

Application of Integrated Hydrologic and River Basin Management Modeling for the Optimal Development of a Multi-Purpose Reservoir Project

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Abstract Multi-purpose reservoir development have been always a big challenge for the management of water resources. This paper describes an integrated approach for investigating catchment hydrology in the development of a hydropower and a canal irrigation system based on model analyses. The investigation aims to adequately determine an optimal domestic and irrigation water resources allocation scheme based on an assessment of the reservoir water balance and capacity for hydropower. The soil and water assessment tool (SWAT) which characterizes basin hydrology and the water management and planning model MODSIM which provides a decision support system for water allocation optimization, were used in this study. The integrated approach was applied to Prek Te River basin in Cambodia. The water demand aspect was examined based on domestic water use, irrigation water, environmental flow, and water losses. An operational rule curve was developed for hydropower operation with respect to a power potential of 13 MW. Hydrologic modeling revealed 90 % dependable water of about 2.7 m³/s during the dry season and 214.3 m³/s during the wet season, indicative of a wet-season dependent reservoir for storage. Results from the 26-years simulation period also showed that diversions for domestic water and irrigation water supply were 92.3 % dependable for a 13 MW capacity hydropower development. The integrated approach was shown to be a valuable decision support tool for water resources management with the determination of an optimum policy for multi-purpose reservoir operation based on available basin water supply.

Keywords Hydropower · Irrigation · MODSIM · SWAT · Water balance

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1 Introduction

The water resource system in a river basin can be operated to provide water for food, power, transportation, recreation, and environmental protection. Without effective integrated management, these multi-sectoral uses can impair the system and create conflict. Therefore, the equitable and sustainable use of water resources has become a core component of local and national strategic management plans. An important component of water resource management is the allocation of water to major water users while maintaining the minimum levels required for social and environmental uses and addressing the equity and development needs of society (Cap-Net UNDP 2008). In the sustainable management of water resources, knowledge of water balance and water yield in a river catchment is indispensable at the watershed and basin levels. A primary challenge in water resource development is designing and operating infrastructure projects that provide social benefits while preventing the loss of natural ecosystem services due to dam development.

Hydropower dams provide the society with substantial benefits; however, if poorly planned, designed, or operated, they can also have serious consequences for the ecological health of rivers and the economic and social well-being of communities dependent upon the goods and services provided by healthy rivers (Karin et al. 2009). The specification and provision of environmental flows are key to sustainable hydropower development and water management. Subject to the development of hydropower, an irrigation system that receives water from a hydropower reservoir can be more challenging to manage since it needs more cooperation from water user equitable distribution. Water availability is important for irrigation development, and efficient water management is one of the key elements for the successful operation of irrigation schemes. Therefore, water resources planning and management at basin scale is such a large and complex problem that makes it essential to use effective modeling tools in order to obtain an optimum plan for river basins development (Shourian et al. 2008).

In the Lower Mekong Basin (LMB), there is considerable potential for further development of tributary hydropower. Subject to the coordinated operation of hydropower dams, there is an opportunity for increased dry season flows to be used, without affecting the baseline flow, to expand irrigation and improve agricultural capabilities (MRC 2011). The Prek Te River is a lower Mekong River tributary located in Cambodia. Water scarcity is the major concern for developing agriculture in this region, where 40 % of the crop land is destroyed by a lack of water every year. On the contrary, the Prek Te River receives a large volume of water from the mountainous areas during the rainy season, providing the potential for developing a medium-scale hydropower and irrigation system. Recently, the Cambodian government has planned hydropower development of the Prek Te River (called Prek Te III) with a potential installed capacity of 13 MW (JICA 2007). The Cambodia National Mekong Committee (CNMC) set this basin development goal in its investment roadmap to improve water security and integrated agricultural development (CNMC 2011). Therefore, there is a need to develop quantitative methodologies adapted to a regional context within the LMB that are capable of supporting water resource management at the watershed level.

In a decision support system, models are usually employed for selecting the optimal approach for assisting water managers in making appropriate decisions. Modelling is a critical tool in integrated assessment (Croke et al. 2007). Therefore, this study aims to investigate the characteristics of catchment hydrology based on model simulation analyses by accounting for the effect of future river basin development scenarios on a potential upland reservoir built for power generation and a downstream canal irrigation system. This investigation is performed

by combining the application of the hydrological model Soil and Water Assessment Tool (SWAT) embedded in a Geographic Information System (GIS) and MODSIM which is a generalized river basin management model as a decision support system. SWAT provides the hydrologic and water resources information with development scenario in the watershed while MODSIM provides a decision support system for water allocation optimization.

2 Materials and Methods

2.1 Study Area

The Prek Te River is a tributary of the lower Mekong River and is located in Cambodia. It has a long catchment area of 4372 km², draining water via valleys and falls from the mountainous area in Mondul Kiri province and crossing alluvial plains before flowing into the Mekong River in Kratie province (Fig. 1). The proposed Prek Te III hydropower dam is located about 50 km from the junction with the Mekong River. The landscape slopes down toward the Mekong from east to west. The highest elevation in the basin is 927 m (msl) in the mountainous area in Mondulkiri province, and the lowest elevation is 14 m (msl) close to the Mekong River.

The climate of this area is governed by monsoons; the southwest monsoon brings rains from May to September–October. During the northeast Monsoon in November to December, temperatures drop and rainfall becomes low. The northeast monsoon is hot, dry, and less humid with particularly high evapotranspiration in March and April. Daily temperature varies between a maximum of 36.7 °C during the hottest months of April and May to 19 °C in December and January. The annual precipitation in the Prek Te basin is about 2600 mm, but there is a large difference between the amounts of rainy season precipitation and dry season precipitation. In the rainy season, from May to October, this area receives about 2200 mm of precipitation, whereas in the dry season, from November to April, it receives only 300 mm of precipitation.

2.2 Modeling Procedure

In this study, SWAT is used to simulate two conditions. The first run is to daily simulate the existing natural conditions for calibrating the river runoff with the observed flow data for 2013 to 2014. The second run is from 1989 to 2014 to simulate the scenario of a reservoir in the proposed location using the calibrated parameters. From SWAT output, the net evaporation rate

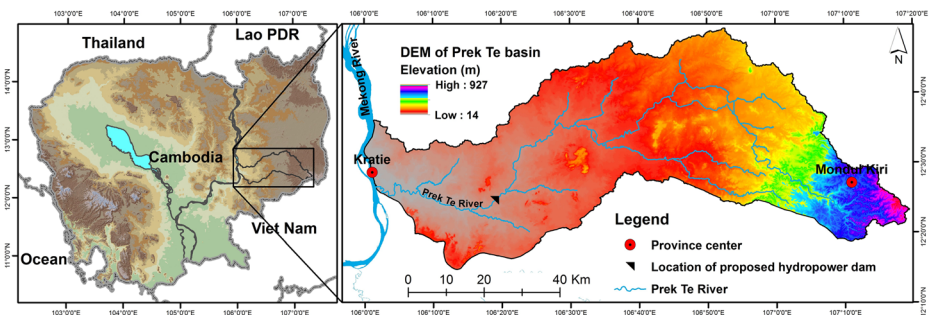


Fig. 1 Location of Prek Te River basin and its DEM

of reservoir and seepage loss fraction were determined and the 90 % of dependable reservoir inflow with the flow from downstream sub-watershed were used as the input for MODSIM to simulate hydropower and downstream water allocation. Figure 2 shows the conceptual framework of model combination procedure.

In order to set up reservoir simulation in the SWAT model, area and volume are required for different operational conditions, such as initial volume of the reservoir, area and volume of the reservoir at the principal spillway, and area and volume of the reservoir at the emergency spillway. Furthermore, hydropower reservoir system simulation by MODSIM requires reservoir information such as minimum, maximum, and initial reservoir volume. Regarding power generation, MODSIM needs plant efficiency, the elevation-area-volume curve, and the target storage time series. To determine these reservoir characteristics, the Spatial Analyst Tool in the GIS was used. The digital terrain model (DTM) of $50\text{ m} \times 50\text{ m}$ was processed to create 1 m interval elevation contours for calculating both surface area and volume at various elevations. From these values, the elevation-area-volume curve was created.

2.3 Description of the SWAT Model

SWAT is applied to model the hydrology of the Prek Te River basin. SWAT is considered computationally efficient in its prediction (Neitsch et al. 2009). It was developed by the Agricultural Research Service of the United States Department of Agriculture to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large and complex watersheds with varying soil, land use, and management conditions over long periods of time (Arnold et al. 1998). ArcSWAT is the new version of SWAT and is used as an interface between ArcGIS and the SWAT model. This study used ArcSWAT version 2012.10_1.14 embedded within ArcGIS 10.1.

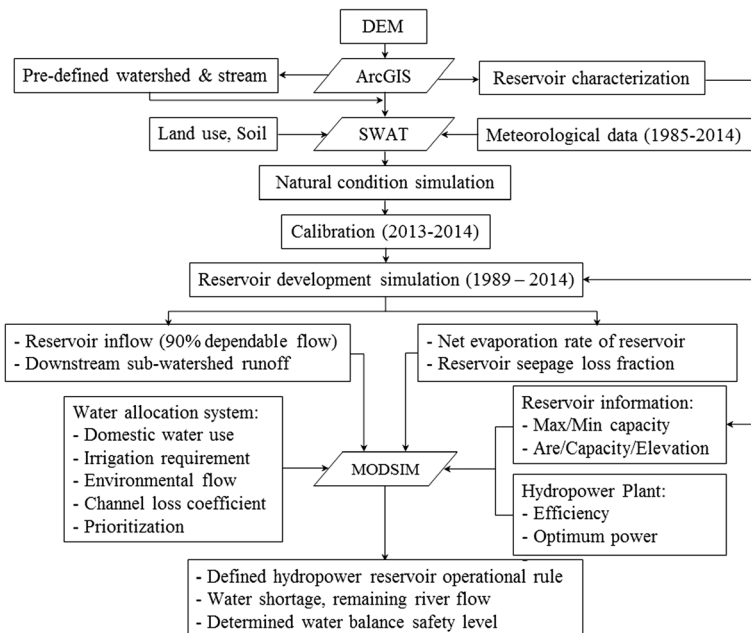


Fig. 2 Conceptual framework of model combination procedure

The hydrologic cycle of the SWAT model is based on the water balance equation, which considers the unsaturated zone and shallow aquifer above the impermeable layer as a unit. Equation (1) is the key equation for predicting the hydrology of the watershed (Neitsch et al. 2009).

$$SW_t = SW_0 + \sum_0^t (R_{day} - Q_{surf} - ET - P - Q_{gw})_i \tag{1}$$

where t is time in days, SW_t and SW_0 are the final and initial soil water contents, respectively (mm), R_{day} is the amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff on day i (mm), ET is the amount of evapotranspiration on day i (mm), P is the amount of water entering the vadose zone from the soil profile on day i (mm), and Q_{gw} is the amount of return flow on day i (mm).

2.4 Description of MODSIM Model

MODSIM is a generic river basin management originally conceived in 1978 at Colorado State University (Shafer and Labadie 1978), making it the longest continuously maintained river basin management software package currently available from an open source. MODSIM is designed to develop basin-wide strategies for short-term water management, long-term operational planning, drought contingency planning, water rights analysis, and resolution of conflicts among urban, agricultural, and environmental concerns. The basic principle underlying MODSIM is that most physical water resource systems can be accurately simulated as capacitated, directed flow networks (Labadie 2010). MODSIM has the capability to simulate reservoir operations and hydropower generation (Labadie 2010).

Components of the system are represented as a network of *nodes*, both storage (i.e., reservoirs, groundwater basins, and storage rights accounts) and non-storage (i.e., river confluences, diversion points, demand locations, streamflow gauging stations, and return flow locations), and with *links* or *arcs* (i.e., canals, pipelines, natural river reaches, and decreed water rights) connecting the nodes. Although MODSIM is primarily a simulation model, the network flow optimization provides an efficient means of ensuring the allocation of flows in a river basin in accordance with specified water rights and other priority rankings, including economic valuation (Labadie 2010).

MODSIM simulates water allocation mechanisms in a river basin through sequential solution of the following network of flow optimization problems for each time period $t = 1 \dots T$

$$\text{Minimize } \sum_{k \in A} c_k \cdot q_k \tag{2}$$

$$\text{Subject to } \sum_{k \in O_i} q_k - \sum_{j \in I_i} q_j = b_{it}(q) \text{ for all nodes } i \in N \tag{3}$$

$$l_{kt}(q) \leq q_k \leq u_{kt}(q) \text{ for all links } k \in A \tag{4}$$

where A is the set of all arcs or links in the network; N is the set of all nodes; O_i is the set of all links originating at node i (i.e., outflow links); I_i is the set of all links terminating at node i (i.e.,

inflow links); b_{it} is the (positive) gain or (negative) loss at node i at time t ; q_k is the flow rate in link k ; c_k is the costs, weighting factors, or water right priorities per unit flow in link k ; and l_{kt} and u_{kt} are the lower and upper bounds, respectively, on flow in link k at time t . Note that parameters b_{it} , l_{kt} and u_{kt} are defined as functions of the flow vector q in the network. These nonlinearities are due to flow-dependent calculations of evaporation, groundwater return flows, channel losses, and instream flow requirements, and are primarily associated with the artificial arcs (Labadie 2010). Equations (2), (3) and (4) are solved with the Lagrangian relaxation algorithm RELAX-IV (Bertsekas and Tseng 1994), which is up to two orders of magnitude faster than the revised simplex method of linear programming.

2.5 SWAT Model Setup

2.5.1 Spatial Data for Sub-Watershed Delineation and HRU Definition

- DTM:** A regular grid DTM of 50 m by 50 m resolution (provided by the Mekong River Commission) was used to delineate the sub-watershed and define streams and HRU in ArcGIS and ArcSWAT.
- Land use:** JICA (2003) classified land use in Cambodia. The present study used this classification within the study area and updated it by overlaying the forest cover and agricultural land maps produced by the Ministry of Agriculture and Fisheries and Forestry of Cambodia, 2014. From the land use maps in Fig. 3a, it can be seen that the paddy field mostly covers the area from the Mekong River bank to the proposed hydropower dam. The study on canal irrigation development is conducted in this area.
- Soil data:** A soil map was obtained from the Mekong River Commission. In the study area, seven major soil groups, based on the FAO classification, were found: *Acrisols*, *Cambisols*, *Ferrasols*, *Gleysols*, *Leptosols*, *Planosols*, and *Vertisols*. *Acrisols* and *Leptosols* can be found in either alone or mixed with other soil groups (Fig. 3b). Chesworth (2008) has described these soil groups in the Encyclopedia of Earth Sciences.

The watershed and streams were primarily defined from DTM by using ArcGIS. The pre-delineated watershed and pre-defined stream feature dataset were edited based on

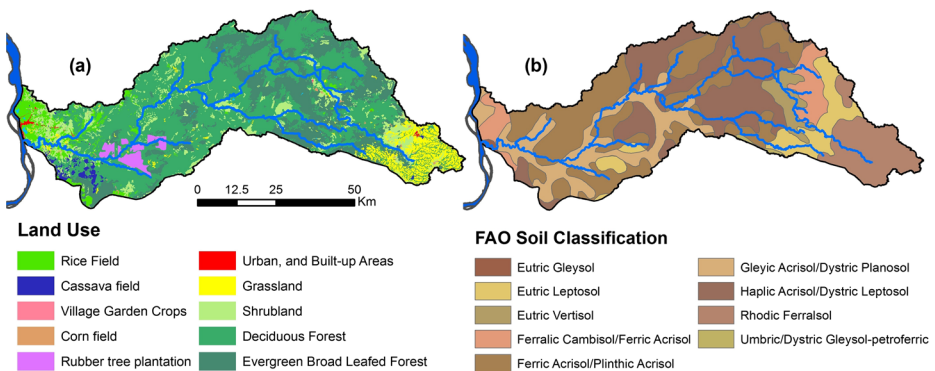


Fig. 3 a Present land use; b Soil classification in Prek Te catchment

the actual hydrologic situation and topographic change. Close to Mekong River bank, the watershed boundary was delineated based on the existing national road which plays as the levee along Mekong River. The pre-defined streams and watershed were loaded into the watershed delineator menu in ArcSWAT to complete watershed delineation process and add the reservoir (Fig. 4a). The spatial data of land use, soil, and slope classification have been imported overlaid, to define the multiple hydrologic response units (HRUs) within the watershed with threshold percentage of 0/10/10. There are 532 HRUs distributed within the watershed.

2.5.2 Meteorological Data

Daily meteorological datasets from 1985 to 2014 for precipitation, temperature, wind speed, solar radiation, and relative humidity at four weather stations (three in Cambodia and one in Vietnam) were obtained from the Mekong River Commission (Fig. 4a). These long-term weather datasets were used for weather generation in SWAT since some stations missed some weather parameters in some years. However, daily precipitation data were acceptable for the model simulation.

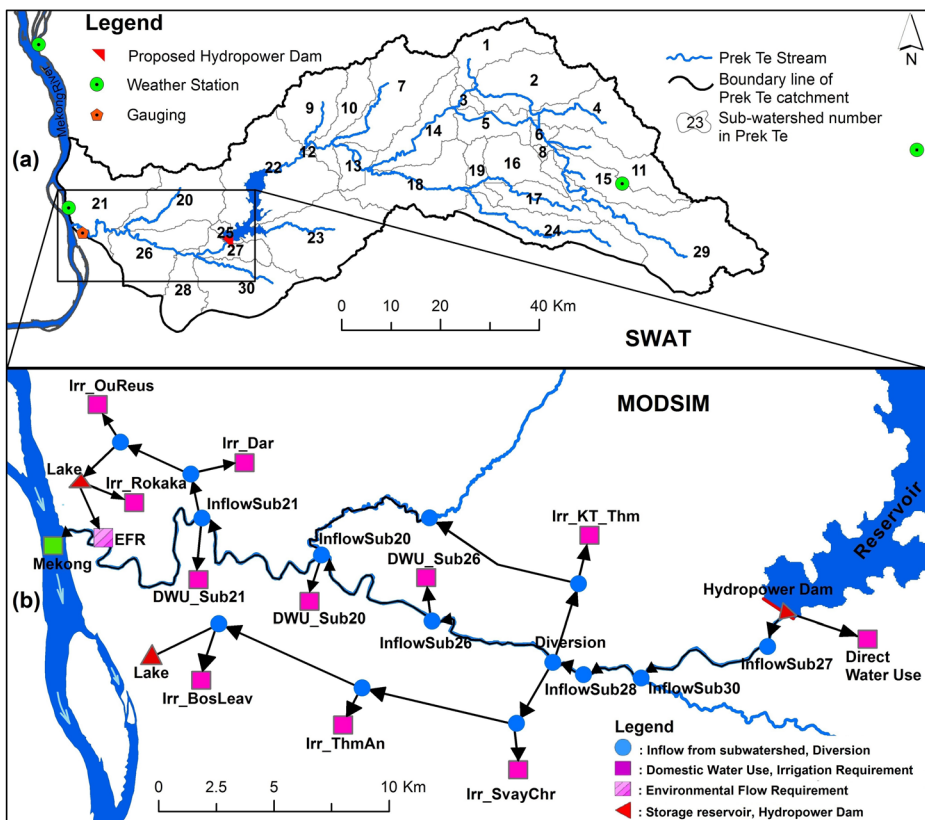


Fig. 4 a Watershed system in SWAT; b River network and water allocation system in MODSIM

2.6 MODSIM Model Setup

2.6.1 River Basin Network Development

A schematic network of the river and irrigation canal is necessary to set up the model. The featured icons in the figure have specific characteristics and functionality. General network setting requires information on units, time step, and scale. There are seven irrigation area locations in the system, as seen in Fig. 4b. All demand icons with a label starting with “*Irr_*” represent the irrigation area. Domestic water use in each sub-watershed is represented by the demand icons with labels starting with “*DWU_*.” The environmental flow requirement icon is set near the monitoring point close to the river mouth. The environmental flow requirement icon is the flow through demand, which is labeled “*EFR*.” A network sink icon (green square) is labeled as Mekong. A hydropower dam was set at the proposed location crossing the Prek Te River. In this study, the time step is set to 5 days, giving six steps per month for all calculations. The simulation is run from 1/1/1989 to 12/26/2014.

2.6.2 Hydropower Reservoir

In order to simulate the hydropower, MODSIM requires reservoir and hydropower plant information and priority. For the reservoir information it requires area-capacity-elevation curve, maximum and minimum storage. MODSIM incorporates water loss due to surface water evaporation and seepage. Evaporation rate seepage coefficient were calculated from the output of SWAT. Power plant elevation is constantly set to 39 m with its efficiency of 90 %. The maximum power was set to 1.5 MW in every month and the plant generates 24 h per day. Model consists of priority function of water allocation. The first priority is hydropower generation at the design capacity of 13 MW, the second is to meet the demand at the downstream for domestic water use, the third is the EFR, and the fourth is the IWR.

2.6.3 Water Requirement Principle

Domestic Water Use Domestic water use (DWU) is based on an independent household survey of the communities living along the Prek Te. The survey identified the percentage of households in each corresponding community that used water from the Prek Te River. The survey found that the average domestic water consumption is 12.8 m³ per household per month. From this information, DWU in the corresponding sub-watershed was calculated by overlaying these administrative sub-divisions with the sub-watershed divisions. DWU for sub-watershed number 20, 21 and 26 are 84.5 m³/day, 259.7 m³/day and 1026.8 m³/day respectively. For the scenario of hydropower dam development, there would be a further demand on the use of water directly from the reservoir. This direct water use is assumed to be 2 m³/s.

Irrigation Water Requirement The net irrigation water requirement (IWR) is defined as the water required by irrigation to satisfy crop evapotranspiration (USDA 1997). Therefore, irrigation water need is defined as the amount of crop water required after excluding the effective precipitation (Brouwer and Heibloem 1986). Brouwer and Heibloem (1986) provided formulas for determining irrigation water needs as *Crop water need* = $K_c \times ET_0$, and $IWR = \text{Crop water need} - ER$, where K_c is a crop factor that varies during the growth stage, and ET_0 is the potential evapotranspiration. ET_0 is the relation between the climate condition

and the reference surface. The present study calculates ET_o using the FAO Penman-Monteith method (Allen et al. 1998). SWAT can effectively calculate this variable based on input data (Neitsch et al. 2009).

The term ER indicates effective rainfall, which is determined from the relationship with the FAO method for the irrigation water need of paddy rice: $ER=0.8P-25$, if $P > 75$ mm/month, $ER=0.6P-10$, if $P < 75$ mm/month. The IWR is dependent upon crop variety, cropping pattern, and schedule. This study focuses on paddy rice and corn, as shown in Table 1 which indicates the cultivation area with duration and period of growing of different crop varieties. Land preparation for transplanting paddy rice requires 210 mm/day of water, taking into account a percolation rate of 2.5 mm/day. In this study, the value of irrigation efficiency was selected as 0.66 and the irrigation return flow was 17 % of the IWR, as used by the Ministry of Water Resource and Meteorology of Cambodia. The irrigation channel loss coefficient was set to 0.05 in the MODSIM network.

Environmental Flow Requirement As the water requirement for food production and other human needs, the environmental flow requirement (EFR) must be quantified in order to assess the amount of water needed to sustain a freshwater ecosystem (Pastor et al. 2014). This value refers to the quantity and timing of water flows required to maintain the components, functions, processes, and resilience of aquatic ecosystems that provide goods and services.

For the environmental flow release from hydropower dam, the Ministry of Land, Infrastructure, and Transport of Japan suggested a minimum flow of 0.1 to 0.3 m³ per second for each 100 km² of the catchment (Nakamura et al. 2006). The EFR value for irrigation projects in Cambodia is 0.1 m³/s/100 km² of the river basin area and is measured at the outlet of the river. Based on this value, an EFR of 4.37 m³/s needs to be maintained as minimum flow at the outlet of the Prek Te River.

2.6.4 Safety Level of the Water Balance

Water balance computation defines the safety level for all proposed irrigation schemes. The safety level at each irrigation scheme is defined by the formula

$$\text{Safety Level} = (x + 1)/n \quad (5)$$

where x is the number of occurrences of 20-day successive deficits (irrigation failure), and n is the total number of simulated years (herewith, $n = 26$ years). In this study, each irrigation scheme is considered successful if the safety level is less than 5/26. This criteria means the

Table 1 Crop varieties and cropping schedule in the study area within the Prek Te River basin

No.	Crop variety	Duration	Start date	End date	Area (ha)
1	Early Wet Season Rice Direct Sowing	105 days	01 April	16 July	5420.45
2	Wet Season Rice Transplanting	115 days	16 July	26 Oct	3559.51
3	Wet Season Medium Rice Direct Sowing	140 days	16 May	06 Oct	9700.00
4	Dry Season Rice Direct Sowing	90 days	01 Dec	28 Feb	3049.96
5	Corn CP88 in Early Wet Season	106 days	11 Apr	25 July	323.87
6	Corn CP88 in Dry Season	106 days	01 Dec	25 Mar	269.48

project has been designed to permit shortage less than 19.2 % of the years during the severe drought of record.

3 Results and Discussion

3.1 SWAT Calibration for the Prek Te River Basin

3.1.1 Natural Condition Simulation

First, the SWAT model was set up to simulate water discharge in the Prek Te River basin under natural conditions (i.e., without the proposed reservoir) and calibration was performed against observed discharges at sub-watershed 21, where gauging took place from April 2013 to December 2014. The most sensitive parameters and their calibrated values were identified by executing a sensitivity analysis and auto-calibration with a Sequential Uncertainty Fitting (SUFI2) algorithm (Abbaspour et al. 2007), which is linked to SWAT via the calibration package SWAT-CUP. By using automatic and manual calibration interactively researchers can easily identify the fitted parameters for SWAT calibration including sensitivity analysis. Table 2 shows the calibrated parameters in SWAT for modeling discharge of the Prek Te River. The calibrated value of each parameter is for multiplying or replacing in the manual calibration of ArcSWAT. CN2 is the most sensitive calibrated parameters. The highly runoff from agricultural land which indicated by high CN2 up to 68 in this kinds of land use.

To evaluate the hydrological model performance, the coefficient of determination (R^2) and Nash-Sutcliffe Efficiency (NSE) (Nash and Sutcliffe 1970) were calculated. Comparison between the observed and simulated values gave $R^2=0.8$ and $NSE=0.78$. The calibrated result of the daily flow of the Prek Te is shown in Fig. 5. Based on the criteria given by Arnold et al. (2012), the simulated daily flow showed good agreement with the observed values. Based on this result, the lowest natural flow in the dry season is $2 \text{ m}^3/\text{s}$.

Table 2 Calibrated parameters of the SWAT model for Prek Te River flow

Parameter	Description	Min. value	Max. value	Calibrated value
r_CN2	SCS curve number for soil moisture2	35	98	0.78
v_ALPHA_BF	Base flow alpha factor	0	1	0.89
v_GW_REVAP	Groundwater “revap” coefficient	0.02	0.2	0.15
v_GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0	5000	500
v_GW_DELAY	Groundwater delay (days)	0	500	46.25
v_REVAPMN	Threshold depth of water in the shallow aquifer for “revap” to occur (mm)	0	500	300
r_SOL_AWC	Available water capacity of the soil	0	1	3
r_SLSUBBSN	Average slope length	10	150	0.21
r_HRU_SLP	Average slope steepness	0	1	0.97
v_ESCO.HRU	Soil evaporation compensation factor	0	1	0.95

Note: r: multiply calibrated value with the initial value of parameter, v: replace calibrated value of parameter

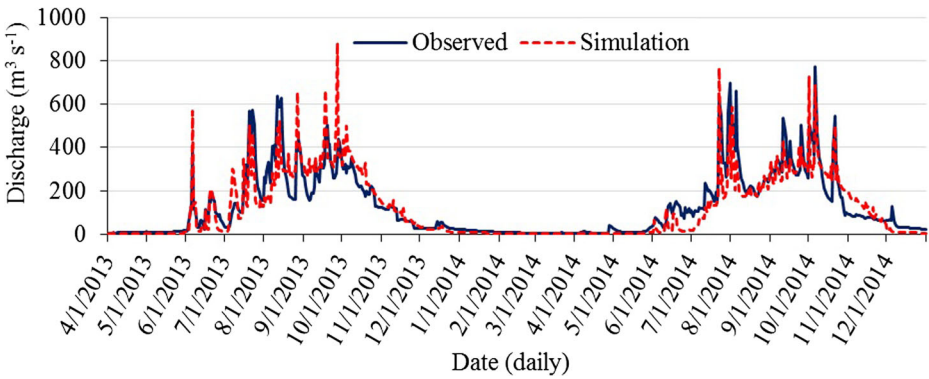


Fig. 5 Observed and simulated daily discharge of the Prek Te

3.1.2 Reservoir Development Scenario Simulation

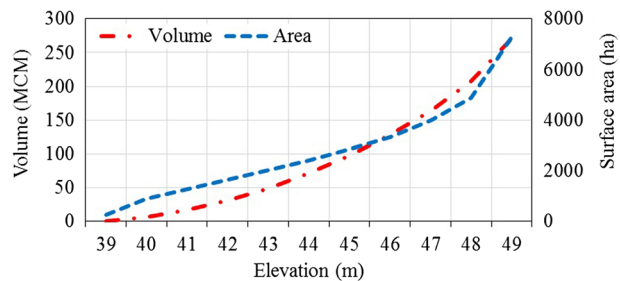
Second, the calibrated parameters were used to simulate the reservoir development at sub-watershed 25 from 1989 to 2014. The reservoir characteristics were determined by ArcGIS, as shown by the elevation-area-volume curve in Fig. 6. The initial reservoir volume is taken to be 1 MCM. The reservoir surface area and volume when the reservoir is filled to the principal spillway are 6000 ha and 240 MCM, respectively. The reservoir surface area and volume when the reservoir is filled to the emergency spillway are 7294.73 ha and 270 MCM, respectively. The 90 % dependable flow was calculated to be 2.7 m³/s in dry season and 214.3 m³/s in wet. This dependable flow from modeling result indicates that reservoir storage depends on wet season flow.

3.2 MODSIM Simulation Result

3.2.1 Hydropower and Reservoir Operation

Generally, during reservoir operation, a higher water level may increase the potential for a safe water supply, but it may also result in an emergency spill or cause flooding. On the other hand, low inflow may result in shortages in water supply. Therefore, the storage level should be regulated with considering to optimum hydroelectric energy generation which plant can generate up to 24 h per day and operate through the year. Figure 7 shows the operational rule curves simulated from historic reservoir inflow data for 26 years from 1989 to 2014. The lower rule was determined from the minimum storage at the end of each month in dry season and minimum storage at the beginning of each month in rainy season. The full storage is 270 MCM, and the lowest or dead storage is 20 MCM.

Fig. 6 Elevation-Area-Volume curve of reservoir



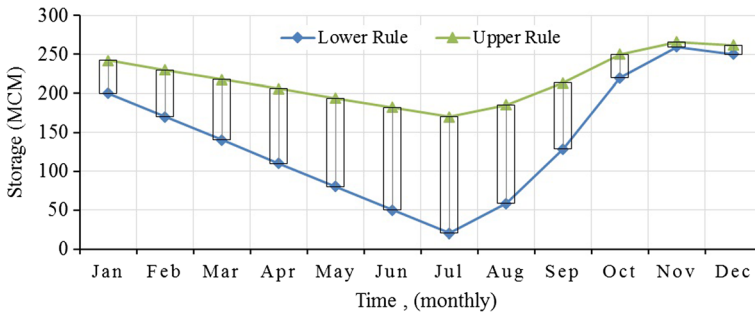


Fig. 7 Operational rule curve of the Prek Te hydropower reservoir based on simulated storage volumes from 1989 to 2014

The simulation shows that the proposed reservoir can potentially generate hydropower up to 13.61 MW per year with designed turbine flow of 17 m³/s. The full flow to turbine for power generation is from May to December which indicates that the hydropower plant can fully operate 24 h per day during this period. However, within dry season in the month of January to April the operation time should be adjusted to 18 h per day.

3.2.2 Water Allocation and Water Balance Safety Level

After hydropower, the next priority in this water allocation system model is domestic water use. Entire domestic water use from sub-watersheds 20, 21, and 26 is satisfied and no deficit occurs. In this case, water allocation managers have to consider domestic water use as highest priority. This means that they must maintain water flow in the stream to satisfy domestic use before allocating water for irrigation purposes.

For irrigation purposes, water must be allocated from the Prek Te stream to irrigation areas via the proposed canal irrigation schemes. MODSIM performs water balance checking for every time step in each irrigation scheme. The deficit will be occurred if the net available flow through canal irrigation is found to be less than IWR. The total water shortage is the sum of water shortage from each scheme and plotted with total demand and the supplied flow at

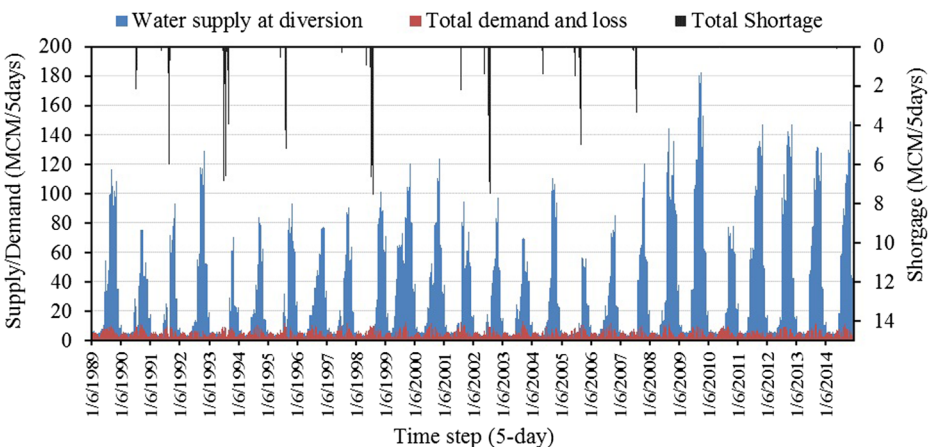


Fig. 8 Water balance analysis by MODSIM in every 5-days time step from 1989 to 2014

Table 3 Water balance safety level analysis for the proposed irrigation systems in the Prek Te basin

No.	Irrigation scheme	Area of irrigation coverage (ha)	Cropping Intensity (CI)	Water Balance Safety Level	Water Balance Safety Level Criteria
1	Irr_KT_ThM	5441.13	100 %	1/26	<5/26
2	Irr_BosLeav	2392.46	115 %	3/26	
3	Irr_SvayChr	4927.01	101 %	2/26	
4	Irr_Dar	3090.79	113 %	1/26	
5	Irr_RokaKa	898.85	142 %	1/26	
6	Irr_OuReus	1830.59	131 %	1/26	
7	Irr_ThmAn	1870.81	106 %	3/26	

diversion (Fig. 8). The water shortage for successive 20 days could happen in 1993, 1998, 2002, 2005, and 2007 in Irr_BosLeav, Irr_ThmAn, and Irr_SvayChr. This deficits are likely to happen in July and August of the year which has longer dry season. In those years of water deficit, the draught took over and there is no rainfall in the watershed until July or August.

Computation of the water balance safety level using Eq. (5) for each irrigation scheme is shown in Table 3 and indicates that all seven proposed irrigation schemes met the safety level criterion for water balance, i.e., less than 5/26. Water deficit occurs in Irr_BosLeav and Irr_ThmAn, as indicated by a safety level of 3/26. This means that twice between 1989 and 2014, there were more than 20 days of successive water deficits at these irrigation schemes. However, this is still considered acceptable based on the criterion of 5/26.

The flow through the requirement node shows that the EFR is successfully maintained at minimum flow of 4.37 m³/s for the 26 years of data simulation. Meanwhile, the network sink node shows the output of remaining water flow to the Mekong River is still high in the rainy season.

4 Conclusions

The present approach attempts to incorporate the comprehensive application of available tools and emerging technology into watershed management. The interactive use of the SWAT and MODSIM models is an advancement in providing more reliable information to help effective decision-making on water allocation and watershed management. Based on the calibration results, the SWAT model provided a good simulation of Prek Te River flows when compared with observed flows. Hydrologic modeling revealed 90 % dependable water of about 2.7 m³/s during the dry season and 214.3 m³/s during the wet season, indicative of a wet-season dependent reservoir for storage. By adapting 90 % of dependable flow in to the reservoir, the hydropower can be generated at least 13.61 MW which is acceptable if compares to the government plan. MODSIM provided the storage output which help to easily determine the operational rule curve for hydropower reservoir operation. Moreover, the prioritization of water allocation can be set in the model to allow for energy generation to meet design capacity then downstream priority order was set to be domestic water demand, environmental flow requirement and irrigation demand. Safety level analysis of water balance computation from 26-years of simulation shows that few irrigation schemes may experience water shortage, but this would occur over a short period of time and would still be within the acceptable safety

level criterion. In this case, the water shortage can happen in July or August if there is no rainfall until these months of the year. However, the result also indicates that 92.3 % of the simulation period water resources of Prek Te River can potentially secure the needs for future river basin development. The outflow to the Mekong River remains high in rainy season, potentially allowing for the expansion of the irrigated area in the Prek Te River basin by developing another reservoir. The integrated approach was shown to be a valuable decision support tool for water resources management with the determination of an optimum policy for multi-purpose reservoir operation based on available basin water supply.

To obtain successful and effective implementation on water allocation in areas such as the Prek Te River basin, short-term and long-term river forecasts are needed to predict water availability in the river system. This requirement leads to intensive hydro-meteorological data collection, especially for catchments located upstream of dams. Therefore, the improvement and strengthening of hydro-meteorological networks within this basin is recommended.

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