Mindanao Journal of Science and Technology Vol.12 (2014) 129-146

Land Cover Changes and Flood Dynamics in the River Basin of Tanay, Rizal, Philippines

Romeo C. Pati
College of Agriculture
University of Rizal System
Sampaloc Tanay, Rizal, Philippines
rcpati2004@yahoo.com

Date received: April 14, 2014
Revision accepted: July 15, 2014

Abstract

The interaction of land cover changes and the flood were examined using simulation and land cover change analysis. Hydraulic Engineering Center – River Analysis System was used to simulate the flood flow using the derived hydrograph under different land cover scenarios in the flood plain of the river. The hydrograph of the river networks were simulated using rainfall data and watershed characteristics as input to the Hydraulic Engineering Center –Hydrologic Modelling System. The model was calibrated using the measured water depths and discharge of the river cross-section. The watershed is dominantly covered by orchard plants and grasses with an area of about 2286.68 and 1157.4 ha, respectively. Flood simulation predicted the flood depths and delineated the spatial extent of flooding in the flood plain of the river for the different land cover. Approximately 16.4 ha can be saved from flooding if the grasslands in the upper portion of the watershed are reforested. The major environmental adaptive measures that need to be done are the development of a comprehensive community-based rehabilitation and management of Tanay watershed and the protection of the remaining watershed of the area.

***Keywords**:* flood mapping, hydrograph, land cover analysis

---

1. Introduction

Typhoon-induced flooding is among the most commonly occurring natural disasters in the world (Razi, *et al*., 2010). A ten-year study of the extreme flood disasters in the world from 1950 to 1998 revealed that the number of flood events increased almost three-fold (Loster, 1999). This is also observed in the country during the last 5 years. Philippines have been identified as one of the most vulnerable country in Southeast Asia due to its high exposure to cyclonic storms and floods (Yusuf and Francisco, 2009).

It is expected that the magnitude and frequency of flooding in many parts of the country will increase due to the unequivocal effect of global warming. This contributes to an increase in flood hazard triggered by an extreme rainfall. The flood events induced by intense rainfall in the provinces of Rizal, and Laguna in 2011, Zamboanga, Samar and Leyte in 2013, are indicative of this projection.

One of the common features of the areas that have been affected by flooding is the changes in land-use and land cover over the past years. These areas have suffered from extensive deforestation. This resulted to a change in the hydrologic pattern in the area and caused negative impact downstream (Chomitz *et al.*, 2007). Deforested watershed cannot regulate water flows of rivers and streams. The high rate of flood flow induces higher rate of soil erosion, thus, silting water courses, and other bodies of water (Chomitz *et al.*, 2007). With a smaller 'tree fountain' effect, soil may absorb lesser amount of water causing higher run off rate (Chomitz *et al.,* 2007).

Vegetation plays an important role in infiltration and slows the movement of runoff, allowing more time to seep into the ground (Melching, 1995). The surface soil layer in a forest or a pasture generally has greater infiltration capacity than a compacted soil surface (Giertz *et. al.*, 2006). Changes in land cover from woodland to agricultural land also lower the infiltration rate of the soil (Giertz *et .al*, 2006).

The massive alteration of land cover in the watershed of Tanay is thought as one of the contributing factors to heavy flooding in the low-lying areas of the town during the typhoon Ondoy. Seven barangays were flooded leaving more than 50 fatalities and thousands of affected families. A study that examines the effect of land cover on the flood dynamics is needed to identify the areas that need protection and reforestation to reduce flooding.

Quantification and prediction of the effects of land cover changes in the dynamics of flood is helpful in risk mitigation and policy making. Watershed development plan can be created and policies can be passed into law to better protect the environment.

To help mitigate the impact of flooding, a study was conducted to analyze the effects of land cover changes on the flood regime of the river basin in Tanay, Rizal.

2. Methodology

2.1 Land Cover Assessment

The land cover of the study area was derived using the latest land satellite image and other thematic maps of the area using unsupervised classification tool of the IDRISI software. Ground truthing was undertaken to verify the veracity of the derived land cover of the watershed. Corrections and adjustments were also performed to capture the present land cover of the area.

2.2 Identification of the Priority Areas for Rehabilitation and Reforestation

The areas that can be reforested were determined based on their present land-use and their potential as reforestation area. Field surveys were conducted to assess the condition of the different area. The potential areas that can be reforested were delineated using the information obtained during the field survey. Consultation with the Municipal Environment and Natural Resources Officer was also undertaken to validate the areas that can be reforested.

2.3 Peak Flow Hydrograph Simulation

The peak flows in the different river network were simulated using Hydrologic Engineering Center Hydrologic Modelling System (HEC-HMS) software (Figure 1). It is a generalized modelling system capable of representing many different watersheds.

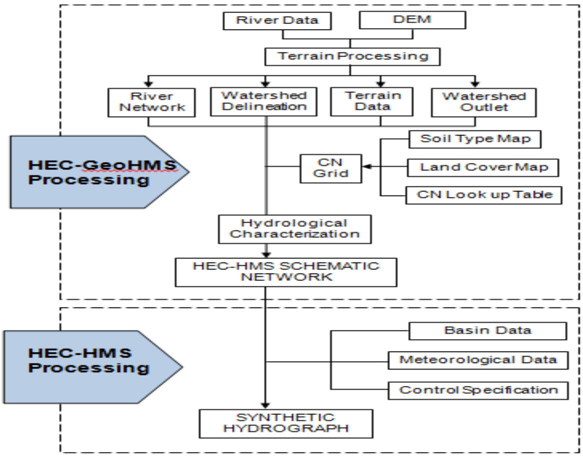

Figure 1. Flowchart for the synthetic hydrograph modelling (Maidment 2002)

The program constructs the model of the watershed by separating the hydrologic cycle into manageable pieces and constructing boundaries around the watershed. A mathematical model is developed for each energy flux and used by the program in simulating the dynamics of water flow (Zorkeflee, *et al.*, 2009). The software covers the hydrologic analysis procedures such as event infiltration, hydrologic routing and derivation of unit hydrograph (USACE, 2009).

The hydrologic data needed in the simulation was processed using the HEC-GeoHMS extension of the ARCGIS. Using its terrain pre-processing tool the terrain data, river data, subbasin and watershed boundaries were processed using a 30m resolution Digital Elevation Model (DEM) of the area. The terrain pre-processing performs a preliminary analysis of the terrain and prepares the dataset for further processing (USACE, 2009).

Using the created data in terrain pre-processing, the basin processing was used to extract the aggregated subbasins of the watershed including the spatial data needed in hydrologic modelling. The output is the basin characteristics such as the river length and slope, the basin centroid and the longest flow path (USACE, 2009).

The Curve Number (CN) grid was also derived to estimate the total storm runoff from total storm rainfall. It estimates the channel runoff, surface runoff, and proportion of subsurface runoff. It was processed using the technique developed by the Soil Conservation Service (SCS) of the United States Department of Agriculture (USDA) (Ponce, 1996). The data inputs are the soil type map, land cover of the watershed and a look-up table (Table 1).

Table 1. Curve Number look-up table and land cover description.

Object ID	LUV Value	Description	Hydrologic Soil Group			
			A	B	C	D
1	1	Water Bodies	100	100	100	100
2	2	Annual Crops	67	77	83	87
3	3	Orchards	43	65	76	82
4	4	Grasslands	49	70	80	87
5	5	Forests	30	58	71	78
6	6	Residential	57	72	81	86

The CN grid together with the derived hydrologic and watershed data were used to create the schematic network that contains the hydrologic characteristics of the watershed. The network was imported in the HEC-HMS for the simulation of the flow hydrograph of the different river reaches.

A 3-hourly rainfall data (80 mm total rainfall) of the February 22 thunderstorm obtained at the PAGASA synoptic station located within the watershed was used as input in calibrating the model. This was done by comparing the computed peak flow of the selected river reach with the simulated peak flow of the hydrograph. The peak flow was computed using the measured water velocity and cross-section of the river.

2.4 Flood Modelling and Assessment

Hydraulic Engineering Center – River Analysis System (HEC-RAS)was used to simulate the water elevation during a storm event using physiographic factors such as river cross-section, slope, type of river embankment, and the flow hydrograph of the river (Figure 2).

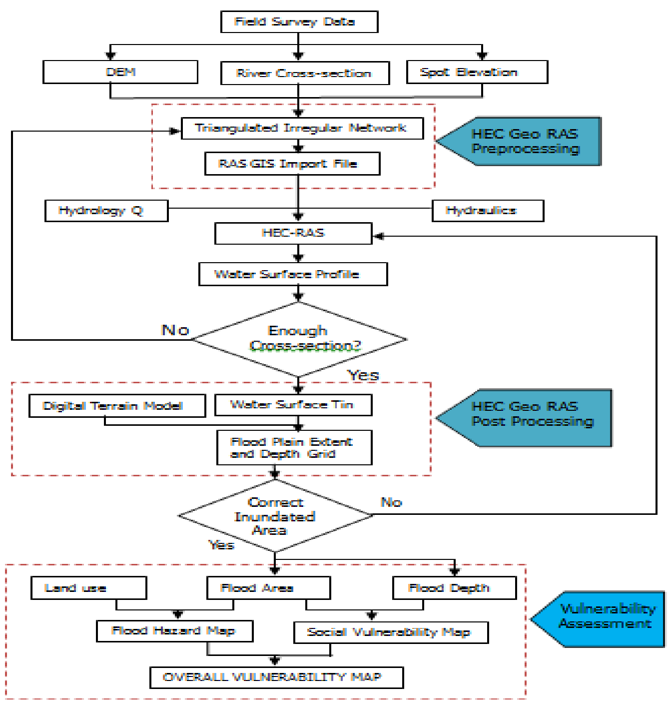

Figure 2. Flow chart for the flood mapping (Maidment, 2002)

Prior to modelling, the data were processed using the HEC-GeoRAS extension of the ARCGIS. The DEM of the watershed was first converted to Triangulated Irregular Network (TIN). The surveyed river data were overlaid in the TIN and used to extract the river geometric data such as river center line, river cross-section cutlines and flow paths.

Cross-section cut lines were used to extract the elevation data from the TIN of the area. The extracted elevation was used in creating the ground profile across the channel flow. Creating an adequate number of cross-sections to produce a good representation of channel bed and flood plain is ensured by following the prescribed guidelines in the HEC-RAS Users' Manual.

Before importing to HEC-RAS, checks were done to ensure that the needed data contain the TIN of the study area, the required layers tab containing the River, XSCutLines and XSCutLines3D for Stream Centerline, XS Cutlines and XSCutlines Profiles. The data that was imported was carefully verified for consistency with the data that was created in HEC-GeoRAS. After verification, the profile of the river cross-section was manually created in HEC-RAS using the Geometric Data Editor. River cross-section elevations were entered in the river cross-section window and were further edited to match the measured cross-section in the graphic Cross-section cutline Editor. Manning's roughness coefficients were likewise manually entered in the Editor. The peak values of the simulated hydrographs were also inputted in the Steady Flow Data Editor. Finally, the simulation was executed by clicking the Compute button (USACE, 2002).

A RAS export file was created and re-imported in ARCGIS. A flood hazard map was generated using the simulated water elevation. It was classified according to its potential to flooding. The classifications along with their corresponding depth are as follows:

Low	0.20 to 0.59 m	Moderate	0.60 to 1.49 m
Extreme	1.50 to 3.5 m	Very Extreme	3.55 and above

2.5 Model Calibration

A calibration area was set several meters after the intersection of the major river reaches. The level and velocity of water were measured every hour for the duration of the thunderstorm.

The model was calibrated by comparing the simulated depth and measured depth during the February thunderstorm. The computed peak discharge and the simulated peak discharge of the hydrograph were also compared.

3. Results and Discussion

3.1 Present Land Cover of the Area

The dominant land cover of the watershed is the orchard agro-ecosystem (Figure 3). The plants that commonly grow are mango, banana, coconut and other fruit bearing trees. It has a total area of about 2286.68 ha. Grassland is next with a total area of 1157.40 ha. The agricultural production areas are mostly planted with rice, corn, vegetables and root crops such as cassava is 230.02 ha. The residential areas are the lowest with an area of 212.59 ha (Table 2).

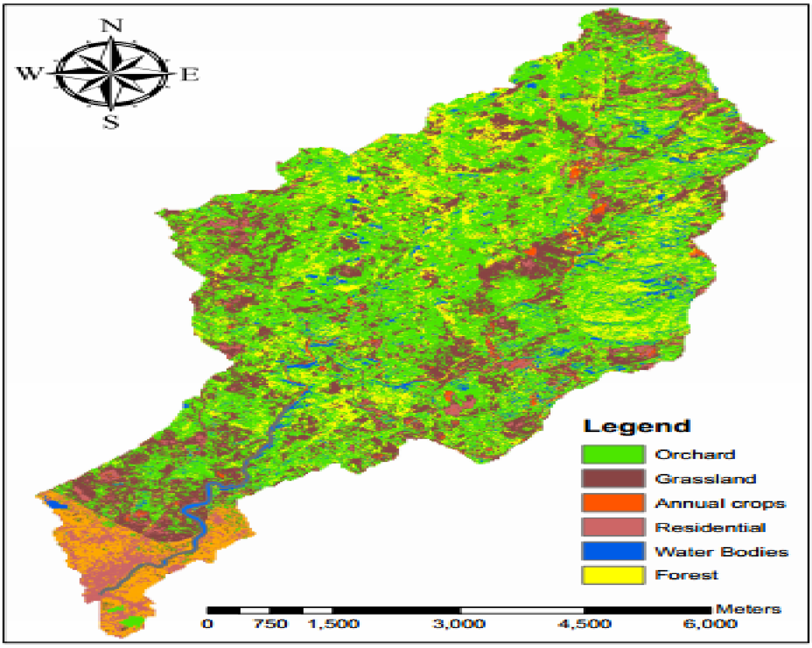

Figure 3. The present land cover of Tanay River watershed

Table 2. Estimated land cover area of the Tanay River watershed

Type	Area (hectares)
Orchard	2286.68
Forest	766.14
Grassland	1157.40
Waterbodies	176.84
Residential	212.59
Annual Crops	230.02
Total	**4829.67**

The land cover in the upper portion of the watershed is dominated by mixed deciduous trees, buho (*Schizostachyum lumampao*) and shrubs. The deciduous trees are mostly found in the steep areas of the watershed. Patches of small crop production areas are found in valleys and gently rolling areas of the upper portion of the watershed.

The flood plain of the river is mostly occupied by residential areas and commercial establishments. Rice and vegetable production areas are found mostly at the edge of the flood plain adjacent to the lake and the gently rolling areas of the watershed. The transition zones of the flood plain and the mountainous areas of the watershed are planted mostly with orchard plants such as mango, coconut, banana and other perennial crops.

3.2 Potential Areas for Reforestation

The mountainous areas in the upper portion of the watershed are the potential venue for reforestation and conservation initiatives. Large areas are covered with grasses and shrubs and have not been inhabited by human (Figure 4). A large portion of the area is within the proclaimed ancestral domain of the Dumagats, hence a potential venue for reforestation and conservation programs. These areas are also guarded by the barangay patrol under the Bantay Kalikasan program of the town of Tanay. Reforestation and conservation programs are also undertaken yearly in the area.

3.3 Land Cover Scenarios

Three land cover scenarios (present, scenario 1 and 2) were prepared to assess their effects of flooding in the flood plain of the town. These are: the

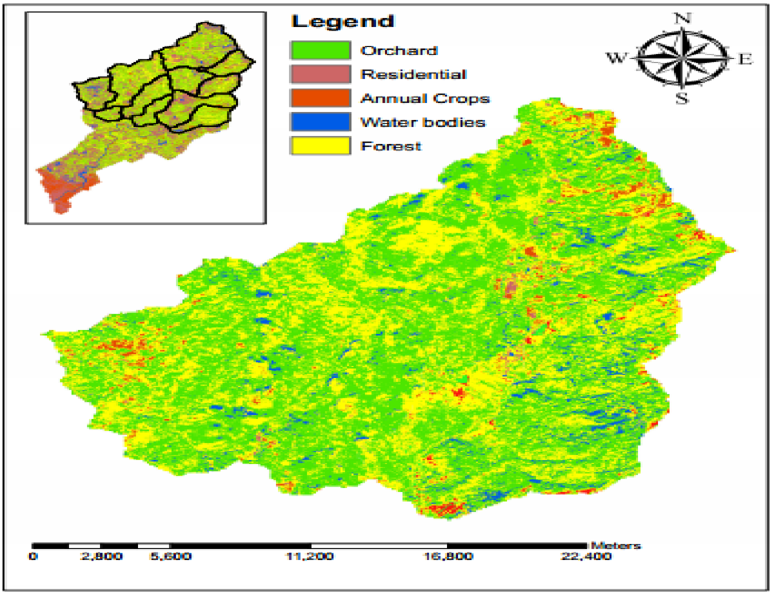

Figure 4. Modified land cover in the upper portion of the watershed (scenario 1)

present land cover of the watershed (Figure 3); reforestation of the grasslands in the upper portion of the watershed (Figure 4); and reforestation of the upper left portion of the watershed (Figure 5).

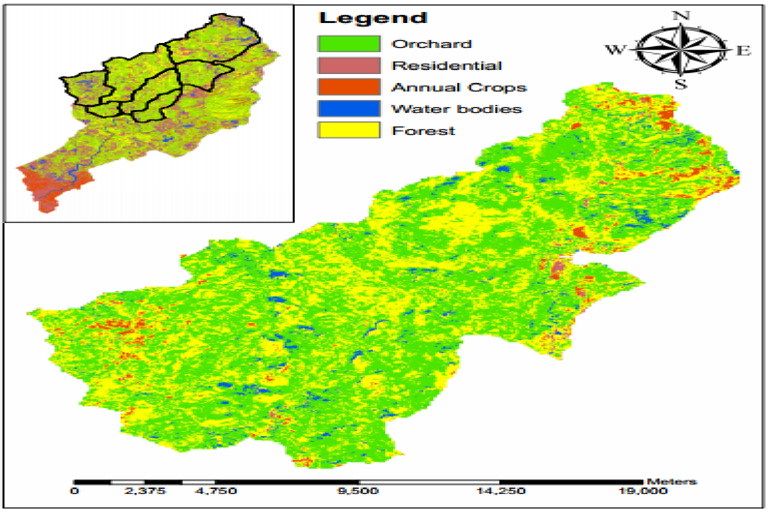

Figure 5. Modified land cover in the upper left portion of the watershed (scenario 2)

If the proposed grassland areas in the upper portion of the watershed are reforested, the total forest area will increase from 766.14 to 1423.40 ha. About 1230.07 ha is located in the upper portion of the watershed and 193.33 ha are found outside the proposed reforestation area. For the second scenario, the estimated grasslands that will be converted to forests are about 441. 45 ha. The forest area will increase to 1207.59 ha.

3.4 Hydrograph Analysis and Derivation of the Water Depth

The unit hydrograph of the middle and lower river network was derived using the modified land cover scenarios as input to HEC-HMS and HEC-RAS, respectively. The peak discharge of the hydrographs was used in simulating the water level in different locations on the river.

The simulated peak discharge of the unit hydrograph in the middle river network using the derived present land cover is 16.9 m^3s^{-1}. The peak discharge decreased to 13.4 m^3s^{-1} when the grasslands in the upper portion of the watershed are converted to forests (Figure 6). The depth of water in this portion of the river also decreased from 60 to 52.0 cm.

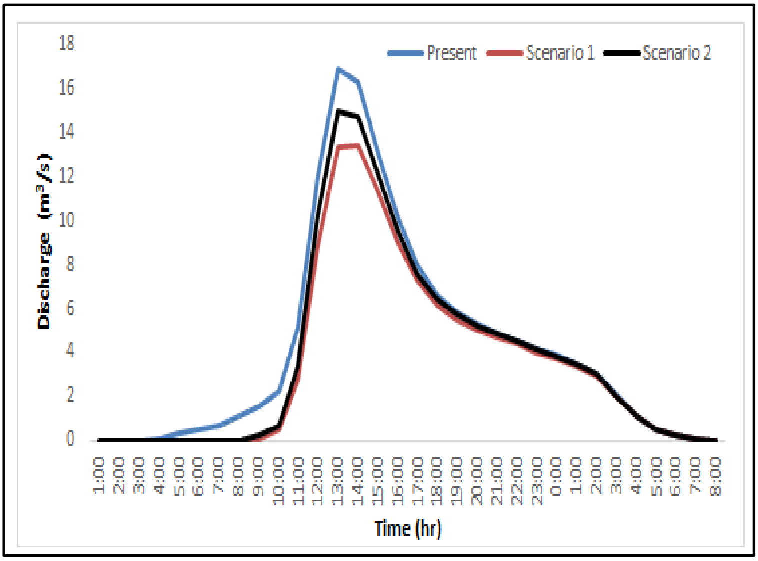

Figure 6. Simulated hydrographs of the middle river network using 80 mm total rainfall

There was also a considerable decrease of simulated peak discharge at the lower reach of the river. The discharge decreased from 43.8 to 35.7 m^3s^{-1} when the grasslands in the upper portion of the watershed are reforested.

3.5 HEC-RAS Model Calibration

Before the simulation, the model was calibrated using the water elevation that was measured during a storm on February 22, 2013.

The measured water depth of 61 cm coincided with the simulated depth of 60 cm (Figures 7). The computed river discharge of 15.7 m^3s^{-1} in the middle river network, is, however, lower than the simulated peak discharge of 16.9 m^3s^{-1} under the present land cover condition. The difference could be due to an error in the computation of the river cross-section. The river has an asymmetrical bottom, which cannot be easily captured using surveying instruments.

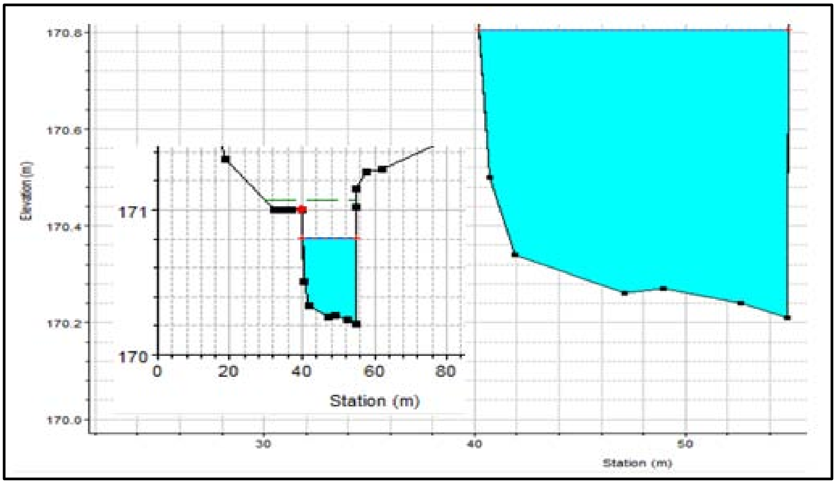

Figure 7. Simulated water depth in the middle of the river network using a peak discharge of 16.9 m^3s^{-1}

3.6 Flood Flow Simulation

The flood flow was simulated using the derived flow hydrograph of the river for different land cover scenarios under extreme rainfall event (418 mm total rainfall). The simulation using the present land cover condition of river watershed (Figure 3) predicted that a total area of 5.17km^2 is affected by low to extreme flooding (Table 3). Almost half of the flooded area is in Barangay Plaza Aldea, the largest barangay in the lowland part of Tanay.

A total area of 2.801 km^{2}is exposed to extreme flooding and approximately 1.24 km^{2}is exposed to moderate flooding (Table 3). Most of the areas exposed to low flooding are found in Barangays Plaza Aldea, Katipunan Bayani, Tandang Kutyo and Wawa (Figure 8).

Table 3. Estimated flooded area (sq km) and classification for the present land cover of the watershed

Barangay	Low	Moderate	Extreme	Very Extreme	Total
Plaza Aldea	0.187	0.495	1.372	0.242	**2.296**
Tabing Ilog	0.000	0.004	0.021	0.015	**0.040**
Mag-ampon	0.000	0.024	0.072	0.036	**0.132**
Katipunan Bayani	0.028	0.109	0.579	0.026	**0.742**
Tandang Kutyo	0.034	0.062	0.087	0.108	**0.291**
Kay Buto	0.010	0.071	0.411	0.356	**0.848**
San Isidro	0.000	0.093	0.119	0.029	**0.241**
Pinagkamaligan	0.000	0.015	0.026	0.010	**0.051**
Wawa	0.018	0.362	0.113	0.035	**0.528**
Total	**0.277**	**1.235**	**2.801**	**0.857**	**5.170**

The large portion of Barangay Kay Buto that was classified as very extremely flooded is found in the low-lying areas, along the shore of Laguna Lake. On the other hand, the extremely flooded areas of Barangay KatipunanBayani were mostly rice fields found in between two national highways with higher elevation (Figure 8).

The simulation predicted a reduction in the total flooded area in the flood plains of the river if the grasslands in the upper portion of the watershed (Figure 4) are forested. The expected decrease in water depth is about 0.36 m or a total of 16.4 hectares will not be affected by flood (Figure 9). About 12.4 hectares is located in Barangay Plaza Aldea.

The total area which is classified as very extremely flooded is 0.761 km^2. The areas that are classified as extremely flooded decreased from 2.8 to

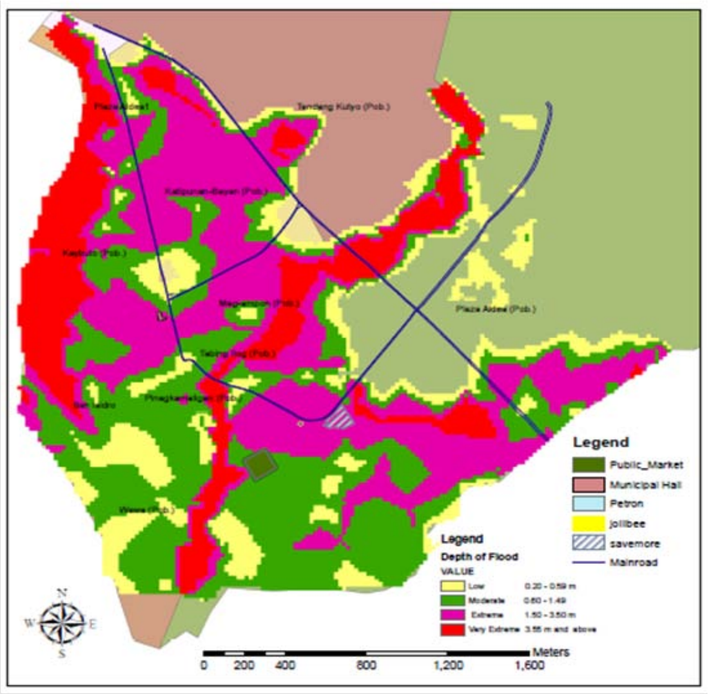

Figure 8. Simulated depths and extent of flooding using extreme rainfall data and the present land cover of the watershed

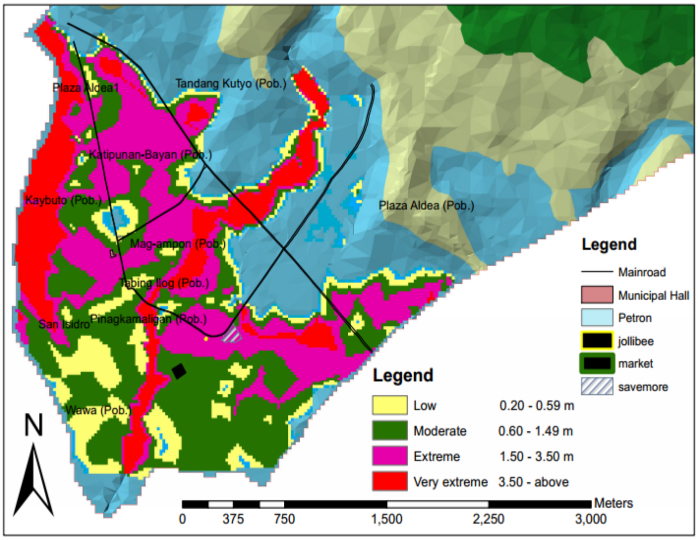

Figure 9. Simulated depths and extent of flooding using extreme rainfall data and the 1^{st} land cover scenario of the watershed

about 2.15 km^2. On the other hand, the low and moderately flooded areas increased to 0.59 and 1.51 km^2, respectively (Table 4). The decrease in flood depth resulted in the reduction of very extremely and extremely flooded areas and an increase of low to moderately flooded areas in the low-lying areas of the town.

Table 4. Estimated flooded area (sq km) and classification for the 1st land cover scenario of the watershed.

Barangay	Low	Moderate	Extreme	Very Extreme	Total
Plaza Aldea	0.253	0.720	0.998	0.201	**2.172**
Tabing Ilog	0.000	0.008	0.020	0.011	**0.040**
Mag-ampon	0.006	0.034	0.061	0.032	**0.133**
Katipunan Bayani	0.058	0.130	0.527	0.011	**0.727**
Tandang Kutyo	0.045	0.047	0.078	0.099	**0.268**
Kay Buto	0.024	0.135	0.346	0.341	**0.846**
San Isidro	0.025	0.118	0.076	0.023	**0.242**
Pinagkamaligan	0.003	0.028	0.012	0.010	**0.052**
Wawa	0.176	0.286	0.030	0.033	**0.526**
Total	**0.590**	**1.507**	**2.148**	**0.761**	**5.006**

For the second scenario, (Figure 5) a decrease of 0.20 m flood depth is expected or a total of 12.9 hectares of land in the flood plain will not be affected by flood under extreme weather condition. About 10 hectares in Barangay Plaza Aldea are spared from flooding (Figure 10). The very extremely flooded area is 0.83 km^2. It is reduced from 2.80 to about 2.26 km^2. On the other hand, the low and moderately flooded areas increased to 0.48 and 1.46 km^2, respectively (Table 5).

3.7 Validation of the Simulated Flood Depths

The model was able to spatially delineate the flood event during typhoon Ondoy. The flood depths during the typhoon Ondoy in the residential areas of Tabing Ilog, Plaza Aldea, Pinagkamaligan and San Isidro coincided with the simulated flood depths (Figure 11).

The simulated flood depths in Tabing Ilog and Plaza Aldea were 1.55 and 2.9 m, respectively. The actual flood depths in these areas, based on the measured flood depths as described by the residents, were 1.45 m and 2.8 m, respectively.

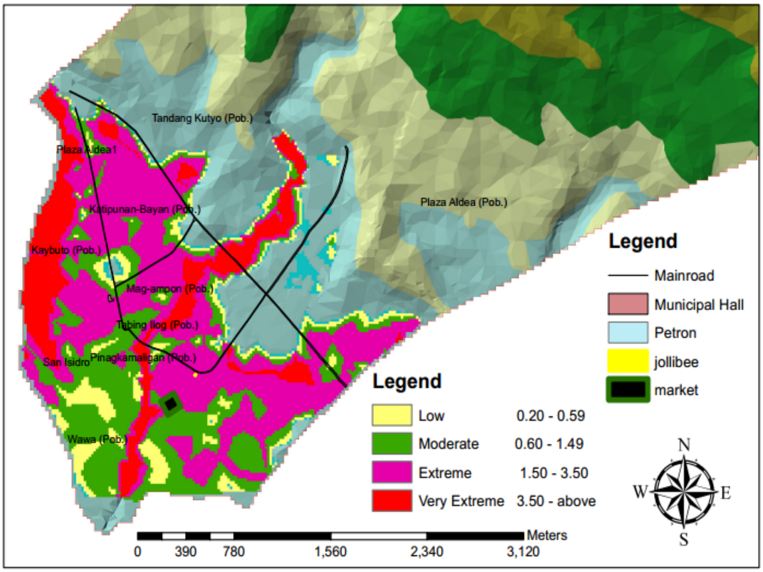

Figure 10. Simulated depths and extent of flooding using extreme rainfall data and the 2nd land cover scenario of the watershed

Table 5. Estimated flooded area (sq km) and classification for the 2nd land cover scenario of the watershed

Barangay	Low	Moderate	Extreme	Very Extreme	Total
Plaza Aldea	0.224	0.658	1.083	0.230	**2.196**
Tabing Ilog	0.000	0.007	0.019	0.014	**0.040**
Mag-ampon	0.004	0.031	0.062	0.036	**0.133**
Katipunan Bayani	0.048	0.121	0.539	0.022	**0.730**
Tandang Kutyo	0.042	0.049	0.077	0.105	**0.272**
Kay Buto	0.018	0.121	0.354	0.354	**0.848**
San Isidro	0.011	0.124	0.081	0.027	**0.242**
Pinagkamaligan	0.000	0.027	0.015	0.010	**0.052**
Wawa	0.137	0.322	0.034	0.034	**0.528**
Total	**0.485**	**1.460**	**2.264**	**0.832**	**5.041**

There were, however an instance where the model over-estimated the flood depth, particularly in areas where there has been an extensive land modification. In Katipunan Bayani, the simulated flood depth is 2.1 m, whereas the actual flood depth is 1.1 m only.

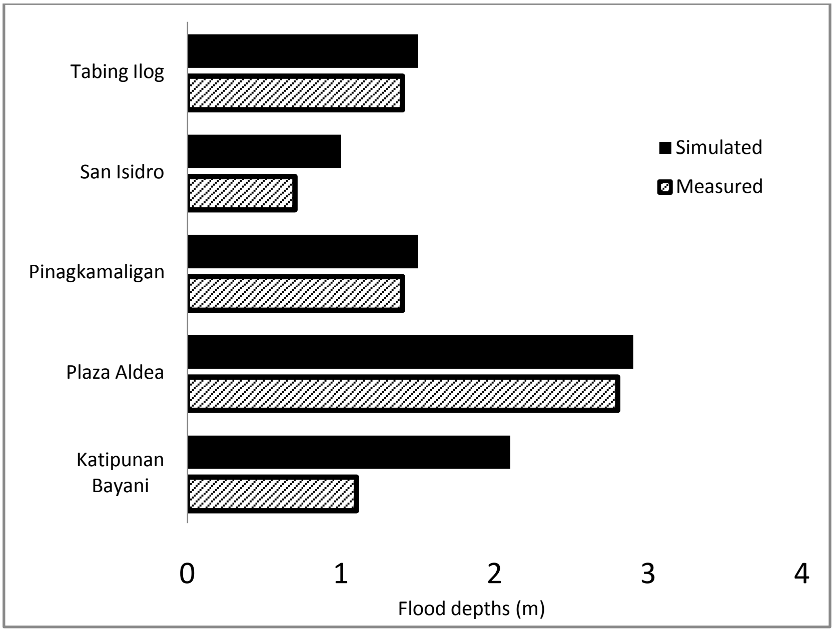

Figure 11. Simulated and measured flood depths during Typhoon Ondoy

4. Conclusions and Recommendations

The watershed of Tanay is predominantly covered by orchard plants and grasses with an area of 2286.8 and 1157.40 hectares, respectively. The flood plain of the river is mostly occupied by residential areas and commercial establishments

The upper portion of the watershed is the most viable area for reforestation. Most part is not inhabited and has been the venue of reforestation and conservation initiatives of Tanayans, Rizalenos and other private organizations

Simulation predicted a reduction of peak discharge in the lower river network if the grasslands in the upper part of the watershed is reforested. The flood water depth for 418 mm total rainfall can be lowered by as much as 36 cm, or a total of 16.4 hectares is spared to flooding.

Creation and implementation of holistic environmental programs that will restore the original state of the watershed in the upland barangays of the town is a must. It is also vital to strengthen the local policy framework that protect and conserve the remaining watershed to reduce excessive runoff, thereby reducing the geo-physical vulnerability of the barangays in the flood plain of Tanay.

5. Acknowledgement

The researcher acknowledges the contribution of the following institutions to this study:

1. Department of Science and Technology – Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development
2. University of Rizal System
3. Local Government Unit of Tanay, Rizal

6. References

Chomitz, K.M., Buys, P., De Luca, G., Thomas, T. S., and Wertz-Kanounnikoff, S. (2007). At loggerheads Agricultural expansion, poverty reduction, and environment in the tropical forests. Washington, DC: The World Bank.

Giertz, S., Diekkruger, B., and G. Steup (2006). Physically-based modelling of hydrological processes in a tropical headwater catchment in Benin (West Africa) – process representation and multi-criteria Hydrol. Earth Syst. Sci. Discuss., 3, 1–57, 2006.

Loster, T. (1999).Flood trends and global change.Geoscience and Research Group. Munich Reinsurance Company.

Maidment, D. R. (2002). Arc Hydro: GIS for Water Resources. Redlands, CA: ESRI Press.

Melching,C.S.(1995). Reliability estimation in computer models of watershed hydrology. In Singh, V. P., ed., Reliability estimation in computer models of watershed hydrology. Water Resources, 69-118.

Ponce, V.M. and Hawkins, R. H. (1996). Runoff Curve Number: Has it Reached Maturity? J. Hydro. Eng., ASCE, 1(1), 11-19.

Razi, M. A. M, Ariffin A. W and N. A. M. Arish, (2010). Flood estimation studies using hydrologic modeling system (HEC_HMS) for Johor river, Malaysia. Journal of Applied Sciences, Vol 10. pp 930-939.

USACE. (2002). HEC-RAS River Analysis System, Hydraulic Reference Manual, US Army Corps of Engineers. Hydrological Engineering Center, Davis, California.

USACE. (2009). HEC-GeoHMS Geospatial Hydrologic Modelling Extension User's Manual. Hydrological Engineering Center, Davis, California.

Yusuf, A. A., and H. Francisco (2009). Climate Change Vulnerability Mapping for Southeast Asia, EEPSEA Special and Technical Paper tp20091s1, Economy and Environment.Program for Southeast Asia (EEPSEA).

Zorkeflee, A.H., Nuramidah, H and S.Y. MOHD. (2009). Integrated river basin management (IRBM): Hydrologic modelling using HEC-HMS for sungaikurau basin, Perak. Proceedongs of the International Conference on Water Resources, (ICWR'09), River Basin Management Society, pp: 1-7.