ASSESSING THE HYDROLOGIC EFFECTS OF URBANIZATION THROUGH NUMERICAL MODELING USING SWAT: A CASE STUDY OF LAGUNA DE BAY BASIN

J.M. Jamilla 1, J. Serrano 1, B.C. Hernandez 1, E. Herrera 1,2

1 National Hydraulic Research Center, University of the Philippines, Diliman, Quezon City, 1101, Philippines – (jmjamilla, jserrano, bbhernandez) @up.edu.ph
2 Institute of Civil Engineering, University of the Philippines, Diliman, Quezon City, 1101, Philippines – eugene.herrera@coe.upd.edu.ph

KEY WORDS: Land Cover Change, Hydrology, Runoff, ArcSWAT, GIS, Water Balance

ABSTRACT:

Laguna de Bay, having a surface area of about 900 km² is the largest freshwater lake in the Philippines, and is the most important water body in Metro Manila with its variety of uses ranging from aquaculture, irrigation, water supply and flood control. Due to its available resources and strategic location, over extraction, land conversion, and urbanization, have resulted in massive changes in the lake's watershed. The objective of this study is to simulate the impact of land cover change, particularly urbanization, on the hydrology of Laguna de Bay watershed. By hypothetically converting brushland to urban areas and using ArcSWAT to simulate the effects of urbanization, discharge and water balances were assessed. The long-term hydrologic simulations showed an annual increase of 20.6 m³/s (68) in surface runoff and a 12.8 m³/s (26%) decrease in groundwater recharge for the entire watershed as urban areas increase. The mean seasonal flows were 75.2 m³/s during the dry season and 149.4 m³/s during the wet season for the original land cover, and 70.2 m³/s and 154.1 m³/s for the urbanized land cover, during the dry and wet seasons, respectively. Water percolating into the aquifers beneath the ground were also lessened by 13.6 m³/s (23%). The calibration of Marikina subbasin resulted to a satisfactory percent bias (PBIAS), Nash-Sutcliff (NSE), and the ratio of the root-mean-square error to the standard deviation of measured data (RSR). Other subbasins resulted in a relatively lower performance rating due to limited available monitoring stations within the basin.

1. INTRODUCTION

Laguna de Bay, also referred to as Laguna Lake, is the largest freshwater lake in the Philippines, and the third largest in Southeast Asia. It serves as a major source of fisheries and aquaculture in the country. It is also a major transportation route between the towns along the shore of the lake. The Bay is also used for power generation, irrigation, industrial cooling, an important source of potable water, and flood detention basin for mitigating Metro Manila waters (Vargas-Nguyen, 2015). Due to its available resources and strategic location, over extraction, land conversion, and urbanization, have resulted in massive changes in the lake's watershed.

For the past decades, there has been major land cover changes in the basin – from 65.11% of agricultural land in 1988, it significantly decreased to 29.53% in 2015. There is also an annual decrease of 6.56% of forest cover in the lake's watershed (Valerio 1990). Majority of these conversions are due to rapid industrialization and urbanization. From 4.48% in 1988, built-up areas increased to 9.90%, 17.18%, and 17.77% in 2004, 2010, and 2015, respectively.

According to the Wealth Accounting and the Valuation of Ecosystem Services (2015), in 2014, Biochemical Oxygen Demand (BOD) load in the lake was composed of 2% forest waste, 3% solid waste, 5% agricultural waste, 9% industrial waste, and 81% domestic waste. This means that land conversion due to urban sprawl is one of the major causes of water quality deterioration of Laguna Lake.

1st Hydrologic models can be used to simulate how water moves within a watershed. They are also capable in replicating the impacts of different land cover, soil, and even water conservation structures within a basin. These models are important tools in understanding the hydrological behaviour of watersheds which can be very beneficial, especially for policy makers, in implementing necessary conservation measures and efforts concerning watershed management (Prasad et al., 2020).

The objective of this study is to simulate the impact of land cover change, particularly urbanization, on the hydrology of Laguna de Bay watershed. Expanding impervious surfaces reduces infiltration during storm events which eventually leads to an increase in surface runoff and a decline in aquifer recharge (Zhou et al., 2013). This means that more urbanized areas have higher risk for flooding, water shortage, and water quality deterioration.

2. DATA AND METHODS

2.1 Study Site

Laguna Lake is the largest lake in the country having a surface area of about 900 km² and an average depth of 2.5 meters. Laguna de Bay Basin is divided into 24 sub-basins which are bounded by Laguna province in the east, west, and southwest, Rizal in the north and northeast, and Metro Manila in the northwest. The maple-shaped Laguna Lake has a total shoreline length of 285 km and is sectioned into four (4) segments namely West Bay, Central Bay, East Bay, and South Bay.
The rainfall distribution within the basin varies at different times of the year. Generally, higher precipitation is experienced at the West Bay where the mountainous parts of the watershed are located. The Central, South, and some parts of the East Bay experience wet and dry seasons. The rest of the East Bay have wet seasons and experience short dry seasons.

2.2 Data Used

2.2.1 Digital Elevation Model: DEM from Interferometric Synthetic Aperture Radar (IFSAR) with a spatial resolution of 10 meters was used for the extraction of morphological parameters (e.g., basin boundary, river network, etc) and the basis in performing the watershed delineation.

2.2.2 Soil: The soil type was obtained from the Food and Agricultural Organization (FAO) database. This database contains soil profile information from various field projects and the soil profile information contained in the volumes that accompanied the Soil Map of the World (FAO-UNESCO, 1971-81). For the study area, the soil types used were classified into seven (7) categories.

| FAO Soil ID | Soil Unit       | Description                                      |
|-------------|-----------------|--------------------------------------------------|
| Nd66-2-3b   | Dystic Nitosols | Low-activity clay, P Fixation, strongly structured |
| To26-2bc    | Ochric Andosols | Allophanes or Al-humus complexes                  |
| Bg8-2-3a    | Gleyic Cambisols| Moderately developed soils                       |
| Lo68-2-3b   | Orthic Luvisols | High base status, high-activity clay             |
| Ne65-3bc    | Eutric Nitosols | Low-activity clay, P Fixation, strongly structured |
| To27-2-3b   | Ochric Andosols | Allophanes or Al-humus complexes                  |
| Vp65-3a     | Pellic Vertisols| Alternating wet-dry conditions, rich in swelling clays |

Table 1. FAO Soil Classification of the study area.

2.2.3 Land Cover: The 2015 land cover map was obtained from the National Mapping and Resource Mapping Authority (NAMRIA). It was further processed using Geographic Information Systems (GIS) to be ready for input into the SWAT model. Table 2 shows the reclassified land cover categories based on the SWAT land cover classifications.
Land cover plays a significant role in the hydrology of watersheds as it characterizes the topography of the area being modelled.

2.2.4 Meteorological Data: Spatially distributed local weather gauges covering the simulation period of 1995 to 2019 were obtained from the Philippine Atmospheric, Geophysical and Astronomical Administration (PAGASA). Supplementary rainfall and other weather parameters such as temperature, relative humidity, wind speed, and solar radiation were also acquired from the Department of Science and Technology–Advanced Science and Technology (DOST–ASTI), Effective Flood Control Operation System (EFCOS), and International Rice Research Institute (IRRI).

2.2.5 Discharge Data for Calibration and Validation: Observed river flows or discharges are important components in hydrologic models. These discharges can be used to calibrate and validate simulations to assure that the watershed parameters set are representative of their in-situ data.

Department of Public Works and Highways (DPWH) discharge data and ASTI water level data were utilized for the calibration and validation of the SWAT models used in this study.

2.3 Methodology

The methodology of this study consists of four main steps: (1) SWAT input preparation, (2) SWAT simulation, (3) calibration and validation, and (4) output visualization.

Table 2. Reclassification of land cover classes for SWAT Modelling.

| NAMRIA Land Cover Classification | SWAT Classification |
|----------------------------------|---------------------|
| Closed/Open Forest               | Forest              |
| Built-up                         | Urban               |
| Annual/Perennial Crop            | Agriculture         |
| Grassland                        | Range-Grasses       |
| Brush/Shrubs                     | Range-Brushes        |
| Inland Water/Fishpond            | Water               |
| Mangrove Forest                  | Wetland-Forested     |
| Marshland/Swamp                  | Wetland-Non-forested |
| Open/Barren                      | Barren              |

2.3.1 SWAT Input Data: DEM and soil data were further pre-processed in GIS to be ready for input into the SWAT model.

For this study, the reclassified SWAT-ready 2015 land cover was further recategorized. Brushland, which was 19% of the 2015 land cover of Laguna de Bay basin, was chosen among all the vegetation to be converted to built-up because first, it is susceptible to urbanization due to its landscape, and second, its area covered was not as small as the grassland (4%) and not as big as the agricultural land (30%). This hypothetical land conversion was done to simulate the impact of land cover change, particularly, urbanization, on the hydrological processes involved in Laguna de Bay Basin using SWAT models.

For the meteorological data, all available local weather stations within and near the basin were utilized to ensure that the hydrological models would accurately predict streamflow and any other water movement within the basin.

Figure 4. General workflow of the study.

Figure 5. Weather stations used in the SWAT models.
the same inputs for the rest of the parameters such as DEM, soil, and weather data with simulation period of 1995-2019.

2.3.3 Calibration, Validation, and Visualization: After generating the SWAT models for the original land cover, these simulations were calibrated and validated using SWAT-CUP. SWAT-CUP is a computer program used for sensitivity analysis, calibration, validation, and uncertainty analysis of a SWAT model.

Sensitivity analysis was performed for each subbasin. This is a crucial part of the model development as it involves analytical evaluation of input parameters needed in model validation (Khalid et al., 2016). Parameters with p-value of less than 0.05 were selected for each subbasin. A variable with a low p-value (less than 0.05) indicates that changes in the said variable’s value are related to the changes in the response variable. This means that there is only a 5% chance that the results would occur in a random distribution. Thus, there is a 95% probability of being correct that the parameters chosen would have some effect on the results. For this simulation, GW_REVAP, REVAPMN, GWQM2N, CN2, SOL_AWC, SLSUBBSN, OV_N, ESCO, and HRU_SLP were among the sensitive parameters used in the calibration and validation.

Due to limited daily discharge data available, three (3) methods were used to generate discharge data needed in calibrating and validating the models: (1) for Marikina subbasin, observed daily discharges from Sto. Niño, monitoring station were used, (2) for Biñan subbasin, a rating curve was generated to convert observed water level data from Soro-Soro Bridge to daily discharge data using a hydraulic model, and (3) Area-discharge ratio calculations which equates the ratio of the streamflow of two (2) stream locations to the ratio of their respective drainage areas, were performed to estimate the flows for the remaining 22 subbasins.

The calibrated parameters from the original land cover models were integrated to the urban land cover models using python scripts before running them again in SWAT Output Viewer, where the calibrated flows and water balances were extracted.

3. RESULTS

3.1 Land Cover Change

In 2015, the land cover of Laguna de Bay Basin was composed of 18% built-up and 19% brushland. By hypothetically converting brushland to urban areas, the new land cover classification resulted in 37% built-up. Table 3 shows the area and percentages for each land cover classification.

| Land Cover Classification | Original Area (km$^2$) | % | Urbanized Area (km$^2$) | % |
|---------------------------|------------------------|---|-------------------------|---|
| Forest                    | 201                    | 5 | 201                     | 5 |
| Agricultural Land         | 1131                   | 30| 1131                    | 30|
| Built-up                  | 680                    | 18| 1404                    | 37|
| Grassland                 | 147                    | 4 | 147                     | 4 |
| Brushland                 | 725                    | 19| -                       | - |
| Water                     | 932                    | 24| 932                     | 24|
| Barren                    | 8                      | 0.2| 8                       | 0.2|
| Non-forested Wetland      | 2                      | 0.1| 2                       | 0.1|

Table 3. Land Cover Change Classification.

Figure 7. Original (left) and urbanized (right) 2015 land covers.

Due to limited daily discharge data available, three (3) methods were used to generate discharge data needed in calibrating and validating the models: (1) for Marikina subbasin, observed daily discharges from Sto. Niño, monitoring station were used, (2) for Biñan subbasin, a rating curve was generated to convert observed water level data from Soro-Soro Bridge to daily discharge data using a hydraulic model, and (3) Area-discharge ratio calculations which equates the ratio of the streamflow of two (2) stream locations to the ratio of their respective drainage areas, were performed to estimate the flows for the remaining 22 subbasins.

Tanay subbasin yielded the largest percentage of converted brushland to built-up areas resulting in 78% of its area as urban, followed by JalaJala and Sta. Maria with 72% and 54% of paved surfaces, respectively.

3.2 River Discharges

Continuous land cover change can have major impact on the peak discharges and water balance within the watershed. Table 4 shows the annual average discharges for the whole Laguna de Bay Basin.
The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVI-4/W6-2021
Philippine Geomatics Symposium 2021, 17–19 November 2021, virtual meeting

Table 4. Annual Average Peak Discharges for Laguna de Bay Basin.

| Year | Discharges using the original land cover (m³/s) | Discharges using the urbanized land cover (m³/s) | Δ in Peak flows |
|------|-----------------------------------------------|-----------------------------------------------|-----------------|
| 1995 | 622.40                                       | 794.62                                       | 28%             |
| 1996 | 741.15                                       | 787.33                                       | 6%              |
| 1997 | 614.55                                       | 739.96                                       | 20%             |
| 1998 | 775.77                                       | 954.86                                       | 23%             |
| 1999 | 728.76                                       | 788.72                                       | 8%              |
| 2000 | 639.17                                       | 792.85                                       | 24%             |
| 2001 | 668.07                                       | 667.76                                       | 0%              |
| 2002 | 451.68                                       | 548.60                                       | 21%             |
| 2003 | 1055.03                                      | 1119.52                                      | 6%              |
| 2004 | 595.08                                       | 927.77                                       | 56%             |
| 2005 | 524.00                                       | 679.98                                       | 30%             |
| 2006 | 511.70                                       | 515.60                                       | 1%              |
| 2007 | 836.09                                       | 815.83                                       | -2%             |
| 2008 | 626.00                                       | 616.10                                       | -2%             |
| 2009 | 1013.45                                      | 1170.60                                      | 16%             |
| 2010 | 505.11                                       | 648.82                                       | 28%             |
| 2011 | 805.42                                       | 1033.57                                      | 28%             |
| 2012 | 1903.38                                      | 1945.01                                      | 2%              |
| 2013 | 1416.92                                      | 1657.55                                      | 17%             |
| 2014 | 975.54                                       | 1253.68                                      | 29%             |
| 2015 | 960.97                                       | 1217.75                                      | 27%             |
| 2016 | 612.36                                       | 812.36                                       | 33%             |
| 2017 | 1488.65                                      | 1702.71                                      | 14%             |
| 2018 | 788.07                                       | 1026.63                                      | 30%             |
| 2019 | 764.53                                       | 864.51                                       | 13%             |

Table 4 shows that urbanization increased the peak discharges around 138 m³/s (18% increase) annually. The mean seasonal flows were 75.2 m³/s during the dry season and 149.4 m³/s during the wet season for the original land cover, and 70.2 m³/s and 154.1 m³/s for the urbanized land cover, during dry and wet season, respectively.

The long-term hydrologic simulations as seen in Figure 8 show that the annual average peak discharges for Tanay subbasin increased with the increase of the urban land cover. On the hand, Pagsanjan, which was composed of 78% agricultural land and only 12% urban area, showed minimal increase in peak discharges. Watershed with a significant amount of vegetation would result in slower movement of water into the river channels, increasing the lag time, as vegetation intercepts precipitation. Water is also lost due to transpiration and evaporation, which also reduces the peak discharges of a river.

3.3 Water Balance

As impervious surfaces continue to expand, the lesser the storage capacity for water in urban areas become. With this, urban streams would overflow more quickly, have higher peak discharges, with higher flow velocities which would increase the risk of flooding during storm events. Table 5 shows the comparison between the surface runoff and groundwater recharge using the two (2) land covers.

Table 5. Annual Average Surface Runoff and Groundwater Recharge for Laguna de Bay Basin.

| Year | Original land cover | Urbanized land cover |
|------|---------------------|----------------------|
|      | Surface runoff (mm) | Groundwater recharge (mm) | Surface runoff (mm) | Groundwater recharge (mm) |
| 1995 | 0.89                | 1.2                  | 1.58                | 0.86                  |
| 1996 | 0.99                | 1.73                 | 1.64                | 1.3                   |
| 1997 | 0.94                | 1.67                 | 1.6                 | 1.23                  |
| 1998 | 1                   | 1.17                 | 1.64                | 0.82                  |
| 1999 | 1.01                | 1.93                 | 1.67                | 1.47                  |
| 2000 | 1.08                | 1.82                 | 1.89                | 1.34                  |
| 2001 | 0.71                | 1.27                 | 1.28                | 0.91                  |
| 2002 | 0.74                | 1.32                 | 1.31                | 0.95                  |
| 2003 | 1.01                | 1.5                  | 1.67                | 1.09                  |
| 2004 | 0.77                | 1.29                 | 1.37                | 0.93                  |
| 2005 | 0.99                | 1.84                 | 1.75                | 1.38                  |
| 2006 | 0.82                | 1.62                 | 1.42                | 1.21                  |
| 2007 | 0.97                | 1.64                 | 1.66                | 1.21                  |
| 2008 | 0.99                | 1.56                 | 1.62                | 1.14                  |
| 2009 | 1.01                | 1.7                  | 1.79                | 1.22                  |
| 2010 | 1                   | 1.83                 | 1.68                | 1.38                  |

This contribution has been peer-reviewed.
https://doi.org/10.5194/isprs-archives-XLVI-4-W6-2021-193-2021 | © Author(s) 2021. CC BY 4.0 License.
on the average, an annual increase of 20.6 m³/s (68%) in surface runoff and a 12.8 m³/s (26%) decrease in groundwater recharge for the entire watershed were observed as urban areas increase. Water percolating into the aquifers beneath the ground were lessened by 13.6 m³/s (23%).

The annual average surface runoff when the original land cover was simulated was 14.3 m³/s for the dry season and 46.8 m³/s for the wet season. For the urban land cover, the runoff for the dry and wet seasons increased by 55% and 71%, respectively, resulting in 22.1 m³/s and 80 m³/s surface runoff increase. Consequently, groundwater recharge was reduced for the urban land cover by 22% (10 m³/s) during the dry season and 29% (15.4 m³/s) during the wet season.

| Year | Original land cover | Urbanized land cover |
|------|---------------------|----------------------|
|      | Surface runoff (mm) | Groundwater recharge (mm) | Surface runoff (mm) | Groundwater recharge (mm) |
| 2011 | 1.12               | 1.97                 | 1.93               | 1.47             |
| 2012 | 1.56               | 2.24                 | 2.47               | 1.66             |
| 2013 | 1.28               | 2.09                 | 2.02               | 1.62             |
| 2014 | 0.82               | 1.17                 | 1.38               | 0.85             |
| 2015 | 0.9                | 1.18                 | 1.5                | 0.85             |
| 2016 | 0.73               | 1.28                 | 1.28               | 0.96             |
| 2017 | 1.12               | 1.49                 | 1.59               | 1.18             |
| 2018 | 0.89               | 1.3                  | 1.41               | 1.01             |
| 2019 | 0.74               | 1.2                  | 1.13               | 0.95             |

Table 5 (continued). Annual Average Surface Runoff and Groundwater Recharge for Laguna de Bay Basin.

| Subbasin     | Calibration | Validation |
|--------------|-------------|------------|
|              | NSE | PBIAS | RSR | NSE | PBIAS | RSR |
| Sta. Maria   | 0.32 | 11.5 | 0.83 | -0.17 | 29.9 | 1.08 |
| San Juan     | 0.35 | 52.5 | 0.81 | -0.22 | 9.2  | 1.11 |
| Pagsanjan    | 0.35 | 21.8 | 0.81 | -0.3  | 62.6 | 1.14 |

Table 7 (continued). Calibration and Validation Results.

3.4 Calibration and Validation

The accuracy of the models was also tested through calibration and validation. This was done to compare the simulation results such as flows with the actual discharges.

**Table 7. Calibration and Validation Results.**

![ Calibration plots for (a) Marikina subbasin, (b) Biñan subbasin, and (c) Sta. Maria subbasin. ](image)
The calibration of Marikina subbasin resulted in a satisfactory percent bias (PBIAS), Nash-Sutcliffe (NSE), and the ratio of the root-mean-square error to the standard deviation of measured data (RSR), while Sta. Maria yielded a good performance rating for PBIAS only. Other subbasins resulted in a relatively lower performance rating due to limited available monitoring stations within the basin.

4. CONCLUSION AND RECOMMENDATIONS

Hydrologic models were setup using the DEM, soil, land cover, and meteorological data, which were all pre-processed in GIS. These were used as inputs in ArcSWAT to simulate the effects of urbanization within the Laguna de Bay watershed. Results showed that developed lands tend to have higher surface runoff during the wet season and lesser aquifer recharge during the dry season, which leads to a short lag time and an increase in peak discharges.

Urban development has adverse effects on the quality and quantity of groundwater and surface water features. Common consequences are increased peak discharges and frequency of flooding. In addition, as groundwater infiltration reduces, precipitation that previously filled aquifers is instead transported to surface water bodies, altering the flow pattern, causing erosion, among other things. Infiltrating rainwater also acts as a major mechanism for the quality of both ground and surface water. More vegetation means more filters to contaminants in stormwater penetrating the ground.

Urbanization, which generally increases overall runoff, can lead to reducing this filtering mechanism, resulting in higher contaminant loads to water bodies. Furthermore, decrease in the recharge of groundwater can cause water supply shortage during the dry season.

The population density in Laguna de Bay Basin continues to increase hence, the need to urban expansion is inevitable, particularly in the northwest, western, and southern portions of the basin. Rampant land conversions to residential uses and constructions of new settlements close to the shoreline can be very problematic, especially during the wet season, where flooding would presumably occur.

This continuous urban expansion also results in sedimentation of the lake by impeding the flow of turbid waters. In addition, the backflow of Pasig River, which is the sole drainage outlet of Laguna Lake, bring in solid wastes, dissolved pollutants, and saline water during the dry season. On the contrary, this saltwater intrusion is beneficial to the lake’s fishermen because of its effect on turbidity, which is a suitable environment for milkfish aquaculture.

Uncontrolled and unplanned land conversions continue to threaten the entire ecosystem of the entire Laguna de Bay watershed. With these, proper sewage and waste management, zoning, monitoring of the lake and its tributaries, and other rehabilitation efforts should be implemented to maintain the long-term viability of the lake not only as an economic area but also, as a water storage reservoir.

ACKNOWLEDGEMENT

This research study is made possible through the funding support of the Department of Science and Technology – Philippine Council for Industry, Energy, and Emerging Technology Research and Development (DOST-PCIEERD).

REFERENCES

Abbaspour, K. C., (n.d.): SWAT Calibration and Uncertainty Programs. Retrieved 2021

Corona, José A.I., Tarendra Lakhankar, Soni Pradhanang, and Reza Khanbilvardi. 2014. "Remote Sensing and Ground-Based Weather Forcing Data Analysis for Streamflow Simulation" Hydrology 1. no. 1: 89-111. https://doi.org/10.3390/hydrology1010089

Ecosystem Accounts Inform Policies for Better Resource Management of Laguna de Bay. Wealth Accounting and Valuation of Ecosystem Services. (2015). Retrieved from www.wavespartnership.org

Eduvaldo, A.O., Silva M.T., Ferreira, T.R., Paiva, A. T. C., Assis dos Santos, C., Meiguins de Lima, A. M., de Paulo Rodrigues da Silva, V., de Assis Saviano de Sousa, F., Cadoso Gomes, D. J., 2021: Impacts of land use and land cover changes on hydrological processes and sediment yield determined using the SWAT model, International Journal of Sediment Research. doi.org/10.1016/j.ijscr.2021.04.002

FAO Corporate Document Repository Working Paper (Part I, Philippines, Seasonal Fishkill Problem in Laguna de Bay) 24: 62 pp.

Khalid, K., Ali, M. F., Rahman, N. F., Mispan, M. R., Haron, S., H., Othman, Z., Bachok, M. F., 2016: Sensitivity Analysis in Watershed Model Using SUFI-2 Algorithm. doi.org/10.1016/j.proeng.2016.11.086

Konrad C. P., 2016: Effects of Urban Development on Floods. U.S. GEOLOGICAL SURVEY. Retrieved from https://pubs.usgs.gov/fs/fs07603/.

Li, C., Liu, M., Hu. Y., Shi, T., Qu, X., Walter, M. T., 2018: Effects of urbanization on direct runoff characteristics in urban functional zones. doi.org/10.1016/j.scitotenv.2018.06.211

Prasad, V., Yousef A., Sharma, Navmeet., (2020). Hydrological modeling for watershed management. Journal of Natural Resource Conservation and Management. Vol. 1. 29-34. 10.51396/ANRCM.1.20.2020.29-34.

Urban Water Balance. Sustainable Technologies. (n.d.). Retrieved October 12, 2021

Vargas-Nguyen, V., 2015: Laguna de Bay, Philippines: Environmental Literacy

Zhang, H., Wang, B., Liu, D. L., Zhang, M., Leslie, L. M., Yu, Q., 2020: Using an improved SWAT model to simulate hydrological responses to land use change: A case study of a catchment in tropical Australia. doi.org/10.1016/j.jhydrol.2020.124822

Zhou, F., Xu, Y., Chen, Y., Xu, C.Y., Gao, Y., Du, J., 2013: Hydrological response to urbanization at different spatio-temporal scales simulated by coupling of CLUE-S and the SWAT model in the Yangtze River Delta. doi.org/10.1016/j.jhydrol.2012.12.040

This contribution has been peer-reviewed.

https://doi.org/10.5194/isprs-archives-XLVI-4-W6-2021-193-2021 | © Author(s) 2021. CC BY 4.0 License.

199