Gap analysis of the flood management system in Metro Manila, Philippines: a case study of the aftermath of Typhoon Ondoy

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Abstract For decades, floods caused by heavy rains have repeatedly inundated critical areas in Metro Manila, which prompted the Philippine government to establish a flood management system consisting of both structural and non-structural measures. However, most of the operational flood mitigation infrastructure was proven inadequate during the onslaught of typhoon Ondoy. The storm brought rains that exceeded the rainfall intensities of the country's previous typhoons. The aftermath of this disaster paints a bleak scenario for the highly urbanized Metro Manila as the effects of climate change increase the likelihood of storms having the same, or even higher, intensities as Ondoy. This study deals with the identification of gaps in Metro Manila's flood management system using the records and observations made during and after typhoon Ondoy. The primary focus of this study was on the performance of the flood control structures, flood forecasting and early warning systems in Metro Manila. The flood control structures were assessed based on the results of field inspection and observations during and after the storm. The flood forecasting and warning systems were evaluated using the information available from various government offices, and from the results of key informant interviews and surveys. The study revealed that factors such as inadequate hydraulic design of the flood control structures in the rivers and drainage systems, lack of an accurate flood forecasting system and lack of proper maintenance of the flood warning system, contributed to the unprecedented flooding on 26 September 2009, which inundated around 34% of Metro Manila. The study concludes by stressing the need for distributed and enhanced flood mitigation programmes, planned and constructed flood control structures, and establishment of effective flood forecasting and early warning systems. The existing flood management programmes should be reviewed and revised in accordance with a new safety level for flood prevention and control.

Key words flood management; gap analysis; Metro Manila, Philippines; typhoon Ondoy

INTRODUCTION

Tropical storms are intensely energetic transient weather systems that develop over regions of a very warm ocean surface, usually within 30°S to 30°N of the Equator (Rasmusson *et al.*, 1993). Most tropical storms, as illustrated by McDonald *et al.* (2005), originate from the Pacific and Indian oceans and occur during the first half of the year in the areas north of the Equator (0° to 30°N), and during the second half of the year in the areas south of the equator (0° to 30°S). The cost of damage caused by tropical storms both in terms of lives and economic losses can be devastatingly high, and changes to tropical storm patterns due to climate change can have overwhelming impacts on modern societies, especially in the megacities of developing countries (Braun and Aβheuer, 2011). The International Bank for Reconstruction and Development (IBRD) identified several megacities in the tropical region, including Metro Manila in the Philippines, which lies between 14°23′N and 14°44′N north of the Equator, as highly vulnerable to the consequences of extreme meteorological events, such as floods (The World Bank, 2010). Metro Manila experiences six to ten tropical cyclones every year, usually during the months of July to September.

Metro Manila (Fig. 1), the Philippine's capital region and the country's centre of economic and political activities, is situated on a semi-alluvial fan that was formed from sediment flow coming from the northern and eastern river basins. It opens to Manila Bay on the west and Laguna de Bay Lake to the southeast (Pineda, 2000). According to the 2007 census, Metro Manila has a population of around 11.5 million (National Statistics Coordination Board, 2011) with a population density of around 18 000 persons per km^2. With a contribution of 33% to the country's GDP, Metro Manila has the biggest share of the country's 17 administrative regions. O'Neill *et al.*

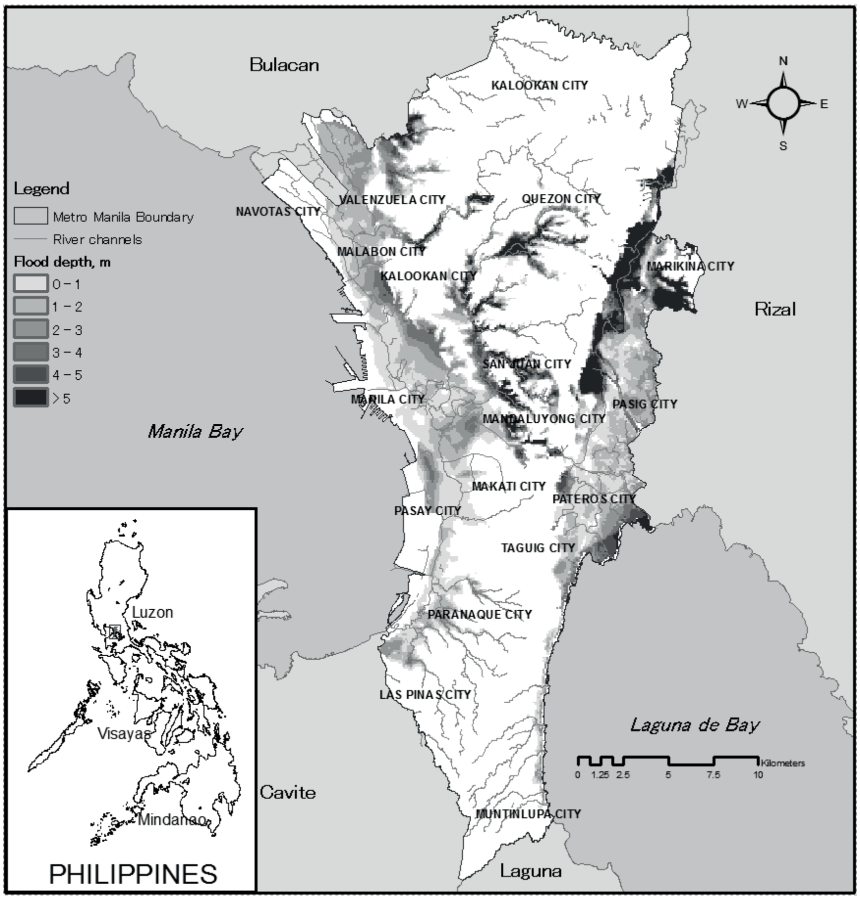

Fig. 1 Location of Metro Manila with maximum inundation depths during typhoon Ondoy.

(2005) of Goldman Sachs foresee that the Philippines will be among the top 20 largest global economies by 2025, and Metro Manila will most likely play a central role. However, incidents of floods have constantly slowed down Metro Manila's economic growth rate. Tabios *et al.* (2000) explained that parts of Metro Manila would easily succumb to flood, even at moderate precipitation, due to the poor drainage system and unmitigated runoffs, which are primarily caused by poor solid waste management (near the open channels), improper land use and the high rate of urbanization. The negative impacts of flooding in Metro Manila range from minor inconveniences, such as heavy traffic and suspension of school activities (Page, 2000), to catastrophic levels, such as loss of lives and damage to public infrastructure and property. Flood usually, and could easily, occur in the region's low-lying areas (i.e. Valenzuela City, Navotas City and Manila City) and some elevated areas (i.e. Quezon City and Marikina City) during storm and monsoon periods.

Large-scale projects aimed to mitigate the effects of floods in Metro Manila, including both structural and non-structural measures, have been commissioned by the Philippine government since the early 1990s (Fano, 2000). Structural measures such as river dikes, flood gates and pumping stations, to name a few, were built to prevent and control the storm water runoff in the river channels. Non-structural measures such as the telemetric flood forecasting and warning systems in the Marikina, Pasig and San Juan basins were installed by the Department of Public Works and Highways (DPWH) to reduce the flood risk in the surrounding communities (DPWH, 2009). Several large-scale structural flood control projects were completed up to the early part of 2009 (Gatan, 2009). According to the Metropolitan Manila Development Authority (MMDA), around 2500 hectares, or 4% of the total land area, remained flood-prone in Metro Manila in 2008. This is a huge improvement from the 13 100 hectares (20%) flood-prone area in 2002 (MMDA, n.d.). However, in September 2009, when tropical storm Ondoy directly crossed over Central

Luzon, around 21 700 hectares (about 34%) of the metropolis was submerged by flood waters, affecting around 4.9 million residents, and leaving behind 464 casualties and 37 missing individuals with some US$ 240 million worth of damage in property, infrastructure and agriculture (Rabonza, 2009).

One of the aims of this paper is to analyse the situation that led to the aforementioned unprecedented events by looking at the characteristics of typhoon Ondoy and the state of Metro Manila in the aftermath of the typhoon. A similar study was conducted by Izzo *et al*. (2010) in which they characterized typhoon Noel, including estimation of the rainfall return period, to evaluate the effects of typhoon Noel on the Dominican Republic. In the Philippines, a post-disaster needs assessment study completed in 2009, assessed the level of damage wrought by typhoon Ondoy, which was aimed to determine the recovery and reconstruction strategies for Metro Manila (The World Bank, 2009). However, the post-disaster needs assessment study focused only on the identification of the recovery and reconstruction needs based on the assessment of the damages and losses caused by the typhoon Ondoy, with only a vague inclusion of the assessment of the existing flood management system. This paper thus aims to clearly define certain gaps that existed in the flood management system of Metro Manila during the onslaught of typhoon Ondoy, and particularly the performance of the structural flood control measures and the reliability of the flood forecasting and warning systems. The performance of the structural flood control measures were qualitatively assessed based on the results of field investigation and surveys conducted by Woodfields Consultants, Inc. in October 2009. The assessment of the effectiveness of the flood forecasting and flood warning systems was performed using results of key informant interviews and other available information from various government offices. To the best of our knowledge, there is no published literature that evaluates the performance of the existing flood management system in Metro Manila based on the extreme meteorological event in September 2009, particularly the identification of gaps between the desired effectiveness and actual flood management system. The results of this study may provide insights to decision makers and urban planners, especially in other developing countries, for finding solutions to flood risks reduction.

CHARACTERISTICS OF TYPHOON ONDOY

The tropical storm

The storm Ondoy was first detected on 24 September 2009 as a tropical depression near the east of Luzon. It intensified into a tropical storm on 25 September. Figure 2 shows the track of Ondoy as it travelled from east to the west of Luzon. The storm's maximum centre wind was 105 km/h, with a gustiness of around 135 km/h, and movement speed from 11 to 19 km/h.

Return periods and inundation

To further characterize Ondoy's strength in terms of rainfall in Metro Manila, the return periods of the maximum 1-h and daily rainfall depths at the Science Garden station were estimated using the Gumbel distribution (Stedinger *et al*., 1993). Figure 3 shows the plot of the estimated return periods for the maximum 1-h, 12-h and daily rainfall depths as recorded at the Science Garden station. The plots were acceptable at a significance level of 5% using the Kolmogorov-Smirnov test. Results indicate that Ondoy's rainfall return periods on 26 September 2009 for the 1-h, 12-h and daily rainfall depths were 50 years, 130 years and more than 400 years, respectively. The enormous gaps between the return periods imply that Ondoy's impacts were much higher, and that the possibility of devastatingly high water accumulation was much greater at longer duration.

The authors conducted field interviews and surveys on 11 to 13 November 2009 within Metro Manila to determine the extent and maximum depths of the inundation created by typhoon Ondoy. Figure 1 reveals that a third of the metropolis was inundated to depths ranging from less than 1 m to more than 5 m, with duration of 3 to 8 hours in most of the affected areas. High inundation occurred mostly near the banks of the Marikina and San Juan channels. The inundation in Pateros

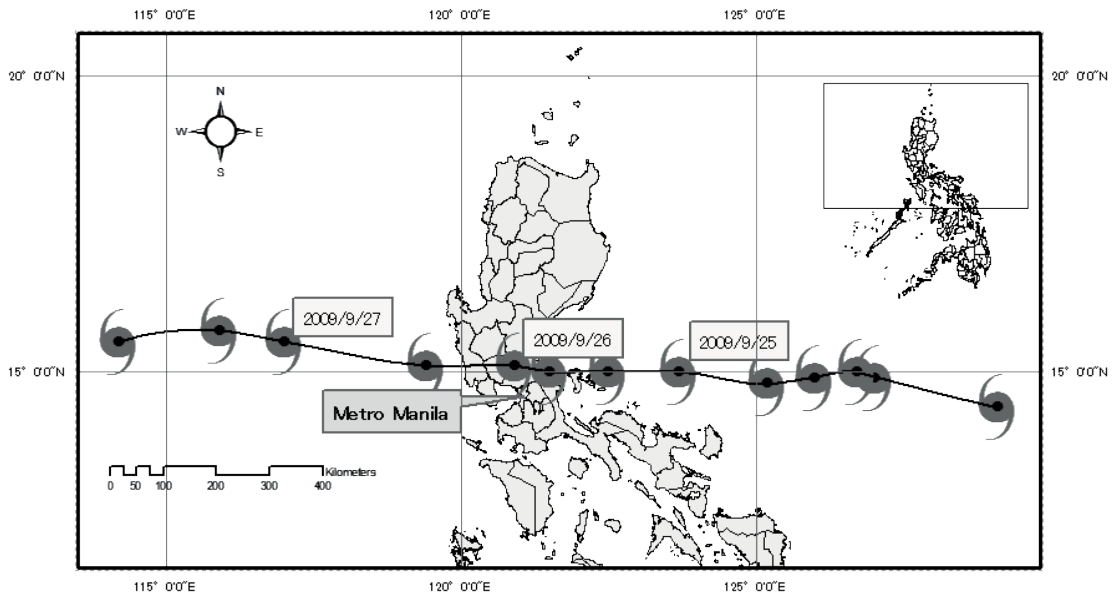

Fig. 2 Typhoon track of typhoon Ondoy (source: PAGASA).

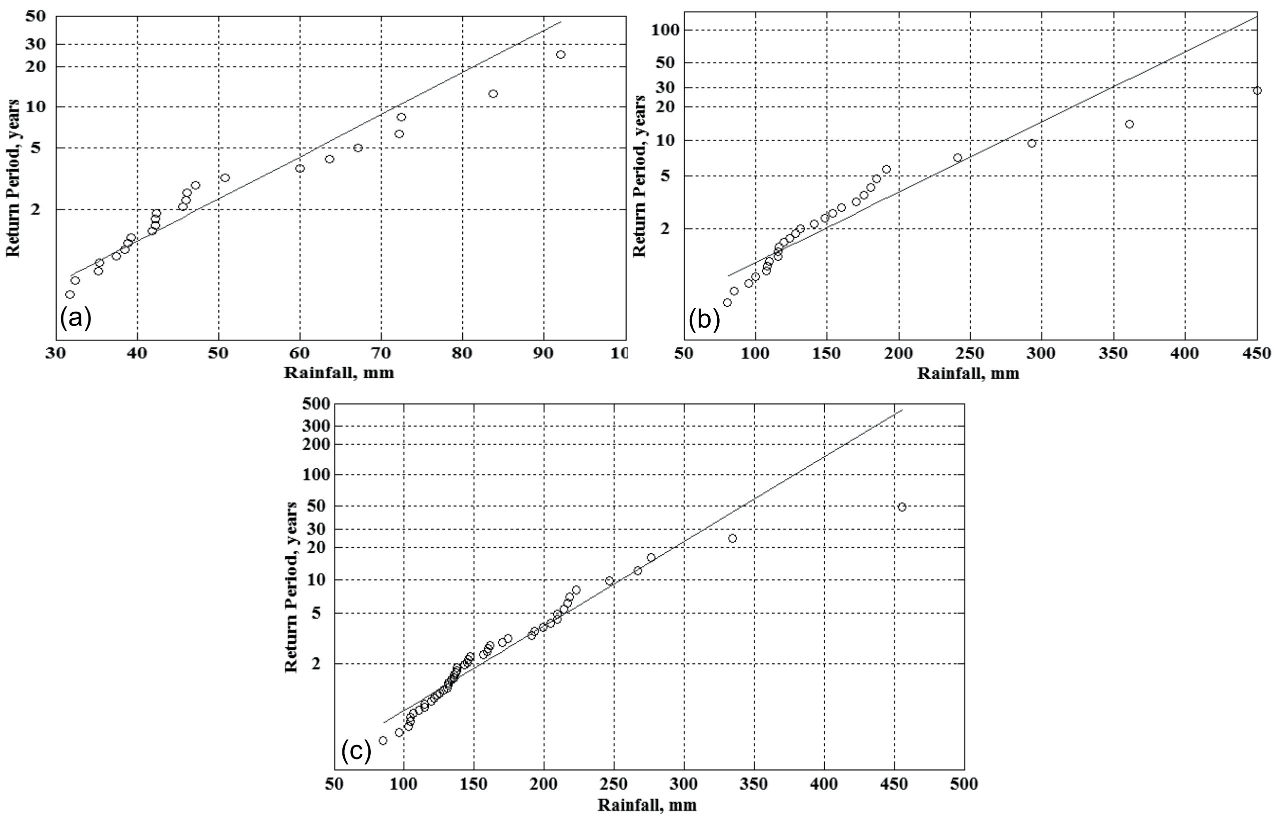

Fig. 3 Return period of the annual maximum: (a) 1-h, (b) 12-h and (c) daily rainfall in Science Garden.

and Taguig City near the shores of Laguna de Bay Lake can be attributed to the lake's water level increase during the storm.

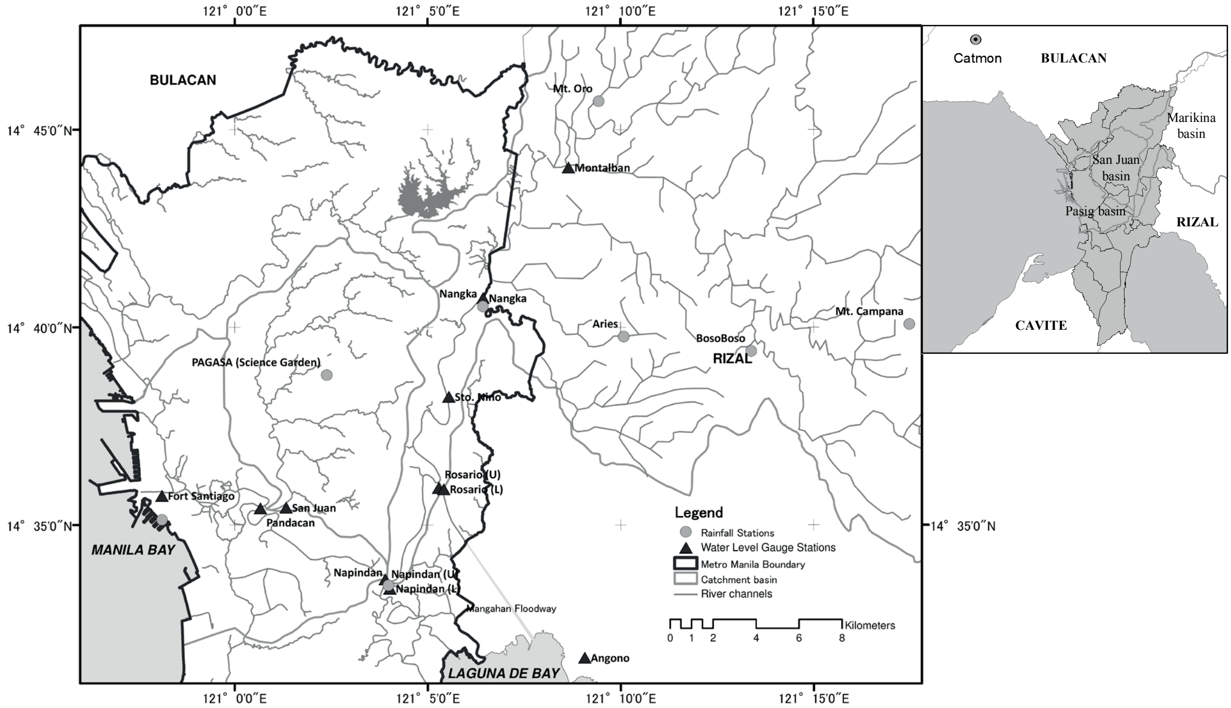

Fig. 4 Location map of rainfall and water level gauging stations (source: PAGASA and EFCOS).

GAPS IN METRO MANILA FLOOD MANAGEMENT SYSTEM

Flooding and flood control structures in Metro Manila

Floods were observed in Metro Manila, particularly in Manila City, in as early as the eighteenth century. However, flood mitigation was initiated only during the early part of the 20th century, when storm drains were incorporated into the design of main roads (Liongson, 2000). In 1952, a comprehensive study of the drainage system of Manila City and its suburban areas was completed (Fano, 2000). The improvement of the drainage systems (i.e. channel dredging, river widening, river training works, etc.) since then became the main measure for flood mitigation. Construction of large-scale flood control structures (i.e. large-scale weirs, large-scale flood gates and high capacity pumping stations) was started only in the early part of the 1980s. Further developments for flood mitigation are still being continued under the construction projects of the DPWH (DPWH, 1998) and flood risk reduction programs of the MMDA. According to the MMDA, the flood prone areas of Metro Manila have been reduced from 20% of Metro Manila's total land area in 2002 to about 4% in 2008. However, the flood created by typhoon Ondoy in 2009 covered at least 34% of the metropolis. The sudden increase in the flooded areas in 2009 indicates that the flood control structures collectively performed poorly during this event. These structures were overwhelmed by the onrushing floods, mainly because most were designed using 10 and 30 year discharge return periods for the drainage works and flood protection works (i.e. protection from river overflow), respectively (Gatan, 2009). It is surmised that Metro Manila did not have the capability to prevent flooding due to Ondoy, but the risks to the population could have been reduced by proper implementation of non-structural flood mitigation measures, such as accurate flood forecasting and flood warning, combined with an effective emergency response. The succeeding sections assess the gaps in the flood forecasting and flood warning systems in Metro Manila.

Flood forecasting

The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) is the primary source of information about storm intensity and possibility of floods in Metro Manila. However PAGASA's forecasting capability in 2009 was limited only to the following: prediction of the storm's intensity (i.e. wind speed, gustiness, etc.); prediction of floods in certain river basins using rainfall depths and water levels; and giving real-time updates on the status of major dams for possible water release and flash floods. Also, PAGASA does not have the technology to estimate the amount of rainfall before intense precipitation. Specifically, PAGASA's flood forecasting system includes: (a) basin flood forecasting, and (b) a flood forecasting and flood warning system for dam operation (FFWSDO). For the basin flood forecasting, only four river basins in Luzon are being monitored, which unfortunately does not include Metro Manila. However, the FFWSDO covers four major dams in Luzon, but again, does not include the major flood prone areas of Metro Manila. In fact, the dams that are being monitored by PAGASA had no significant contribution to the flooding in September 2009.

The other flood forecasting system in Metro Manila is the Effective Flood Control Operation and Warning System (EFCOS) whose components are installed in the Marikina, Pasig and San Juan river basins, as shown in Fig. 4. The EFCOS was originally installed in 1978, improved in 1993 and rehabilitated in 2001. The main purpose of EFCOS is to reduce the occurrence of floods in the cities of Marikina, Pasig, San Juan and Manila (Fig. 1) through the operation of its weirs (at the Rosario station) and hydraulic control structures (at the Napindan station) that are aided by a water level forecasting system. Figure 4 shows the location of 9 raingauge stations and 11 water level gauging stations within the Pasig, San Juan and Marikina basins. All raingauge stations are monitored and maintained by the PAGASA. The water level gauging stations are monitored and maintained by the MMDA. EFCOS is also designed to prevent channel overflow on the east and west banks of the Manggahan Floodway (DPWH, 2009).

The forecasting capability of EFCOS is embedded in its data processing system located at the control station near the Rosario raingauge station. Real-time rainfall depths and water level data are used for flood simulation (updating every 10 mins) through a telemetry system that connects the raingauges in Mt Campana, Mt Oro, Boso-boso, Aries, Nangka, Science Garden and Napindan; and the water level gauges in Montalban, Nangka, Sto. Niño, Rosario, Napindan, Angono, Pandacan and Fort Santiago (Fig. 4). The operation of the Rosario weir, which opens to the Manggahan floodway, is based on the predicted water level at the Sto. Niño water level gauging station. Figure 5 shows the hyetographs and water level graphs of selected rainfall and water level gauging stations located in the upper stream, middle stream and lower stream of EFCOS. When the water level at the Sto. Niño station is predicted to reach 15.2 m, with a corresponding tidal level of 11.4 m in Manila Bay (Badilla, 2008), the gates at the Manggahan floodway should be opened to redirect some of the water towards the Laguna de Bay Lake. Unfortunately, the operation of the flood forecasting system was stopped in 2006 due to "budget constraints". Since then, only the water levels and rainfall depths have been monitored, but they are not used to predict floods. Thus, Metro Manila essentially had no operational flood forecasting system when typhoon Ondoy came. On 25 September 2009, rain started to occur at around 18:00 h lasting until 24:00 h; and on 26 September 2009 by around 03:00 h, the water level at the Sto. Niño station had reached a level of 15.27 m (Fig. 5(b)) with a level of 11.83 m in Fort Santiago (the water level gauging station closest to the river mouth near Manila Bay), but the gates at the Manggahan floodway were not immediately opened. The rains continued at around 07:00 h of 26 September, and further intensified until 12:00h. Consequently, the water rose to at least a height of 21.6 m at the Sto. Niño station, and the water level at the Rosario weir exceeded the normal level by at least 5 m, which may have caused the very deep inundation in the upper stream of EFCOS, within Marikina City.

The main gap in this situation is the absence of an effective flood forecasting system, which was due to the lack of an operational data processing system. In addition, the "breaks" or missing data in the water level graphs of Montalban, Nangka, Sto. Niño, Pandacan and Fort Santiago

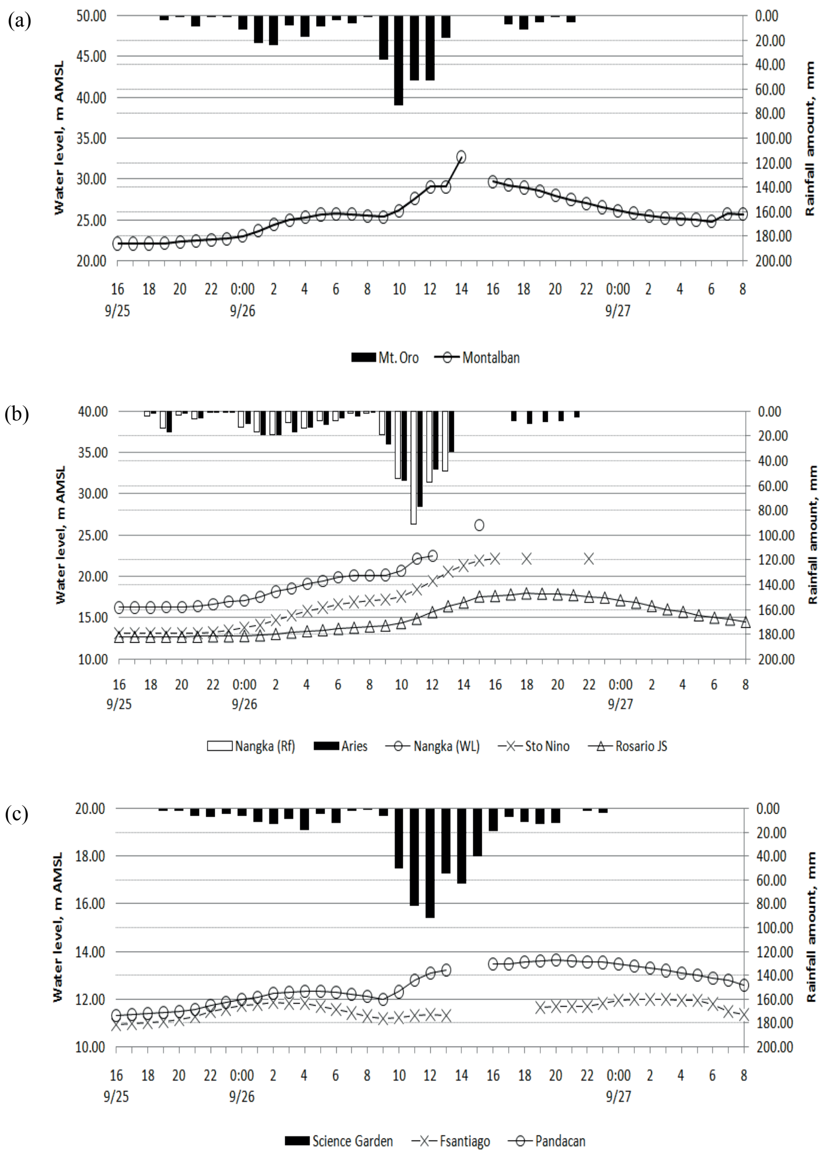

Fig. 5 Hyetographs and water level graphs representing: (a) upper stream, (b) middle stream, and (c) lower stream of the EFCOS (data Source: PAGASA, EFCOS).

stations indicate that there were interruptions in the operation of the water level sensors. Based on a key informant interview at EFCOS, these interruptions were caused by the submergence of the water level sensors during the typhoon, which indicates a gap in the planned water level monitoring operation because the sensors were not designed to be high enough to measure all of the water level increase caused by typhoon Ondoy.

The rainfall stations of EFCOS, though continuously operational, had ceased sending real-time information to PAGASA since 2006 due to a damaged link between them. This link had not been re-established before typhoon Ondoy came. Thus, a flood warning based on these data was not released by PAGASA during the storm.

Flood warning system

Flood warning systems usually go hand-in-hand with forecasting systems. In the case of Metro Manila, PAGASA issues warning information about possible flooding via the local media (i.e.

radio, television and internet). The warning released by PAGASA is usually not based on hydrological simulation. On 25 September 2009, PAGASA issued a flood bulletin for the whole of Metro Manila during typhoon Ondoy on the basis of storm warning signals (i.e. the wind speed of the storm). Accurate prediction of the location and extent of flooding was not available. Because the issuance of flood bulletins relies heavily on PAGASA, one of the gaps that need to be filled is the data processing and flood simulation capability. Although EFCOS has a built-in warning system, it is installed only along the east and west banks of the Manggahan Floodway. The EFCOS warning system consists of speakers (megaphones) and radios. These are activated when the Rosario weir is about to be opened. A message announcing the release of water is sent to all the nine warning stations along the Manggahan Floodway. However, because the EFCOS is no longer operational, the warning system was also not used during typhoon Ondoy. Clearly, the gap that exists here is the absence of an effective warning system. Advanced warning systems do not exist in other flood-prone areas; however, community-based early warning systems are adopted by some small communities as a means to cope with frequent flooding. Here, water levels of rivers are directly observed by locally-based volunteers. When the water level of a river reaches a critical height, a warning is sent throughout the community by means of megaphones, sirens and/or church bells. This practice was proven useful by several small communities during typhoon Ondoy.

CONCLUSION AND RECOMMENDATIONS

The magnitude of the rainfall deposited by typhoon Ondoy in Metro Manila was unprecedented, resulting in overwhelming floods and a tremendous amount of damage. The flood control structures of Metro Manila were rendered ineffective in preventing the devastating effects of the tropical cyclone. Further investigation on the hydraulic designs of the flood control structures that failed during typhoon Ondoy will be very useful in improving the safety levels of the drainage system and channels in the critical sub-basins of Metro Manila.

Given that the structural measures have limitations, the damages and casualties may have been reduced if there had been timely and sufficient flood warnings. The primary reason for this is that there was no reliable flood forecasting and warning system installed in the flood prone areas of Metro Manila, and there is no reliable real-time data link for rainfall monitoring between the government offices concerned. Funds must be allocated for the research and development of effective flood forecasting and early warning systems, as well as for its operation and maintenance long term. Aside from improving the infrastructure for better communication and data transfer, it is further recommended that a system be put in place that can estimate and predict the amount of rainfall within and around Metro Manila, in which the data is collected and processed by flood forecasting offices using flood simulation models. The existing flood warning system should be enhanced to provide effective dissemination of flood bulletins, especially in frequently flooded areas. Community-based flood warning systems should be strengthened and must be encouraged in all flood-prone communities. Training on emergency response should also be provided to all constituents who were affected by typhoon Ondoy.

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