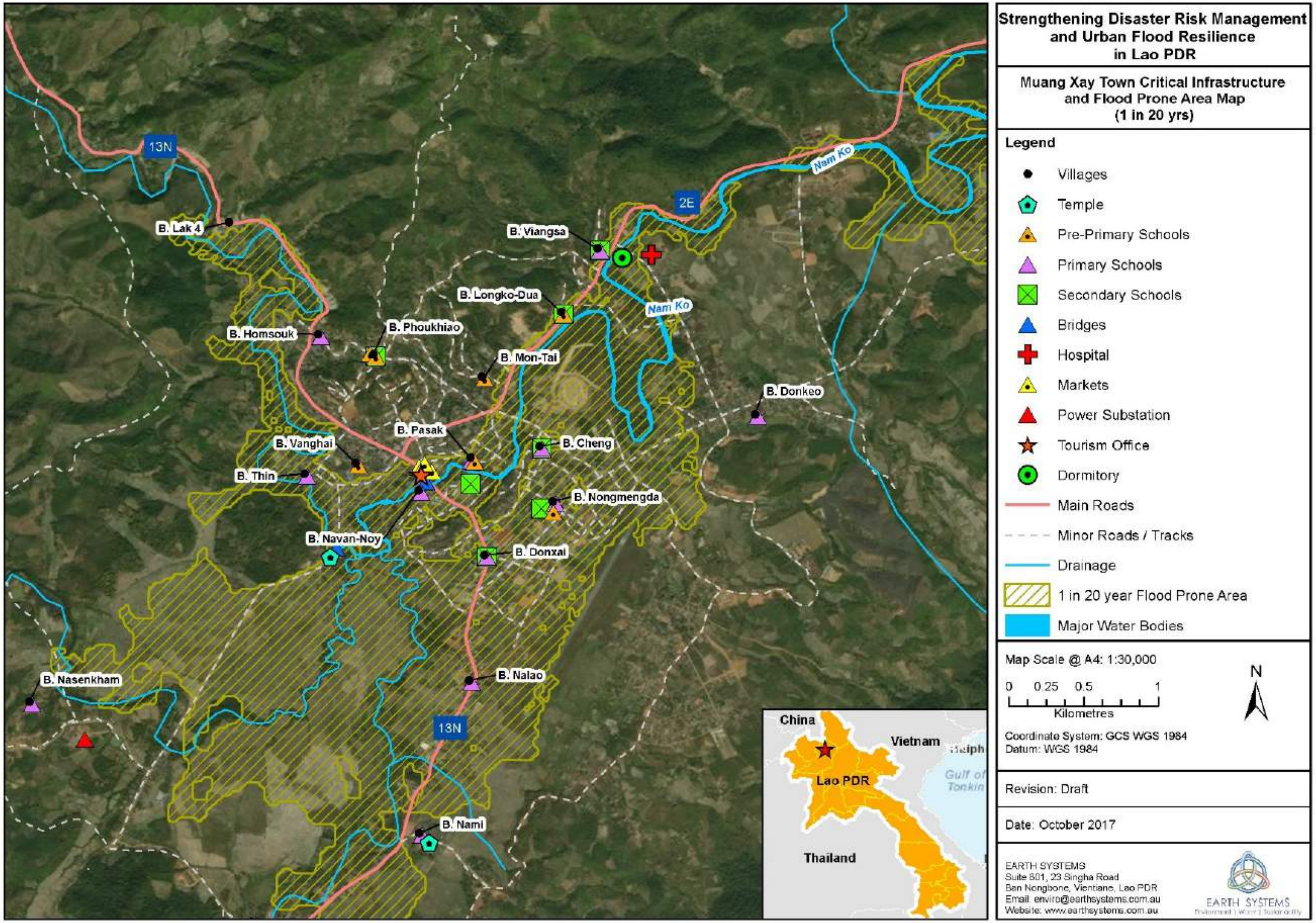


Fig. 4.8 *Critical infrastructure and expected flood prone area for a 1 in 20-year flood event (Source: Earth Systems, 2017)*

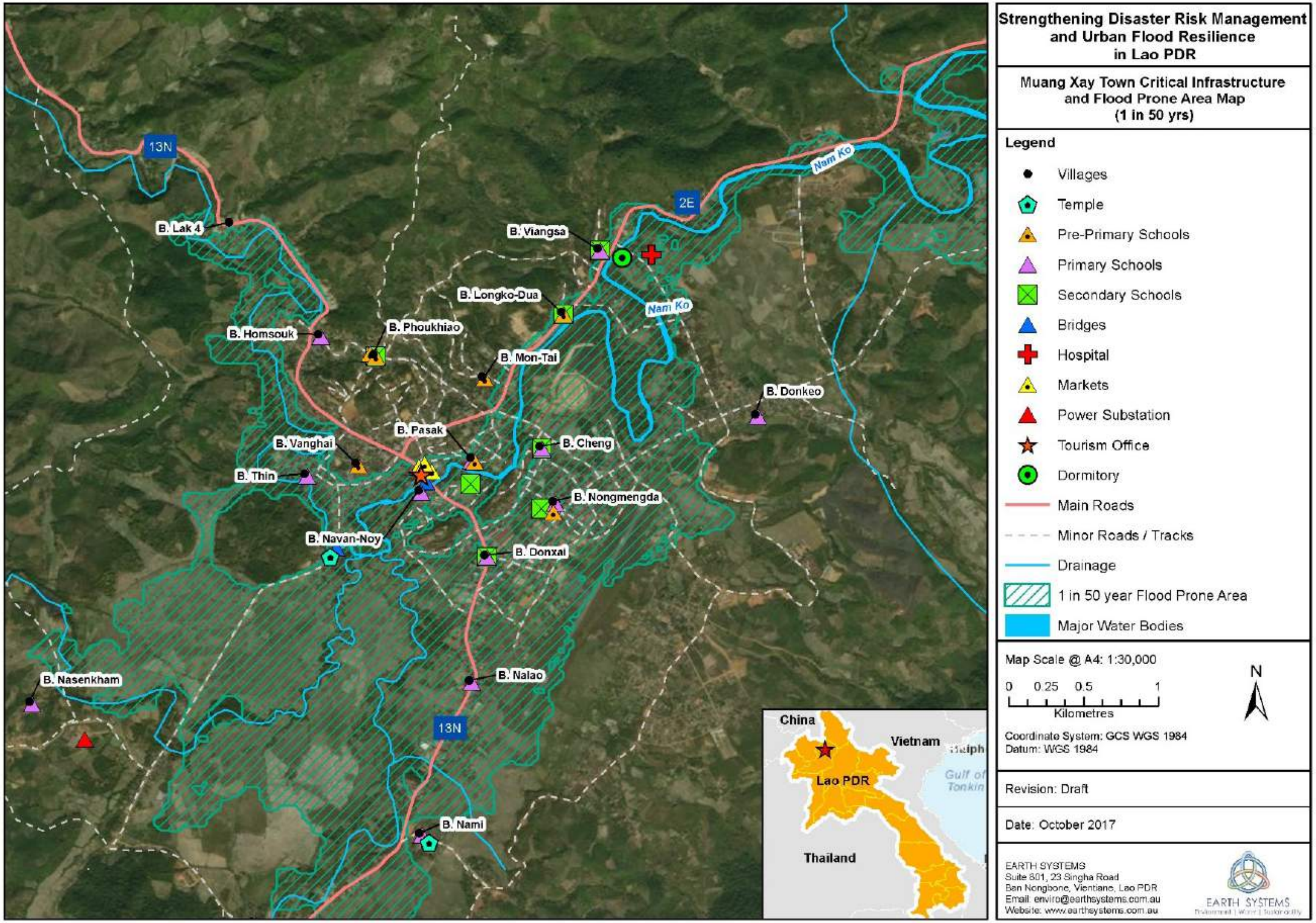


Fig. 4.9 *Critical infrastructure and expected flood prone area for a 1 in 50-year flood event (Source: Earth Systems, 2017)*

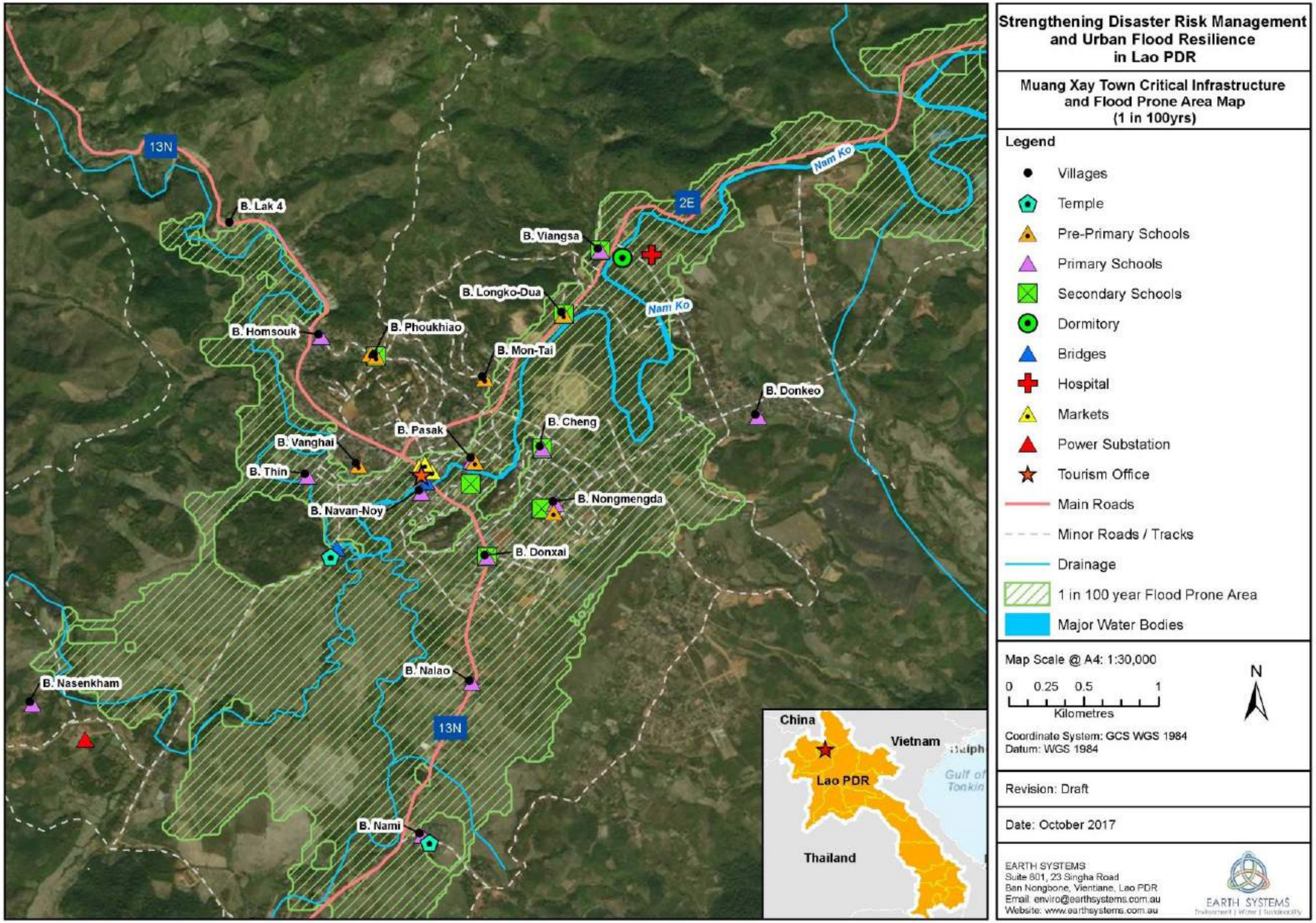


Fig. 4.10 *Critical infrastructure and expected flood prone area for a 1 in 100-year flood event (Source: Earth Systems, 2017)*

05 EVALUATING NON-STRUCTURAL MEASURES

The development of a well-balanced strategy for IFRM consider different types of measures depending on the flood type. The adoption of an adequate combination of structural and non-structural measures helps communities to reduce the negative impacts of flooding and to adjust to flood hazards.

This section focuses on non-structural measures. Flood forecasting and early warning are effective measures to minimize the negative impacts of flooding. However, there are factors that influence the effectiveness of such systems, i.e. data sources, communication, decision support, dissemination or notification, coordination, and responses or actions. Hydro-meteorological data (notably rainfall and evaporation) are essential to flood forecasting and early warning systems. Key observations on river discharge and river water levels are therefore vital for the effectiveness of non-structural measures.

In addition to the well-known infrastructural measures, Sustainable Urban Drainage Systems (SUDs) have proved efficient in the reduction of flood damage and flood extent. SUDS are adaptive or resilient measures that usually aim to 'absorb, delay, store and drain' water to help reduce peak run-off. This is specifically relevant for climate change induced higher rainfall intensities. Typical SuDS measures are infiltration trenches, permeable pavement, detention basins, retention basins, bio-swales, green roofs, rainwater butts, and storage tanks. Applicability of several of these measures depends largely on the local topography, geology, socio-economic development and climate conditions.

In holistic planning, flood resilience measures should be designed within the context of the broader ecosystem, considering the spatial planning and architectural style of the area to be implemented. Aiming to improve flood resilience in Muang Xay, this section will further explore non-structural issues such as data collection, communication channels, community resilience, and community organization for flood mitigation and adaptation.

Community resilience in flood-prone areas

Community resilience to disasters is seen as a key component of disaster risk management. Strengthening community resilience can complement structural measures for flood protection and in some cases be even more effective than engineering solutions. Community resilience can be measured as the extent to which communities can respond to, and recover from, shocks or stresses such as flood events (Figure 5.1 a). Resilient communities are able to function and sustain critical systems under stress; adapt to changes in the physical, social or economic environment; be self-reliant if external resources are limited or cut off, and learn from experience to improve over time.

Disaster resilience has four components: community connectedness; risk and vulnerability; planning and procedures; and available resources (Figure 5.1 b).

Information relating to the resilience of communities in Muang Xay was collected during consultations including semi-structured interviews with GoL and mass organisations, interviews with village authorities and

a)

b)

Fig. 5.1 Community resilience models
a): *Measuring community resilience* (*Source: Torrens Resilience Institute 2015*)
b): *Model for community resilience* (*Source: Torrens Resilience Institute 2015*)

focus group discussions with villagers in five flood-prone villages of Muang Xay and organisational focus groups with professional organisations involved in flood management.

The above-mentioned consultations identified both strengths and challenges in terms of community resilience to flood events in Muang Xay.

Strengths in the community included:

- High levels of literacy and participation in education;
- Good access to health services;
- Awareness of support options during flood events;
- Younger members of the community are skilled in the use of smartphone technology; and
- Many people in flood-prone areas have built two-storey houses so that they can move people and assets above the water level if required.

Challenges for community resilience include:

- Some key village infrastructure is currently located in flood-prone areas;
- A lack of knowledge and resources for flood protection of homes and other assets;
- Lack of training and community planning related to flood risk management;
- Lack of dedicated village level disaster management committees;
- Many older community members including many village authorities cannot use smartphones and other IT;
- Lack of funds to repair public and private infrastructure damaged in flood events;
- Lack of affordable and viable flood insurance options;
- Loss of incomes during and after flood events; and
- Lack of knowledge about building flood resilient infrastructure.

SELECTED BEST PRACTICES EXAMPLES TO INFORM FUTURE URBAN PLANNING AND FLOOD RISK MANAGEMENT

A number of best practice examples of flood risk management non-structural measures have been selected for their potential to be adopted in Muang Xay. Examples include locally appropriate processes and design measures to improve existing infrastructure, adoption of blue-green measures in urban planning, options to enhance data collection and analysis and communications during flood events. Potential measures for strengthening community organisation and resilience in relation to flood events are also included.

It is recommended that key urban drainage be subject to ongoing maintenance and debris removal. Debris and trash racks (such as drainage grates - many already exist) should be installed in localised flooding areas to prevent damage to infrastructure. If required, urban drainage should be retrofitted for capacity to 1:5 to 1:10 ARI storms to assist with lowering damage from pluvial flooding events.

All bridges and instream structures should be assessed for debris flow damage potential using appropriate guidelines such as US DoT and if necessary debris flow trash racks and post and rail racks should be installed at major culverts and bridges if required. Bridge piers should be protected by debris sweepers if part of the main highway network or are key critical infrastructure roads.

Considering the 'absorb, delay, store and drain' approach, blue-green measures in urban systems aim to recreate a naturally oriented water cycle while contributing to the amenity of the city by bringing water management and green infrastructure together. Blue-green measures can be an effective tool for flood mitigation in growing urban areas like Muang Xay.

Blue infrastructure includes ponds, flowing waterways, wet detention basins and wetlands that exist within the drainage network. Green infrastructure refers to natural land and plant-based ecological treatment systems and processes, such as open space, parks, recreation grounds, woodlands, gardens, green corridors, vegetated ephemeral waterways and planted drainage assets that undergo a wet/dry cycle due to runoff.

There are many examples of blue-green measures implemented for flood risk management and city development along riparian areas. The city of Dordrecht in the Netherlands is a good example of a thematic approach of blue-green ecosystem design solutions for flood mitigation in urban areas (Figure 5 3). During consultations in the present study, stakeholders in Muang Xay expressed a desire for beautiful green urban spaces. Future urban planning and detailed design of the proposed investments for Muang Xay should therefore incorporate holistic planning principles such as those adopted in Dordrecht where possible.

Data collection and analysis

Information technology has allowed for the development of powerful tools to support data collection and analysis in a range of applications. Selected examples of tools and their applications that could be used in Muang Xay in either the short or medium term are provided below.

Humanitarian Open Street Map and UN-ASIGN

The Humanitarian Open Street Map Team (HOT) manage information collected for a range of potential applications including disaster management. Information can be collected by virtually anyone with a smartphone or tablet using open source software and potential applications for disaster management include community disaster preparedness mapping and mapping to support humanitarian aid efforts. HOT implements projects across the world to meet identified needs in partnership with governments and development partners (including the World Bank).

Above: *Thematic approach of blue-green measures for flood mitigation in urban areas in the city of Dordrecht.* *(Source: ADPC 2017)*

UN-ASIGN is a free application to support emergency response and disaster risk reduction. The application allows individuals to collect and disseminate crowd-sourced photos and reports about the situation in a given area during a natural disaster or humanitarian crisis. Information is time stamped and geo-tagged and uploaded to a central UN server which allows for comparison of disaster extent in a given area over time. The application has successfully been used in Haiti, Pakistan, Nigeria, Nepal and for flooding in Thailand.

Lao Di / MM system for recovery and reconstruction

Several disaster information systems have been developed for application in Lao PDR. LaoDi has been developed in partnership with MONRE under the United Nations Integrated Disaster and Climate Risk Management Project in Lao PDR (IDCRM) and is designed as a repository for disaster information. LaoDI is based on the UN's Disaster Information Management System (Desinventar) and is a tool that helps to analyse disaster trends and their impacts in a systematic manner to facilitate improved planning for prevention, mitigation and preparedness measures in order to reduce the impact of disasters on communities.

LaoDI is still in the early stages of development and its effectiveness is currently limited because of the lack of data available in the database. In the short term, the LaoDI system could be best utilised best to support decision making in Muang Xay. This would require better systematic communication and information exchange between local and community level authorities in Muang Xay and MONRE who is responsible for managing the database.

Flood data apps

There are a number of smartphone applications recently developed for data collection and flood preparation. Examples include FloodMap and the Red Cross Flood app. The FloodMap app is currently only applicable to the US but already has contributed to flood risk information sharing and benefited, homebuyer's, property developers and insurance professionals to identify flood risks in different areas.

Communication Channels

Traditional information channels during disaster events in Muang Xay include television, radio, telephone, village meetings and village loudspeakers. Telecommunications company Unitel also has an emergency hotline that can be used in a disaster event but is currently not equipped to handle large volumes of calls and it works independently from GoL. Lao PDR currently ranks seventh in Southeast Asia for internet use with over 1.5 million internet users and had more than 55 mobile cellular subscriptions for every 100 people in 2016. The deadly Nepal earthquake in 2015 is an example of what is possible when leveraging available technology during and after a crisis. While voice services were overwhelmed, the internet was still up and running. Both Facebook and Google enabled services allowed citizens and travellers to post information about their situation or to try to find missing family and friends.

One disadvantage of over-reliance on mobile technology is that it may alienate those members of the community that are technology illiterate or do not own smartphones and this bears consideration when designing locally appropriate communications protocols for DRM. Another is that it relies on operational networks and services may be cut for short or even extended periods during flood events.

Community Organisation

Strong community organisation is vital to resilient communities that are able to respond to the risks that disasters present to livelihoods, the local economy, infrastructure and the environment. There are currently no village level disaster prevention and control committees in the villages consulted in Muang Xay despite them all being in flood-prone areas.

06 EVALUATING STRUCTURAL MEASURES

This chapter summarizes the effects of the implementation of infrastructural measures on flood risk mitigation. The priority investments options considered in this analysis include river bank protection, dike construction, river bed improvements, construction of flap gates, river side parks, and reservoirs upstream of the city. In addition, this chapter provides an environmental and social assessment of each of the GoL proposed investments as well as other potential structural solutions identified in the flood risk assessment.

The GoL proposed investments were treated to an initial site environmental and social screening exercise during the study. Results of the screening exercise are presented in this chapter along with an initial assessment of the other above mentioned potential structural solutions. The ISO31000 Risk Management and Assessment framework approach was adopted to develop an environmental and social risk assessment for flood-prone villages in Muang Xay region.

PRIORITY INVESTMENTS PROPOSED BY GOL

River flooding is seen as the main cause of flooding in Muang Xay. Interventions to reduce river peak levels are therefore important. The proposed interventions focus on increasing the discharge capacity of the river in combination with bank protection. As defined by the GoL The structural solutions for Muang Xay proposed by the GoL include river bank protection, urban discharge systems with enhanced infiltration, dike construction, riverbed improvements, -flapgates and riverside parks (Figure 6.1).

Dikes or river levee banks

Dikes or river levee banks are earthen flood protection embankments, and are proposed for various locations across Muang Xay spanning a total distance of approximately 8km. The banks of the river sections are to be raised to withstand higher flood levels. Future dike levels should be at least 1m above highest current embankment level.

Flap gates

The schematized urban drainage network is considered to be extended with flap gates. This allows only one-directional flow from the drain towards the river. If the water level in the river is above the bed level of the drainage network, this flap gate blocks any inflow into the drainage system.

Up to 26 flap gates have been proposed by DOW at strategic locations along the waterways in Muang Xay. According to the DOW, the flap gates are designed to improve and regulate drainage mainly in small tributaries to the Nam Kor River. There is no current final design for the flap gates but they are expected to span between 4m to 6m.

River improvement

The intervention of river improvement as proposed by the Government focuses on increasing the discharge capacity of the river in combination with bank protection. Details on the local context of the river

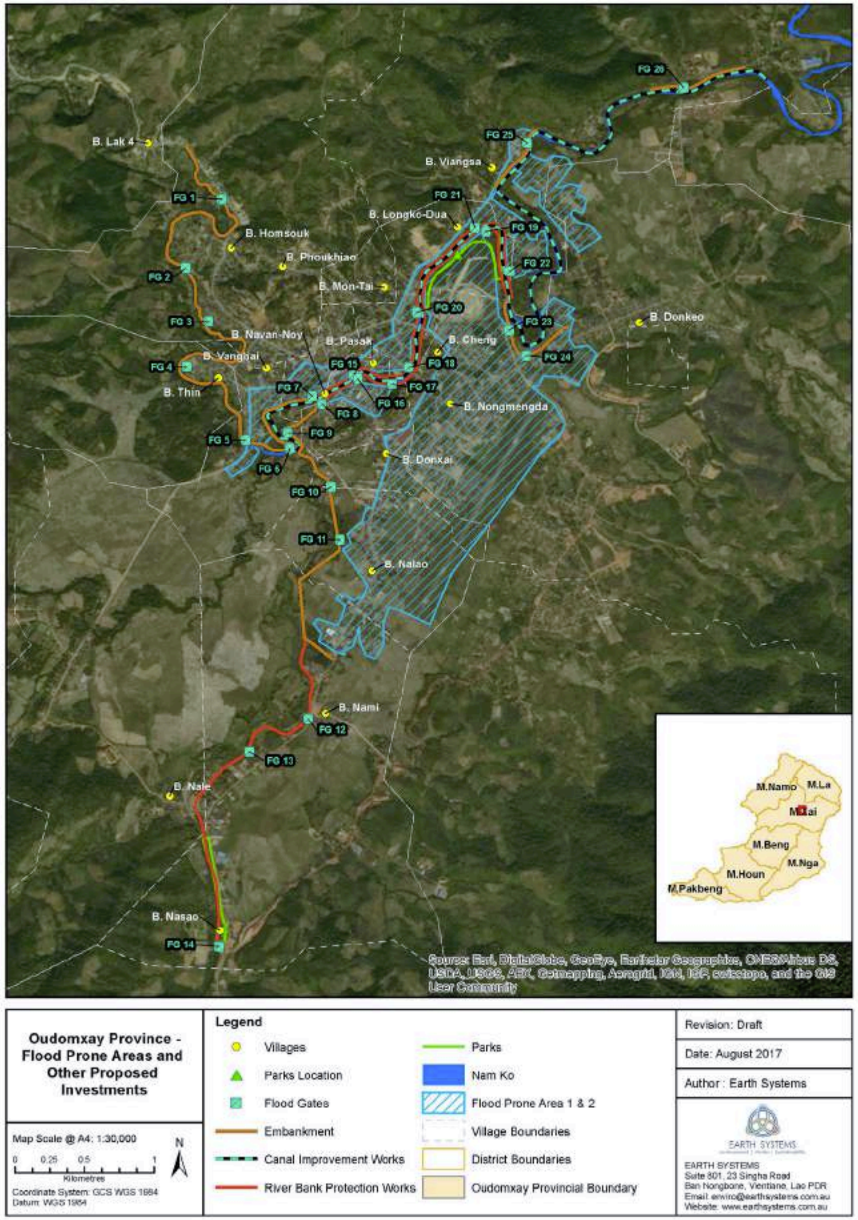
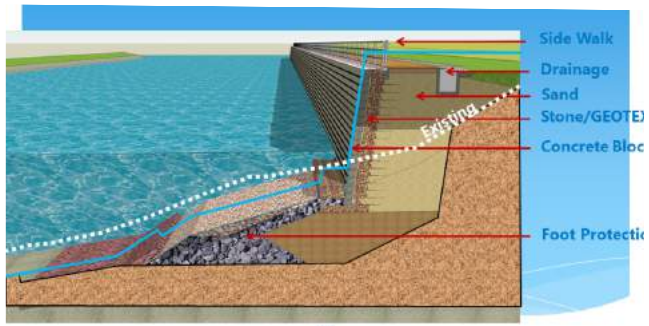


Fig. 6.1 *Location map showing proposed investments*
(Source: Earth Systems, 2017)

a) [14]

b)



[16]

c)

Above a): *Artist impresion of Park 1*
Above b): *Schematic of the master plan Park 2*
Left c): *Concept of typical cross section of riverside improvements*
(Source: Deltares, 2017)

improvement are unavailable yet. Hence, for the river improvement measure, the present study initially assumed a trapezium profile (1:1.5), a lower roughness value of n= 0.030 s/m1/3 (i.e. a smoother bed and wall surface), and a dike level of 1m above the highest embankment. For the bank protection measure we also assumed a trapezium profile (1:1.5) and a lower roughness value but no dike level.

River parks

The proposed river parks could contribute to the beautification of Muang Xay city. It is assumed that these parks will enlarge the storage of the floodplain at a level of 1m below the nearest bank heights. The river park along the Nam Mao River is assumed to become 3 ha in size, while the river park along the Nam Kor River is assumed to become 14 ha.

Shortcut of the river meander in the Nam Kor

The meander downstream of the Nam Kor GS extends the river with 2.5km while a shortcut, would be approximately 0.3km in length. Such a shortcut would decrease the backwater effect of the meander on the water level by reducing the flow path. We assumed a design cross-section and bed level based on the cross sections that were surveyed upstream and downstream of the shortcut.

Initial results

The impact of these interventions has been assessed by comparing the flood extent and the expected annual damage (EAD) after implementing each intervention with the reference (no interventions) flood situation. The flood extent and the expected annual damage of each intervention were assessed for return periods of 2, 5, 10, 25, 50 and 100 years. For each of the interventions maps of flood extent, EAD and reduction in EAD (compared to the reference case) were constructed, as well as a chart expressing the reduction of the flood extent, a table showing the reduction in damage, affected population, and the number of affected schools and temples.

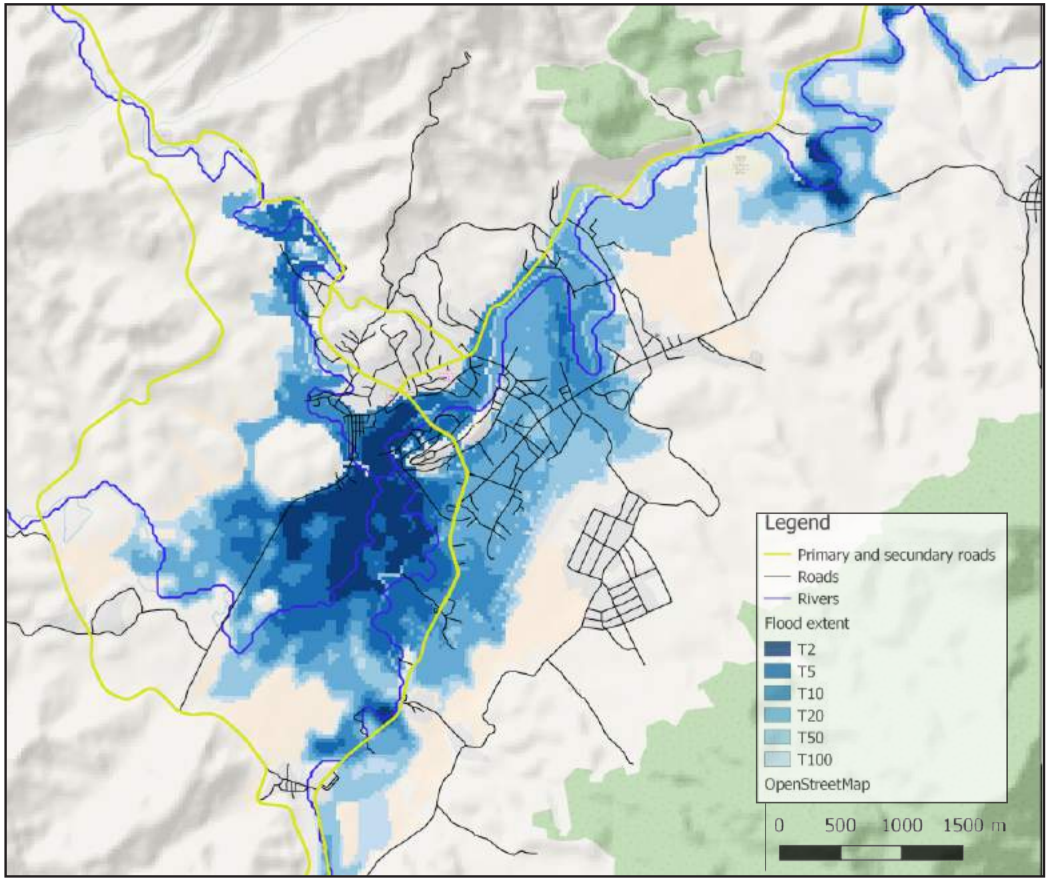


Fig. 6.2 *Simulated flood extent map after the implementation of all measures (flood event August 2008) (Source: Deltares, 2017)*

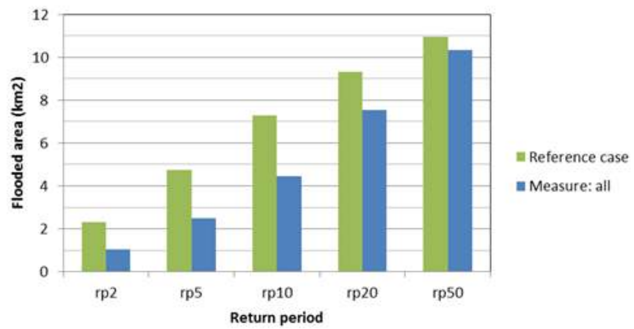


Fig. 6.3 *Expected reduction of flooded area after implementation of all measures (Source: Deltares, 2017)*

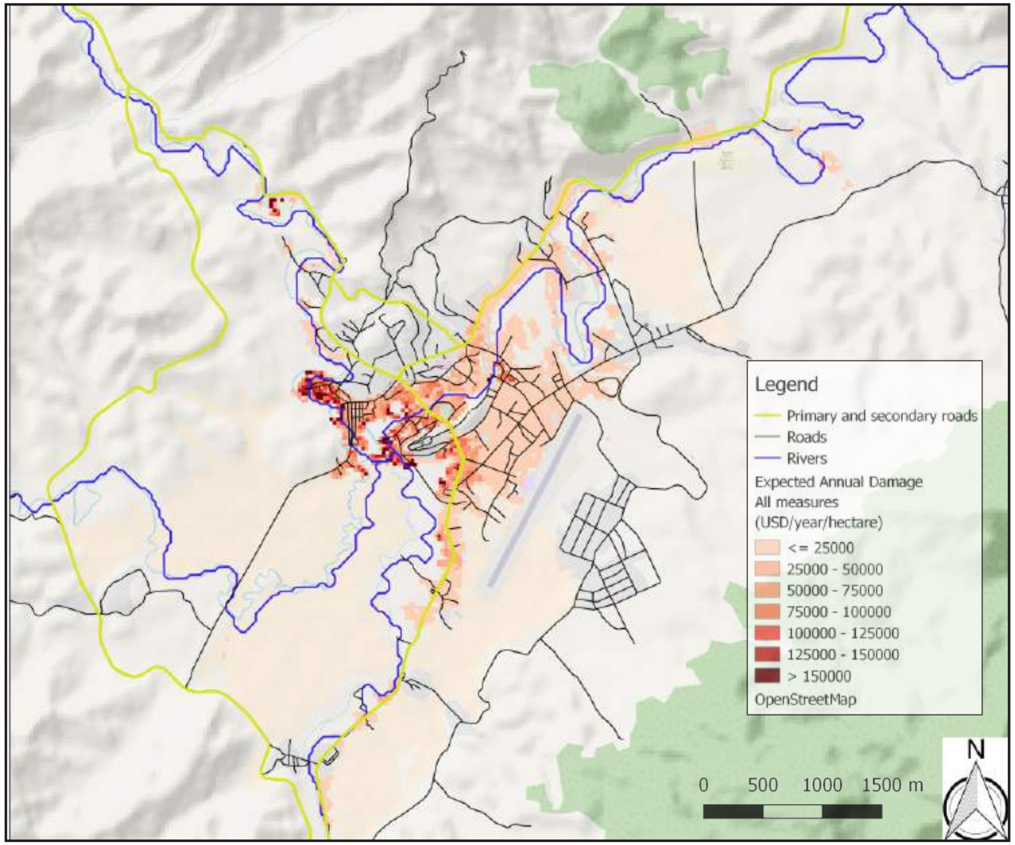


Fig. 6.4 *Expected Annual Damage after implementation of all measures. (Source: Deltares, 2017)*

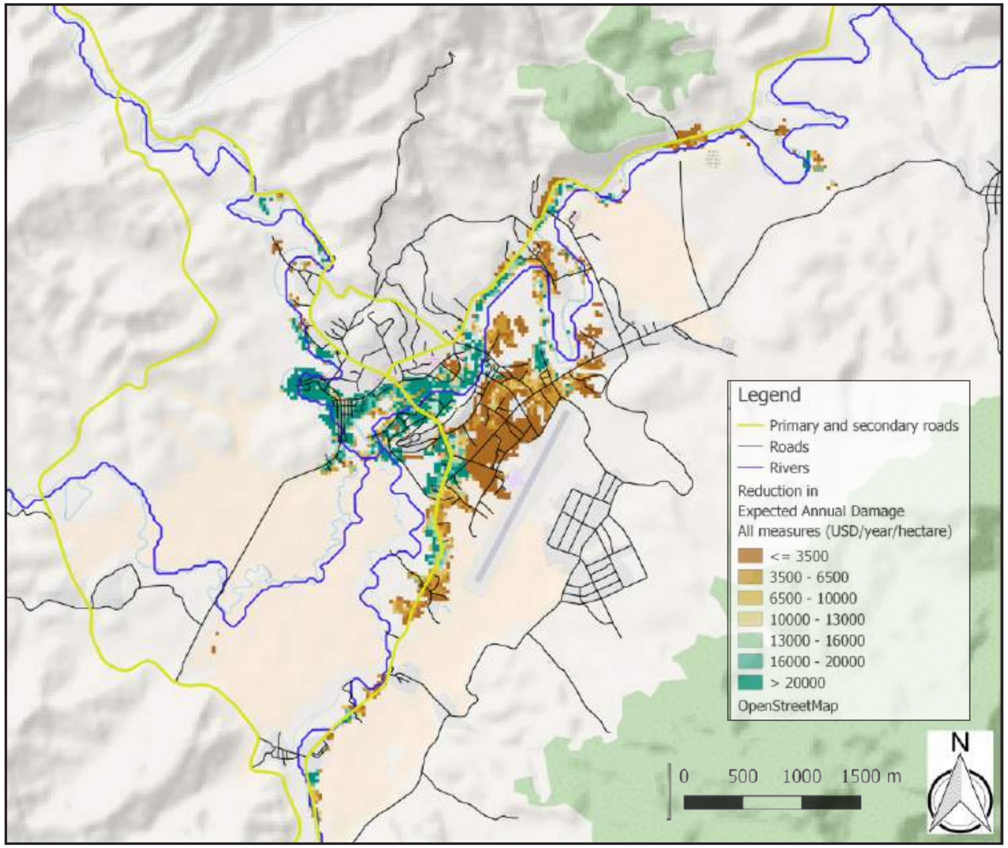


Fig. 6.5 *Reduction in EAD after implementation of all measures combined . (Source: Deltares, 2017)*

This information is presented in detail in Report 2 of this study. The present section summarizes the detailed analysis by showing the impacts on river flooding for the combination of all structural interventions.

The combination of measures provides a significant reduction in all areas of the flood extent (Figure 6.2). Figure 6.3 displays the reduction in flooded area in km2, ranging from a maximum reduction of 55% for a return period of 2 years to 6% for a return period of 50 years.

The expected annual damage for all interventions combined is shown in Figure 6.4 and the associated reduction in EAD compared to the flooding of 2008 is given in Figure 6.4. It is estimated that the combination of all interventions reduces the EAD considerably. In a large part of the area, the EAD has reduced by at least 13,000 USD/year/ha (green colour in Figure 6.5). Results shows that the decrease in damage and population is up to ~75% for the lower return periods. Also, yearly expected damages and population affected is reduced by 41% and 43% respectively. Schools are extremely vulnerable to flooding, but by implementing a combination of all the structural interventions, the risk of flooding decreases considerably. In general, flood reduction may decrease up to 50% if all the structural interventions proposed by the GoL are implemented.

OPTIMIZATION OF STRUCTURAL INTERVENTIONS

The initial results of the implementation of the interventions proposed by the GoL were discussed with stakeholders, the World Bank and GoL during a workshop held in September 2017. In addition, a series of dedicated field visits in September provided further detailed information on certain system characteristics. An important conclusion was that some measures are very effective (river improvements, dikes, shortcut) while others are not so effective (parks, flap gates) in reducing flood risk at the spatial scale of the river catchment in which Muang Xay is situated. This section describes the next step to further optimize the most promising design options in a package of infrastructural interventions to maximally reduce flood risk. The premise is that river flooding is the dominant cause of flooding in Muang Xay. The priority in the approach is therefore to mitigate the problem of river flooding. River flooding takes place at the scale of the river valley floor, surrounded by the higher grounds. Interventions should therefore also be focused on solving the problems at that same scale level.

Rather than only assessing the impact of certain measures on all return times, the interventions are optimized for a 20-year return time. A 20-year return time approximately coincides with a discharge that can be maximally accommodated through the urban river profile without radically widening the riverbed into the urban fabric, i.e., without considerably removing housing and infrastructure.

River basin approach

Starting from a river basin perspective, the rivers of Muang Xay were subdivided into three sections: upstream of the city, downstream of the city, and in the city centre ('midstream'). The infrastructural measures were therefore re-designed and added to the intervention package in a stepwise approach:

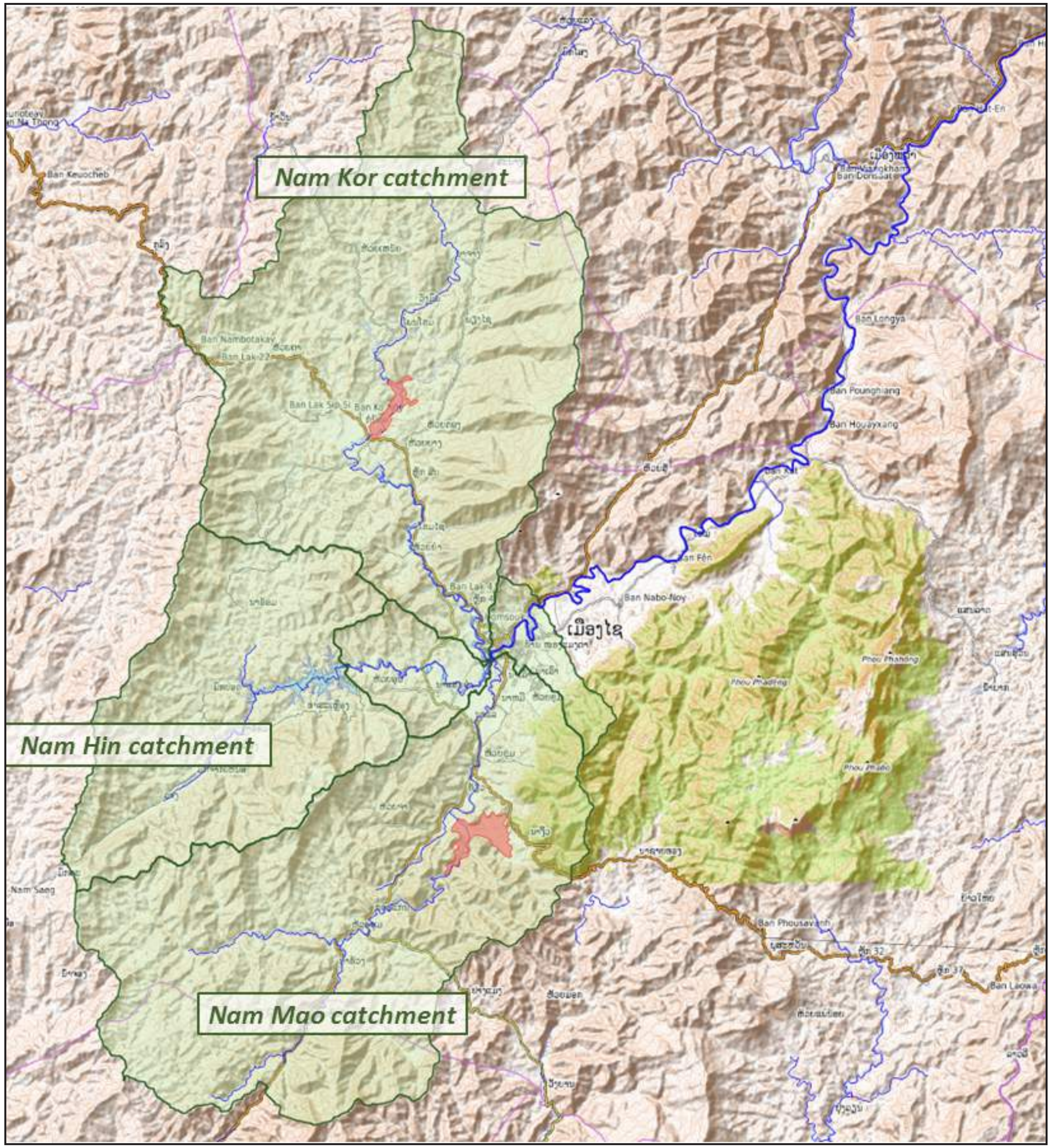


Figure 6.6 *Hypothetical catchment locations of potential new reservoirs in the Nam Kor and Nam Mao catchments. The reservoir in the Nam Hin catchment is an existing reservoir. (Source: Deltares, 2017)*

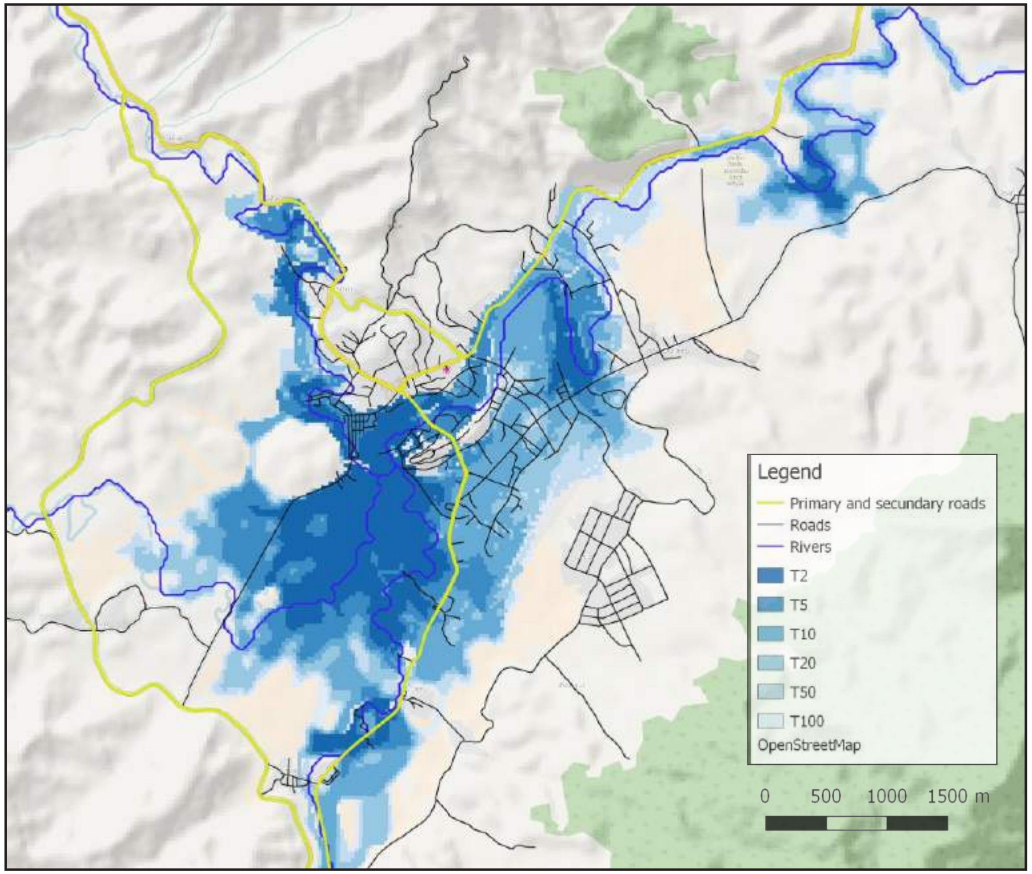


Fig. 6.7 *Simulated flood extent for the updated flood event of August 2008 (Source: Deltares, 2017)*

Upstream

Upstream of the city, interventions focus on reducing the discharge arriving at the city centre. In the Netherlands and in a number of other countries, a well-known water management principle is to 'retain, store, use, reuse, and only discharge when necessary'. Interventions should, therefore, be focused on water retention, water storage and peak shaving. In addition to the interventions already proposed earlier, the upstream analysis also includes the assessment of two additional reservoirs for retention and storage. Figure 6.6 shows a map with the hypothetical reservoirs that were assumed in the calculations.

Downstream

Downstream of the city, interventions focus on increasing the discharge leaving the city centre. In other words, river conveyance should be maximally improved. An option that specifically applies to Muang Xay is short-circuiting the impressive river meander in the Nam Kor. The measures considered for this case include river improvements and shortcut (short-circuiting the river meander).

Midstream

Along the river stretch in the city centre, in between upstream and downstream, there is little room for water, and the focus was on flood protection by creating levee banks or dikes to prevent the water from overtopping the river banks. Attention was paid to removing obstructions (e.g. bridges) from the river course.

Optimized results

Based on the field inspections, the hydraulic model was further improved. The dimensions of a number of structures were adjusted and the conveyance integration techniques were applied with more detail to the local side wall resistance at specific sections of the model schematization.

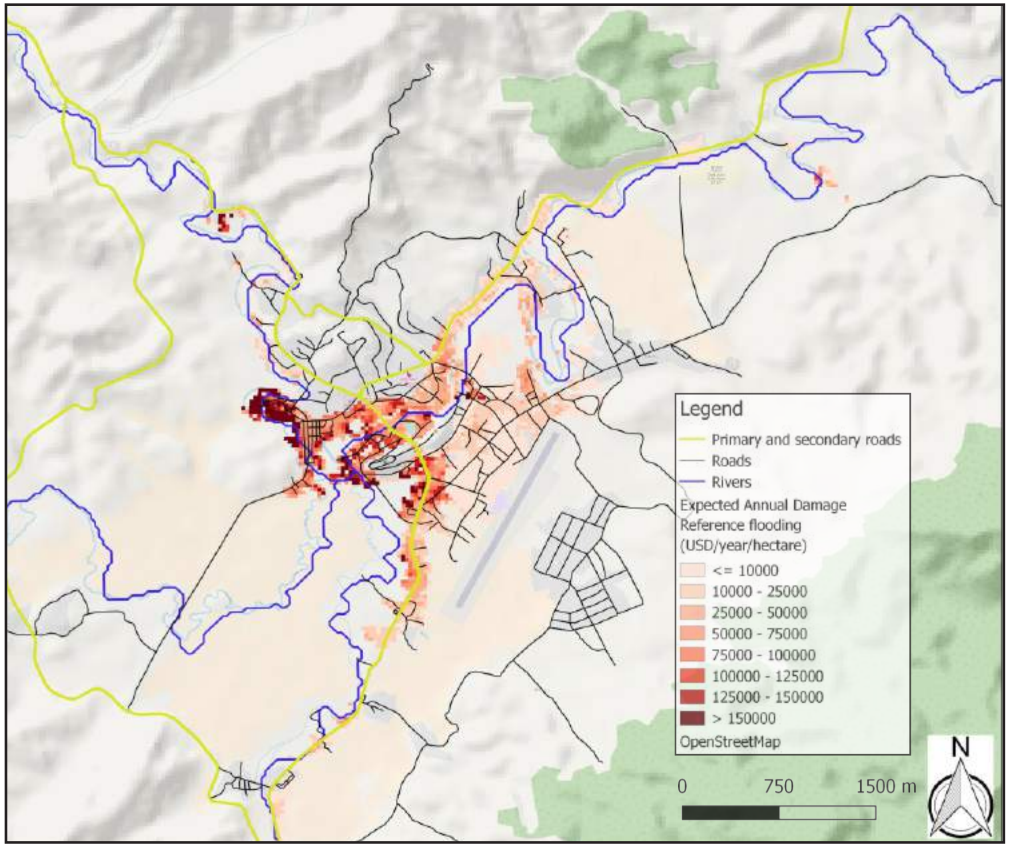


Fig. 6.8 *Expected Annual Damage (USD/year/ha) for the updated reference case. (Source: Deltares, 2017)*

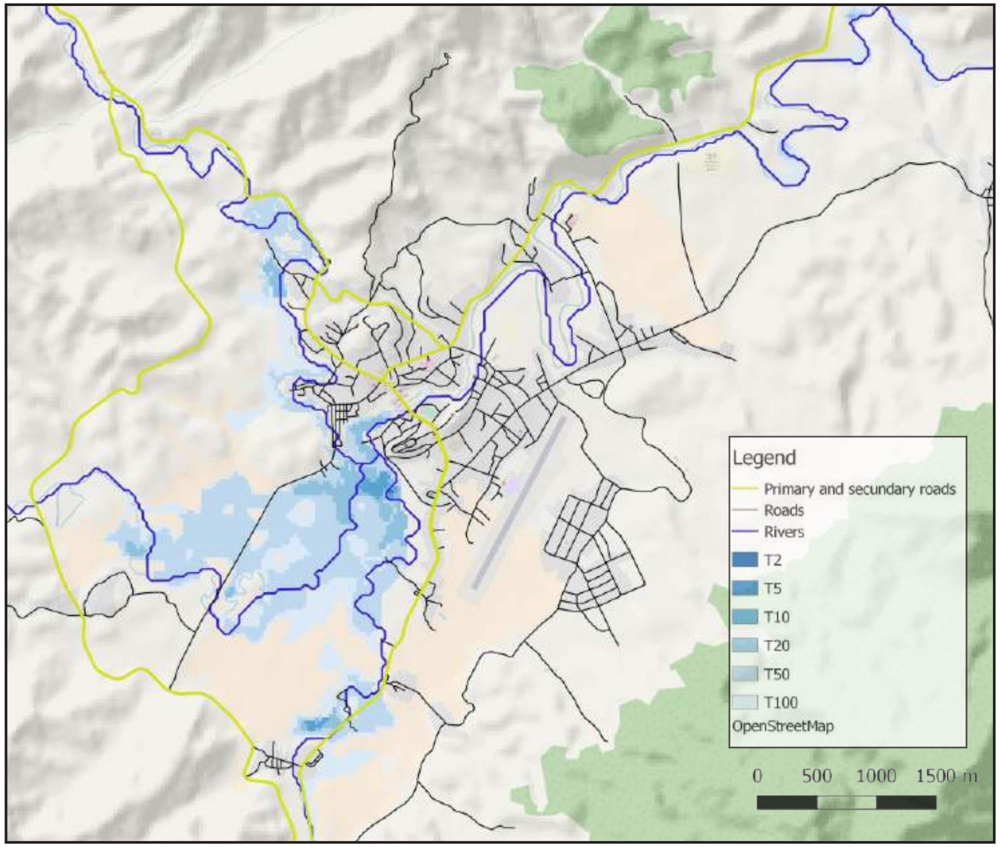


Fig. 6.9 *Simulated flood extent after implementing all four measures (river improvements, schorcut, dikes and reservoirs) compared to the reference case (flood event of August 2008) (Source: Deltares, 2017)*

These adjustments to the model schematizations resulted in an updated flood hazard map as presented in Figure 6.7. The simulated flood extent for a 20 year return period is approximately 9.2 km2. The maps for the various return periods were used as input for the damage model. The damage model then computes damages for a range of return periods. The resulting damages were subsequently translated to the expected annual damage as an indicator of flood risk. The EAD for Muang Xay after optimization of the hydraulic flood model is 10.9 M USD.

As in the previous section, the impact of all interventions has been assessed by comparing the flood extent and EAD after implementing each intervention with the reference case. These results are presented in detail in Report 2 of this study. The present section only summarizes the detailed analysis by showing the impacts on river flooding for the combination of all structural interventions.

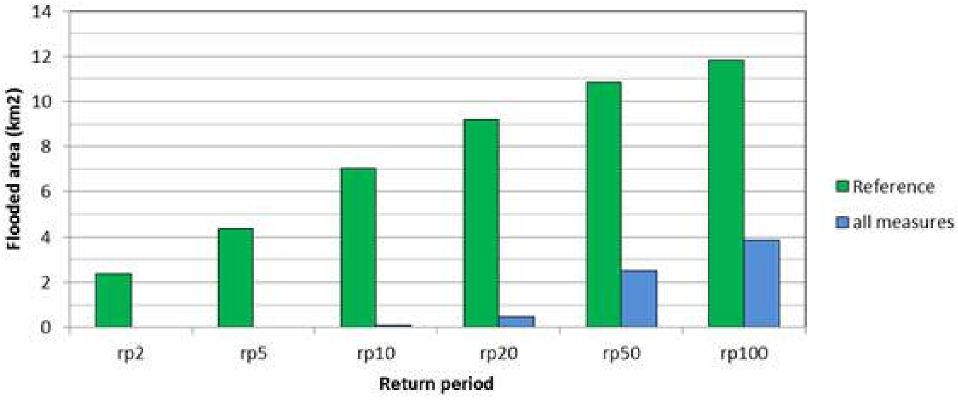


Fig. 6.10 *Expected reduction of flooded area after implementation of all four measures. (Source: Deltares, 2017)*

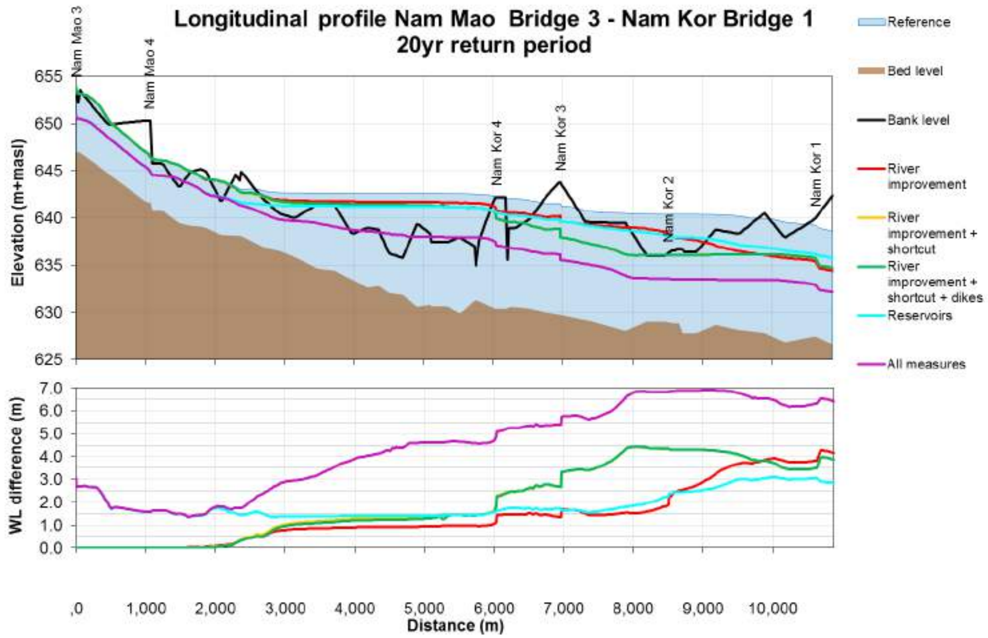


Fig. 6.11 *Longitudinal profile showing the decrease in water levels resulting from the implementation of all four measures for a 20-year return period. (Source: Deltares, 2017)*

The combined effect of all structural interventions implemented upstream, downstream and midstream of Muang Xay, shows a substantial reduction in flood extent for all return periods. The flood extent for a 2-year return time and for a 5-year return time is completely eliminated. For the 10-year and 20-year return period only a limited flood extent remains. For a 50-year and 100-year event the flood extent is limited to the rural area in the west of the city centre and does not bypass the river anymore (Figure 6.9). Figure 6.10 displays the reduction in the flooded area, ranging from a maximum of 100% for 2-year return period to 68% for 100-year return period.

The combined effect of the set of measures on water levels in a longitudinal profile from Nam Mao Bridge 3 to Nam Kor Bridge 1 shows a considerable reduction in water levels, ranging from 1.5 to 4 m upstream and from 5 to 7 m downstream near the city centre of Muang Xay (Figure 6.11).

Results show an enormous decrease in yearly expected damage. Almost 98% of the damage cost can be avoided if all the interventions are implemented. Additionally, a reduction of almost 100% on yearly affected population is achieved. It can be concluded

Conclusions

The updated designs of the flood mitigating measures and the subsequent updated flood damage and risk assessment show that with a combination of downstream, midstream and upstream measures flood risk can be substantially reduced in the urban area of Muang Xay.

The primary solution for reducing the flood risk is increasing the discharge capacity of the Nam Kor river downstream of the confluence of the three rivers. The discharge capacity of the Nam Kor river downstream of the confluence is currently limited as the flow has to squeeze through the narrow river profile at Muang Xay centre. At extreme flow conditions the combined inflow of the Nam Kor, Nam Hin and Nam Mao rivers exceeds this capacity and hence flooding occurs.

The most promising flood mitigation measures from the set of measures proposed earlier by the GoL were re-designed in order to create a 20-year return period protection level for the city centre of Muang Xay. To increase the discharge capacity, river improvements and the implementation of a meander shortcut were re-designed. Additional dike works were re-designed along certain stretches along the river to protect the urban area of Muang Xay. With implementing this set of measures, flood risk in the urban area of Muang Xay can be prevented and the total damage reduces with 77% compared to the reference case without interventions.

In this approach, following the reasoning by the GoL for one-sided flood protection dike works, the floodplain of the river valley (west of the city centre) essentially functions as a water retention area. A more detailed analysis could perhaps reduce uncontrolled flooding here in favour of more controlled water inlet and storage.

In addition to these measures, the potential effect of hypothetical upstream reservoirs in the Nam Kor and Nam Mao catchments were explored. Simulation results show that such reservoirs potentially have a large effect in reducing the flood hazard due to the effect of reducing the maximum peak discharges.

When all design options, including the hypothetical reservoirs, are combined into one intervention package, the model results show that the flood risk for Muang Xay almost completely reduces to zero. No flooding is simulated anymore in the urban area for return periods up to 100 years and for lower return periods (2-years and 5-years) flooding is completely eliminated. The total damage (EAD) is reduced by 99%.

It has to be stressed that the current conclusions are based on very little local and open data. Uncertainty is therefore substantial and should be reduced before a more detailed design is possible.

ENVIRONMENTAL AND SOCIAL ASSESSMENT OF POTENTIAL INFRASTRUCTURAL FLOOD MITIGATION MEASURES

A table with environmental and social rating criteria has been created for each of the potential structural solutions. Five environmental and three social criteria were developed based on a literature review of impacts from flood mitigation infrastructure as well as consultations in Muang Xay, the environmental and social screening exercise and the environmental risk assessment.

As part of the environmental and social assessment for this study, a screening exercise was conducted for the proposed investments using templates developed in the project Environmental and Social Management Framework (ESMF 2017). The exercise was conducted in September 2017 and involved site visits to reference sites for all of the proposed investments. A number of local and national government line agencies participated in the screening exercise including the DOW, the PONRE, the UDAA, the Department of Housing and Urban Planning (DHUP) and the Public Works and Transport Institute (PTI).

Each of the reference sites was assessed according to the five types of screening covered in the ESMF forms: initial screening, project safeguards screening, flood risk management infrastructure, ethnic groups, and land acquisition and resettlement.

Park 1

According to discussions with the World Bank on the 2nd October 2017, the current design for Park 1 would involve a significant conversion of non-critical habitats and would result in a narrowing of the existing Nam Mao river channel which could potentially exacerbate flood problems instead of providing flood mitigation. The World Bank, therefore, consider Park 1 as a Category A project in its current state which makes it ineligible for funding. It is suggested that alternative designs are considered that either mitigate flooding or are at the least, flood neutral during this study.

Park 2

The land beyond the riparian areas at the Park 2 site is already heavily developed and consists of a sports stadium with a ring road. The riparian areas are predominantly vegetated with grasses, weeds and some larger trees. There is also some evidence of annual cropping and perennials

6.1 Environmental and social rating criteria

Environmental criteria	Social criteria
Flow regime Sediment / channel structure Water quality Habitat / biodiversity / natural resources Construction impacts	Protection of individual assets Protection of community assets Protection of community assets

Source: Earth Systems 2017

such as bananas. The design of the site at Park 2 would involve a significant conversion of non-critical habitats along the Nam Kor River and potentially includes deepening and widening of the riverbed. The proposed river diversion would help to reduce flooding at the Park 2 site but may also have implications for flooding downstream. In addition, the diversion would effectively cut off approximately 2.5km of existing waterway which would greatly alter the landscape and have a significant impact on existing water resource use in the area.

The current design including the diversion may make the proposed investment a Category A project and this requires consideration at the detailed design stage.

Environmental assessment

Initial modelling indicates that the current park design will provide little flood mitigation. While deepening and widening of the river and the proposed river diversion may reduce localized flooding, it may also increase the likelihood of flooding downstream and this requires close investigation during the detailed design phase.

River improvement and riverbank protection

The river improvement works are likely to significantly alter the surface water hydrology of the waterways at the three sites while the river bank protection will involve removal of a significant amount of vegetation and potentially, the acquisition of some land within the river ROW that is currently occupied by villagers for residential or commercial purposes. The screening category for each of the proposed investments is highly dependent on final design but would be a Category B at the minimum due to the above-mentioned considerations.

Environmental assessment of flood risk management infrastructure

Both the river improvement and river bank protection works will result in a significant change in local surface water hydrology on the Nam Kor River. The river improvement works are expected to facilitate rapid removal of excess water from the inner urban area during heavy rainfall events but the downstream implications of the investment require further investigation.

Flap gates

DOW representatives were of the belief that any adverse impacts from the flap gates would be modest, confined to small areas, temporary (during high flow events) and easy to control. Under these circumstances, World Bank policies may not be triggered by the proposed investment but more investigation is required at the detailed design phase.

Environmental assessment of flood risk management infrastructure

According to DICT the proposed floodgates are not located in any areas of cultural significance. PONRE were unsure if there are any rare or endangered species of flora or fauna at proposed flap gates sites (or affected by changed stream flow due to flap gates) and this requires further investigation. Modelling showed that the flap gates are unlikely to provide effective flood mitigation.

Dikes / river levee banks

According to DOW, there are currently no final designs for this proposed investment and this limited the screening activity to largely a hypothetical assessment. Depending on the design of the embankments, a number of World Bank policies may or may not be triggered.

Environmental assessment of flood risk management infrastructure

Surface water hydrology will be expected to change due to increased channel velocities during elevated flow peaks in areas subject to embankment works and a large amount of vegetation will need to be removed from riparian areas along the 8km of embankments. The removal of riparian vegetation will impact on macroinvertebrate and possibly fish populations locally.

Environmental and social screening of other potential flood mitigation measures

Nam Kor shortcut

The river diversion (shortcut) has been proposed to remove a flooding bottleneck where the Nam Kor River meanders adjacent to the Park 2 site in order to increase water discharge during flood events. According to DOW, there are currently no final designs for this proposed investment and this limited the screening activity to largely a hypothetical assessment. It is likely that the development of the shortcut would trigger a number of World Bank policies including OP 4.01 Environmental Assessment, OP 4.04 Natural Habitats and OP 4.12 Involuntary Resettlement. OP 4.10 Indigenous People may or may not also be triggered.

Upstream reservoirs

Upstream reservoirs have been considered as a measure to reduce flooding in Muang Xay during flood events although design, operation and siting of the potential reservoir are conceptual at this stage. Initial modelling is based on the Nam Hin Reservoir which was constructed between 2001 and 2009 at a cost of approximately US$4.625M. It is likely that the development of the reservoir would trigger a number of World Bank policies including OP 4.01 Environmental Assessment and OP 4.04 Natural Habitats. OP 4.12 Involuntary Resettlement and OP 4.10 Indigenous People may also be triggered depending on siting of the reservoir.

Environmental assessment of flood risk management infrastructure

Storage of water in reservoirs alters water quality. Anaerobic processes often dominate due to lack of oxygen transfer in standing water. Stratification in the reservoir can create temperature changes within the water body and this needs to be considered in the release of water from the reservoir. The reservoir may impact migratory fish in the area by changing surface water hydrology and natural flow regimes. Reservoirs can also interrupt the natural flow of sediment and organic material which provides vital nutrients for downstream food webs.

ENVIRONMENTAL RISK ASSESSMENT ISSUES AND FINDINGS

In this section, only the change in environmental risk due to the operation of potential flood mitigation works is assessed. Several environmental issues have been identified as already having effects on the environment of Muang Xay, some of these may be exacerbated by flood protection works and will require careful management to prevent further issues. Key environmental issues for the installation of flood protection works and measures are described in Table 6.2.

The ISO31000 Risk Management and Assessment framework approach was adopted for the mitigation of the environmental impacts caused by the implementation of the infrastructural measures. A qualitative risk assessment approach was adopted based on the risk formula, risk = hazard x exposure. The assessment of key flood protection measures and impacts is undertaken using a pre and post mitigation framework to highlight the relative value of management measures to lower identified environmental threats and hazards. The results of the assessment of key risks to environmental and social aspects are presented in Table 6.3.

6.2 Flood protection measures and potential associated environmental issues

Flood Protection Measure	Environmental Issues
River Levee Banks, Dikes	Sedimentation and Bank erosion during construction Loss of riverbank amenity Noise and vibration during construction Increased flow velocity and riverbed scouring
Instream Dams and Weirs	Sedimentation during construction Fish passage and fish migration barriers Sediment deposition Reduction/increases in water temperature Reduced bedload sediment nutrient supply Eutrophication and oxygen sag Debris accumulation
Floodgates and Flaps	Prevention of fish passage Debris accumulation Localised flash flooding Poor urban drain water quality due to lack of dilution during flood periods
Flood parks	Sedimentation and Bank erosion during construction Noise and vibration during construction Odours from sediment, mud and debris after flooding Storage of flood water of poor water quality and evapo-concentration of flood water
River diversions	Sedimentation and Bank erosion during construction Loss of riverbank amenity Noise and vibration during construction Increased flow velocity and riverbed scouring
Nam Kor shortcut	Noise and vibration during construction Loss of habitats in the river meander Loss of riverbank amenity in the river meander Increased flow velocity and riverbed scouring
Upstream reservoirs	Sedimentation during construction Fish passage and fish migration barriers Sediment deposition Reduction/increases in water temperature Reduced bedload sediment nutrient supply Eutrophication and oxygen sag Debris accumulation

Source: Earth Systems 2017

6.3 Flood mitigation work environmental risk assessment

Environmental Threat	Expected Pre-mitigation Impact Significance	Key Management and Mitigation Measures	Residual Impacts and Significance
Sedimentation	MODERATE	Construction stormwater controls Riparian and forest land use controls Stormwater and sewage treatment Sediment design in flood parks	Reduced impact of habitat loss – LOW
Reduced water quality	LOW	Construction stormwater controls Riparian and forest land use controls Stormwater and sewage treatment Sediment design in flood parks	General water quality issues are at low risk of being impacted by flood works – LOW
Riverbank erosion and collapse	HIGH	Appropriate geotechnical and flood structural engineering Rip rap design and bank armouring Riparian zone management Planning controls to prevent building and non-compliant development on riverbanks Construction stormwater controls	All instream and bank structures subject to flood design assessment. This should largely prevent bank collapse – LOW
Riparian zone loss	MODERATE	Replacement of riparian vegetation where possible Retention of areas of habitat throughout flood work areas Use of riparian zones for flood abatement, velocity inhibition	Some riparian zone loss is inevitable but can be minimized, and preserved with planning – MODERATE
Aquatic habitat loss	HIGH	Replacement of aquatic habitat where possible Retention of natural pool/riffle design throughout flood work areas Retention of riparian vegetation Retention of woody debris in stream substrate	Aquatic habitat loss can be minimized, and prevented with good engineering design Locally – MODERATE, Overall – LOW
Loss of fish passage	MODERATE	Replacement of aquatic habitat where possible Retention of natural pool/riffle design throughout flood work areas Engineering design of fish passage structures in high-velocity areas or hydraulic barriers. Creation of short "swim distances" between preserved habitat areas	Fish passage can be maintained with good engineering design – LOW
Loss of river and riparian amenity	HIGH	Sensitive multipurpose/use river bank and hydraulic design Incorporation of flood structures in riverine architecture and community planning Strategic location of flood protection infrastructure	River amenity value loss can be minimized, and prevented with good engineering design – MODERATE
Water quality impacts of in-stream structures	HIGH	Design of instream and off stream storages to minimise oxygen and temperature effects Mixing zone modelling to ensure water quality is maintained Design of drainage to prevent build-up of sediment or low oxygen water Management of construction phase stormwater Sedimentation design in flood parks	Water quality fluctuations can be minimized with good engineering design and stormwater management – MODERATE
Dust, Noise and Vibration impacts	HIGH	Construction sites are kept wet for dust suppression Hours of operation used to prevent noise problems Construction vehicles and systems selected for noise sensitive areas Traffic management	After noise and dust controls are enacted during construction –LOW

Source: Earth Systems 2017

07 POTENTIAL FLOOD MITIGATION INVESTMENTS

The outputs of proposed structural flood mitigation investments and non-structural measures for flood risk management combined with the preferences expressed by stakeholders during the workshop series provided the basis for the development of a benefit-costs analysis (BCA). Flood risk modelling and the damage assessment considered both the original and variations of the set of structural measures proposed by the GoL. Non-structural flood risk management measures include opportunities for urban planning, community managed early warning systems and DRM. The environmental and social assessment and stakeholder values identified during consultations were also considered in the analysis.

The BCA includes an assessment of direct benefits and losses in relation to the potential investments over a return period of 2 years through 100-year return periods. An optimism bias (OB) of 60% and 30% have been incorporated to account for the uncertainties typically associated with projects in early stages of development. Discount rates of 12% and 6% have been applied over a 20 year time period. The analysis estimated benefit-cost ratios, net present value and internal rates of return for nine Investment options classified as budget constrained and non-budget constrained.

This section summarizes the BCA and a multi-criteria analysis (MCA) of nine different short, medium and long term investment packages that were developed for the consideration of decision makers. The nine investment packages are detailed below:

Package 1 (short term / budget constrained): River bank protection / extended river improvement works only. Community preference - low.

Package 2 (short term / budget constrained): The original GOL proposal (River bank protection / river improvement works, dikes / levees and River park 2). Community preference - medium.

Package 3 (short term / budget exceeded by US$1M): River bank protection / extended river improvement plus the Nam Kor shortcut. Community preference - medium.

Package 4 (short term / budget exceeded by US$1M): The original GOL proposal (River bank protection / river improvement works, dikes / levees and River Park 2) plus the Nam Kor shortcut. Community preference - high.

Package 5 (short term / budget exceeded by US$0.8M): River bank protection / extended river improvement plus River park 2. community preference - medium.

Package 6 (medium term / budget exceeded by US$1.8M): River bank protection / extended river improvement plus River park 2 plus the Nam Kor shortcut. Community preference - high.

Package 7 (medium term / budget exceeded by US$1.8M): River bank protection / extended river improvement plus dikes / levees plus River park 2 plus the Nam Kor shortcut. Community preference - high.

Package 8: (long term / under budget by US$3M) Reservoirs only. Community preference - medium.

Based on two reservoirs similar to the Nam Hin Reservoir, which was constructed at a cost of ~US$4.5M.

Package 9: (long term / budget exceeded bu US$13M) Flood prioritization (T20 damage=0) + all options. Community preference – high.

BENEFIT-COST ANALYSIS

The benefit-costs analysis conducted as part of the Oudomxay flood management project addressed the objectives of IFRM: that is to minimize loss of life, livelihoods and assets from flooding while maximizing the net productive benefits derived from floodplains. The combinations of investment and non-structural initiatives were formulated from modelled flood reduction investments proposed by the Government of Lao PDR and community needs and responsibilities derived from a series of facilitated participatory based processes.

Muang Xay flood management decisions will be partially focused on how to allocate the cost of taking risk placed on society, assigned amongst governments (central, regional and local governments), and affected interests (such as private companies), communities and individuals. The benefit-cost analysis is primarily aimed at flood managers and decision makers, including key community groups, involved in formulating flood management strategies and policies. The results are intended to provide rapid access to information that compares risk-sharing mechanisms and allocations as part of the overall Muang Xay flood management strategy.

7.1 Cost summary of proposed structural and non-structural investments for flood management

	Investments	Unit	Length	Cost US$
Structural investments	River Bank Protection	m	7,834	6,658,900
	Levees/dikes	m	9,279	4,175,550
	Flap gates	No	26	208,000
	River Improvement	m	2,000	300,000
	Riverside Park	No.		800,000
Non-structural investments	Zoning, planning, building codes			1,000,000
	Project management			1,000,000
			Total cost	**14,142,450**

Source: Lao PDR Ministry of Public Works and Transport and Department of Water (2017)

The relative costs of implementing structural and non-structural measures evaluated in Chapter 4 and 5 are summarized in Table 7 1. These costs are used as a base for the development of the benefit-cost analysis.

The initial damage calculation for Muang Xay estimates the number of houses in 6,360 households located in 22 villages within the Muang Xay precincts and mean household size of Muang Xay of 5.52 members. The damage calculation for return periods 2, 5, 10, 20, 50 and 100 years used to calculate the EAD of the flood event in August 2017 are summarized in Table 7 2. These values represent the initial set of reference damage costs used for further BCA analysis.

The cumulative damage reductions for the set of flood interventions, including the Nam Kor shortcut across return periods were imputed into the first iteration of the BCA calculations and detailed in Table 7 3. Note that the estimated reductions exceed the 40% reduction in flood-affected population set out as a primary objective of the project.

Optimism bias is the tendency for appraisers and decision makers to be overly optimistic in early assessments of project costs, time scales and benefits in comparison to the actual effectiveness of flood reduction and the associated values. An optimism bias of 60% is typically used for projects at an early stage of consideration (see for example UK Environmental Agency 2017) . At the more detailed project stage, a figure of 30% is more commonly used. The BCA of flood investment options for Muang Xay applies a sensitivity analysis approach by modifying the optimism bias coefficient (ranging from 30-60%) to estimate potential losses and damages in addition to the direct costs that occur due to flooding.

The value of the discount rate influences the relative costs and benefits related to flood management strategies through time. The discount rate represents the cost to those affected by floods (and their expected level of reward) of abstinence from present-day consumption, by postponing flood mitigation to some future date. The World

7.2 Expected annual damage across six return periods (baseline: flood of August 2008)

Return period (y)	Damage (USD, M)[1]	Population affected (no.)	Utilities and services electricity supply, education (USD, M) [2]	PWT: roads and bridges (USD, M) [2]	Agriculture (USD, M) [2]
2	5.7	2,200	0.15[a]	0.75[a]	0.40[a]
5	15.8	6,300	0.20[a]	1.00[a]	0.50[a]
10	31.2	11,800	0.259[b]	1.50[b]	0.61[b]
20	49.7	13,600	0.28[b]	2.4[b]	1.15[b]
50	68.6	14,800	0.35[a]	4.5[a]	3.0[a]
100	79.2	15,200	0.70[a]	7.0[a]	5.0[a]
Yearly expected (EAD)	10.9	3,500	0.97	0.43	

Source: [1] Task 2 report. [2] Government of Lao PDR (RT10=2013, RT20=2017), [a]: linear interpolation estimates only; [b] Govt of Lao PDR

7.3 Estimated reduction in damage and population ,and schools affected after implementation of all proposed structural measures including shortcut

Return period (y)	Reduction in Damage (%)	Reduction in Population affected (%)	Reduction in Schools affected (no.)
2	96.2%	95.5%	0
5	90.0%	90.5%	2
10	85.8%	89.0%	8
20	86.1%	89.0%	18
50	44.8%	19.4%	20
100	29.7%	9.0%	21
Yearly expected (EAD)	76.6%	80.3%	2

Source Report 2 (section 6)

** Values represent the reduction in damages after implementation of all proposed structural measures including the shortcut of the Nam Kor river.*

Bank NPV estimates of the proposal were based on a discount rate of 12 percent, as per World Bank guidance where discount rate is calculated as twice the national growth rate.

For comparative purposes, the Muang Xay BCA analysis adopted a conventional approach of selecting sensitivity bounds that attempt to reflect alternate versions of the discount rate appropriate to the investment context. A 12% (as per World Bank) and 6% discount rate were applied over the 20 year time period.

RESULTS

The first step in the development of alternative investment packages was the development of four investment scenarios based on the original GoL proposal (refer to Table 7-1) and community preferences identified during consultations and participatory workshops. The four investment scenarios are as follows:

Lao PDR Scenario 1: estimates the NPV and BCR of flood damage reduction for structural investments only: River bank protection, levee/dike construction, river improvements and the Riverside park. The zoning and planning was assumed to have zero effect on flood reduction damages.

Lao PDR Scenario 2: estimates the NPV and BCR of the structural investments of Scenario 1 plus reductions associated with non-structural investments (that is urban planning, flood zoning and enforcement). Non-structural investments were assumed to result in a further 10% reduction in flood damage.

Lao PDR Scenario 3: estimates the NPV and BCR of the structural investments of Scenario 2. The budget line originally assigned to flap gates was reassigned to developing a community based early warning system (focussed on improved response times to reduce the costs of damaged good, chattels and contents).

Lao PDR Scenario 4: estimates the NPV and BCR of the structural investments of Scenario 3 plus the additional tourism and economic benefits derived from the River park. Tourism benefits were entered as negative costs and conservatively estimated as an annual return of River park = $16,000 (20% return p/a based on WB estimates) + a 2.7 multiplier (indirect and induced effects: WTTO 2015); with growth estimated at 5.7% pa.

The estimates of present value, net present value and benefit-cost ratios at a discount rate of 6% and 12% (r) and optimism bias (OB) of 30% and 60% for the 4 scenarios are summarized in Table 7 4. It can be observed that the value of a 60% optimism bias increases the estimated cost by US$7.81M. The objective of project management then is to minimize the cost inflation imposed to address predicted cost increases and ideally reduce the additional costs to zero. The optimism bias is generally reduced to 30% when design details have been finalized and fully costed.

7.4 Summary of investments options r=6% and 12%, OB=30% and 60%

	Baseline	**Lao PDR scenario 1: structural**	**Lao PDR scenario 2 + zoning and planning (a)**	**Lao PDR scenario 3 + early warning**	**Lao PDR scenario 4 + tourism [a]**
BC metric	Discount rate 12%, OP 60% (US$ m)				
PV damages	122	80.42	73.50	66.59	66.59
Avoided losses		41.69	48.61	55.52	55.52
NPV		22.4	29.3	36.2	38.1
BC ratio		2.16	2.52	2.88	3.19
IRR (NPV =0)		48%	58%	70%	82%
	Discount rate 12%, OP 30% (US$ m)				
PV damages	122	80.42	73.50	66.59	66.59
Avoided losses		41.69	48.61	55.52	55.52
NPV		26.0	32.9	39.8	41.5
BC ratio		2.66	3.10	3.54	3.95
IRR (NPV =0)		82%	120%	148%	168%
	Discount rate 6%, OP 60% (US$ m)				
PV damages	211	153.71	140.47	127.27	127.27
Avoided losses		56.82	70.06	83.26	83.26
NPV		36.2	49.5	62.7	65.0
BC ratio		2.76	3.40	4.04	4.56
IRR (NPV =0)		48%	58%	70%	82%
	Discount rate 6%, OP 30% (US$ m)				
PV damages	211	153.71	140.47	127.27	127.27
Avoided losses		56.82	70.06	83.26	83.26
NPV		40.1	53.3	66.5	68.6
BC ratio		3.40	4.19	4.98	5.67
IRR (NPV =0)		82%	120%	148%	168%

Source: Earth Systems 2017

Return period (y)	Damage reduction	Damage reduction (with Nam Kor shortcut)	Damage reduction Reservoirs	Damage reduction Reservoirs all options
2	91.4%	94.6%	97%	100.0%
5	79.7%	86.4%	95%	100.0%
10	65.6%	74.4%	91%	100.0%
20	56.3%	65.9%	79%	100.0%
50	31.2%	44.5%	53%	96.5%
100	19.5%	28.7%	35%	92.9%

The net present value and BC ratios are positive for all the investment scenarios across all discount rate and optimism bias options. The accounting for additional tourism benefits (entered as negative costs) assigned to the River parks has the highest BC ratio. Internal rates of return range from 46%-168% across the investment scenarios and sensitivity analyses.

ALTERNATIVE FLOOD DEFENCES

A revised set of investment options was modelled including extending the river bank improvements and river dredging to 12 kms compared to the original 7.83 kms and the construction of upstream reservoirs. The total cost (applying the original per metre rates) of the extension equals US$12M or the total of the proposed budget. The NPV and BC ratio was calculated using damage reduction values for the extended river improvements (with and without) the Nam Kor shortcut, the reservoirs only and the full set of flood management investments as modelled in this study (see Report 2).

At a discount rate of 12%, OB of 60% and assuming the 10% additional flood damage reduction of the planning investment, the NPV and BC ratio for the river extension only package was estimated at US$ 54.6M and 3.72 respectively. The river extension only package meets the budget constraint of US$11.9M. The original Lao PDR Government proposal is associated with an NPV and BC ratio of $38.1M and 3.19 respectively. Both options assume the non-structural and community early warning system reduce flood damage by 10% each, representing the recommended combination of budget constrained structural and non-structural flood management interventions.

The NPV and the BC ratio of the extended river improvement were estimated at US$51.8M and 3.71 by adding the River park and attendant benefits estimated for tourism (increasing investment expenditure by US$ 0.8M). Including the Nam Kor shortcut (increasing investment expenditure by US$ 1.0M) increases the NPV to 60.6 and the BC ratio to 3.79. Including both the Nam Kor shortcut and the River park increases the investment expenditure by $1.8M and decreases the NPV to 59.7 and the BC ratio to 3.64.

The trade-off for the higher NPV and BC ratio of the extended river improvement only compared to the original Government proposal is the omission of the River park in the investment portfolio and associated tourist and cultural benefits. The cost of the Nam Kor shortcut was estimated at US1.0M compared to the $US0.8M estimate for the River park. Substituting the Nam Kor shortcut with the River park achieves the requirements of the community but reduces the NPV by US$13.5M and the BC ratio 3.72 or a reduction of 17%.

A final investment option introduced an upstream reservoir option and the full set of investments. The option calculates the NPV and BC ratios for the combined flood damage reduction of river extension, dikes, the Nam Kor shortcut, River park and upstream reservoirs. The option represents a flood risk approaching zero for a 20 year return time. Reservoir costs were estimated at US$9M based on the construction costs of the recently completed Nam Hin dam in Muang Xay. Importantly, the costs are approximations only as the final site has not been determined and the final costs are likely to vary. The option represents the ideal flood risk management option where the budget is not constrained.

At a discount rate of 12%, OB of 60% and assuming the 10% additional flood damage reduction of the planning investment, the NPV and BC ratio of the reservoirs only were calculated at US$ 63.6 and 3.5 respectively.

The reservoirs only option (approximate cost only of US$9M) is associated with an NPV of US$63.6M and a BC ratio of 3.5. Including the extended river improvement and dikes / levees (increasing the investment expenditure by US$13M) revises the NPV and BC ratio to US$58.9 and 2.16. The additional tourism benefits of the River Park increase costs by a further US$0.8M and the NPV and BC ratio were calculated at US$ 58.3 and 2.14 respectively.

MULTI-CRITERIA ANALYSIS PACKAGES

The nine investment packages were subjected to a multi-criteria analysis which included benefit cost (BC) ratio, expected annual damage (EAD) reduction, budget exceedance, alignment with community preferences, and environmental and social ratings (Table 7 5). For BC ratio and EAD reduction the highest ranking package was given a score of nine and all other packages were given as score out of nine expressed as a percentage of the highest score. Budget exceedance was also scored out of nine with the lowest cost package scoring a nine, highest cost scoring a one and other packages scaled in between. High community preference (high community amenity and high flood reduction) scored a value of 9, medium preference scored 6 (either high flood reduction or high community amenity) and low community preference (low community amenity and low flood reduction) scored 3. Environmental and social ratings for the respective investment packages were averaged out of 8 based on ratings from Report 3 (Chapter 5).

Across all investment combinations, Package 8: Reservoirs only, has the highest composite score and is therefore ranked highest across the five dimensions of flood risk reduction, largely due to the high BCA and being $3M under budget. Note the reservoirs only package is associated with the highest level of uncertainty, offers minimal short-term flood reductions, and potential sites have not been evaluated. Package 6 (Extended river protection / improvement + Park 2 + Nam Kor shortcut) is the next highest ranked package although it exceeds the current budget by almost US$2M. Package 3 (extended river protection / improvement + Nam Kor shortcut), Package 4 (GOL proposal + Nam Kor shortcut) and Package 5 (extended river protection / improvement + river park) were equally ranked the next highest. Package 9 (all options combined) is the lowest ranked of the nine investment packages, mainly due to the magnitude of budget exceedance.

Across all investment combinations, Package 8: Reservoirs only, has the highest composite score and is therefore ranked highest across the five dimensions of flood risk reduction, largely due to the high BCA and being $3M under budget. Note the reservoirs only package is associated with the highest level of uncertainty, offers minimal short-term flood reductions, and potential sites have not been evaluated. Package 6 (Extended river protection / improvement + Park 2 + Nam Kor shortcut) is the next highest ranked package although it exceeds the current budget by almost US$2M. Package 3 (extended river protection / improvement + Nam Kor shortcut), Package 4

7.5 Multi-criteria analysis of packages

Investment packages	BC ratio	EAD reduction	Budget exceedance	Community preference	Environmental and social*	Total score
Package 1 Budget constrained: Extended river protection / improvement only. Community preference - low.	7 (3.72)	6 (61%)	7	3	6	29
Package 2 Budget constrained original GOL proposal. Community preference -medium	6 (3.19)	4 (41%)	7	6	5	28
Package 3 Extended river protection / improvement + Nam Kor shortcut. Community preference - medium. Budget exceeded by US$1M	6 (2.99)	6 (69.2%)	6	6	6	30
Package 4 Original GOL proposal plus Nam Kor shortcut. Community preference - high. Budget exceeded by US$1M	6 (2.99)	4 (48.6%)	6	9	5	30
Package 5 Extended river protection / improvement + River park. Community preference - medium. Budget exceeded by US$0.8M	7 (3.71)	6 (61%)	6	6	5	30
Package 6 Extended river protection / improvement + River park + Nam Kor shortcut. Community preference - high. Budget exceeded by US$1.8M	8 (3.79)	6 (69.2%)	4	9	5	32
Package 7 Extended river protection / improvement + dikes + park + Nam Kor shortcut. Community preference - high. Budget exceeded by US$5M	6 (3.15)	7 (76.6%)	2	9	5	29
Package 8 Reservoirs only. Community preference - medium. Environmental impacts unknown. Under budget by approximately US$3M*	9 (4.53)	7 (79.4%)	9	6	5	36
Package 9 Flood prioritization (T20 damage=0) + all options. Community preference – high. Environmental impacts unknown. Budget exceeded by approximately US$13M	4 (2.14)	9 (98.7%)	1	9	5	28

* Where multiple structural solutions are employed, environmental and social ratings are averaged.

** Based on two reservoirs similar to the Nam Hin Reservoir which was constructed at a cost of ~US$4.5M.

(GOL proposal + Nam Kor shortcut) and Package 5 (extended river protection / improvement + river park) were equally ranked the next highest. Package 9 (all options combined) is the lowest ranked of the nine investment packages, mainly due to the magnitude of budget exceedance.

DISCUSION OF SHORT, MEDIUM AND LONG-TERM PACKAGE RECOMMENDATIONS

An important aspect of this study has been the need to involve the local community in the development of a structural investment package that provides effective flood mitigation as well as aligning with community aspirations. This needs to be factored into recommendations for short, medium and long-term investment options for Muang Xay.

Short term (this project) recommendation: Package 4 with prioritization of river improvement / river bank protection and dike works to work within the project budget.

In terms of the short-term investment packages, Package 3 (extended river protection / improvement + Nam Kor shortcut), Package 4 (GOL proposal + Nam Kor shortcut) and Package 5 (extended river protection / improvement + river park) were ranked equal highest ranking in the multi-criteria analysis. Package 4 had the highest community preference and is therefore the recommended short-term package although Package 5 is the best short-term investment package based purely on flood mitigation potential. Both packages exceed the current budget by approximately US$1M but there is scope for partial implementation of both packages in order to work within the project budget without significantly reducing EAD. For example, river bank protection works have been costed based on use of rip rap in riparian areas. Low cost alternatives such as vegetative solutions (i.e. vetiver grass) could be used as a more attractive and cheaper alternative. Also, the length of river improvement / river bank protection works could be shortened by prioritising locations to optimise effectiveness of the investment during the detailed design phase. Similarly, dike works can be potentially optimised by prioritising embankments in certain areas based on modelling conducted (refer to Report 2).

Medium term recommendation: Implementation of extended river improvement works.

If Package 4 (GOL proposal + Nam Kor shortcut) is implemented during this project then a logical medium term solution would be to extend the river improvement works. Based on initial estimates, the extended river improvement works would cost approximately an extra US$4M and in combination with Package 4, could provide approximately 76.6% reduction in annual EAD compared to the base case (refer to Package 7).

Long term recommendation: Development of flood reduction reservoirs.

The viability of additional upstream reservoirs will be investigated during the detailed design phase of the project. Initial modelling indicates that the addition of two reservoirs similar in size to the Nam Hin Reservoir in combination with the recommended short and medium-term investments, could provide up to 98.7% annual reduction in EAD. Based on construction costs for the Nam Hin Reservoir, the cost of two additional reservoirs would be approximately US$9M.

08 CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Flood risk was assessed for the city of Muang Xay in Oudomxay Province, Lao PDR. In addition, the reduction of flood risk was evaluated for a number of infrastructural design options.

Assessing flood risk

A hydrological and hydraulic simulation model was constructed based on the available data of the region. The limited availability of data posed considerable limitations on the modelling of flood risk. In general, there is a lack of data on hourly rainfall, multiple rainfall stations, stage discharge relations, and specifics on the reservoir and reservoir operation.

River flooding appeared to be the dominant process in the events in 2008, 2013 and 2017. The analysis shows that the primary solution for reducing the flood risk is to increase the discharge capacity of the Nam Kor river downstream of the confluence of the three rivers Nam Kor, Nam Hin and Nam Mao. The discharge capacity of the Nam Kor river downstream of the confluence is limited as the flow has to squeeze through the narrow river profile in Muang Xay centre. At extreme flow conditions the combined inflow of the Nam Kor, Nam Hin and Nam Mao rivers exceed this capacity and hence flooding occurs.

The expected annual damage (EAD) calculated for the current situation without any interventions in place (the reference case) amounts to ~11 million USD per year over the enitre area. The EAD is highest in the western part of the town near the convolution of the three rivers, with values of over 150,000 USD/year/ha in the area with population densities of over 15,000 people/km2. EAD values for the eastern part of town are generally lower than 100,000 USD/year/ha.

Impact of interventions proposed by the Government of Lao PDR

We analysed the impact of all infrastructural interventions as proposed by the Government of Lao PDR (GoL). An important conclusion was that some measures are very effective (river improvements, dikes, meander shortcut) while others are not so effective (river parks, flap gates) in reducing flood risk at the spatial scale of the river catchment in which Muang Xay is situated. The computations show that a significant flood risk reduction can be achieved with the implementation of the package of interventions as proposed by the GoL. The computations show a reduction of expected annual damage and the number of people that is affected by the flood risk of

~50% when all proposed interventions are combined.

Further optimization of design options

In order to further reduce flood risk, the design of the most promising infrastructural interventions was further optimized and flood risk recalculated. Instead of assessing the impact of each measure on all return times, the design of the interventions was optimized to create a 20-year return period (T=20) protection level for the city centre of Muang Xay. A T=20 protection level approximately coincides with a discharge that can be maximally accommodated through the urban river profile without radically widening the river bed into the urban fabric, i.e., without considerably removing housing and infrastructure.

The updated designs of the flood mitigating interventions and the subsequent updated flood damage and risk assessment show that flood risk can be substantially further reduced in the urban area of Muang Xay. When implementing a combination of river improvements, a meander shortcut and dike works, a T=20 flood in the urban area of Muang Xay can be prevented and the total damage (EAD) reduces with ~8.3 M USD (~77%) per year. In this approach, following the reasoning by the GoL for one-sided flood protection dike works, the flood plain of the river valley (west of the city centre) essentially functions as a water retention area. More detailed analysis could perhaps reduce uncontrolled flooding here in favour of more controlled water inlet and storage.

In addition to these measures, the potential effect of hypothetical reservoirs in the Nam Kor and Nam Mao catchments were explored. Simulation results show that reservoirs potentially have a large effect in reducing the flood hazard due to the decrease in maximum peak discharges.

When all design options, including the reservoirs, are combined into one intervention package, the model results show that the flood risk for Muang Xay almost completely reduces to zero. No flooding is simulated anymore in the urban area for return periods up to 100 years and for lower return periods (T2 and T5) flooding is completely eliminated. The total damage (EAD) is reduced with 99%.

It has to be stressed, however, that the current conclusions are based on very limited local and open data. Uncertainty is therefore substantial and should be reduced before more detailed design is possible.

RECOMMENDATIONS

Further detailing of design options

In the preparation of the detailed design phase we recommend to further elaborate and detail the design options that were considered in the present study. River improvement, shortcutting of the Nam Kor meander and dike works are the logical first step to prepare for the detailed design phase.

A first exploration of implementing upstream reservoirs for water storage in the Nam Kor and Nam Mao rivers proved to be very promising. Even though the present analysis was very preliminary, we recommend to further investigate the feasibility of realizing reservoirs in the preparation of the detailed design phase.

After detailing the priority interventions at the catchment scale, we recommend to zoom in on:

1. The city centre, to complement river flood protection with localized options on flap gates, river parks, urban drainage and greening of the river banks.
2. The rural area west of the city centre, to increase flood protection for lower return times in combination with controlled retention for higher return times. The single

sided dike on the east side of the river that protects the city centre could be complemented with a lower dike on the west side to protect the rural area with rice paddy fields for the lowest return times without losing the storage capacity for higher return times.

3. The interference of the proposed flood intervention design with the construction of the future railway line west of the city. It is thinkable to design the railway in such a way that it may be neutral to flood risk or even be part of the flood protection design and contribute to reducing the risk.

We recommend to continue the dialogue on flood protection levels as was done in the workshops of the present study. After having explored all flood protection options, choosing flood protection levels for different zones within and outside the city (i.e. zonation) is a policy decision and essentially a political choice.

Data collection and monitoring

We encountered a lack of data on hourly rainfall, multiple rainfall stations, stage discharge relations, and specifics on the reservoir and reservoir operation. Although it is realized how difficult, time consuming and costly it is to acquire these data, we do recommend to install monitoring programs to start with building a database record of these data sets that will greatly contribute to future hydrological studies.

Future hydraulic modelling

The current model set-up can be extended with global rainfall forecast products or regional/local rainfall forecasts to move towards a flood forecasting system for the Muang Xay area. When the information of the urban micro drainage system is made available, this can be added to the existing flood modelling framework. The August 2017 flood event could be used for model validation as soon as more information becomes available, such as (hourly) rainfall data, water levels, discharge, flood extent, flood depth, and damage.

Damage modelling

The current damage assessment is based on limited data and on several assumptions. It is therefore recommended to collect more detailed exposure data, more detailed damage categories and better estimates of the potential damage. It is also recommended to formulate local vulnerability functions based on empirical data, experience of the local community and/or observed flood damage. In addition to improving the calculation of direct damage it is recommended to identify and assess indirect damage as well.

Short, medium and long-term structural investments packages

It is recommended that Package 4 (GOL proposal + Nam Kor shortcut) is developed within this project which could reduce annual EAD by up to 50% based on initial modelling (refer to Report 2). River improvement / river bank protection and dike works within the package will need to be optimised in order to reduce costs as the package is currently US$1M over budget.

In the medium term, extended river improvement works could further reduce annual EAD to approximately 75% compared to the base case at an additional cost of approximately US$4M.

Over the longer term, the further addition of two reservoirs (at a cost of approximately US$9M) could almost eliminate flooding in Muang Xay for a 1 in 100 year event.

09 GUIDELINES FOR AN INTEGRATED URBAN DISASTER RISK PLAN

The implementation of structural and non-structural measures in Muang Xay is necessary to prevent further losses of life and assets in the city. Therefore, a set of guidelines were developed to assist with the development of an integrated urban disaster risk plan for the city:

REGULATORY STRENGTHENING

Strong support for government urban planning and DRM agencies is critical to the success of plan development. Strategies for regulatory strengthening within the project include but are not limited to:

- Development of urban design standards to support implementation of the Urban Planning and DRR Manual;
- Integrate DRM and environmental protection into land use regulations, building codes and housing standards;
- Employment of a three-step planning package in future urban plan development (structure plan, urban area plan and detailed / action area plan). The package needs to be flexible and allow for periodic review, classified land use zoning options and risk-sensitive land use planning options. The package also needs to integrate mechanisms for public participation into the planning process to ensure that planning reflects public expectations and planning solutions account for local needs;
- Development of a specific sub-plan for protection of critical infrastructure in flood-prone areas of the city;
- Development of a detailed urban risk assessment guideline; and
- Development of new zoning areas to support the integrity of the plan including survey and delineation of riparian buffer areas and enforcement of no development zones

CAPACITY BUILDING

Planning institutions including PTRI and DHUP have identified the need for capacity building in several areas to support plan development and project implementation. Training activities will also be relevant to other GoL authorities, particularly from the designated implementing agencies. Proposed activities include:

- Conduct of GIS training to support urban planning incorporating elements such as risk assessment and database management;
- Training on resilient infrastructure design and construction; and

- Development of tailored general training packages to support plan development and project implementation. Modules could include flood modelling, water sensitive urban design, urban drainage design and maintenance, gender mainstreaming, and resettlement action planning.

ACTIONS TO SUPPORT FLOOD RESILIENCE IN MUANG XAY

Actions to support flood resilience identified in the project included the adoption of blue-green measures and activities to promote community resilience.

Blue-green measures for flood resilicience in Muang Xay

- Support DOW to identify and implement moderate cost, locally appropriate retrofitted flood mitigation and drainage control measures to existing infrastructure in waterways around the city;
- Support villages to take ownership of riparian areas and establish dual purpose 'green zones' (flood mitigation, visual amenity, production of raw materials etc.) by incorporating 'low cost', effective vegetative solutions such as vetiver grass.

Promoting community resilience in Muang Xay

- Establishment of village level disaster committees (VDPCC's) across Muang Xay prioritising villages most prone to flooding;
- Implement a community level feedback mechanism for the project through the VDPCC's. Once established, VDPCC's have a mandate through to the national level and this should help to ensure the effectiveness of the feedback mechanism; and
- Conduct detailed flood hazard mapping exercises in flood-prone areas of the city. In the absence of detailed flood risk data for Muang Xay, flood hazard mapping exercises will yield important information. They will also help to promote community flood hazard awareness;
- Implement flood risk management awareness raising programs within communities and schools based on programs already planned for the central level; and
- Trial mobile applications for early warning and DRM data collection at the community level.

Other recommendations for the next phase of the project

Leveraging partnerships:

- Identify and pursue partnerships to leverage development in key areas (ie. Plan International - gender issues, WFP - establishment of village disaster prevention and control committees, flood hazard mapping, ADB – planned drainage project); and
- Engage telecommunications companies and relevant GOL departments about supporting specialised services during disaster events.

Environmental and social aspects:

- Conduct of an environmental and social impact assessment (ESIA) with associated sub-plans (ie. ESMMP, RAP) to IFC Performance standards once the proposed investment package has been selected and detailed designs are complete. This will ensure that a city-wide approach is considered including the potential cumulative impacts from other proposed investments such as the Lao-China railway and the ADB drainage project;
- Development of site specific construction environmental management and monitoring plans (CEMMP's) for each of the proposed investments to manage and mitigate environmental impacts to the

aquatic ecosystem and the township environment;

- Ensure that recommendations from the Gender Action Plan are incorporated into the next phase of the project; and
- Development of environmental engineering guidelines to guide design and development of proposed investments and ensure compliance with CEMMP's.

It is believed that the implementation of the above recommendations will improve planning and coordination for urban planning and disaster risk management, increased flood resilience among local communities, a reduction in the threats posed by flood events for existing and planned infrastructure and positive outcomes for environmental and social management.

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