Existing Water Balance in the Bago River Basin, Myanmar

H. T. Phue* and S. Chuenchooklin
Department of Civil Engineering, Faculty of Engineering, Naresuan University, Phitsanulok, 65000, Thailand.
*E-mail: hnut61@email.nu.ac.th

Abstract. Water systems have complex constituent interactions requiring development and evaluation of management amidst uncertainties of climate and constrained natural resources. This paper outlines water resources planning is developed based on the current water resources availability and demand situation by using Water Evaluation and Planning (WEAP) model to evaluate an existing water balance of the Bago River Basin, Myanmar. The study area is approximately 2,660 km² and the Bago River is the main water resources for demand purposes of Bago township with gauging stations. The water resources planning from upstream of Bago river to Bago Township was calibrated and validated with quantitative statistics (coefficient of determination, $R^2$; Nash-Sutcliffe efficiency, NSE; and Root mean square error, RMSE). The calibrated results fitted to the observed data during 2011–2015 with $R^2 = 0.99$, NSE = 0.88, and RMSE = 24 m³/s, and validated in 2016–2018 with $R^2 = 0.99$, NSE = 1, and RMSE = 10 m³/s, respectively. The results showed the model advanced through WEAP is highly proficient and exhibited great performance to manage available water resources and indicated that currently the basin has sufficient water to meet the water demands in the basin.

1. Introduction
With the increasing pressure on existing water resources, the present framework of the water system is becoming highly inefficient. The inability of the existing system to meet the current water demands was due to the poor water management adopted in the past. There is a huge competition to access water resources at the global level, national level and local level due to population growth, climatic variations, changing of economic development, hydrologic and hydraulic conditions. Understanding the hydrology of a catchment and modelling different hydrological processes within a catchment are therefore very important for assessing the environmental and economic well-being of the catchment. The water balance of a basin is the key aspect in water resources development and management programs.

Water managers and policy makers require tools in order to achieve a balance in water supply and demand, to ensure equitable use of water resources, protect the environment, develop priorities in shared water resources [1]. There are many hydrological and hydraulics models for the water balance. For example, WBalMo Model is an interactive simulation tool for river-basin management by balancing the respective time series with monthly water use demands and reservoir storage changes [2], SWAT (Soil and Water Assessment Tool) includes complex physical hydrology modules as rainfall-runoff, irrigated agriculture, and was used to determine the important hydrologic components of the river basin with focus on water conservation and management [3], SEI’ Water Evaluation and Planning model (WEAP) can be applied for accounting of water supply and demand in the upper Chattahoochee River Basin of Georgia [4], and the Catchment Water Allocation Tool (CaWAT) was used for water resource planning; it is based on water balance accounting [5]. Among them, WEAP has been used worldwide in order to
account operation of water balance with monthly time step, and it can be applied in a single catchment to a complex trans-boundary river basin.

BRB flows through the southern part until it joins the Yangon River and the freshwater resources are particularly important for irrigation and domestic usages. Increasing water demands have reduced water resources available during the dry seasons, and they have also intensified water problems in this study area. It is one of the most useful river basins in lower Myanmar for hydropower generation, irrigation use, fisheries, and navigation use. So far no one study has reported to study water balance in this study area with an application of the WEAP model. Therefore, the main objective of the study is to examine an existing water balance of the Bago River Basin, Myanmar.

2. Study Area

The Bago River basin lies within the latitude 16° 40’ 30” and 18° 25’ 48” N, and longitudes 95° 54’ 39.6” and 96° 44’ 38.4” E. The whole river basin is located in Lower Myanmar between the two larger systems between Sittaung River (420 km) on the east and the Ayeyarwaddy (1550 km) [6]. The total area of the Bago River Basin is 3,220 km² and the total river length is about 331 km long, however, the study was conducted only up to Bago township shown in Fig.1. Therefore, the basin area of the study is 2,660 km² and the river length is about 245 km long. The study area has only two meteorological stations, namely Bago and Zaung Tu, respectively. This basin has a tropical monsoon climate, with average annual rainfall of 3194 mm and the average maximum daily temperature is 41.5°C (in April) and the average minimum temperature is 17.5°C (in January) due to the long-term analysis the periods from 1999-2018. The total population of the study area is 353816 [7]. In the BRB, Zaung Tu Dam (407MCM) for electricity and Zaung Tu weir for irrigation (beneficial area of 115 km²) was constructed near Zaung Tu village in 1996. For the purpose of domestic and irrigation use of Bago Township, earth dam namely Mazin dam was constructed in 1998. Moreover, three earthen dams namely Kodukwe, Salu and Shwe laung dam were constructed in 2011 for the purpose of flood control during the rainy season and the irrigation water use for the dry season. Bago Township is one the main water user in the basin.

Figure 1. Location of the Study Area (MIMU, 2018).
3. Methodology

3.1. WEAP Model Development and Application

WEAP is a user-friendly software tool that is developed by the Stockholm Environmental Institute (SEI) to assist decision makers in managing water demand and supply, and evaluate water management options. It can analyse a wide range of issues, such as water demand, streamflow, reservoir operations etc. The Linear programming algorithm iterates all supply preference to optimize the demand coverage and operates depends on the user defined constraints. It is one of the useful water balance tools, and distributed physical hydrology and demand models of municipal and agricultural demands at different spatial and temporal scales. WEAP model will be developed and applied to evaluate the existing water balance of the study area by taking into account the different factors that may affect demand and supply sources. The following Fig.2 shows flow chart of the WEAP application [8]. The main components of WEAP model that required various parameters and variables to carry out its simulation are illustrated in the following Fig. 3 and Fig.4.

![Figure 2. Flow Chart of WEAP Application.](image)

![Figure 3. The Main Components of Water Supply and Demand System in the study area.](image)

![Figure 4. Schematic Diagram of the study area in WEAP Modelling.](image)
3.2. Data Acquisition

To generate the existing water balance of the BRB by using WEAP Model, the required data will be collected from the different sources for this study area. The observed daily rainfall, maximum and minimum temperatures and the monthly evaporation, wind speed, relative humidity and river discharge for 20 years from 1999 to 2018 were obtained from the Department of Meteorology and Hydrology (DMH), Myanmar, which covers two gauging stations: Bago and Zaung Tu. The average annual temperature, humidity, wind speed, and evaporation are (maximum = 33, minimum = 21) (°C), 73 %, 167 km/day, and 4.4 mm/month, respectively. The average annual rainfall is 3200 mm and then those data are used in computing of ET₀ and crop water requirement using Cropwat 8.0. DEM used in the model was about 30 x 30 m resolution collected from SRTM to create a study area boundary and Landsat satellite image obtained from this website https://earthexplorer.usgs.gov/ to classify landuse. Population data were obtained from the Department of Population Ministry of Immigration and Population, Bago Region and the domestic water use rate were obtained from Bago Township Development Committee (Bago, TDC). In addition, land use in 2018 from Department of Agricultural Land Management and Statistics (DALMS), Bago. Water utilization of agriculture, irrigation area, and soil data were obtained from the Ministry of Agriculture, Livestock and Irrigation (MoALI), Bago. Dams and weir data which covered the study area such as inflow and release flow of dams and so on were obtained from Irrigation and Water Utilization Department (IWUMD), Bago.

3.3. Dataset in WEAP

3.3.1. Demand sites

Agricultural and domestic sites were major demand sites for this study. Water demand is calculated by multiplying the activity level, a measure of social and economic activity such as population or households for cities and hectares in an agricultural area, with the water use rate [8]. Domestic water usage rate per capita per day is considered as 0.114 cubic meters (Bago, TDC). In the calculation of crop water demand, the reference crop evapotranspiration (ET₀) is estimated by using the FAO Penman-Monteith Method (Cropwat 8.0 software). According to the regions of the study area, U.S. Bureau of Reclamation Method was used for calculation effective rainfall as given in equation (1):

\[
\text{Effective Precipitation, } Pe = \begin{cases} 
  120.6 \text{ mm, if Monthly precipitation (P) } > 120\text{mm} \\
  0.8 \text{ P, if } 50\text{mm} < \text{Monthly precipitation (P)} < 120\text{mm} \\
  \text{P, if Monthly Precipitation } < 50\text{mm} 
\end{cases} 
\] (1)

The main crops of the study area are wet season rice, dry season rice, upland crop and orchard and the cropping pattern as shown in Fig.5. Crop growth stages were divided into four: initial, development, mid and late stages. In this study area, most of rice is transplanting rice, upland crop is oil seeds, and orchard is mango those are representative for water demand of crops in WEAP study. When normal year, there are full growing rice in the wet season, but the rice area is ranged between 40*10^4 - 70*10^4 ha during dry season, upland crop area also ranged between 100*10^4 - 140*10^4 ha, respectively which depended on rain condition of dry or wet year. The average of wet season rice, dry season rice, upland crops and orchard are 352, 61, 115 and 50 (1x10^4) ha, respectively.

| Crop Types       | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Wet season rice  |     |     |     |     |     |     |     |     |     |     |     |     |
| Dry season rice  |     |     |     |     |     |     |     |     |     |     |     |     |
| Upland crops     |     |     |     |     |     |     |     |     |     |     |     |     |
| Orchard          |     |     |     |     |     |     |     |     |     |     |     |     |

Figure 5. Cropping pattern of the main crops in the study area.
3.3.2. Supply and Resources
The Bago river, average annual runoff is estimated at 1,066 MCM and there are five dams, namely Zaung Tu, Kodukwe, Shwelaung, Salu, Mazin dam with a capacity of 407, 183, 123, 111 and 32.3 (MCM), respectively and Zaung Tu diversion weir purposes for irrigable area (11500 ha) (see in Fig-1). Zaung Tu Dam purposes for hydropower generation and the other four dams’ purposes of flood control in the wet season and for irrigation in the dry season in the study area. Head flow data of the river and the maximum inflow of the diversions are necessary to insert for the simulation of the rivers and diversion system. In this model, the head flow data were used from the release flow of Zaung Tu dam because it located the upstream of the Bago River. The study area had considered Zaung Tu weir as a diversion node which locate on the downstream of Bago River. There are 7 transmission links and the maximum capacities of the sources are used as maximum flows of the transmission links in this model, and there is no constraint in every link and the supply preferences for all nodes is taken as 1 referring as first priority. Local reservoirs in WEAP are managed independently on river streamflow and are needed to enter monthly Inflows. The zones of the reservoirs of the study area are defined depending on their real operation’s behavior.

3.4. Model Calibration and Validation
The present situation of this study can be evaluated according to the result of the Current Accounts, Reference Scenario (1999-2018). The parameters controlling the generation of river runoff were calibrated and validated using the historical measurement of streamflow obtained from the downstream gauging station located on Bago River. The available continuous streamflow records (1999-2018) are sufficient and appropriate for calibration and validation purposes. However, due to availability of other related input data, the authors chose to use data sets from 2011 to 2018 for calibration and validation of the model. The first 5 years (2011-2015) are dedicated for calibration while the remaining 3 years (2016-2018) are dedicated for validation. The adjustable parameters of the WEAP model were calibrated by trial and error. The following quantitative statistics were used for each set of simulated and historical streamflow.

3.4.1. Coefficient of determination ($R^2$)
The coefficient of determination ($R^2$) outlines the degree of collinearity between simulated and observed data. $R^2$ ranges from 0 to 1, given higher values indicating less error variance. Values, which are greater than 0.5 are considered acceptable [9]. The computation of $R^2$ is shown as below:

$$R^2 = \left(1 - \frac{\sum_{i=1}^{n} (y_i - \bar{y})^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2}\right)$$  \hspace{1cm} (2)

3.4.2. Nash-Sutcliffe efficiency (NSE)
The Nash-Sutcliffe efficiency (NSE) means a standardized statistic which controls the relative magnitude of the remaining adjustment (“noise”) compared to the measured data adjustment (“information”) [10]. NSE arrays between −∞ and 1.0 (1 inclusive), with NSE = 1 being the optimal value. The values of NSE between 0.0 and 1.0 are generally regarded as acceptable levels of performance, whereas values < 0.0 indicates unacceptable performance. NSE is computed as shown below:

$$NSE = 1 - \frac{\sum_{i=1}^{n} (y_i - \bar{y})^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2}\right)$$  \hspace{1cm} (3)

3.4.3. Root Mean Square Error (RMSE)
The root means square error (RMSE) has been used as a standard statistical metric to measure, model prediction error in meteorology, air quality, and climate research studies; a smaller RMSE value indicates better model performance [11]. The computation of RMSE is shown as below:
\[ RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (Y_{i}^{sim} - Y_{i}^{obs})^2} \]  

where, \( Y_{i}^{sim} \): the ith simulated streamflow, \( Y_{i}^{obs} \): the ith observed streamflow, \( Y^{obs} \): the mean of observed streamflow, \( Y^{sim} \): the mean of simulated streamflow.

4. Results and Discussion

4.1. Model Performance of Streamflow

The hydrologic calibration and validation of the reference model. The monthly streamflow recorded at the Bago gauging station was compared against the simulated values from the model. The simulated streamflow results show that the model replicates the observed flows reasonably well.

4.1.1. Calibration and Validation of Streamflow

At the station, the simulated monthly flows match the observed values very closely with Coefficient of determination, \( R^2 = 0.99 \), Nash Sutcliffe efficiency, NSE of 0.88 and Root Mean Square Error, RMSE was estimated at 24 m\(^3\)/s, respectively during calibration as shown in Fig.6. Validation is the process of running the model with an independent set of data and comparing the simulated results with the observed data. If the simulated results closely match the observed data, then the model is calibrated. The simulated results for the validation period reasonably well agree with the observed data (see in Fig.7). Performance statistics of the validation results are \( R^2 = 0.99 \), NSE= 1 and RMSR= 10 m\(^3\)/s, respectively.

4.1.2. Result of Existing Water Demand from WEAP

The water demand means the requirement at each demand site, before demand site losses, reuse and demand-side management savings are taken into account (SEI, 2015). According to the simulation results of the years from 1999 to 2018 for water demands in this study area, which are shown in Fig.8 and Fig.9. The average annual water demand for the agriculture demand site is 1,107 MCM per year and only 13 MCM per year for the domestic demand site from the periods (1999-2018). The ranging annual water demand is 863 to 1441 MCM with the standard deviation (SD) of 165 MCM. According to the standard deviation, the high demands are in 2000, 2002, 2003, 2004, 2009 and 2014, the normal demands are in 2001, 2006, 2007 and 2015 and the lower demands are the left years. During the dry season, the monthly water demands were greater than the river flow because of monthly variation in crop water requirements of the main crops of this study area. During the wet season, which is the time period from May to October, there is sufficient flow, which can gratify the water demands of the demand sites.
4.2. Discussion of the Results

4.2.1. Existing Water Supply, Coverage and Unmet Water Demand

The water supply delivered means the amount of water supplied to demand sites, listed either by source (supplies) or by destination (demand sites). Those are including rainfall-runoff over the study area and released flow from existing 4 dams, which are considered as streamflow of BRB. According to the result of the amount of water supply delivered in the study area (see in Fig.10), which is less than the amount of annual water demands for all year and the same variable. The average annual water supply delivered amount for the demand sites is approximately 566 MCM per year from 1999 to 2018 and the average monthly amount of water supply delivered is 47.73 MCM per month. The demand site coverage in the study area had been steadily stated in the year 1999-2018 to 100% except in 2014 with 94%.

The existing scenario was developed for the period 1999-2018 and the unmet demands obtained from WEAP are shown in Fig.11. It showed the values of the total annual unmet demand of 1.8 MCM per year for agricultural demand site 1 and 5.8 MCM per year for agricultural Demand site 2. The figure given below also indicated that the water supply demand for domestic use was fully met.

5. Conclusion and Recommendation

The conclusion is based on above results and those analyses have shown that BRB has a sufficient supply of the sources covered all kinds of water demand particular with the full cultivated area in the wet season.
However, the secondary crop area during the dry season should be relied on remaining water in the sources at the end of the wet season.

The recommendation for further BRB with efficient water management in next 20 years, WEAP should be applied as the decision-making tool for all kinds of the water development projects with the climate change scenarios.

Acknowledgments
The author would like to express gratitude to Thailand International Cooperation Agency (TICA) Scholarship Program, and Water Resources Research Center (WRRC), Faculty of Engineering, Naresuan University in Thailand for their supporting knowledge and Department of Meteorology and Hydrology (DMH), Department of Population, Irrigation and Water Utilization Department (IWUMD), Bago, and Ministry of Agriculture, Livestock and Irrigation (MoALI), Bago of Myanmar for their providing very useful data and information.

References
[1] Loon, A. V., & Droogers, P. (2006). Water evaluation and planning system. Kitui-Kenya (No. 2). WatManSup Report.
[2] Loucks, D. P. (2006). Generic simulation models for facilitating stakeholder involvement in water resources planning and management: a comparison, evaluation, and identification of future needs. In Proceedings of the iEMSS third biennial meeting: “Summit on Environmental Modelling and Software”, Burlington.
[3] Ajeeth, C., & Thomas, R. (2013). Water balance study on Karuvannur River basin using SWAT. In Proceedings of International Conference on Materials for the Future-Innovative Materials, Processes, Products and Applications, ICMF (pp. 287-290).
[4] Johnson, W. K., & HECD, C. (1994). Accounting for Water Supply and Demand. An Application of Computer Program WEAP to the Upper Chattahoochee River Basin, Georgia.
[5] Cai, X., Kam, S. P., Yen, B. T., Sood, A., & Chu Thai, H. (2014). CaWAT—A catchment water allocation tool for integrated irrigation and aquaculture development in small watersheds.
[6] Htut, A. Y., Shrestha, S., Nitivattananon, V., & Kawasaki, A. (2014). Forecasting climate change scenarios in the Bago River Basin, Myanmar. J. Earth Sci. & Clim. Change, 5(9).
[7] MIP, 2014. Bago Township Report. The 2014 Myanmar Population and Housing Census.
[8] SEI. (2015). Water Evaluation and Planning System (WEAP): User Guide for WEAP 2015. Stockholm Environment Institute, U.S Center.
[9] Santhi, C., Arnold, J. G., Williams, J. R., Dugas, W. A., Srinivasan, R., & Hauck, L. M. (2001). Validation of the swat model on a large river basin with point and nonpoint sources 1. JAWRA Journal of the American Water Resources Association, 37(5), 1169-1188.
[10] Nash, J. E., & Sutcliffe, J. V. (1970). River flow forecasting through conceptual models’ part I—A discussion of principles. Journal of hydrology, 10(3), 282-290.
[11] Addis, H. K., Strohmeier, S., Ziadat, F., Melaku, N. D., & Klik, A. (2016). Modeling streamflow and sediment using SWAT in Ethiopian Highlands. International Journal of Agricultural and Biological Engineering, 9(5), 51-66.