

# Improving predictions of the effects of extreme events, land use, and climate change on the hydrology of watersheds in the Philippines

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**Abstract.** Due to its location within the typhoon belt, the Philippines is vulnerable to tropical cyclones that can cause destructive floods. Climate change is likely to exacerbate these risks through increases in tropical cyclone frequency and intensity. Thus, robust hydrological modelling are needed to protect populations and infrastructure. The main aim of this research is to assess the effect of climate change, extreme events, and changing land use on the hydrological response of the Cagayan de Oro watershed in southern Philippines (1400km<sup>2</sup>). This was done by applying the following models: the Land Utilisation and Capability Indicator (LUCI) for ecosystem services and watershed modelling, the Hydrologic Modeling System (HMS) for watershed modelling, and the River Analysis System (RAS) for inundation modelling. The preliminary results of this study are presented in this paper: initial LUCI results and ecosystem services maps, and indicative HMS and RAS results of storms of different return periods. The wider implication of this study is to support proactive flood risk management through understanding the potential impacts of changing land use on watershed hydrological response, and embedding this knowledge in operation models that can assist with decision-making.

## 1 Introduction

The Philippines is regularly struck by tropical cyclones. An annual average of 20 entering the Philippine Area of Responsibility, of which about nine make landfall and often cause destructive floods (Lasco et al., 2009). In 2011, Typhoon Washi caused heavy flooding and destruction in the Cagayan de Oro region, leaving 1,268 casualties and PHP 2 billion in damages (~USD 46 million in 2011) (National Disaster Risk Reduction Management Council, 2014). Since the Philippines is located within the typhoon belt, the country is vulnerable to the effects of climate change due to possible increases in typhoon frequency and intensity (Intergovernmental Panel on Climate Change, 2012). The vulnerability of the country to tropical cyclones and climate change underscores the need for more proactive disaster risk management. The official programme of disaster mitigation in the Philippines is Project NOAH (Nationwide Operational Assessment of Hazards). This programme mainly uses two models from the Hydrologic Engineering Center (HEC): the Hydrologic Modeling System (HMS) for watershed modelling, and the River Analysis System (RAS) for inundation modelling (Brunner, 2010; Scharffenberg, 2013). Project NOAH uses these models for real-time flood forecasting and makes information such as flood hazard maps available on a public website (Santillan et al., 2013). These models have also been used to analyse the watershed response to extreme events and changing land use, estimating peak flow and occurrence time, and modelling the floodplain inundation (Abon et al., 2011; Mabao & Cabahug, 2014; Santillan, 2011). Although these models can assist in decision-making through running different land use scenarios, they do not identify areas to target for potential management interventions.

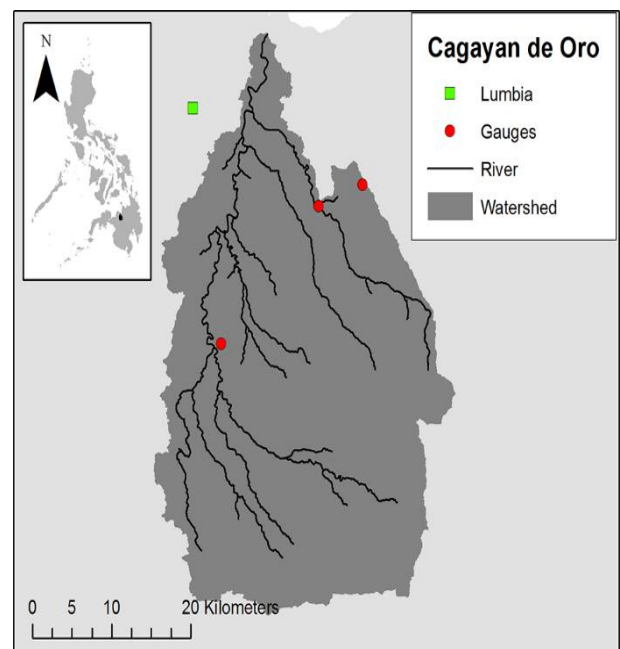


Figure 1. Map of the CDO watershed, river, and rain gauges.

It is important to guide rehabilitation efforts to areas that have the most potential to benefit from management interventions. Reforestation activities in the Cagayan de Oro (CDO) watershed (Fig. 1) tend to occur in easily-accessible areas, which may not be the most important area to target (Center for Environmental Studies and Management, 2014). This research will apply a model developed to aid in scientifically-sound decision-making regarding land management. It will use the Land Utilisation and Capability Indicator (LUCI) model to identify areas providing ecosystem services, trade-offs between services, and impacts of changing land cover (Jackson et al., 2013). This application can contribute to decision-making in the CDO watershed because LUCI identifies areas where management interventions can enhance or degrade ecosystem services. This type of ecosystem services modelling has not been carried out in the watershed, and LUCI's ability to identify priority areas can be a great help to more sustainable land management in the Cagayan de Oro watershed. This research is also the first application of the LUCI framework to a tropical catchment, which will allow testing of how well the model is able to represent hydrological processes in such regions.

By comparing the LUCI model and the HEC models, this research can help identify how these models complement each other, and how LUCI can contribute to disaster mitigation research in the Philippines. The main aims of this research are: (1) to apply the LUCI model to the Cagayan de Oro catchment to help identify priority areas for land management; (2) assess how the hydrological response of the watershed changes under different scenarios of land use, extreme events, and climate change; and (3) identify the models' strengths, weaknesses, and possible areas of synergy.

## 2 Methodology

An overview of the methodology is shown in Fig. 2. The models were assessed to understand their different input requirements and their representation of hydrological processes, and to identify where they can complement each other. The watershed and floodplain model in HMS and RAS were made and parameterised by the Disaster Risk and Exposure Assessment for Mitigation Program (DREAM) (2015). Thematic datasets of land cover, soil, and topography were gathered from various sources and at different scales (local, national, global). Land cover and soil parameterisation for LUCI was carried out through gathering information from existing soil maps and database, from soil pedotransfer functions, or from soil models such as the Soil Water Characteristics model (Saxton and Rawls, 2006). Different scenarios were formulated based on the following:

- Land use changes to reflect management interventions based on LUCI output, management plans, improving mitigation services, or maintaining the status quo
- Extreme events with different return periods, and events influenced by climate change

As this research is still in its preliminary stages, the soil and land cover parameterisation was carried out for the datasets used by the DREAM Program, which were at the local level. These datasets were used to produce ecosystem services and tradeoff maps in LUCI.

In HMS and RAS, extreme events of different return periods (5, 10, 25, 50, and 100-year) were modelled. The scenario rainfall data came from two different rain gauges: the Cagayan de Oro gauge and the Lumbia Airport gauge. Based on the gauge's long-term record, the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) compiled rainfall-intensity-duration-frequency data that was converted into hyetographs that were the input to HMS (DREAM, 2015). The output hydrographs from HMS were then put into RAS for inundation modelling, and the resulting inundation maps were prepared in ArcMap 10.2.2.

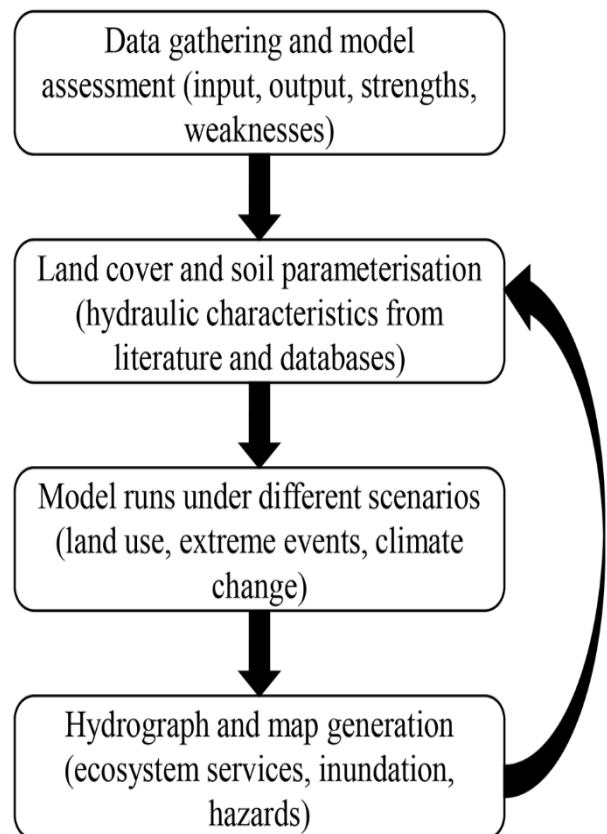
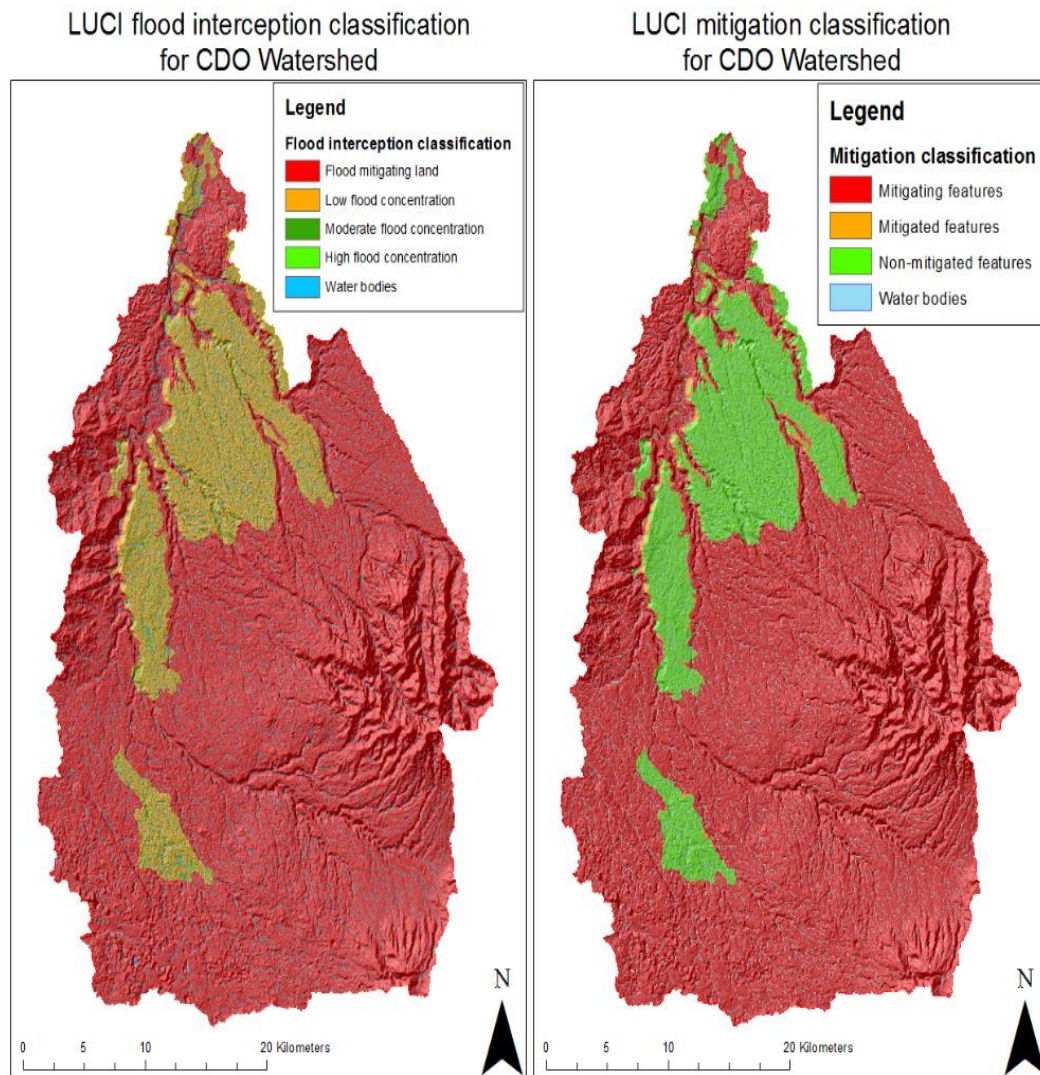


Figure 2. Methodology of the study.

The dataset shown used in the HMS watershed model from DREAM (2015), and was chosen for the initial soil parameterisation in LUCI. The local soil names were correlated with the USDA soil taxonomy (Carating et al., 2014). In order to calculate the soil hydraulic parameters, textural information for each subgroup was taken from the National Cooperative Soil Survey Classification Database (NCSSCD) and used as input for the Soil Water Characteristics (SWC) model (NCSS, 2015; Saxton & Rawls, 2006).

**Table 1. Example of soil parameters derived from SWC using the sand and clay percentages.**

Local name	USDA subgroup	Sand (%) weight)		Silt (%) weight)		Clay (%) weight)		Wilting point (% volume)	Field capacity (% volume)	Saturation (% volume)	Available water (cm/cm)	Saturated hydraulic conductivity (mm/hr)
Adtuyan (clay)	Typic Paleudults	Min	1.9	Min	2.2	Min	0.3	18.1	31.6	46.1	0.14	7.77
		Max	82.3	Max	73.5	Max	68					
		Avg	39.51	Avg	32.56	Avg	27.94					



**Figure 3. Flood interception and mitigation classification for the CDO watershed.**

Figure 3 shows the initial LUCI results for the study site for the ecosystem service of flood mitigation. The red areas are those providing good flood mitigation, meaning that any land management changes are likely to adversely affect that service. The other colours indicate areas that can be targeted for possible management interventions. Specifically, green areas of flood interception represent areas where management interventions could possibly improve flood mitigation services.

This first model run helped identify two aspects that need improving: soil and land cover parameterisation. The soil hydraulic properties were predicted from soil particle sizes taken from a United States soil database and may not reflect the actual conditions in the watershed. The next step in this LUCI application is refining the soil parameterisation by using data from other soil databases, and comparing the parameterisation with soil survey results from the watershed. Similarly, the land cover parameterisation can be improved by identifying the specific land use. For example, an area identified as grassland in the Philippines may have a different hydrological response to the grassland classification in LUCI, which was developed in more temperate climates.

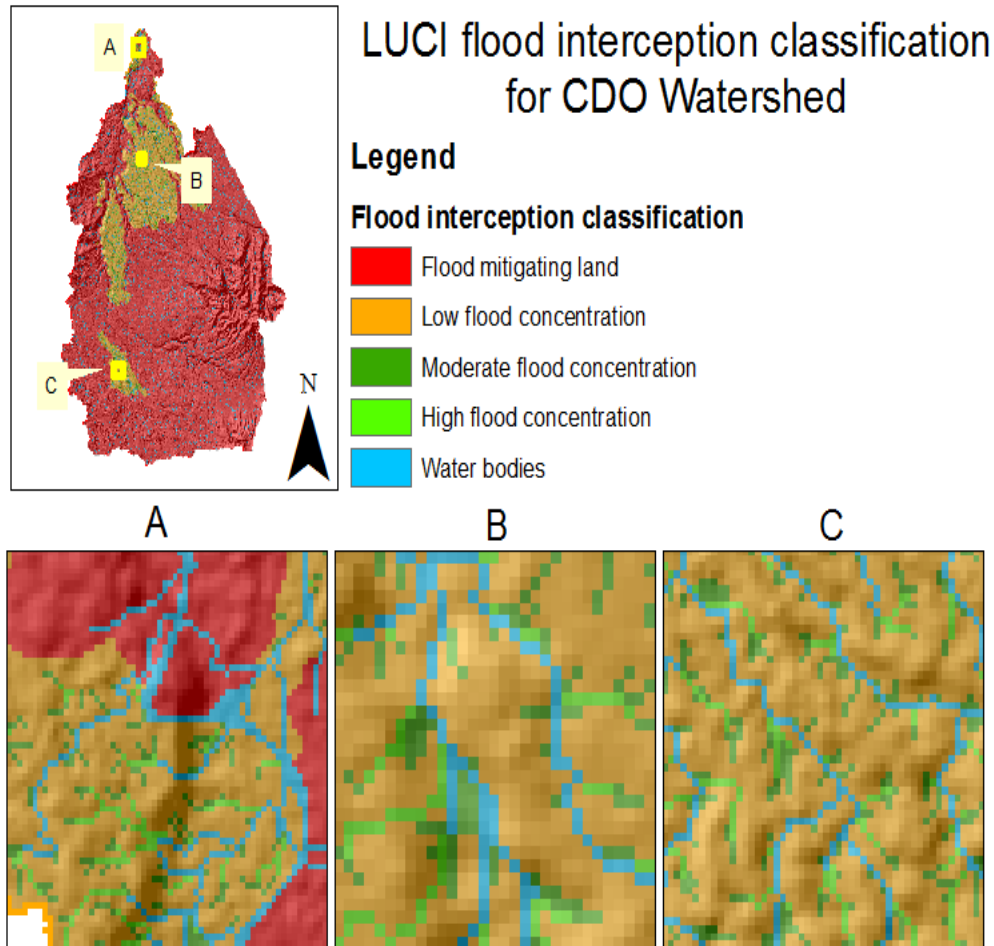
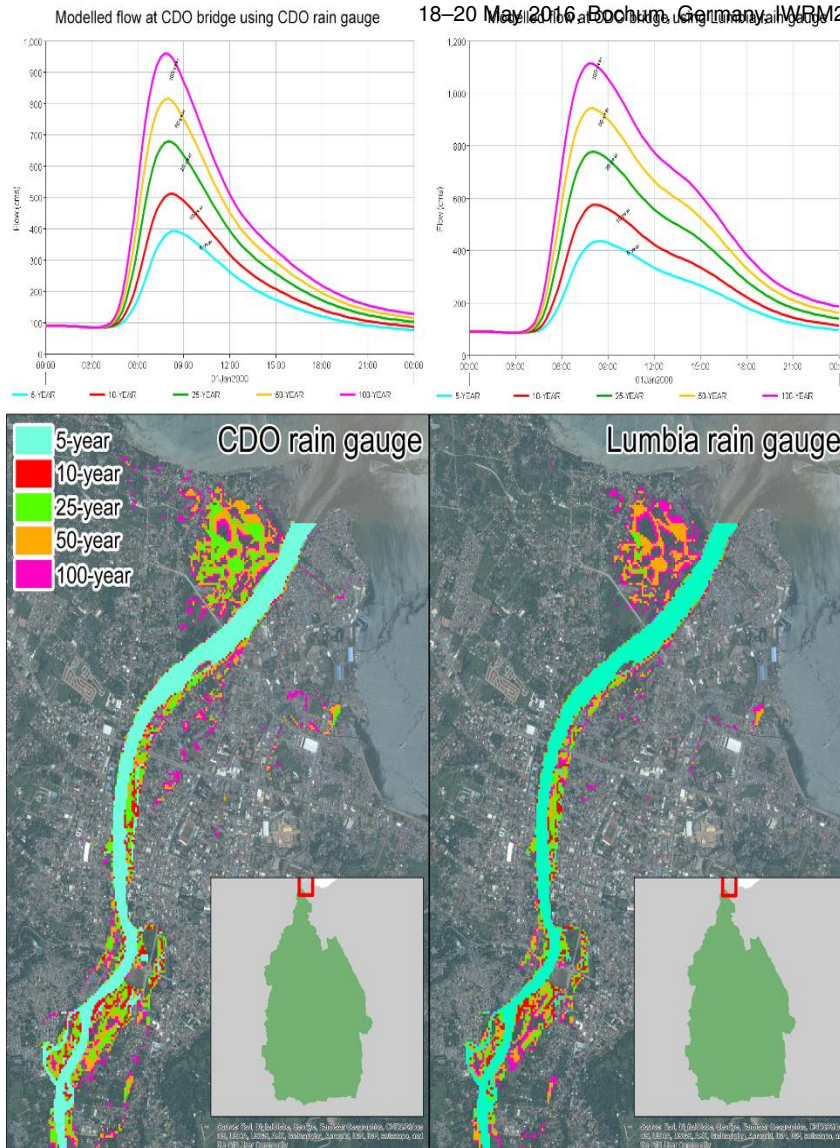


Figure 4. A zoom of some areas of the watershed to show flood interception at a smaller scale.

At the watershed scale, the green areas or areas that are possible targets for management interventions are not immediately obvious. Figure 4 shows that the model has identified possible areas for management interventions at the smaller scale, identifying areas where flow accumulates before streams and rivers. Based on the initial LUCI result, small-scale and targeted management efforts have the potential to be more useful to improving flood mitigation services than choosing large portions of land for reforestation. This is important because the limited funding for watershed rehabilitation was one of the problems identified in the development of the watershed management plan (CESM, 2014). As the soil and land cover parameterisation in LUCI is refined and iterative model runs are done, this application can produce a much clearer picture of priority rehabilitation areas in the watershed and be used to assess the potential result of the local government's rehabilitation plans.





**Figure 3. Hydrographs and inundation extent maps under different return periods, using scenarios from the CDO rain gauge and the Lumbia rain gauge.**

Figure 3 shows the hydrographs and inundation maps from HMS and RAS under different rainfall scenarios, using rainfall data from the CDO and Lumbia rain gauges.

Typhoon Washi brought 180mm of rain within 24 hours (NDRRMC, 2014). From the CDO and Lumbia records, this corresponds to a 20-year or 15-year storm respectively. The estimated discharge of Washi was 2,500m<sup>3</sup>/s with a water level of 9.86m (Mabao and Cabahug, 2014). Another study estimated Washi to be a 57-year storm with a modelled discharge of 4,925m<sup>3</sup>/s (Japan International Cooperative Agency, 2014). However, under the 25-year scenario using both sets of rain gauge data (Fig. 3), the maximum flow is 778.1m<sup>3</sup>/s for the CDO data and 680.3m<sup>3</sup>/s for the Lumbia data. Even under the 100-year scenario, the maximum modelled flow rates are 1,113.5m<sup>3</sup>/s (CDO) and 960.6m<sup>3</sup>/s (Lumbia).

The differing results in the Washi scenario brings up the questions of how well the model is able to represent real-world hydrological processes and watershed response, and the accuracy of the derived rainfall scenarios based on one or two rain gauges. The current HMS model configuration uses the Curve Number

method, which assigns a number to each sub-basin that will influence how much rainfall becomes runoff. Since LUCI is able to perform its watershed modelling at a scale finer than the sub-basin, its hydrograph output will be compared with the output of HMS. This will be done to help in improving model parameterisation to better represent the physical thresholds and hydrological processes in the watershed.

## 5 Conclusions and Further Research

Given the vulnerability of the Philippines to typhoons and their resulting floods, it is important to invest in proactive measures for disaster risk mitigation. Two of the ways this can be done is through robust hydrological modelling for flood forecasting, and through making environmentally-sound land management decisions. Based on the initial LUCI results, the priority areas identified were small areas immediately adjacent to the streams and rivers. This suggests that the small-scale targeted rehabilitation approach may be more useful to improving flood mitigation compared to reforestation large areas within the watershed. The next step for this research is to refine the soil and land cover parameterisation in LUCI to produce more accurate maps that better reflect the hydrological conditions in the watershed, and are more accurate in identifying specific areas for management interventions. By comparing LUCI and HMS under the same scenarios, this research helps assess how the models predict watershed response and how LUCI fits into the bigger picture of land management within the watershed. This research is only in its preliminary stages but by applying LUCI to the Cagayan de Oro watershed, the model

can help identify priority areas for management interventions to enhance ecosystem services, or areas for protection. The bigger picture of this research is being able to use computer models to make better land management decisions, accurately predict floods, and thus protect people and infrastructure.

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