6TH INTERNATIONAL CONFERENCE
ON FLOOD MANAGEMENT
September 2014 - São Paulo - Brazil

QUANTIFYING RESILIENCE TO FLOODING AMONG HOUSEHOLDS AND LOCAL GOVERNMENT UNITS USING SYSTEM DYNAMICS: THE CASE OF METRO MANILA

C.K.Gotangco[1&2], J. See[3], J.P. Dalupang[3], M. Ortiz[1], E. Porio[3], J. Dator-Bercilla[1], A. Yulo-Loyzaga[1], G. Narisma[1&4]

1. *Manila Observatory*
2. *Dept. of Environmental Science, Ateneo de Manila University*
3. *Dept. of Socio-Anthropology, Ateneo de Manila University*
4. *Physics Department, Ateneo de Manila University*

ABSTRACT: System dynamics is a flexible approach for modeling stocks, flows and feedbacks within a system and for tracing behaviors through time. In the context of flood resilience modeling, it can be used to track the loss of system performance due to adverse impacts of flooding at the onset of extreme rainfall, as well as the potential recovery of the system in time due to adaptive measures. A generic system dynamics model for resilience developed by Simonovic and Peck (2013) is adapted to analyze flooding impacts in Metro Manila cities for the socio-economic and organizational sectors. For the socio-economic sector, monetized household assets were selected as the key stock, with the expenditures and damages due to flooding as outflows from the stock, and income and relief/donations as inflows. Complementing this, the organizational sector model mainly tracks the Local Government Unit (LGU) monetized assets and resources. Similarly, damages due to flooding and spending for relief and recovery decrease the stock of resources while inflows from local and external sources (e.g. funds from the national budget or foreign aid) increase the stock. The household and LGU models are tested and used to evaluate potential adaptation scenarios that seek to make resources available for households and LGUs to build resilience.

Key Words: System dynamics, Resilience, Flooding, Metro Manila

1. INTRODUCTION

The concept of "resilience" is a broad one spanning vast literature in both the social and physical sciences. A common feature of resilience across disciplines is the ability to successfully "bounce back" from adversity, and further research has sought to characterize whether such resilience is a state (i.e. based on inherent characteristics), a process, or an outcome (Pooley and Cohen, 2010). Haimes (2009) asserts that resilience is time-dependent, and, in case of systems, requires multi-dimensional metrics to describe, measure and monitor.

Simonovic and Peck (2013) attempt to quantify resilience using a system dynamics modeling platform and the concept of system performance – i.e. resilience is manifested in the (1) ability of the system to absorb shocks, reduce negative impacts and therefore mitigate the deviation from baseline system performance; and (2) the ability of the system to quickly recover from any adverse impacts, re-establish normal system functioning, and, if possible, "build back better" and improve on the baseline system performance. A quantitative resilience index can therefore be calculated by comparing the system performance as affected by the shock or hazard with the initial or baseline system performance. This ratio can be plotted over time at the onset, during and after the hazard, and in this way, provide a means to track and compare system resilience under different conditions and scenarios.

Although developed under the department of civil and environmental engineering, the approach described by Simonovic and Peck (2013) can be adapted for systems that defined over different spatial scales, for a variety of users or sectors, and in terms of even a few key variables of that need to be monitored. This study therefore explores how the systems resilience approach can be applied to describe the dynamics within and between households and local governments. This is a component of a larger study that aims to integrate physical, social, economic and organizational sectors into a city system resilience model that can serve as a decision support tool for local governments.

Specifically, this study aims to develop this tool for the local governments of the highly urbanized National Capital Region of the Philippines, Metro Manila. Inhabited by nearly 12 million people (NSO, 2010), Metro Manila is the financial and economic center of the country comprising of 16 cities and one municipality. It is traversed by several major waterways, e.g. the interconnected Marikina River, Pasig River, San Juan River, Napindan channel, and Manggahan floodway running through the north and across Metro Manila, as well the Tullahan River and Malabon River to the northwest (UNESCAP, 1990). Metro Manila is a coastal city bounded by Manila Bay on the West, and is also proximate to the Laguna Lake in the southeast. In recent years, Metro Manila has suffered from extreme flooding events triggered, for example, by Typhoon Ketsana in 2009, and the enhanced southwest monsoon and 2012 and 2013. Aside from being exposed to typhoons on a regular basis, Metro Manila is becoming increasingly vulnerable due to the stress from a burgeoning population coupled with environmental degradation and diminishing resources. Incidences of flooding have been linked not only to physical variables such as climate and topography, but also to patterns of urban development (Zoleta-Nantes, 2000; Bankoff, 2003). With this in mind, it becomes crucial to develop a suite of tools that can capture not just the physical factors but also the socio-economic and organization factors that affect resilience and how it changes over time.

2. MODELING APPROACH

2.1 General Systems Dynamics Model

The systems resilience approach is operationalized through the use of system dynamics modeling. Systems dynamics (SD) as a field of study involves the analysis of inter-relationships among system components. SD modeling platforms typically allow for a system to be built virtually in terms of stocks, flows, input information and feedback loops. The purpose of such modeling is not so much predictive but descriptive – i.e. it is meant to explore the behavior of a particular system structure and provide insight into the underlying causes of such behavior (Meadows, 2008). In the case of resilience, the SD model is meant to help identify and analyze the components of the system that contribute to or detract from its capacity to absorb or recover from shocks.

In this study, the modeling platform used is Vensim® by Ventana Systems. Stocks, which are variables that accumulate over time, are represented by boxes, while the flows are represented by the arrows with “spigots” connected to stocks that can either add to or take away from stocks over time at a controlled rate (Figure 1). Other text and arrows provide auxiliary information and connections between variables.

The general model template representing a system is shown in Figure 1. This is adapted and simplified from the template developed by Simonovic and Peck (2013). For each system, a key stock that is affected by flooding is identified. A damage function is applied to the stock to represent adverse impacts. This function varies in time and is developed outside the SD model using climate modeling, flood modeling, and geographic information system (GIS) to analyze the intersections of the hazard, the exposed stock of interest, and the pre-existing vulnerability of that stock. Different scenarios of damage may also be developed depending on varying possibilities of physical exposure and levels of vulnerability.

Current system performance throughout the progression of a flooding event is calculated from the difference between the changes in the key stock and the effects of the adaptive capacity measures that counter adverse impacts. Adaptive capacity here is defined in terms of 4 properties: robustness (ability to resist stress), redundancy (ability to continue functioning i.e. due to presence of back-up systems), resourcefulness (ability to identify options and source out needed resources), and rapidity (ability to respond in a timely manner) (Bruneau et al., 2003 as adapted by Simonovic and Peck, 2013).

The “RHO” variable in Figure 1 represents the change in system performance. The system resilience index is basically a normalization of that parameter compared against baseline performance P_0 of that key stock at time t_0 before the onset of the hazard. The index is typically equal to 1 before the onset of the shock (since the current system performance is still equal to the baseline performance), then degrades as the flood causes adverse impacts, but then recovers through the implementation of adaptive capacity measures. The index may surpass 1 should the new system performance after recovery be better than the baseline. (For more details on the calculation for RHO and the resilience index, please refer to Simonovic and Peck [2013]).

This study focuses on the household system as a key system representing the socio-economic sector, and the LGU system as a key system representing the organizational sector of Metro Manila. The city is used as the spatial unit of analysis. While it is undoubtedly true that feedbacks exist between the 17 cities and municipality of Metro Manila in terms of impacts of flood interventions implemented (e.g. engineering measures implemented along any one of the major rivers will affect neighboring LGUs), LGUs still largely make decisions independently based on their own available resources and capacities. This is due to the devolution of administrative and regulatory powers to the LGU level, without an overall authority overseeing the planning of Metro Manila (Josol, 2013). In the context of flood risk management, for example, LGUs are responsible for the safety of their constituencies and will designate flood evacuation centers within their own political boundaries rather than considering areas in other cities. In this study, which is still largely exploratory, the scope is limited to attempting to develop the SD model for a city assumed to be independent. This is the first phase in a larger initiative, which in the future, we hope, will be able to capture the more subtle inter-dependencies among the cities and municipality of Metro Manila.

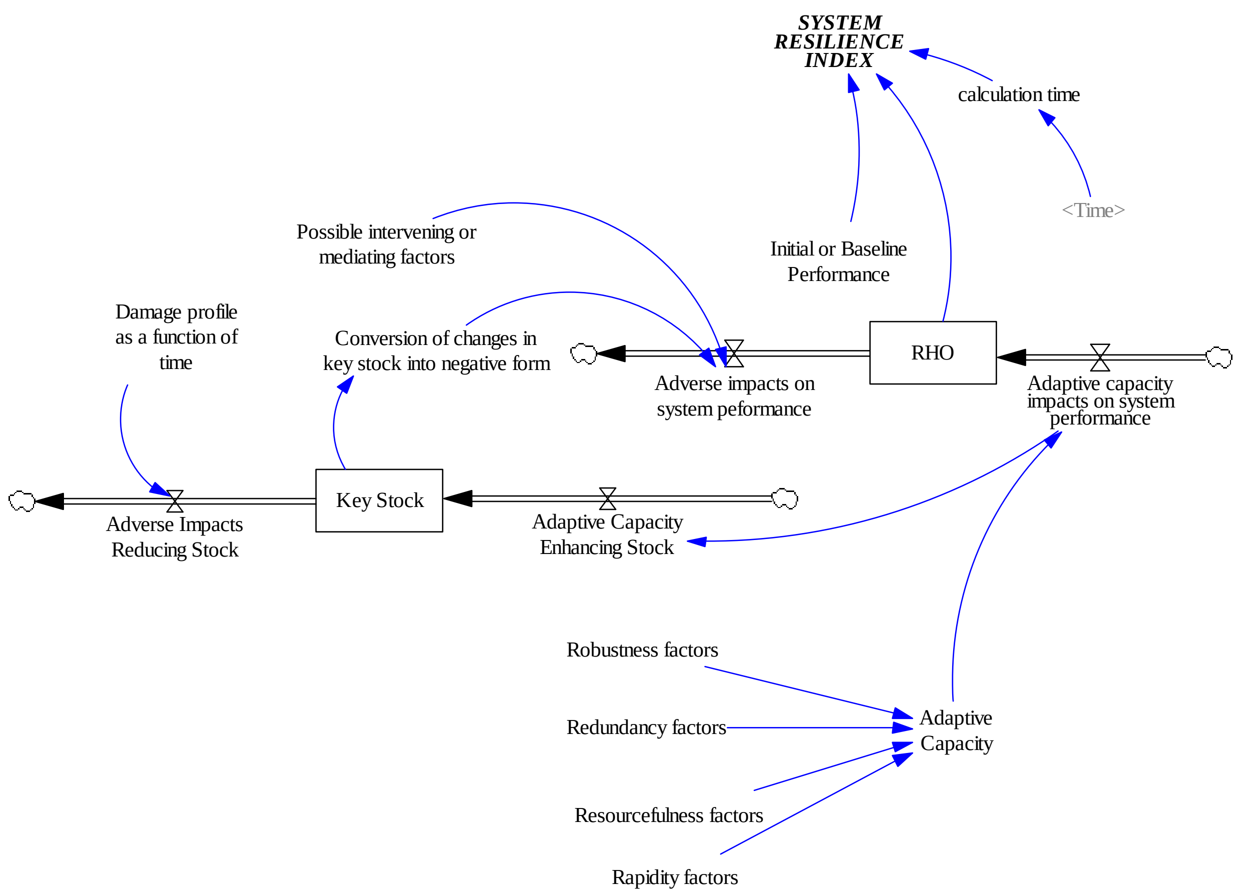

Figure 1: General System Dynamics Model Template (Adapted from Simonovic and Peck [2013])

2.2 Household Model

The household model focuses on household assets as the key stock (Figure 2). Adverse impacts and adaptive capacity are quantified in terms of losses or expenditures and income, respectively.

Under "normal" (i.e. no flood) conditions, each household already has expenditures, such as basic subsistence needs, and income, such as from regular jobs or other alternate sources. Social vulnerability factors are incorporated into subsistence needs in the sense that the average household expenses tend to increase should there be children, senior citizens, sick or differently-abled members in the household. At the onset of the flooding, loss of household assets occurs due to direct damages by the flood, expenditures to repair these damages or replace lost property, and the reduced of income due to lost workdays. However, there may be additional income from other sources (e.g. donations, loans, alternative livelihoods) that will aid households.

The four properties of adaptive capacity for the household model representing the socio-economic sector are hence defined as follows.

- Robustness – based on income derived from regular occupations of the household's working members. The rationale behind this is that having a stable source of income allows the household to provide for their basic and critical needs, and this in turn allows them to better deal with stressors.

- Redundancy – based on income derived from extra or alternative sources of income such as small, home-based "sari-sari" stores, backyard agriculture or animal husbandry and remittances from family members who are overseas foreign workers, if any. Note, however, that these alternate sources might also be damaged (e.g. in the case of small stores) or may become inaccessible (e.g. access to banks or money transfer agencies to retrieve OFW remittances) by the flooding.

- Resourcefulness – based on the additional help that can be sourced from the LGU or non-government organizations in the form on donations, relief goods or cash-for-work recovery programs.

- Rapidity – a measure of how quickly the donations from external sources reach the affected households.

The initial value of household assets before the flooding occurs serves as the baseline value for calculating deviation of system performance (i.e. loss of assets) and hence, the household's resilience index.

The model illustrated in Figure 2 is mainly based on data from surveys of low-income households but because it is possible for flooding to affect low-income, middle-income and high-income households, three versions of the model in Figure 2 can be developed to depict representative households for the three income groups. Different damage profiles can also be constructed to take into account the differences in social and physical vulnerability (e.g. due to housing construction) among the income groups. In such a case, resilience indices from the three models can be aggregated and weighted according to the exposure fractions to produce the final quantitative socio-economic household resilience index. For example, if 80% of the households affected by flooding are low-income, 20% are middle-income and none are high-income, then the final index will comprise of 80% the value of the low-income household resilience index, and 20% from the middle income.

For the case of Metro Manila, data for the household model will mostly be drawn from the survey conducted by Porio (2009) for Japan Bank for International Cooperation. The survey was conducted among 300 urban poor households in 14 communities located in the three flood basins: (1) Pasig-Marikina river basin, (2) West Mangahan, and (3) the KAMANAVA area (Kalookan, Malabon, Navotas, Valenzuela). The survey respondents came from areas that regularly suffer from the effects of rains, typhoons and tidal surges, which are mostly the swamplands and are located in low-lying areas. The pilot model simulations will aim to differentiate the households below and above the poverty line in calculating for the household resilience index.

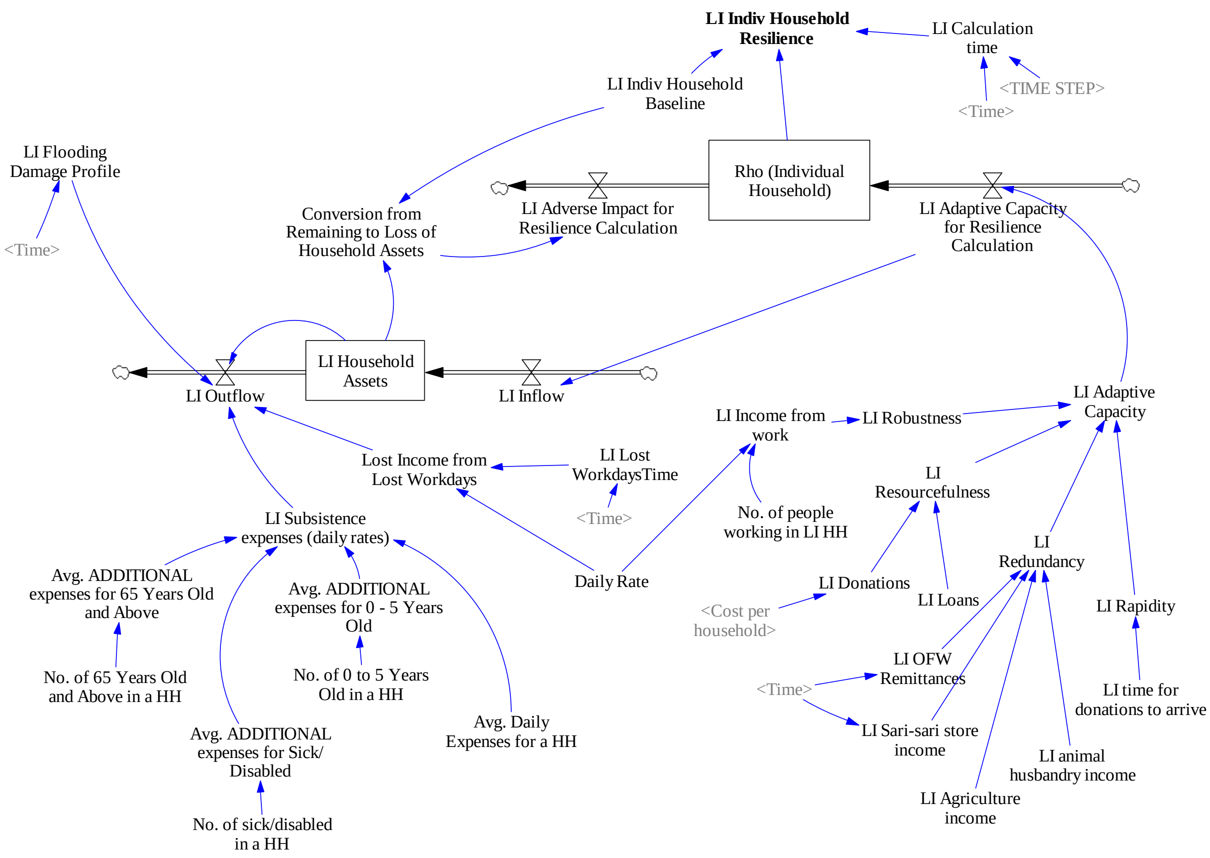

Figure 2: System Dynamics Diagram of a Low-Income (LI) Household Resilience Model

2.3 Local Government Unit (LGU) Model

In the Philippines, cities are considered a level of local government organization and have their own local plans and programs to address climate change and disasters. Several laws highlight the importance of LGUs in disaster risk reduction and management (DRRM) and climate change adaptation. The Philippine Disaster Risk Reduction and Management Act of 2010 (Republic Act (R.A.) 10121) and the Climate Change Act of 2009 (R.A. 9729, amended by the People's Survival Fund Law, R.A. 10174) mandate the state to mainstream disaster risk reduction and climate change adaptation in development processes such as policy formulation, socioeconomic development planning, budgeting, and governance. Other laws and joint memorandum circulars from national agencies also recognize and affirm the role of LGUs and communities in mitigating and preparing for, responding to, and recovering from the impact of disasters, as well as in the formulation of local action plans to deal with climate change.

In parallel with the household model, the LGU model considers LGU assets (Figure 3), both in terms of available funds as well as monetized assets, as the key stock. Adverse impacts and adaptive capacity are also quantified in terms of losses or expenditures and inflows of funds, respectively. The model deals mainly with local resources available to cities during a disaster. The 2010 DRRM Law revised the previous Local Calamity Fund into a Local Disaster Risk Reduction and Management Fund (LDRRMF) to highlight the shift from the former calamity response and rescue paradigm to a disaster risk reduction and management in order to prevent casualties. The LDRRMF provides funding for Local DRRM Plans that are formulated by Local DRRM Councils. The LDRRMF is a minimum of five percent (5%) of the regular income of an LGU. Under “normal” conditions, these regular sources of the LDRRMF come from both local (e.g. taxes) and national government sources.

Local DRRM Councils from other cities can augment this fund, provided that the receiving city has declared a state of calamity. The LGU may likewise receive additional 'income resources,' both in cash and in kind, from other sources such as the national government, local aid from non-government sources, civil society donations and foreign aid.

The model assumes that prior to the onset of flooding, the LGU is already spending their allocated funds for initiatives that help decrease the vulnerability of the city, though it is not within the current scope of the model to explicitly determine how these preparatory activities affect the LGU resilience index. Rather, these initiatives will be taken into consideration in constructing the damage profile for the LGU external to the SD model. This is a point of improvement for the current version of the model as the effect of preparatory activities, though factored into the damage profile, cannot be tested dynamically together with the effect of response and recovery activities.

Local DRRM funds are programmed annually. Thirty percent (30%) is allocated solely for a Quick Response Fund for emergency services. It can only be accessed if the LGU declares itself under a state of calamity. The remaining seventy percent (70%) of funds are used for all equipment and activities for disaster prevention and mitigation, response, rehabilitation and recovery such as, but not limited to, risk assessments, rain gauges and early warning systems, the purchase of life-saving equipment, temporary shelters, portable generator sets, among others. As per the law, unexpended LDRRMF shall accrue to a special trust fund solely for the purpose of supporting disaster risk reduction and management activities of the LDRRMCs within the next five (5) years.

At the onset of the flooding, loss of LGU assets occurs due to direct damages by the flood to public or government property, expenditures from the Quick Response Fund, expenditures to repair damages or replace lost property, and expenditures to help the constituency of the LGU with relief and recovery (Figure 3). This is where the household model and LGU model connect – in the capacity of the LGU to provide relief resources to aid households.

Based on the aforementioned legal provisions, the four properties of adaptive capacity for the LGU model representing the organizational sector are hence defined as follows.

- Robustness – based on stable inflows of funding from local and external sources on which the LGU can rely on to plan and implement policies, initiatives and activities, including disaster preparation and mitigation programs.

- Redundancy – based on the additional resources that can be channeled from the national government or other LGUs, if the latter is available.

- Resourcefulness – based on additional help that can be sourced from local non-government organizations, international non-government organizations and foreign governments.

- Rapidity – a measure of how quickly resources can be made available and mobilized.

As with the household model, the level of LGU assets before the flooding occurs serves as the baseline value for calculating deviation of system performance (i.e. loss of assets) and hence, the LGU’s resilience index. This baseline value includes all equipment, trainings and activities for preparedness as monetized assets.

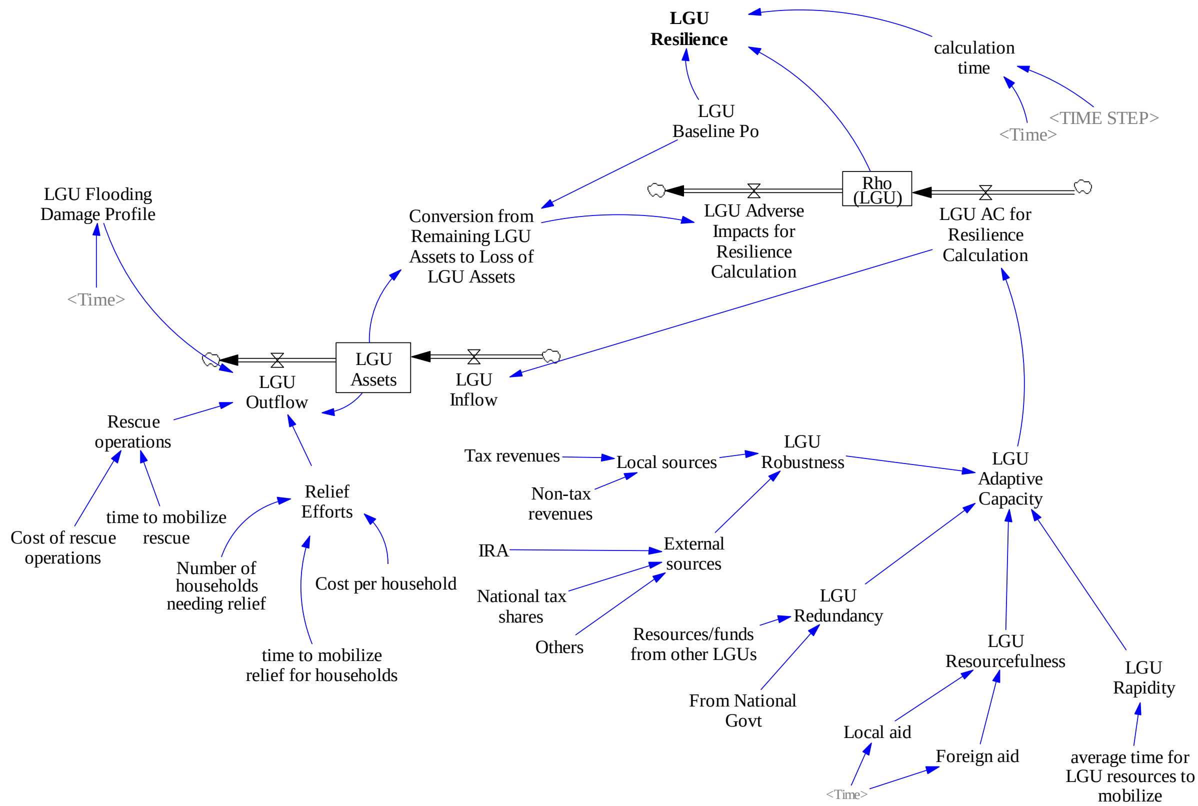

Figure 3: System Dynamics Diagram of LGU Model

For the case of Metro Manila, data for the LGU model will mostly be drawn from the Budget and Planning Offices of cities. These offices prepare and develop the budgets for all local programs, plans and actions. Specific sources of data will be cites' Annual Investment Plans, Local Development Investment Plans and Local DRRM Plans. There is also a need for consultations and key informant interviews to determine what other local assets contribute to the LGU's capacity to respond to the needs of its constituents in times of disaster and also in preparation for climate change.

Meanwhile, the People's Survival Fund will provide at least one billion Philippine pesos for local governments to access for climate change adaptation actions. However, this fund has not yet been mobilized for implementation of local climate change action plans.

3. PRELIMINARY TESTING AND FUTURE STEPS

Preliminary testing purely for the structure of the joined Household-LGU model was conducted. At this stage, using dummy values as input sufficed simply to test if the expected plots of resilience indices would be attained. A one-week major flooding event was assumed. The model was run on the order of days, with time-stepping on the order of a fraction of a day (0.0625 days).

Figure 4 plots the individual household resilience index and the LGU resilience index over time. Both curves exhibit the same behavior, which is the decrease in the resilience index in response to shocks, followed by a slow recovery that is not completed within the span of one month. These plots are aligned with the expected trends as explained in Simonovic and Peck (2013), which indicates that the SD model development is proceeding on the right track in terms of system structures.

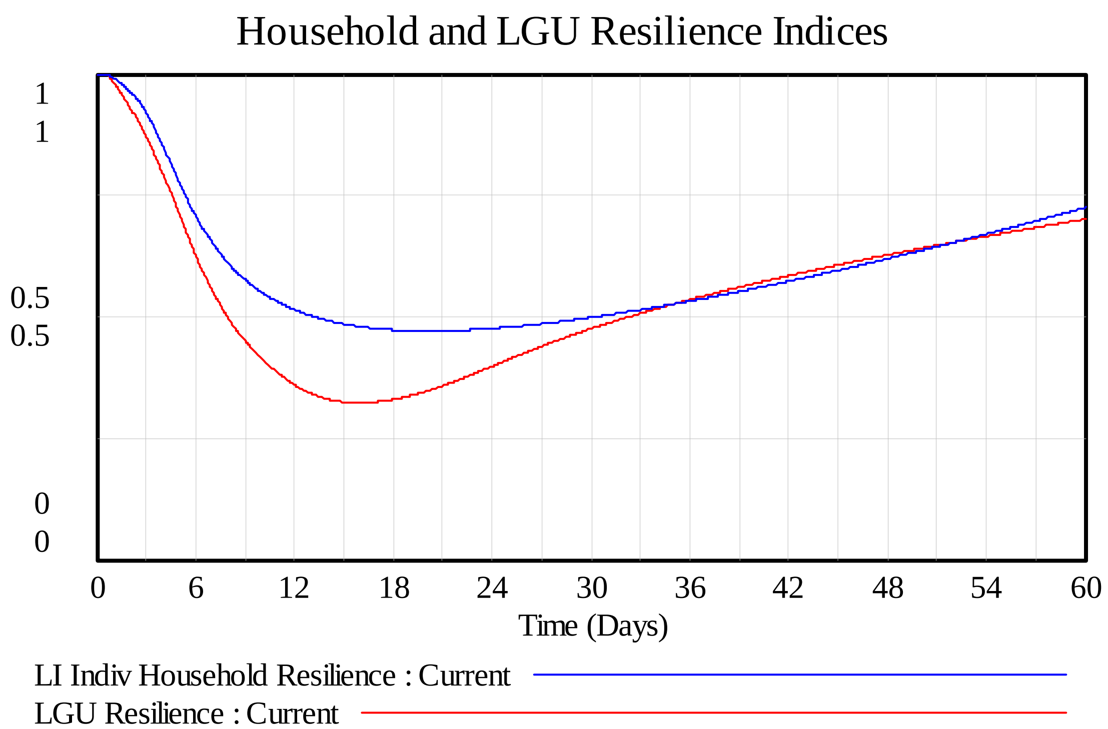

Figure 4. Plots of the (Low-income) Individual Household Resilience Index (blue line) and the LGU Resilience Index (red line)

Future work on the models will be concerned primarily with replacing the dummy variables with actual values based on historical data from the sources mentioned in sections 2.2 and 2.3. The model will be developed for Quezon City, Marikina City and Pasig City, which are all connected by river systems.

In parallel with adapting the model for specific cities, future work will also explore additional refinements to the existing model structures presented in Figures 2 and 3. Although the models were already designed with an initial scoping of available data in mind, not all the cities of Metro Manila may consistently have the same quantity and quality of data. Thus, models structures may still be simplified based on data availability. Other aspects, however, may be disaggregated further, if needed, to capture the dynamics of the system, particularly, the rapidity aspect. If data is available, the rapidity aspect may be differentiated according to the different response times of various groups such as the LGUs vs. non-profit and non-government organizations vs. foreign organizations.

Once the household and LGU resilience models have been finalized, these will be combined with models of other sectors which are being developed separately (e.g. health sector) into an overall resilience model with an aggregated resilience index for a specific city.

4. ACKNOWLEDGEMENTS

This study is being implemented under the project “Coastal Cities at Risk (CCaR): Building Adaptive Capacity for Managing Climate Change in Coastal Megacities.” CCaR is funded by the International Development Research Centre (IDRC) together with the Canadian Institutes of Health Research (CIHR), the Natural Sciences and Engineering Research Council of Canada (NSERC), and the Social Sciences and Humanities Research Council of Canada (SSHRC), under the International Research Initiative on Adaptation to Climate Change (IRIACC).

5. REFERENCES

Bankoff, G., 2003: “Constructing vulnerability: The historical, natural and social generation of flooding in Metropolitan Manila.” *Disasters* 27, 95-109.

Bruneau, M., S.E. Chang, R.T. Eguchi, G.C. Lee, T.D. O’Rourke, A.M. Reinhorn, M. Shinozuka, K. Tierney, W.A. Wallace, and D. von Winterfeldt, 2003: “A framework to quantitatively assess and enhance the seismic resilience of communities.” *Earthquake Spectra* 19:4, 733- 752.

Haimes, Y. Y., 2009: “On the Definition of Resilience in Systems.” *Risk Analysis* 29, 498–501. doi: 10.1111/j.1539-6924.2009.01216.x.

Josol, J.C.. 2013: *Developing a physical hazard index model of Metro Manila for climate change and disaster risk management (CCA-DRM) using a system dynamics approach*. A Master’s Thesis submitted to the Department of Environmental Science, Ateneo de Manila University, Philippines.

Meadows, M., 2008: *Thinking in Systems: A Primer*. Sustainability Institute, Chelsea Green Publishing, White River Junction, Vermont, USA.

National Statistics Office (NSO), 2010: *Population by Region.* Available online at: http://nscb.gov.ph/secstat/d_popn.asp. Last accessed: 18 April 2014.

Pooley, J.A, and L. Cohen, 2010: "Resilience: A definition in context." *Australian Community Psychologist* 22:1, 30-37.

Porio, E., 2009: “Vulnerability, Adaptation, and Resilience to Flood and Climate Change Related Risks Among Riverine Communities in Metro Manila.” *Japan Bank for International Cooperation.* Ateneo de Manila University, 15 July 2009.

Simonovic, S. and A. Peck, 2013: *Coastal Cities at Risk (CCaR): Generic System Dynamics Simulation Models for Use with City Resilience Simulator*. Report No. 083, Dept. of Civil and Environmental Engineering, University of Western Ontario, Canada. Available online at: http://www.eng.uwo.ca/research/iclr/fids/publications/products/83.pdf. Last accessed: 18 April 2014.

United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP), 1990: *Urban Flood Loss Prevention and Mitigation*. United Nations, Economic and Social Commission for Asia and the Pacific, Bangkok.

Zoleta-Nantes, D., 2000: “Flood hazards in Metro Manila: Recognizing commonalities, differences and courses of action.” *Social Science Diliman* 1:1, 60-105.