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Assessing quick-wins to protect critical urban infrastructure from floods
Case study (three urban communities) Bangkok, Thailand

C. Zevenbergen[1,2], K. Kolaka[3], S. van Herk[1,3], M. Escarameia[4], B. Gersonius[1], D. Serre[5], N. Walliman[6], K.M. de Bruijn[7], R. de Graaf[8,9]

[1]UNESCO-IHE, Delft, the Netherlands
[2]TuDelft, Delft, the Netherlands
[3]National Housing Authority, Bangkok, Thailand
[4]HR Wallingford, Wallingford, UK
[5]University Paris Est, EIVP, Paris, France
[6]Oxford Brookes University, Oxford, UK
[7]Deltares, Delft, the Netherlands
[8]DeltaSync, Delft, the Netherlands
[9]Rotterdam University of Applied Sciences, the Netherlands

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ABSTRACT

Compared to the direct impacts to people and property of natural disasters such as flooding, indirect impacts are generally spread over a much wider area. This specifically holds true for critical urban infrastructure: public and semi-public services, ICT facilities, and physical networks. If disrupted or destroyed, these will have a serious impact on the well being of citizens and the operation of organizations, sectors, and government. There is a large existing body of scientific literature on the assessment of economic and non-economic losses resulting from the impact of flooding to critical infrastructure. However, most assessment tools (i.e. models) are highly complex, need to be validated before application to a specific area, and, in many cases, can generate unreliable damage estimates, partly due to the input uncertainties and the limitations of access to data and information. Moreover, many model assumptions and simplifications have to be made in order to enable the detection of relevant and critical thresholds for critical infrastructure functioning.

This paper reports on a recent study developed under the EC FP7 project FloodProBE "Technologies for the cost-effective protection of the built environment" which focuses on the vulnerability and protection of critical urban infrastructure from flooding. It presents a pragmatic and rapid screening procedure, referred to as a "Quick Scan". The purpose of the Quick Scan is to provide guidance for network operators and decision makers on identifying and rating those critical infrastructure networks and hot spot buildings that may be at risk from flooding and assessing where intervention will be most feasible and cost beneficial – the so-called "low hanging fruits" or "quick wins". This approach will help to support the development of effective interventions to alleviate direct and indirect flood impacts. Workshops and interviews with stakeholders and experts have been organised in the pilot cities Bangkok, Paris, and Dordrecht to test and further optimize the Quick Scan and to obtain feedback and lessons learned for the protection of critical urban infrastructure. This paper presents the findings of the workshops carried out with stakeholders of three neighbourhoods in the city of Bangkok in March 2013.

INTRODUCTION

Damage to critical infrastructure assets during flooding can result in significant secondary consequences which on many occasions, such as during the 2007 floods in England (Pitt Review, 2008) and the 2011 floods in Queensland (Inquiry, 2011), may be more serious than the direct damage caused by the flood. More recently, the destruction power and widespread disruption to infrastructure caused by Sandy has ranked this hurricane one of the costliest storm events for insurers (The Insurance Insider, 2013). The large electric and utility losses that left millions without power will probably cause more insured losses than were foreseen from a typical Category 1 event. Much damage could have been avoided if New York's most vulnerable critical infrastructure assets were protected ahead of time. This event has prompted professionals to reconsider the impacts of flooding on the functioning of essential services and the management practices of these services directed to alleviate these impacts. This rethinking is being included in new policies that embrace an integrated approach to flood risk management that include the protection of critical infrastructures to improve emergency relief and recovery (Zevenbergen et al. 2013: Van Herk et al., subm).

Compared to direct impacts to people and property of natural disasters, indirect impacts are generally spread over a much wider area. Flooding may indirectly affect the services and activities of communities in cities. This specifically holds true for critical infrastructure assets: physical sources, services, and information technology facilities, networks, and assets (Lhomme et al., 2012). If disrupted or destroyed, these would have a serious impact on the well being of citizens and the operation of an organization, sector, region or government (Van Ree et al., 2011). There is a large body of scientific literature on the assessment of economic losses resulting from the impact of flooding to critical infrastructure assets (FloodProbe, 2012, www.floodprobe.eu). However, most assessment tools (i.e. models) are highly complex, need to be validated before they are applied to a specific area, and can generate unreliable damage estimates partly due to the many uncertainties and limitations of access to data and information (CIRIA, 2010).

Flood proofing construction and retrofitting techniques to protect new and existing residential structures against the impacts of flooding are widely applied and well documented (e.g. CIRIA, 2006). There is however limited experience with these techniques with regards to critical infrastructure assets and guidance and best practices to floodproofing these assets are scarce (Escarameia et al., 2012). Very recently the EC FP7 project FloodProBE "Technologies for the cost-effective protection of the built environment" which focuses on critical urban infrastructure, has compiled guidance concentrating on building materials and construction processes (Escarameia, 2012).

Based on the above it is concluded that up to the present time there is a lack of insight in the vulnerability of critical infrastructure assets, what the severity of flood impacts could be and what type of protective measures would be feasible and effective. This specifically holds true for these assets within cities. Hence, there is a need for a simple tool to support operators and decision makers to:

1. identify and rate their critical infrastructure assets that may be at risk from flooding;

2. develop feasible and effective measures to minimize damage to these facilities caused by flooding.

This paper presents a pragmatic and rapid screening procedure referred to as "Quick Scan". The purpose of the Quick Scan is to provide guidance on identifying, rating, and protecting (existing) critical infrastructure assets that may be at risk from flooding. As part of the EC FP7 project FloodProBE workshops and interviews with stakeholders and experts have been organised in the pilot cities Bangkok, Paris, and Dordrecht to test and further optimize the Quick Scan and to obtain feedback and lessons learned for the protection of critical urban infrastructure Dordrecht (De Bruijn et al., in prep.). This paper presents the first findings of the workshops carried out with stakeholders of three neighbourhoods in the city of Bangkok, Thailand.

DESCRIPTION QUICK SCAN

The objective of the Quick Scan is (i) to assist operators and decision makers to identify, rate, and protect their (existing) critical infrastructure assets servicing urban communities, which may be at most risk from flooding and (ii) to support them in developing effective interventions to alleviate the damage to these assets which are relatively easily achievable and most cost beneficial (i.e. ‘low hanging fruit’).

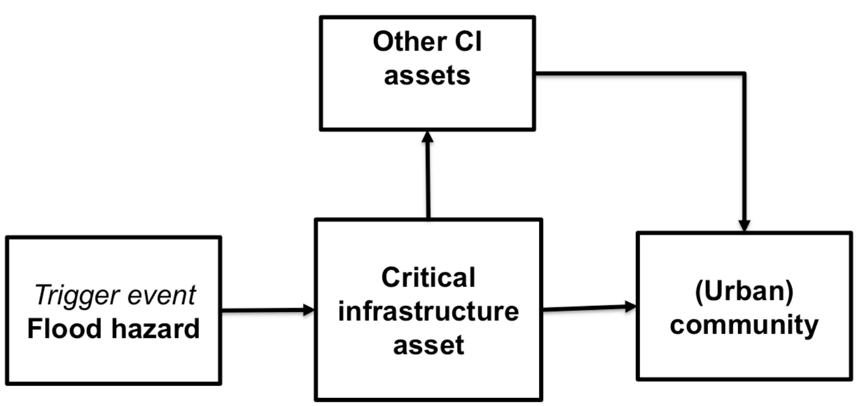
The scope of the Quick Scan is on urban infrastructure networks including the essential nodes or high value assets (referred here as hotspot buildings) of these networks. Both are critical for the continuity of economic activities in cities as well as for the urban population’s basic living needs. Examples of critical infrastructure are technological networks of energy supply, transport services, water supply, information and communication services. Hotspot buildings within these networks include power stations, water treatment plants, control centres of public transport, communication hubs, waste water treatment plants, fire fighting stations and hospitals (FloodProbe, 2012).

Typically, the following list of critical infrastructure is used as a basis for assessment:

- Utility services (electricity, water supply and drainage systems, transportation, telecommunication and gas supply, etc),
- Welfare and social systems (e.g. food distribution centres, financial centres, etc),
- Administrative and emergency service buildings (e.g. fire stations, police stations, flood warning and forecasting office, etc)

Damage to one type of infrastructure can cascade to disruption to other infrastructure, e.g. loss of power supply can impact on the health service of an urban community (see Figure 1). The flood vulnerability therefore largely depends on the degree in which both hotspot buildings and network critical urban infrastructure are affected by flooding and as a consequence are generating damage either directly or indirectly or both. The Quick Scan is based on a pragmatic and rapid assessment and ranking procedure taking specifically into account rough estimates of the consequences and damages of such interdependencies and thus attempts to capture second and third order consequences. It is important to note here that the point of departure of the Quick Scan is the urban community (defined here as a neighbourhood or city district with a clear cut boundary based on density, age composition of the buildings, geographic location, or socio-economic status). This implies that the focus of the assessment is on ‘upstream’ rather than on ‘downstream’ dependencies (in other words: the focus is on the effect of flood damage to a node or network (located either inside or outside the community) on the delivery of a service to that same community (and not to other communities).

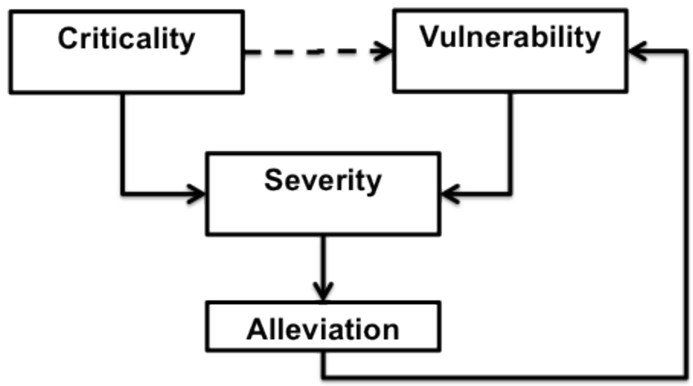
Figure 1. Schematic presentation of cascading affects of flood damage to infrastructure



Critical infrastructure include organizations and systems that have major importance for the society and that, if disrupted or damaged, comprehensively affect supply chains and public safety and could lead to further dramatic consequences. In any vulnerability assessment of critical infrastructure it is therefore essential to have an understanding of these cascading effects and inter-linkages between the organizations and systems involved in providing these essential services.

The framework used here consists of four elements: (1) criticality, (2) vulnerability, (3) severity and (4) alleviation and is adopted from *Dehmukh et al. (2011)* - see Figure 2).

Figure 2. General framework underlying the Quick Scan (adopted from Dehmukh et al, 2011)



Criticality can be expressed by (CIRIA, 2010):

- the severity of the effect (number of fatalities/wounded or monetary damage),
- the extent of the area or the number of people affected
- the rate of recovery from the outage.

Vulnerability relates here to the exposure and sensitivity to disruption or (direct) losses which, in case of critical infrastructure assets, are dependent on the features of the location (frequency and extent of flooding) and the 'condition' of the asset (e.g. susceptibility to flooding, state or repair, design features) (De Bruijn et al., in prep.).

Severity stands for the extent of socio-economic impact on society due to the reduced serviceability level of infrastructure (i.e. 2nd or 3rd order impacts) (*Oh et al., 2009)*.

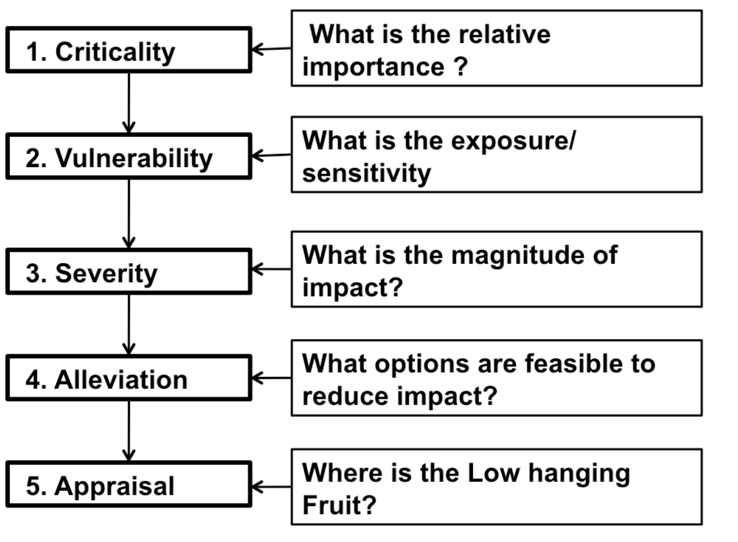
Alleviation entails all the pro-active interventions available to reduce the vulnerability of the critical infrastructure asset (feedback mechanism) and by doing so sustain the level of serviceability of an infrastructure during and after a flood disaster.

BASIC STEPS QUICKSCAN

Based on this general framework to identify, rank and protect critical infrastructure, the following simple procedure comprising five consecutive steps has been developed (see Figure 3):

Step 1; Identify and analyse critical infrastructure assets and rank their criticality. Firstly, the assets relevant for the area of concern (c.q. the community) should be identified including both the nodes (e.g. transformer and substations, water works) and connections (roads, water supply network, electricity cables). In this step the relationship between networks has to be taken into account. If electricity fails, pumps, communication, traffic control systems and most of the infrastructure will not function, unless they have their own power supply (see Figure 4). To carry out this step a network analysis is done 1) by describing the critical networks and the elements they consist of, 2) studying the effects of outfall of one element to the functioning of the network and 3) the effect of outfall of the network on other networks. 4). Finally, the effect of outfall of one or more networks on the community must be assessed (FloodProbe, 2012). As described earlier, the focus is on 'upstream' dependencies, which implies that the assets of concern may be located outside the boundaries of the community in question.

Figure 3. Basic steps of the Quick Scan



Step 2; Analyse both the exposure and sensitivity of the critical assets defined in step 1. For some infrastructure types clear thresholds define the sensitivity of elements e.g. transformer stations in Dordrecht will fail if water depths exceed 30 cm. Based on such thresholds, a focused analysis of potential flood parameters and probabilities ('the exposure') can be carried out. In other cases these thresholds will be less clear. Generally, the principal flood parameter is depth, though duration, salt/fresh water, and flow velocity may be relevant. Flood exposure analysis is normally based on historical data and / or model simulation of potential floods.

The sensitivity depends on the flood resistance and resilience of the critical assets. The sensitivity is dependent on the flood resistance and resistance of the critical assets. An asset is defined here as resistant if it can withstand a particular flood water depth without any damage or failure. An asset is resilient if, when it comes into contact with floodwater during floods, no permanent damage is caused, structural integrity is maintained and, if operational disruption does occur, normal operation can resume rapidly after the flood has receded (De Bruijn et al. in prep., Escarameia, 2012). The vulnerability can be expressed in monetary terms or based upon indicators such as the duration of outage, the number of people affected and combinations of those (De Bruijn et al. in prep.).

Step 3; Based on the results of step 1 (criticality) and 2 (vulnerability) the severity can be assessed taking into account (i) the effect of failure of the assets (nodes and connections) on the delivery of service (first order), (ii) the effect of failure of a (part of one) network or node on other networks (2^{nd} and 3^{rd} order affects such as electricity outage which may impact the functioning of communication and traffic control systems) and (iii) the likelihood of failure (flood exposure and sensitivity).

Step 4; The aim of this step is to identify the options available to alleviate the effects of flooding on the functioning of the critical infrastructure and at what cost. The options comprise flood proofing (resilient and resistant) construction and retrofitting techniques ranging from simple interventions such as temporary closures to permanent elevation. Much information which is available for traditional buildings is also applicable to critical infrastructure assets, albeit that the underlying CBA (Cost Benefit Analysis) may require a different approach. Of the range of resilience techniques available, the work described in FloodProbe concentrated on building materials and construction processes – other flood resilience techniques such as flood protection products have been recently extensively covered by other EC funded projects, e.g. SMARTeST (www.floodresilience.eu). It is also possible to alleviate impacts from failure by reducing the criticality of the sensitive elements e.g. by making the network more redundant in order to make sure that if one node fails, the network will still function.

Step 5; The final step comprises the appraisal phase in which the so called “Low Hanging Fruit” will be identified. Based on the severity ranking (where are the highest impacts?) of step 3 on the one hand and the identification of the options and cost to alleviate these impacts of step 4 to the other, the actions that can be undertaken at (relatively) low cost and with high impact as part of a wider range of interventions to further protect the urban critical infrastructure can be identified.

BANGKOK FLOODING 2011

Thailand, including the Bangkok Metropolitan Region (BMR), is frequently flooded (ADB, 2012). Major flooding occurred in Thailand during the 2011 monsoon season. Beginning at the end of July triggered by the landfall of Tropical Storm Nock-ten, flooding spread through 65 provinces and inundated parts of the capital city of Bangkok in October 2011. Flooding persisted in some areas until mid-January 2012 and resulted in a total of 815 deaths (with 3 missing) and 13.6 million people affected. Sixty-five of Thailand's 77 provinces were declared flood disaster zones, and over 20,000 square kilometres of farmland was damaged. Highways in and around Bangkok play an essential national role for transport of people and goods and thus for the national economy. Highways are situated mostly on elevated structures. Consequently, these services were only partly affected during the flooding. Apart from affecting business directly, the floods also indirectly affected non- flooded factories through supply chain disruptions. Many factories could not produce due to raw material shortage affected by the temporary halt in the production of flooded factories. In addition, workers were not able to reach their factories, even though these factories remained dry, as the (smaller) roads to access those factories were flooded. The Department of Highways and the Department of Rural Roads reported that parts of 1,700 roads, highways and bridges were damaged or destroyed (AON Benfield, 2012).

Moreover, BMR’s crucially important industrial and manufacturing sector was seriously flooded as well. The disaster has been described as "the worst flooding yet in terms of the amount of water and people affected." The economic impact of the 2011 floods ranks this event as the fourth costliest natural disaster in the world with financial losses of approximately US$ 45.7 Billion (The World Bank, 2012). The biggest damages and financial losses were suffered in the industrial and the manufacturing sectors, with a total of approximately US$ 32 Billion (NESDB, 2012). These figures show not only the vulnerability of the industrial sector but also the importance of this sector for both the Thai and the world economy.

CASE STUDY BANGKOK

As part of a comprehensive study to evaluate and test the Quick Scan, this approach has been applied to assess the 'Low hanging Fruit" of three urban communities in the Bangkok Metropolitan Region (BMR). The three urban communities in this study have been developed by the National Housing Authority (NHA). NHA is a state enterprise established in 1973 under the Ministry of Social Development and Human Security that provides affordable housing for low and middle income people[1] in Thailand. In the past 10 years NHA has developed a total of about 290,000 housing units countrywide via its "Baan Eua-Arthorn" (BEA) program of which 65% are in the Bangkok Metropolitan Region. The flood that effected Thailand in 2011 has impacted on a significant fraction of the housing stock of NHA with well over 170,000 properties (residential units) distributed over 165 urban communities in Bangkok and surrounding area.

Case study description and methodology. Table 1 provides an overview of the most relevant features of the three urban communities. These communities are all located in the Bangkok Metropolitan Region, which was flooded during the 2011 flooding, but differ in terms of size, density and building types (see Figure 4). Each community has been investigated by a multi-disciplinary team of experts (covering civil engineering, urban planning, building construction and finance) of NHA staff complemented with external experts following the five consecutive steps of the Quick Scan. During this process, which was supported by independent researchers, the team members conducted field visits and interviews with relevant stakeholders (including service engineers and representatives of the urban communities), organized expert workshops and collected and analyzed various relevant documents including flood impact studies. The case study has been executed in March, 2013 and lasted two weeks.

Table 1 Main features of the three communities involved in the case study

Community	**Ramintra**	**Tung Song Hong**	**Rangsit Klong Sam**
Size (m^2)	124,000	430,000	66,700
Number of units	3,731	4,972	477
Category	condominiums	mixture	two storey house
Number of people	14,900	24,860	2,400

[1] Target groups: the disadvantaged, low-income earners, junior civil servants and government employees, all with not more than 22,000 baht / month income per family (income as of 2006 - present).

Figure 4. Building types of the three selected urban communities (upper right: BEA Ram-intra (condominiums), lower right: Rangsit Klong Sam (two storey houses), upper left and lower right: Tung Song Hong (mixed types)

RESULTS

Based on interviews, site survey and maps the three teams identified and ranked the critical infrastructure assets (step 1) relevant for the three communities. Table 2 provides an overview of this inventory.

Table 2 Overview and ranking (1=highest, 8=lowest) critical infrastructure assets of the three communities

Critical infrastructure	**Ram-intra**	**Tung Song Hong**	**Rangsit Klong Sam**
Water supply systems (network) (WS)	2	2	3
Residential water supply systems (RWS)	4	4	4
Public electricity networks (EN)	3	1	1
Power supply (station) (PS)	-	1	1
Residential sanitation (& drainage) systems (RSS)	4	4	4
Water treatment plants (WT)	-	6	4
Local road infrastructure (LR)	6	5	2
Main roads (MR)	5	7	2
Fuel stations (FS)	7	-	8
Communication networks (CN)	8	8	7
Markets & shopping centres (M)	1	3	5
Hospitals (H)	-	-	6

The ranking of the relative importance of critical infrastructure assets revealed the following general results:

High

- Power supply, including the power supply station (PS) and the electricity network (EN). The Provincial Electricity Authority (PEA) is the mainly responsible for the construction, maintenance and operation of power supply of BMR.
- Water supply systems (network)(WS). The supply of piped water service is the responsibility of the Provincial Waterworks Authority (PWA)

Medium

- Transportation: main road and secondary roads
- Residential water supply and sanitation systems (RWS and RSS) incl. drainage systems (reinforced concrete pipes (RCP) deliver the wasted water, rainfall, etc. to the wastewater treatment plant).
- Shopping centres & local markets (M)

Low

- Communication: telephone communication and community radio station, land-line telephone operated by TOT and True Corp.

Based on flood innudation maps, interviews and assessment reports, the exposure and sensitivety of the critical infrastructure assets have been assessed in step 2. These results revealed that the three communities were flooded for several weeks up to two months with flood depths varying from 0.2m to more than 1 m (see Figure 5). As an example, a detailed flood innudation map of the Rangsit Klong Sam is given in Figure 6. Most secondary roads, local markets and shopping centres were closed for up to two months. Garbage trucks were no longer able to collect trash from some areas, and in many (two storey) homes the toilets were not functioning due to inundation, leaving residents to defecate in the open.

Figure 5. Flood depth in Time (location: Ram-intra Community Housing Project)

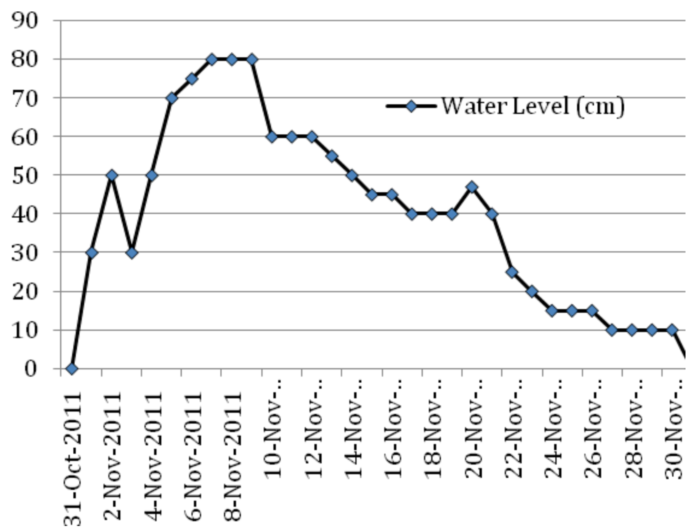
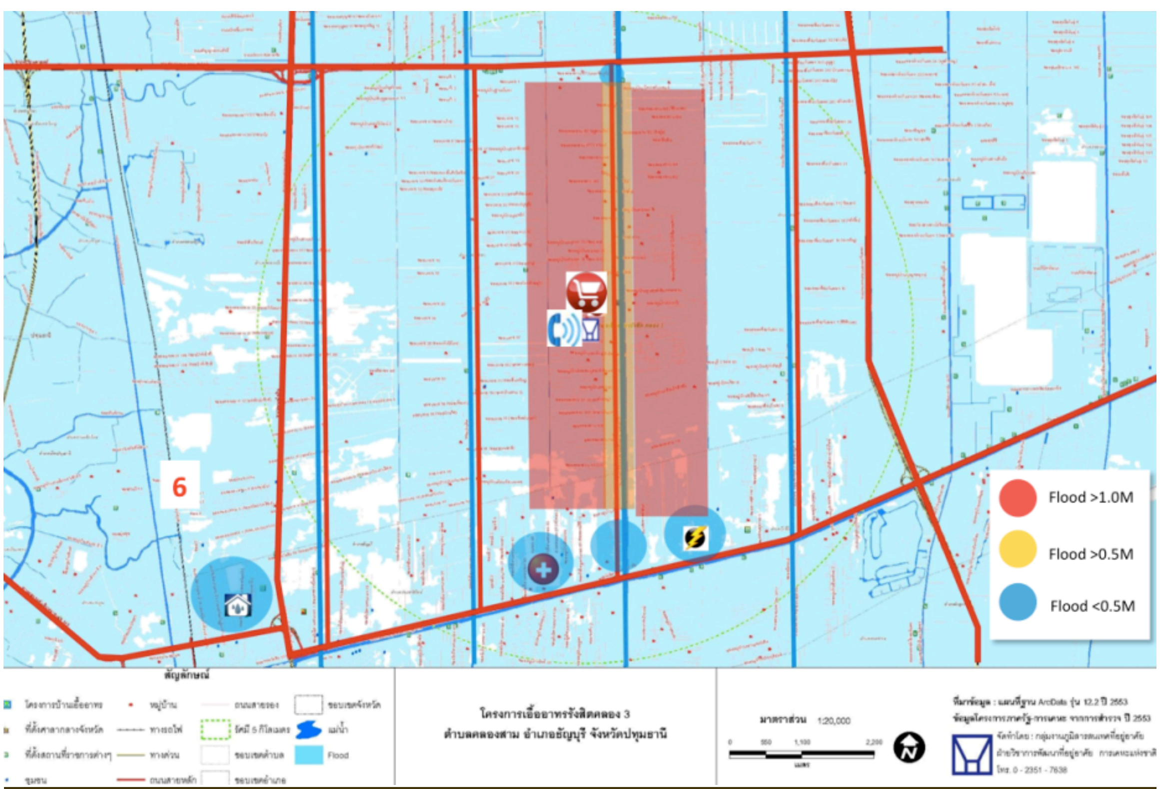


Figure 6. Inundation map Rungsit Klong Sam area.



Although no outbreaks have been reported, the spread of diseases was of major concern particularly given the number of people who could not avoid wading through polluted waters. The hospitals in the Klong Sam sub-district were protected by sandbags and remained open during the flooding. The power supply was not damaged by the flooding: the substations were effectively protected by flood protection walls (e.g. the PEA Thanyaburi Substation) and electric cables and transformers were located 5 m above ground level; also in the majority of the buildings, fuse units and electronic switches were located at elevated level as well. Despite these preventive measures major concerns encompassed the danger of electrocution[2]. The water supply was not affected, because the water treatment plants were well protected by concrete walls and the risk of water contamination through diffusion and/or leakage of pollutants in the network (PVC pipes) was assumed to be very low.

In Figure 7 and Table 3 the results of step 3 (severity) are presented. In Table 3 the severity of the critical infrastructure assets has been classified into four categories cq high-high, high-low, low-high, and low-low criticality and vulnerability. These results show that, despite some differences in severity ratings between the three communities, a few consistent patterns arise. The critical infrastructure assets with the highest severity comprise by and large secondary roads, market and shopping centres and residential water supply and sanitation. High criticality but low vulnerability rank water treatment plants, power supply, main roads and water supply. The severity of communication networks ranks lowest - this is in contrast with assessments in Europe where communication networks rank highest (e.g. CIRIA, 2010).

Table 4 summerizes the results of Step 4 (alleviation) including indicative estimates of the cost and time required for implemenation of the options with the highest severity rating. These results reveal that two types of options have been proposed. The first are structural engineering interventions such as the installation of a concrete wall and extra pumping capacity and the elevation of the road infrastructure. These interventions are relatively costly and require a relatively long time to implement compared to the other options of the second type. The options of the second type comprise temporary measures such as sandbags, elevated temporary walkways (see Figure 8) and simple technology such as elevated, floodproofing toilets and water tanks which can be implemented within a short period of time at relatively low cost. Hence, the latter type of options has been selected in the appraisal phase (step 5) and labelled as the 'Low Hanging Fruit' as these actions can be undertaken at relatively low cost and with expected high impact as part of a wider range of longer term interventions to further protect the critical infrastructure assets.

[2] the majority of deaths, particularly among children, of the 2011 flooding were likely caused by drowning.

Figure 7. Critical infrastructure assets, their impacts and inter-linkages relevant for the context of the three urban communities of this study (Bangkok)

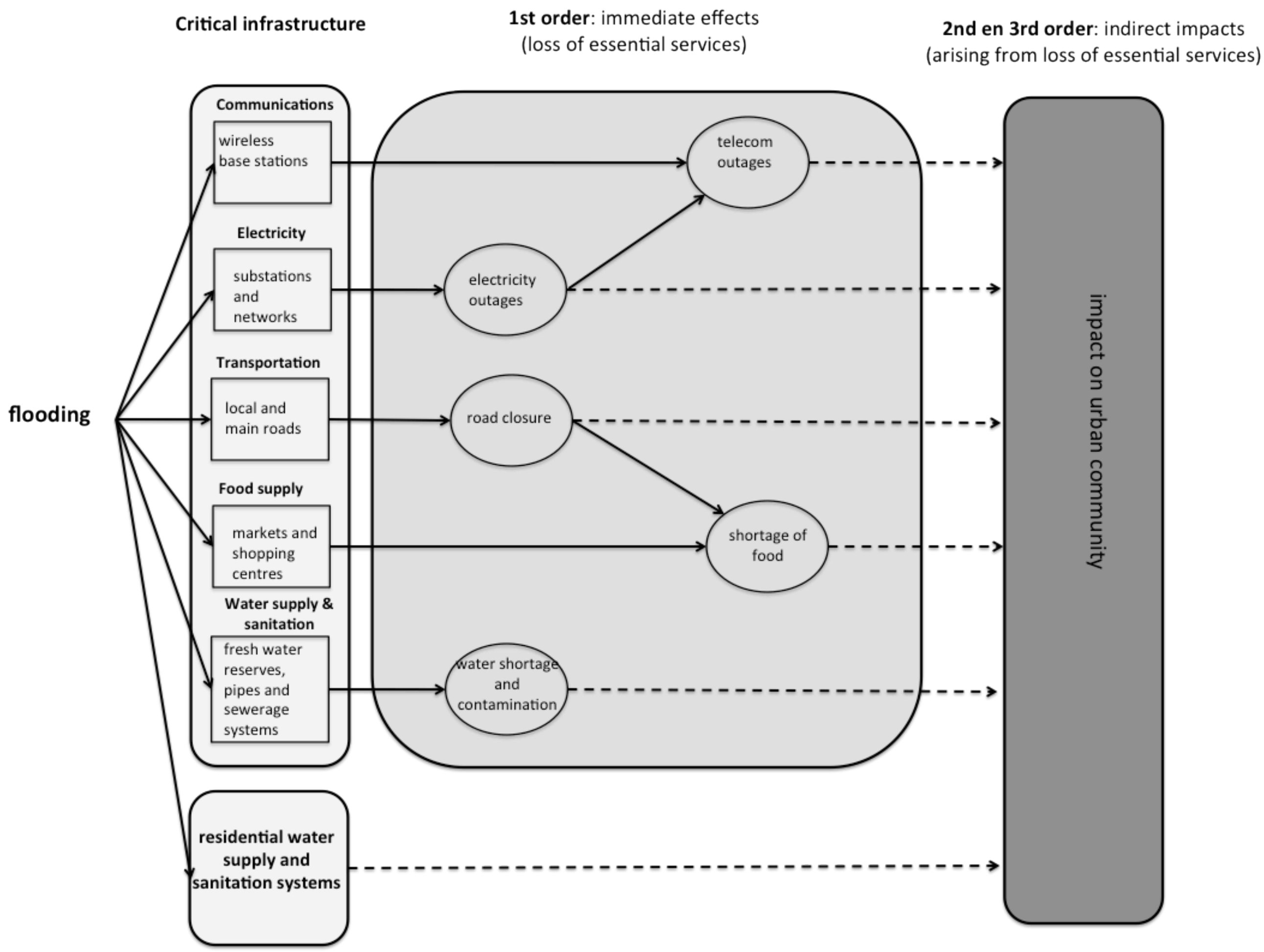


Table 3. Categories of severity (based on criticality and vulnerability rating) of the critical infrastructure assets for the three communities (see also Table 2)

Criticality/Vulnerability	**high/high**	**high/low**	**low/high**	**low/low**
Ramintra	M, LR, WT	PS, WS, RSS, MR, RWS, EN	-	CN
Tung Song Hong	M, LR, RWS	CN, EN, MR, WS,	-	FS, CN
Rangsit Klong Sam	LR, WT, RSS	PS, WS, EN, MR	M, H	CN

Table 4. Otions to alleviate the effects (step 4)

Options available to alleviate the effects		**cost**	**time to implement**
Transportation (LR)			
	Road raising	+++++	+++
	Concrete barrier	++++	++
	Pump station	+++	++
	Temporary walkway	++	+
	Temporary use of boats	+/-	+
Market and shopping centres (M)			
	Concrete wall	+++	+++
	Temporary location	+	++
	Sandbags	+	+
Drainage and sewage system (RSS)			
	Clean up drainage system	+	++
	Public toilet	++	++
	Raise pump station	+	++
	Temporarily toilets	+	+
Residential Water Supply (RWS)			
	Concrete wall	++	++
	Concrete cover	++	++
	Pumps in control room	+	++
	Water tank on the roof	+	+

Legend: Cost: ++++ = 100 – 1000 MB, +++ = 10 – 100 MB, ++ 10 – 1 MB, + = 1 – 0,1MB, Time: +++ > 1 year, ++ = 3 months – 1 year, + = < 3 months (MB=million Baht)

Figure 8. Temporary walkway at a market

Discussion and conclusions

The Quick Scan procedure described in this paper and applied to three urban communities in the Bangkok Metropolitan Region has demonstrated that it provides practical and useful information on designing a structured, step by step assessment to identify, rate and protect urban critical infrastructure. Its framework appears attractive due to its structured character and simplicity. Additionally, the procedure provides practical tools and checklists to support the execution of the consecutive five steps of the procedure. Yet, these same features make this type of procedure to be subjective, which may reduce its accuracy. The quality of the team of experts (education, experience, multi-disciplinarity) and conditions under which team work is conducted and supervised are crucial to its success.

Field visits and interviews revealed that health risk due to contamination of water supply and to contaminated flood water entering the property and anxiety and stress due to service loss such as electricity, water supply and sanitation, and food supply were perceived as the most severe consequences of flooding-related disruption of critical infrastructure assets by the residents of the three communities.

The Quick Scan indicated that the critical infrastructure assets with the highest severity comprised secondary roads, market and shopping centres, residential water supply and sanitation. Actions to alleviate the impact of floods were of two types: structural engineering and temporary measures. Structural engineering interventions included the installation of concrete walls, extra pumping capacity and the elevation of the road infrastructure. Temporary measures included sandbags, elevated temporary walkways and simple technology such as elevated, floodproofing toilets and water tanks which can be implemented within a short period of time at relatively low cost. The latter type of options were labelled as the 'Low Hanging Fruit' as these actions can be undertaken at relatively low cost and with expected high impact as part of a wider range of longer term interventions to further protect the critical infrastructure assets.

The results of the case study can not be directly transferred to other areas. However, they illustrate the methods applicability. The method is also applicable in areas which are considered flood-prone, but where no recent historic floods occurred. However, information on the sensitivity of the critical infrastructure is then more difficult to obtain as has been discussed in the study of CI in Dordrecht (De Bruijn et al. (in prep.)).

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