

Application of Water Evaluation and Planning Model for Integrated Water Resources Management: Case Study of Langat River Basin, Malaysia

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Abstract. Due to the effects of climate change and the increasing demand on water, sustainable development in term of water resources management has become a major challenge. In this context, the application of simulation models is useful to deal with the uncertainty and complexity of water system by providing stakeholders with the best solution. This paper outlines an integrated management planning network is developed based on Water Evaluation and Planning (WEAP) to evaluate current and future water management system of Langat River Basin, Malaysia under various scenarios. The WEAP model is known as an integrated decision support system investigate major stresses on demand and supply in terms of water availability in catchment scale. In fact, WEAP is applicable to simulate complex systems including various sectors within a single catchment or transboundary river system. To construct the model, by taking account of the Langat catchment and the corresponding demand points, we defined the hydrological model into 10 sub-hydrological catchments and 17 demand points included the export of treated water to the major cities outside the catchment. The model is calibrated and verified by several quantitative statistics (coefficient of determination, R^2 ; Nash-Sutcliffe efficiency, NSE and Percent bias, PBIAS). The trend of supply and demand in the catchment is evaluated under three scenarios to 2050, 1: Population growth rate, 2: Demand side management (DSM) and 3: Combination of DSM and reduce non-revenue water (NRW). Results show that by reducing NRW and proper DSM, unmet demand able to reduce significantly.

1. Introduction

In recent years, water resources management has become more complicated and controversial due to the impacts of various different parameters affecting water systems. For example, growing demands due to arising from human activity, changing of socio-economic situations, climate change, environmental considerations, and hydrologic and hydraulic conditions. All the issues together with the fact that water has a vital role in virtually every aspect of human life make water resources an important source of conflict. Thus, decision makers crucially require reliable models to allocate water resources between different stakeholders effectively and efficiently [1-3].

As a solution to this problem, researchers and scholars have emphasized in applying various simulation or optimization modeling techniques to develop decision support systems for improved management of the water resources. Rees et al. 2006 presented practical software to help in making a water balance between natural water resources and water demands [4]. Giupponi 2007 developed a DSS for integrated water resource management (IWRM) to help the decision makers in water allocation between different sectors [5]. Letcher et al. 2007 proposed a generalized conceptual framework which



considered water allocation, agricultural production and water use decisions and their interaction with the river system [16]. Van Cauwenbergh et al. 2008 developed a DSS to grade different sustainable planning and management options according to their socio-economic and environmental performance in fulfilling water demand, water price, technical and economic efficiency, and social and environmental impacts [17]. Liu et al. 2010 addressed the IWRM using an optimization-based approach [18]. Gaivoronski et al. 2011 addressed the problem of water management and obtained a “robust” decision policy [19]. Coelho et al. (2012) proposed a DSS tool for regionalization in support of IWRM through Geographic Information System (GIS) processing, fuzzy set theory and a modified dynamic programming clustering algorithm. It provides the option for decision makers to include socioeconomic, political, and environmental aspects into the analysis [20]. Mianabadi et al. 2014 develop a bankruptcy rule for water resources problems that considers agents' contribution to the total resources as well as their claims for reallocation [21]. Roozbahani et al. 2015 introduced a multi-objective model for sustainable water allocation of transboundary watersheds taking into account economic, social and environmental aspects [12]. Jorda-Capdevila et al. 2016 modelled ecosystem services (ES) for recurrent socio-environmental conflicts in water management decisions [13]. Simulation model can be used to resolve conflicts indirectly as well as providing stakeholders and decision-makers with a systematic decision-making process by improving their understanding of the problem by investigating the consequences of their decisions and actions on the results to achieve a sustainable solution for a conflict [14], [15].

In the present study, we aimed to demonstrate the advantages of an integrated management planning network system as a tool for water conflict resolution. We employed a simple integrated water resources management model developed based on Water Evaluation and Planning (WEAP) to demonstrate how efficient the complexity of a water system can be managed by this methodology. The models illustrate the application of the suggested method to a specific catchment area (Langat River basin, Malaysia). The model seeks to simulate the behaviors of demand and supply components, and at the same time optimize the water allocation to the demand sites at every time step along the horizon under three different possible scenarios. Scenarios analyzes are, 1: Population growth rate, 2: Demand side management (DSM) and 3: Combination of DSM and reduce non-revenue water (NRW). The model was then run for thirty years to calculate the impact on the supply-demand gap by the year 2050. Finally, the model performances were evaluated by model evaluation statistics.

2. Study Area

The Langat River basin is located in the southern and south-eastern parts of the Selangor state of Malaysia. Figure 1 shows the boundary of Langat River Basin basin and the major tributaries of the basin: Langat River, Semenyih River and Labu River. The entire basin has an area of 2350 km², with main tributary, Langat River length of 182 km. This basin has a tropical climate, with average annual rainfall of 2145 mm and annual evapotranspiration of 1500 mm. The present study focused on the upper Langat River basin, which is up to the Dengkil river monitoring station (Station No.2816441). The catchment has been chosen as the study area due to its importance to the country. The catchment has a key role in providing water for domestic and commercial usage to about 2.5 million people living inside and the surrounding area outside of the basin, including Kuala Lumpur, the capital city of Malaysia with highest population density in the country and Federal Territory of Putrajaya and Cyberjaya. There two (2) reservoirs and eight (8) water treatment plants within the basin, which provide treated water to the user. Although it is a very important catchment in the Malaysia, it suffers from flooding situation, water pollution, and water shortage that makes the basin a good case study for an integrated water resources management planning network between different stakeholders and decision makers.

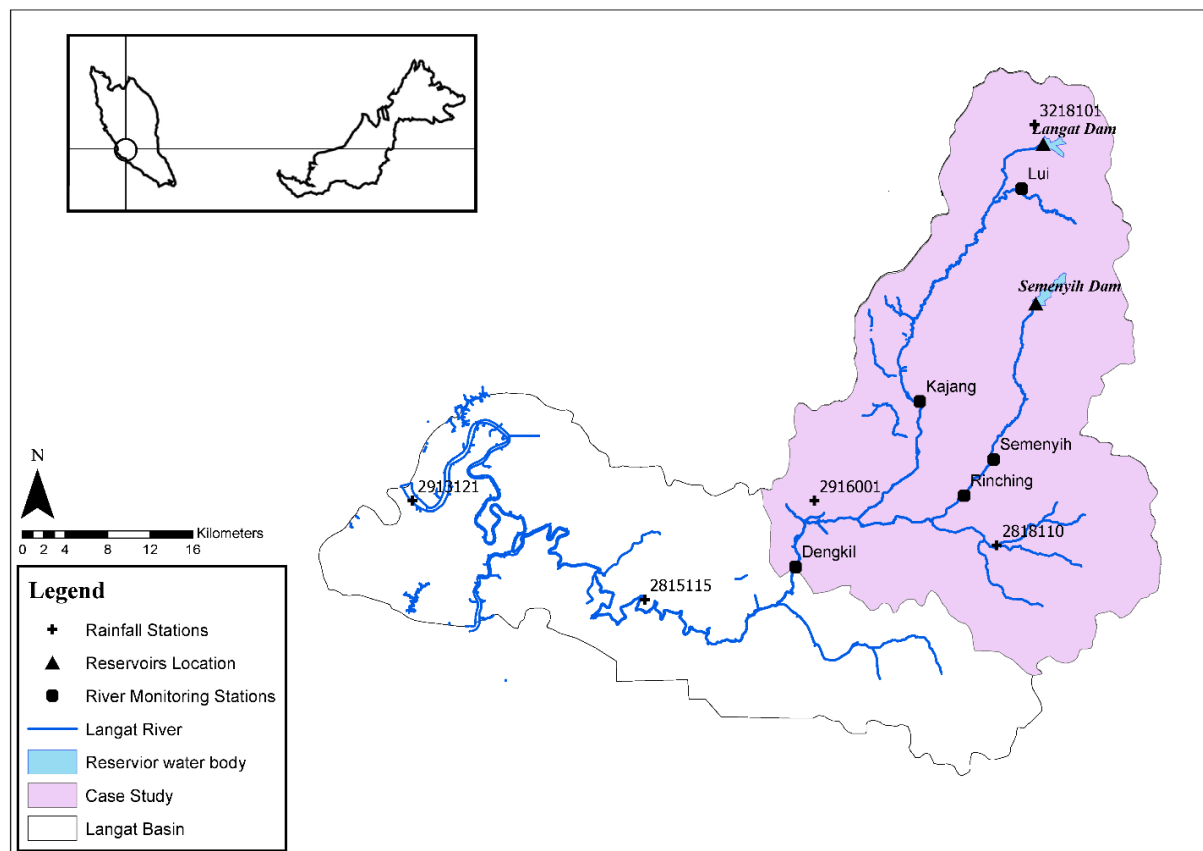


Figure 1. Langat River Basin

3. Methodology

3.1. Model Development

WFAP has a module to model hydrologic processes. The hydrological model is semi-theoretical, continuous time, semi-distributed, and deterministic. As the model is semi-theoretical, it needs calibration and verification. The WEAP does not automatically calibrate the hydrological model; therefore, the calibration must be implemented manually. The Standard method computes the water demand as the product of activity level and water use rate for different sectors, such as, industrial, municipal and agricultural. Demand for all sectors, except agricultural, can be computed only with this method. WEAP uses a one period linear programming routine to allocate resources between demands [16, 17].

Figure 2 shows the overall hydrologic modeling framework. To develop the model structure, the whole study area is divided into ten (10) hydrological catchments (according to available hydrological data) and seven (7) sub-districts which may have considered domestic and non-domestic demands. Besides, we considered two (2) demand sites located outside the study area as exports which supplied by water treatment plants in Langat river basin.

Next, the model structure developed considering involved elements including River (stream), Demand site (service area), Reservoir, Transmission link, Diversion (water treatment plant), Catchment, Streamflow gauge, for monthly time steps between 2005 to 2050 (Figure 3). From the period which flow data are available, data sets for year 2006-2013 are used for model calibration and validation. Figure 4 is the schematic of the model showing WEAP node-network topology overlaid over a few GIS layers.

Last but not least, several scenarios were developed and defined in the model to investigate the water resources problems and probable water issues which may be occur in the near future. Those scenarios

were analyzed and the scenario that showed the best model performance for the Langat River Basin will be figured out.

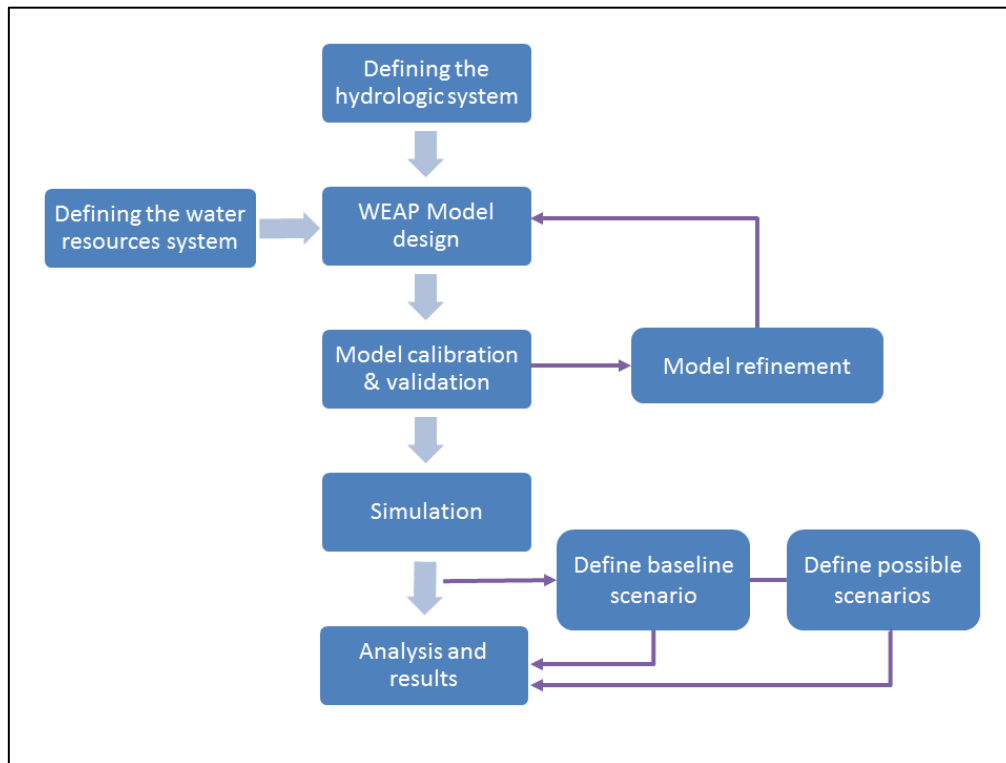


Figure 2. WEAP model framework

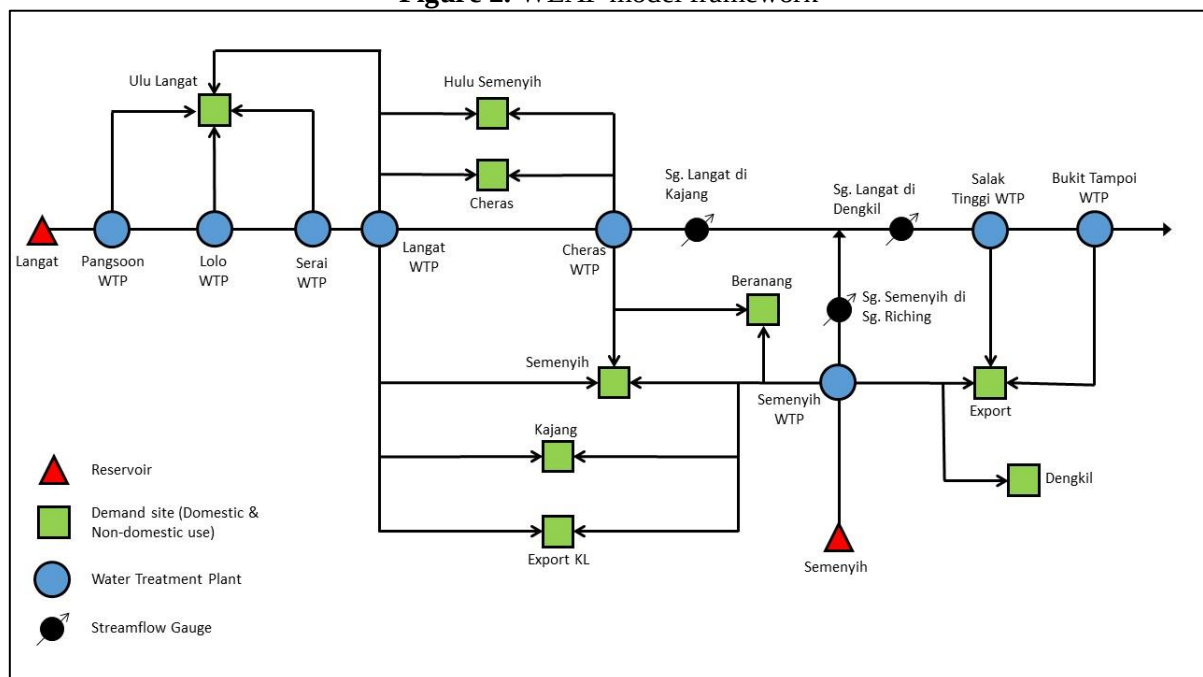


Figure 3. Schematic of the main components of the model

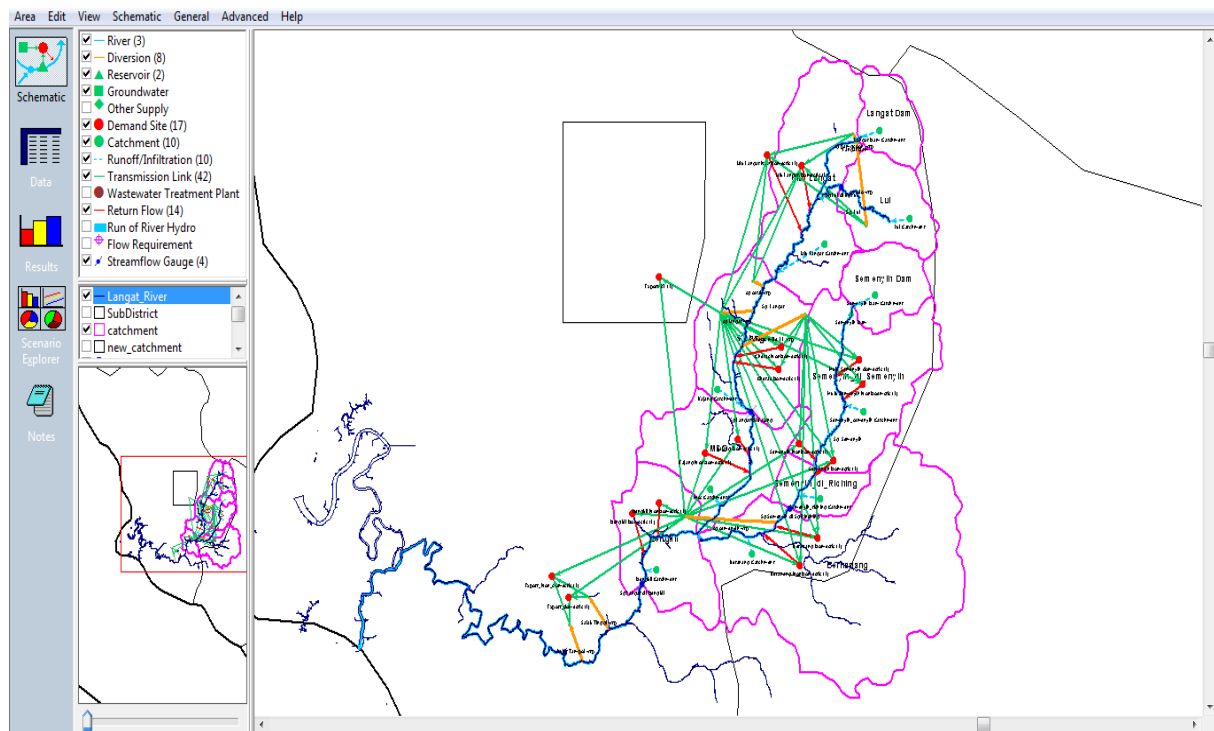


Figure 4. Schematic illustration of the Langat catchment in WEAP application

3.2. Model Calibration and Validation

In the present study, the parameters controlling the generation of runoff from climate inputs were calibrated and validated using the historical measurement of streamflow obtained from 3 gauging stations located on the Lui River, Semenyih River and main stem of the Langat River. Figure 5 is the locations of the streamflow stations on GIS map. The longest available continuous streamflow data from the Sg. Lui, Sg. Semenyih and Sg. Langat gauging stations have been recorded since August 1965, May 1975 and August 1960, respectively. Thus, the streamflow records at these stations are sufficient and appropriate for calibration and validation purposes. However due to availability of other related input data especially climate and population inputs, we chose to use data sets from the period 2006-2013 for calibration and validation of the model. The first 6 years are dedicated for calibration of the model from 2006-2011 while the following 2 years are dedicated for validation of the model from 2012-2013. The adjustment parameters of the WEAP model were calibrated by trial and error. The quantitative statistics (coefficient of determination, R^2 ; Nash-Sutcliffe efficiency, NSE and Percent bias, PBIAS) were computed for each set of simulated and historical streamflow over the period 2006-2013.



Figure 5. Locations of the streamflow stations

3.3. Model Evaluation Statistics

The quantitative statistics used for the evaluation of model performance are the coefficient of determination (R^2), the Nash-Sutcliffe model efficiency (NSE) and the Percent bias (PBIAS).

3.3.1. Coefficient of determination (R^2). The coefficient of determination (R^2) outlines the degree of collinearity between simulated and measured data. R^2 describes the proportion of the variance in measured data explained by the model. R^2 ranges from 0 to 1, given higher values indicating less error variance. Values which is greater than 0.5 are considered acceptable [18, 19]. The computation of R^2 is shown as below:

$$R^2 = \left[\frac{\sum_{i=1}^n (Y_i^{\text{sim}} - \bar{Y}^{\text{sim}})(Y_i^{\text{obs}} - \bar{Y}^{\text{obs}})}{\sqrt{\sum_{i=1}^n (Y_i^{\text{sim}} - \bar{Y}^{\text{sim}})^2 \sum_{i=1}^n (Y_i^{\text{obs}} - \bar{Y}^{\text{obs}})^2}} \right] \quad (1)$$

Where,

Y_i^{sim} : the i th simulated streamflow

Y_i^{obs} : the i th observed streamflow

$\bar{Y}^{\text{sim}}$: the mean of simulated streamflow

$\bar{Y}^{\text{obs}}$: the mean of observed streamflow

3.3.2. Nash-Sutcliffe efficiency. The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance (“noise”) compared to the measured data variance (“information”) [20]. NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. NSE ranges between $-\infty$ and 1.0 (1 inclusive), with $NSE = 1$ being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance. NSE is computed as shown below:

$$NSE = 1 - \left[\frac{\sum_{i=1}^n (Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^n (Y_i^{obs} - \bar{Y}^{obs})^2} \right] \quad (2)$$

Where,

Y_i^{obs} : the i th observed streamflow

Y_i^{sim} : the i th simulated streamflow

$\bar{Y}^{obs}$: the mean of observed streamflow

3.3.3. Percent bias (PBIAS). Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias [21]. PBIAS is calculated as shown below:

$$PBIAS = \left[\frac{\sum_{i=1}^n (Y_i^{obs} - Y_i^{sim}) * (100)}{\sum_{i=1}^n Y_i^{obs}} \right] \quad (3)$$

Where,

Y_i^{obs} : the i th observed streamflow

Y_i^{sim} : the i th simulated streamflow

3.4. Future Possible Scenarios

In order to assess the capability of water supply in meeting the demand for treated water in Selangor, three types of future projections were investigated: population growth, demand side management and supply side management. The key results investigated were water supplied and demand coverage.

3.4.1. Reference scenario. Under this scenario, the projection assumes the supply and use of water same as current situation and associated population growth. The production of water treatment plant is at its current design capacity with population growth rate of 2.57 % (Intercensal Mid-Year Population Estimates of Malaysia and States for the year 2001-2009). The main question asked of the model at this stage is: “How much of the current demand could be met, if the water treatment plant production is at current design capacity and the population is increasing in the future?”

3.4.2. Scenario 1: Population Growth Rate. This scenario assumes a higher population growth rate of 4 % with treated water production capacity at current design capacity to evaluate the impact of population growth towards the water supply and demand of Langat in the future. “How much of the demand for treated water could be met, if the production capacity is at current design capacity and population growth is higher in the future?”

3.4.3. Scenario 2: Demand Side Management (DSM). This scenario evaluates a demand side management strategy and was applied to both the “reference” and “high population growth” scenarios above. Water savings initiatives were taken into the calculation of the model in reducing 10% of the amount of water consumption per capital from 235 ld to 211.5 ld. “If water usage per capital is reduced from 235 ld to 211.5 ld, how much of the water demand could be met by the supply with current design capacity?”

3.4.4. Scenario 3: Combination of DSM and reduce Non-Revenue Water (NRW). Under this scenario, a demand side management strategy incorporates with a supply-side management strategy – reducing water consumption per capital, as well as reducing the non-revenue water (NRW) losses from 33.35 % to 16.68 %, to be assessed against the “reference” and “high population growth” scenarios. “What would be the impact on the water supplied and demand coverage in the future conditions, given plans to reduce NRW for the supply-side and plans to reduce water consumption per capital for the demand side?”

4. Results and Discussion

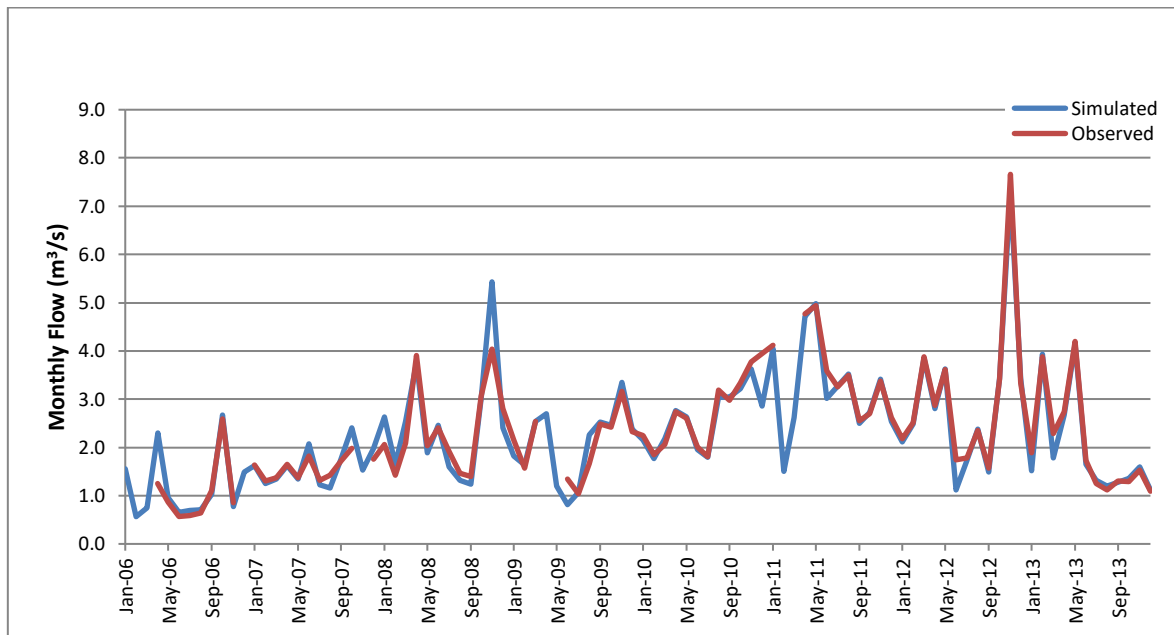
4.1. Model Performance

Figure 6 reveals the hydrologic calibration and validation of the reference model. The monthly streamflow recorded at each of the gauging stations was compared against the simulated values of the model from 2006-2011 for calibration process and 2012-2013 for validation process. The simulated streamflow in Sg. Lui, Sg. Semenyih and Sg. Langat show that the model replicates the observed flows reasonably well.

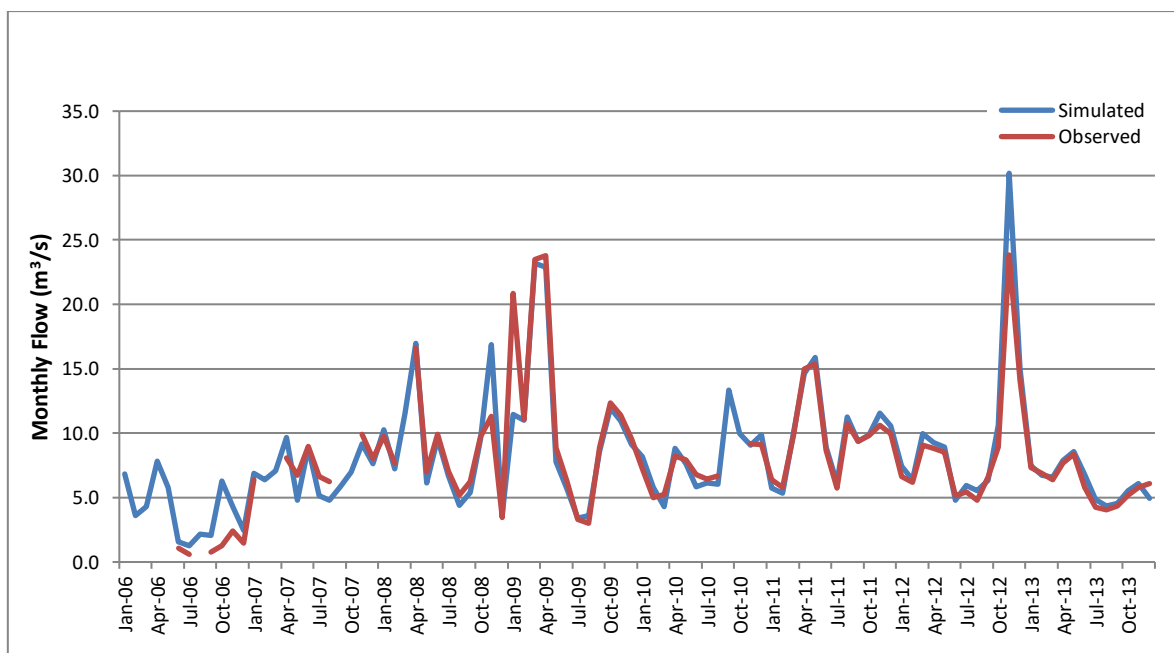
At Sg. Lui, the simulated monthly flows match the observed values very closely with a Nash-Sutcliffe efficiency of 0.96 and $R^2 = 0.96$ during calibration, 0.97 and $R^2 = 0.98$ during validation. The Pbias was estimated as 0.81 % during calibration and 3.14 % during validation (Figure 6a).

At Sg. Semenyih, monthly flows were simulated with a Nash-Sutcliffe efficiency of 0.93 and $R^2 = 0.93$ during calibration, 0.87 and $R^2 = 0.98$ during validation. The Pbias was estimated as 0.41 % during calibration and 7.96 % during validation (Figure 6b).

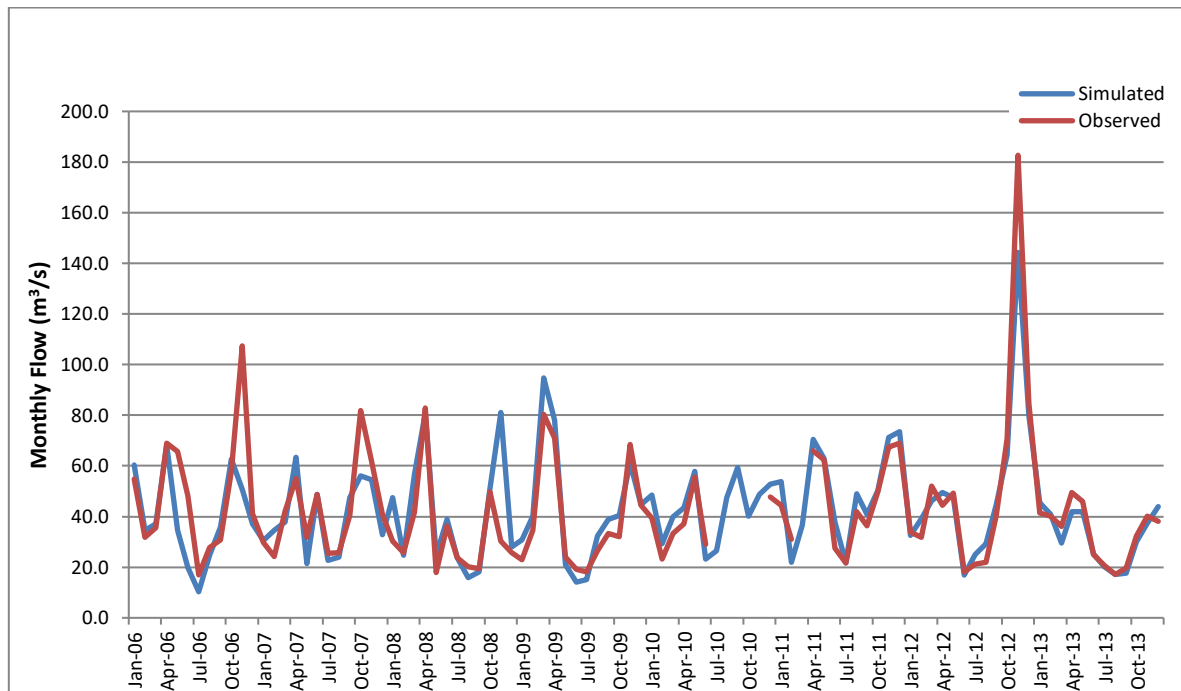
At Sg. Langat, monthly flows were simulated with a Nash-Sutcliffe efficiency of 0.93 and $R^2 = 0.94$ during calibration, 0.92 and $R^2 = 0.97$ during validation. The Pbias was estimated to be 4.14 % during calibration and 4.39 % during validation (Figure 6c).



(a) Sg. Lui di Kg. Lui station



(b) Sg. Semenyih di Kg. Rinching station



(c) Sg. Langat di Dengkil station

Figure 6. Historical monthly streamflow along with the simulated values

4.2. Reference Scenario

Water demand would steadily rise as a result of population increasing at 2.57 % annually from 2005 population of 1,085,670 to reach the capacity of 3,606,835 by 2050. The accompanying projected water demand rises to a maximum of 599.43 MCM compared to the existing demand of less than 300.00 MCM (see Figure 7), which is double of the demand of current situation.

Under the current system of water use and supply, the projection showed that Langat basin area will face water deficits for both domestic and non-domestic sectors by the year of 2019. This is probably due to the supply of treated water from the basin to areas outside the basin especially Kuala Lumpur as more than 38 % of the treated water from Sg. Langat water treatment plant and Sg. Semenyih water treatment plant were supplied for areas outside of Langat basin.

4.3. Scenario 1: Population Growth Rate.

This scenario assumes population growing at a higher rate, 4 % to forecast the impact of population growth towards the supply and demand of water for the period of 2013 to 2050 in Langat basin area with the current system of water usage and supply maintain. The accompanying projected water demand raises to a maximum of 910.16 MCM instead of 599.43 MCM under the reference scenario (see Figure 7).

Figure 7 also shows the projection of annual unmet water demand based on both scenarios: high population growth rate and the reference. The simulation results demonstrate that with high population growth rate, Langat basin area will face water deficits in 2017, which is only 2 years earlier than the reference scenario. However, the annual unmet demand for high population growth rate indicated a maximum of 621.00 MCM in 2050, which is twice the amount of the annual unmet demand of reference scenario (303.01 MCM). This implies that population growth rate shown significant impact on the demand of water in a long-term perspective and reflects the need to develop new technologies, new cooperation, or better water management plans to offset this anticipated shortfall.

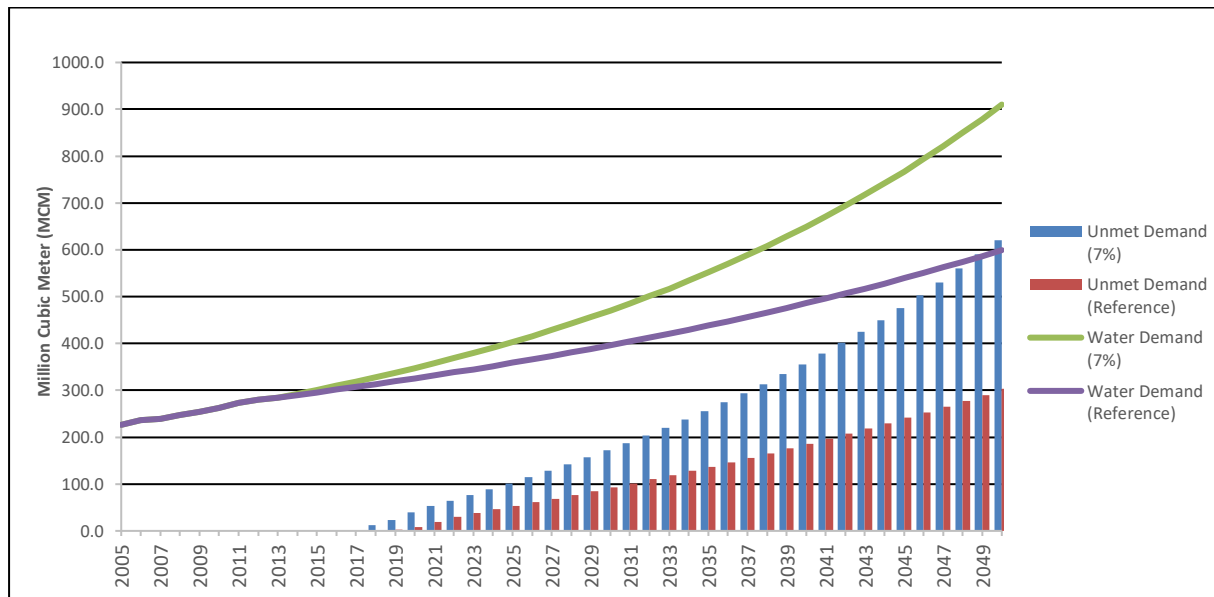


Figure 7. Annual total water demand and unmet demand of reference and population growth scenarios

4.4. Scenario 2: Demand Side Management (DSM)

This scenario was evaluated with the model, by employing both the “reference” and “high population growth” scenarios. Through this scenario, the impact of the application of water conservation and demand side strategy was assessed. Saving of 10% of the water consumption per capital from 235 liter/day to 211.5 liter/day was considered. Figure 8 and Figure 9 show the amount of water that can be saved through the implementation of DSM via the “reference” and “high population growth” scenarios.

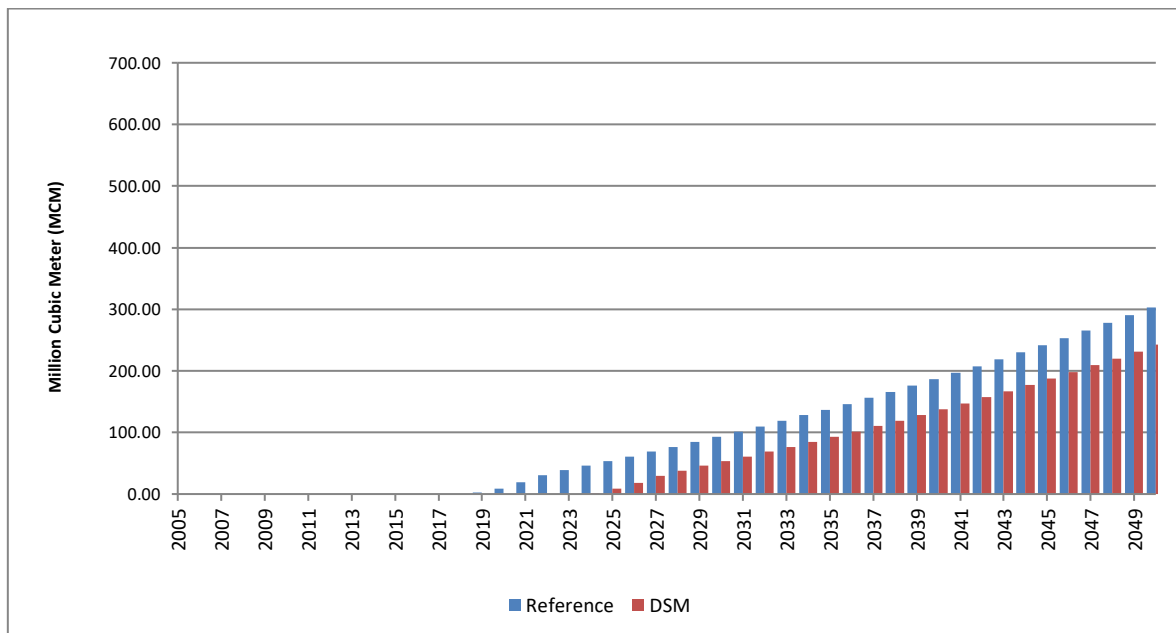


Figure 8. Annual total unmet demand based on implementation of DSM on the reference scenario

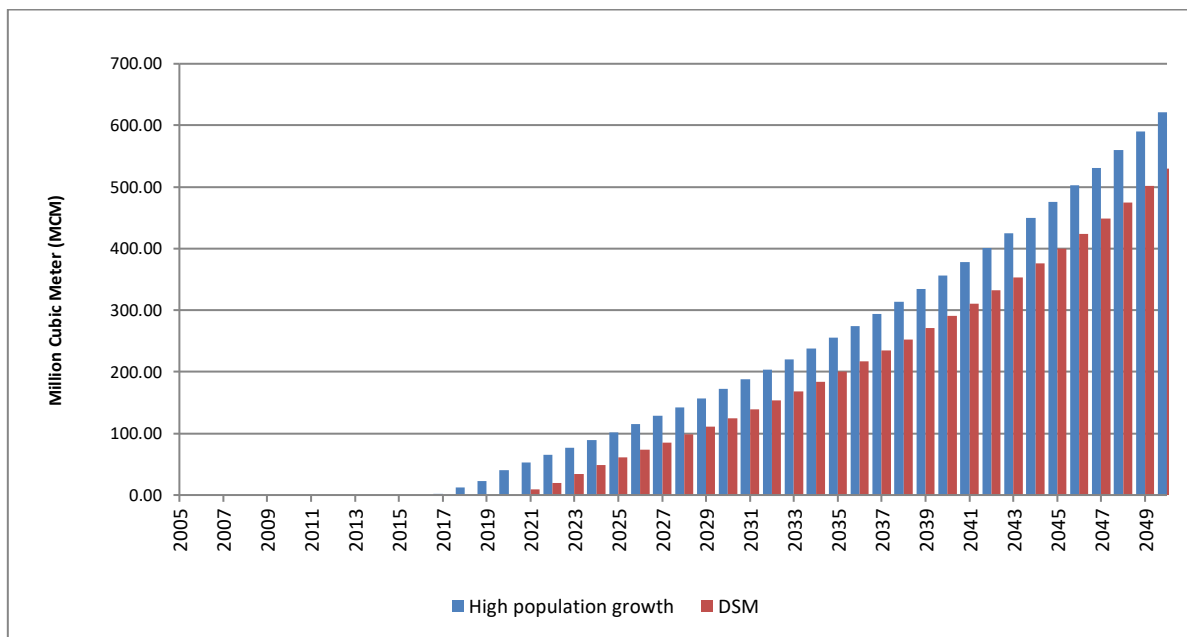


Figure 9. Annual total unmet demand based on implementation of DSM on the population growth rate scenario

Under the reference scenario, the results shown in Figure 8 reveals that with implementation of DSM, the Langat basin water supply is able to keep up with the demand until 2023 by which time demand growth will outstrip gains from the reduced water consumption by DSM. The maximum annual total unmet demand in 2050 is also able to reduce to 243.07 MCM compared to the reference condition (303.01 MCM). Overall, the total amount of unmet demand over the period 2005-2050 was decreased from 4,491.52 MCM to 3,113.88 MCM. On the other hand, the WEAP simulations showed that with demand side management effort of just reducing 10 % of the water consumption per capital, a total of 1,568.28 MCM of water is able to be saved for projection of water demand until 2050.

Under high population growth scenario, the supply is able to keep pace with the demand until 2020 in which after that the demand is greater than the supply (see Figure 9). The model also projected a reduction in the total unmet demand from 8,788.16 MCM to 6,928.18 MCM. Besides, the amount of water saving able to achieve a total number of 1,982.78 MCM for projection of water demand until 2050, indicated that more water is able to be saved as compared to the reference scenario (1,568.28 MCM). This result shows that the saving was proportional to the demand; therefore it had a greater impact in the higher population growth scenario, the one with the higher water demand.

4.5. Scenario 3: Combination of DSM and reduce Non-Revenue Water (NRW)

This scenario incorporates a demand side management and a supply side management strategies--reducing in NRW from current condition of 33.35 % to 16.68 % as well as reduced water consumption per capital, assessed against the “reference” and “higher population growth” scenarios. Figure 10 and Figure 11 compare the water unmet demand that can be reduced through the implementation of DSM together with reduced NRW via both the “reference” and “higher population growth” scenarios.

Under the reference scenario, as a result of reduced losses and water consumption per capital, water supply is able to keep up with demand until 2032, marked a delay of 13 years compared to the reference scenario without DSM and reduced NRW (see Figure 10). In overall, through the implementation of DSM water saving and reduced NRW policies, the shortage is able to reduce by about 62.85 % from 4,491.53 MCM to 1,688.70 MCM considering the population and industrial growth.

Under the high population growth scenario, the results in Figure 11 showed that the supply able to meet 100% of the demand until 2025 which is 9 years later than high population growth scenario without

DSM and reduced NRW. The model also projected 42.11 % reduction in the total unmet water demand, from 8,878.16 MCM to 5,139.85 MCM due to implementation of DSM water saving and reduced NRW policies.

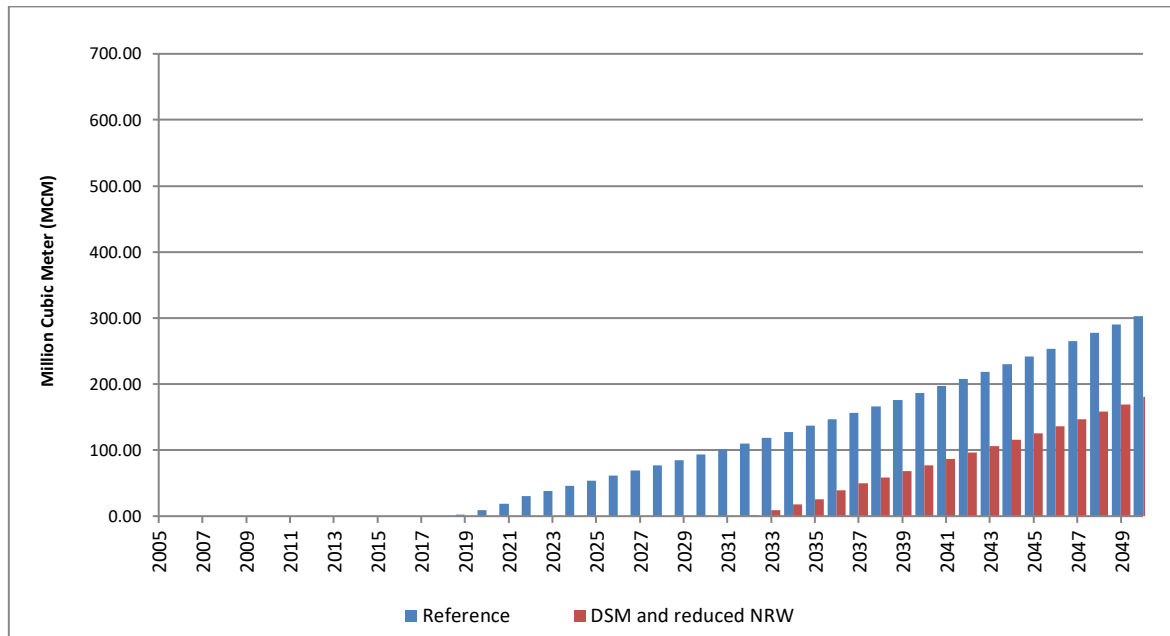


Figure 10. Annual total unmet demand based on implementation of DSM and reduced NRW on the reference scenario

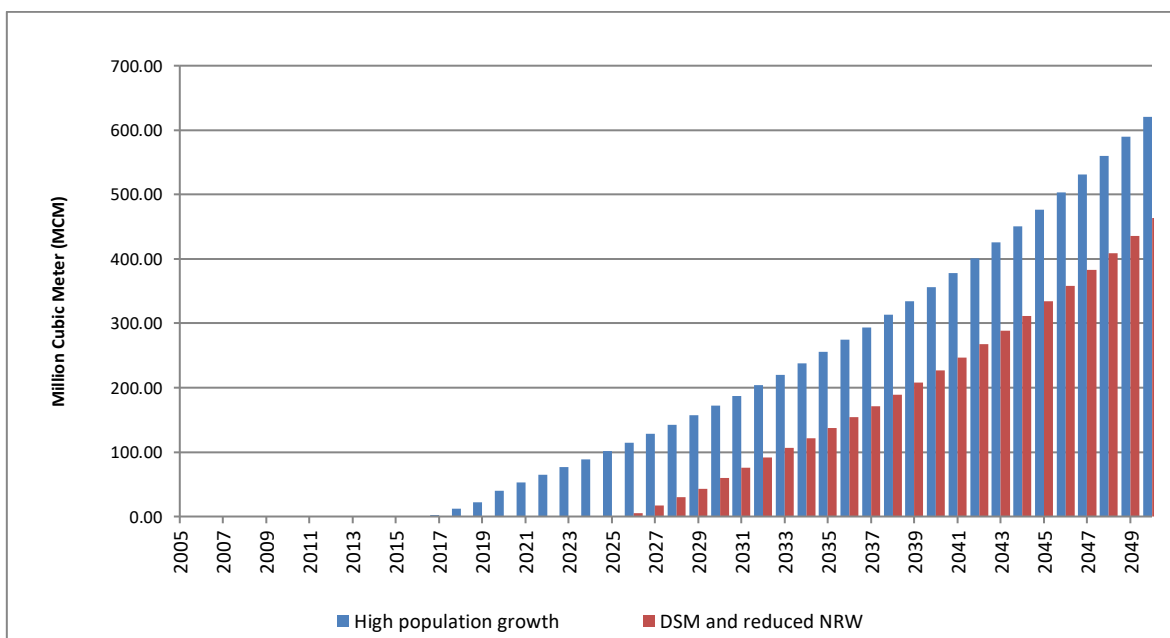


Figure 11. Annual total unmet demand based on implementation of DSM and reduced NRW on the population growth rate scenario

5. Conclusion

In the present study, an integrated hydrologic model was introduced by using WEAP for assessing the water conflict. The model developed through WEAP is highly capable and showed great performance to manage available water resources with water demand. The calibration and validation of model evaluated by the quantitative statistics (coefficient of determination, R^2 ; Nash-Sutcliffe efficiency, NSE and Percent bias, PBIAS) assured the model outputs scientifically sound, robust and defensible. The model able to simulate various possible future scenarios to evaluate current and future water management system of Langat River Basin and acts as an integrated management planning network for decision makers to resolve conflicts over water allocation and policies implied.

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