EFFECTIVENESS EVALUATION OF THE WATER USE PLAN IN THE BA RIVER BASIN

Ngo Thi Thuy[1], Tran Van Tra[2], Trinh Nhu Trang[1], Nguyen Thi Van[1]

[1]The Viet Nam Institute of Meteorology Hydrology and Climate Change

[2]Viet Nam Water Resources Institute

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Abstract: *The Ba River basin has abundant water resources for agriculture and power generation. To respond to the socio-economic development of the basin, the water work system has been planning to improve the efficiency of water resource allocation, serving sustainable development. This study was designed to evaluate the effectiveness of water work plans built on the Ba River basin by assessing their ability to supply water for agriculture, domestic, industries and services. Water balance calculations show that water demand in irrigation areas in the Ba River basin increases significantly corresponding to basin development, especially in the Krong Pa and Nam Bac An Khe regions. With the application of irrigation planning, agricultural development plans and changes in land use structure, water resource allocation in the Ba River basin has been improved in the future. The effectiveness of the planning is obviously shown in the Upper Ayun, Ayun Pa, Upper and Lower Dong Cam where water demand increases sharply and water shortages are controlled, ensuring water supply requirements for irrigation and other sectors of over 85% and over 90%, respectively.*

Keywords: *Ba River basin, water supply reliability, water work plan.*

1. Introduction

Ba River basin is one of the major river basins of Viet Nam, located in three provinces (Gia Lai, Dak Lak and Phu Yen) in South Central and Central Highland regions. The basin occupies an area of 13,900 km^2 with the main river length of 374 km. In the river basin, rainwater and surface water resources are unevenly distributed in time and space. Annual rainfall ranges from 1,300 mm in Phu Tuc and Cheo Reo valleys to about 2,000 mm in the downstream areas. Flood season lasts from September to December accounting around 70% of the annual flow while the dry season from January to August only accounts for 30% of total water in a year. In general, the study area is a high surface water river basin with 7,989 m^3 per capita, about twice as much as the national water volume per capita in the whole country [28]. However, the extreme dry season lasting eight months has forced the Ba River basin under high water stress.

The total population in sixteen districts of the basin's territory is about 1.6 million and concentrated in the downstream areas and along the national highways [3], [18], [30]. According to the statistical data of the provinces in the Ba River basin, approximately 80% of the population lives in the rural areas and works in agriculture sub-sectors including both farming, animal husbandry and aquaculture. The major water users in the Ba River basin are agriculture, domestic, industry, and hydroelectricity. To utilize the huge and uneven water resource, various types of water works have been constructed in the Ba River basin including 257 reservoirs, 177 spill dams and 126 irrigation pumping stations installed in seven irrigation regions of the Ba River basin and operated by organizations in different ministries [29].

To overcome the problem related to high variability, water resource systems have been

Corresponding author: Ngo Thi Thuy

E-mail: tide4586@gmail.com

designed and operated to ensure sufficient water supply and distribution [25]. In theory, a proper water resource system helps reduce the impacts of flooding, alleviates drought, while at the same time maintain a healthy ecosystem. However, in practice, the failure of water resource systems have created water shortages, exacerbated natural disasters, and caused environmental pollution.

Of the many causes of water resource system failure, the major cause is poor planning of water supply and demand. Most water plans project future demand and supply by either extrapolating trend from the past and/or establishing scenarios based on socio-economic development projections for the future. To address the different levels of uncertainties in water resource system planning, different methods and approaches have been proposed. Water resource system planning to deal with uncertainties requires a paradigm shift from predicting the state of the future to preparing and adapting the system to changes [1], [4], [26], [34]. Most of the approaches seeks to evaluate the performance of a decision or strategy by determining the response of the system under various conditions. This includes scenario-neutral approach [1], [19], [20], [34], Robust Decision Making [24], [27], Info-Gap decision theory [1], [33], Decision Scaling [2], [31], and Robust Optimization [32], [33]. Alternatively, other approaches seek to incorporate flexibility analysis within the planning processes. This includes Dynamic Adaptive Planning [21], Adaptive Policy Pathways [22], Engineering Options analysis [26].

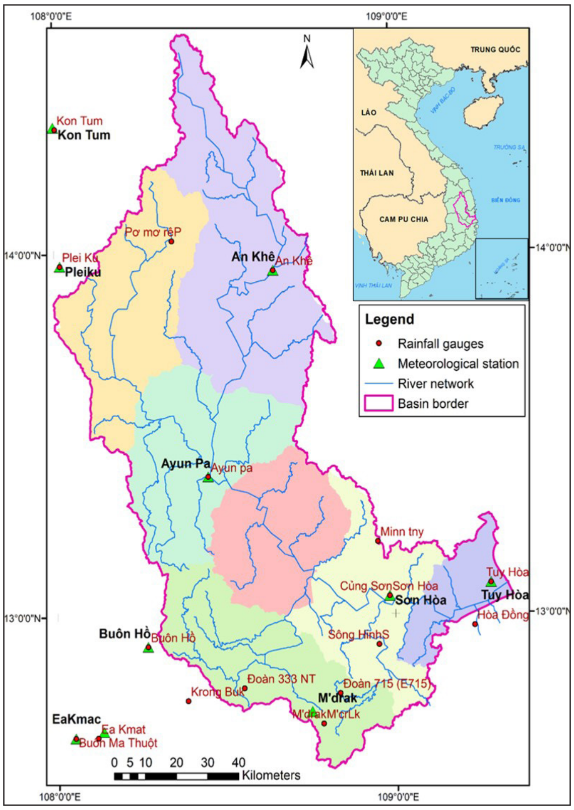

Figure 1. Map of the Ba River basin and its irrigating regions

According to Decision No. 5205/QD-BNN-TCTL [14], there are seven irrigated regions in the Ba river basin namely Nam Bac An Khe, Upper Ayun, Ayun Pa, Krong Pa, Krong Hnang, Upper Dong Cam dam and Lower Dong Cam dam (Figure 1). The total design irrigated area of water works in the Ba River basin is more than 91,000 ha and is planned to increase to 193,550 ha by 2030. To proactively adapt to climate change, the river basin tends to restructure agriculture, modernizing irrigation systems to improve water supply assurance for domestic, industrial, agricultural users. More specifically, the water supply assurance is proposed to reach to 85% in farming area and reach 90% in domestic and industrial use. The proposed planning adjustment expects to effectively use the plenty water resources in the Ba River basin under global and regional changing conditions to reach sustainable development goals.

This study is conducted to adopt a decision scaling framework for water planning to evaluate the robustness of the water system in the the Ba River Basin in the period of climatic condition (1982 - 2020). The Water Work Plan (WWP) of the Ba River Basin is then mapped onto the performance space and its robustness evaluated.

2. Methodology

The Water Work Plan (WWP) is implemented to be appropriate to the Ba basin development and water use plans. In this study, the major components in the WWP are irrigation regions (crop land) and water work. The WWP's performance is represented by assessing indicators of water system's resilience under adverse conditions. More specifically, the water stress indicators are evaluated in irrigation system changes (crop land and water work) and in the period of climatic data availability (1982 - 2020).

To evaluate the basin resilience, water stress in the Ba River basin is considered in two aspects namely, water demand and water deficit. The former presents the total water needs for all requirements of human life, agriculture, industry and tourism. The water deficit is the amount of water that is shortage to fulfil the water demand. The specific description of water stress assessment is provided in the following sections and flowchart (Figure 2).

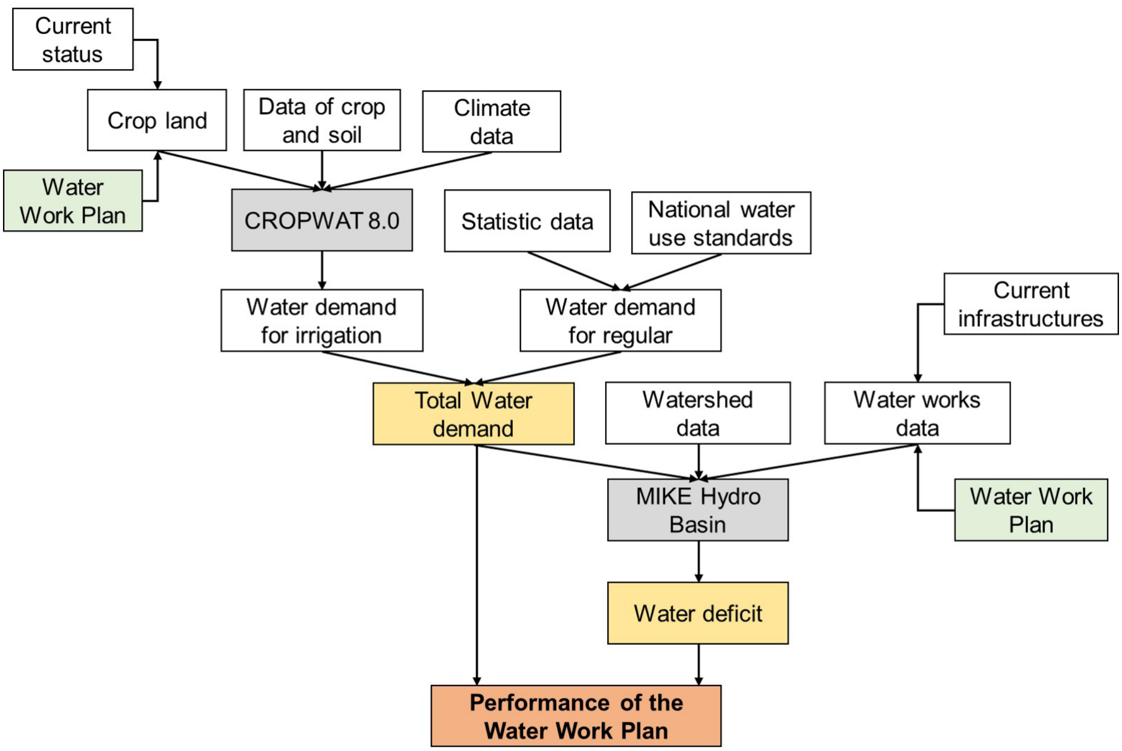

Figure 2. Flowchart to evaluate the Water Work Plan

2.1. Water demand calculation

In this study, water demand is calculated based on both numerical modeling and simple formulas. More specifically, water used for irrigation is a product of irrigated requirement and area of crops. Whereas, the water amount needed for irrigation is evaluated by CROPWAT 8.0 model (FAO, 1998) for eighteen combinations of seven climatic stations and fifteen rainfall gauges (Table 1). The combinations are generated based on the locations of climatic stations and rainfall gauges. The calculation is done for six major crops including winter-spring rice, summer-autumn rice, winter-spring maize, summer-autumn maize, sugarcane and coffee (Table 2 and detailed in Annex Table 1 - Annex Table 2) and for the averaged year of climatic condition, i.e., 50% frequency.

Table 1. Combinations of climatic stations and rainfall gauges

No.	Climatic region	Climatic station	Rainfall gauge
1	East Truong Son	Son Hoa	Son Hoa
2		Son Hoa	Son Thanh
3		Tuy Hoa	Tuy Hoa
4		Tuy Hoa	Son Thanh
5		Son Hoa	Cung Son
6	West Truong Son	Pleiku	Po Mo Re
7		Pleiku	Chu Se
8		Mdrak	Mdrak
9		Buon Ho	Buon Ho
10		Pleiku	Dak Doa
11	Transition	An Khe	An Khe
12		Ayunpa	Ayunpa
13		Ayunpa	Phu Tuc

Table 2. Crop schedule

Crop	Period	East Truong Son	West Truong Son	Transition	
Winter-spring rice	Planting	20-Dec	20-Dec	20-Dec	20-Dec
	Harvest	10-Apr	10-Apr	10-Apr	10-Apr
Summer-autumn rice	Planting	20-Apr	1-May	20-Jun	20-May
	Harvest	10-Aug	20-Aug	10-Oct	10-Sep
Winter-spring maize	Planting	20-Dec	20-Dec	20-Dec	20-Dec
	Harvest	31-Mar	31-Mar	31-Mar	31-Mar
Summer-autumn maize	Planting	20-May	20-May	20-May	20-May
	Harvest	31-Aug	31-Aug	31-Aug	31-Aug
Sugarcane	Planting	1-Apr	1-Jan	1-Jan	1-Jan
	Harvest	31-Mar	31-Dec	31-Dec	31-Dec
Coffee	Planting	1-Jun	1-Jun	1-Jun	1-Jun
	Harvest	31-May	31-May	31-May	31-May

The water demand for domestic, industry and breeding are estimated using statistical data and national standards (QCVN 01:2019/BXD, TCVN 9121:2012 and TCVN 4454:2012).

The inputs for calculation are summarized in following table (Table 3).

Table 3. Data requirement for water demand calculation

Water users	Information	Data sources
Irrigation	Area of crops in irrigation nodes	Current: [3], [18], [30] Planning: [6], [9], [10], [14], [16]
Domestic	Population	Current: [3], [18], [30] Planning: [23]
	Water requirement per capita	QCVN 01:2019/BXD
Breeding	Number of cattle and poultry	Current: [3], [18], [30] Planning: [6], [9], [10], [16]
	Water requirement	Cattle: TCVN 9121:2012 Poultry: TCVN 4454:2012
Industry	Area of industrial zone	Current: [3], [18], [30] Planning: [8], [11], [12], [13]
	Water requirement	QCVN 01:2019/BXD
Service, tourism	10% of domestic use	QCVN 01:2019/BXD

2.2. Water deficit estimation

The volume of water deficit can be estimated by balancing water requirement and water resources availability. The water requirement depends on the properties of each water user as presented above. Water availability in this calculation is the total water volume supplied to water users at the headwork. The water balance is assessed by MIKE HYDRO Basin [17] in the period from 1982 to 2020. The model is implemented for the Ba River basin with the following components:

- Water users: Irrigation and regular users, where regular water users consider demand for domestic, industry, breeding and services. The sketch maps are described in Figure 3.

- Water works including reservoirs, hydropower plants and other type of water infrastructures in the Ba River basin. In which, twelve reservoirs are operated following the inter-reservoir procedure released in 2018 [5], the environmental flow downstream of reservoirs given in Decision No. 73/2022/QD-BTNMT [15] and set up in the model by "minimum release requirement" component. In the current situation, 48 dams and 10 hydropower plants (Kanak, An Khe, Ayun Ha, Krong Hnang, Song Ba Ha, Song Hinh, Dak Srong, Dak Srong 2, Dak Srong 2A and Dak Srong 3B) are simulated in the model. In the future plan up to 2030, there are 55 dams and 10 hydropower plants included in the model.

- Sub-watersheds are provided using DEM and divided based on the water work system. The inflow from these sub-catchments is calculated from the MIKE NAM model for the simulation period (1982 - 2020).

- River branches are generated from river network maps and routed in 1 dimension.

In the model, water deficit is calculated by comparing the water supplied with the total water demand. The water supplied at nodes is simulated through water works operation in which reservoirs are set up for various water use purposes following proper priority.

Water deficit = Water demand - Water supplied

Water demand: Total water demand of water users, is calculated by CROPWAT for irrigation water user and by statistical data for regular water users.

Water supplied: Water amount flow to the water user nodes, is simulated through river branches, sub-watersheds and water works.

The WWP of the Ba River basin is implemented in the model based on the overall goal of the irrigation plans [14] and agriculture development plans of the provinces in the basin [6], [9], [10], [14], [16]. The detailed components of the WWP of the Ba River basin are determined including the areas of each crop type at individual irrigation node. The summary is given in Table 1.

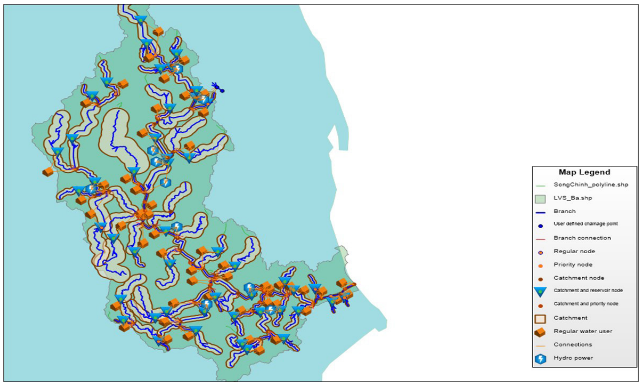

Figure 3. Schematic map of water balance model for the Ba River basin

Table 4. Components of the WWP implemented in the MIKE HYDRO model

Condition	Area of crop (ha)				Number of irrigation nodes
	Paddy rice	*Maize*	*Coffee*	*Sugarcane*	
Current	28,729	3,144	8,706	4,251	45
Planning	40,452	40,444	13,972	4,251	52

3. Results and Discussion

3.1. Water demand in the Ba River basin

The water demand for both irrigation and regular users are calculated using the CROPWAT 8.0 model, statistical data and national standards. The calculation is conducted for the current and planning situations of cropland areas, population and industry. The total water demand for seven regions within the Ba River basin is presented in Figure 4.

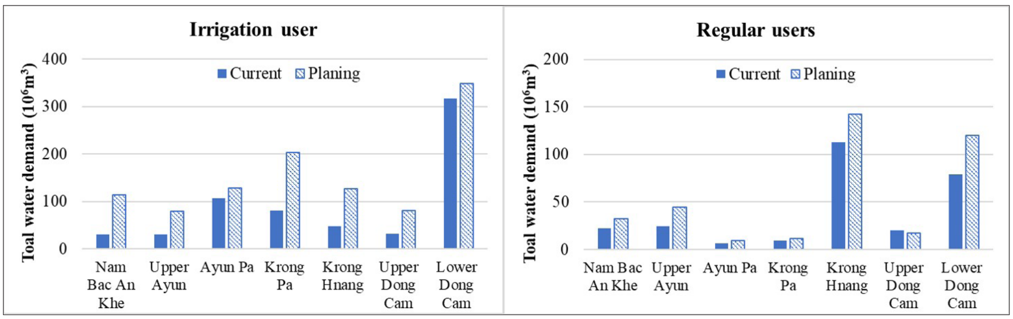

Figure 4. The change in water demand in current and planning situations

In the plan up to 2030, the water needs for irrigation in all regions increase. The change is the greatest in the Nam Bac An Khe region where future irrigating water demand is 4 times more than the current demand, i.e, from around 30 to more than 110 × 10^6 m^3. In Upper Ayun, Krong Pa, Krong Hnang and Upper Dong Cam, the planning water demand is 2.5 times more than the current while it is minor in Ayun Pa and Lower Dong Cam (10 - 19%). With the growth of population, industrial zone area, number of cattle and poultry, the water demand for regular users also increases, especially in Krong Hnang and Lower Dong Cam regions which would be more urbanized in the future with more cities and more industrial zones.

The total water demand in the Ba River basin is 920 × 10^6 m^3 with current water uses and would reach 1,456 × 10^6 m^3 following the planning by 2030, the major water user is Lower Dong Cam occupying 43% in the current and 32% in the future plans. The rapid growth of water demand to satisfy the basin development forces the water work systems need to improve in both capacity and effectiveness.

3.2. Water balance and performance of the water work plan in the Ba River basin

The MIKE HYDRO Basin model is used to balance water demand and water supply in the Ba River basin in current and planning conditions of water work and cropland. The water balance in seven irrigation regions of the Ba River basin is provided in Table 5. In which the water supply reliability represents the capability to meet the water demand of the water work system and estimated by the proportion of supplied water to water demand.

Table 5. Water balance for irrigation in the Ba River basin

Irrigation region	Water demand (10^6 m^3)		Water deficit (10^6 m^3)		Water supply reliability (%)	
	Current	*Planning*	*Current*	*Planning*	*Current*	*Planning*
Nam Bac An Khe	30.58	114.13	0.18	22.15	99	81
Upper Ayun	30.69	78.87	6.32	9.54	79	88
Ayun Pa	107.14	127.66	26.03	25.81	76	80
Krong Pa	81.49	202.78	2.30	30.46	97	85
Krong Hnang	47.33	127.11	10.76	29.17	77	77
Upper Dong Cam	32.12	80.87	9.31	13.13	71	84
Lower Dong Cam	316.71	347.63	33.27	33.97	89	90
Total	**646.05**	**1079.05**	**88.18**	**164.22**	**86**	**85**

*Note: Water demand reliability = (1-Water deficit/Water demand)*100%*

Even though the water shortages in the Ba River basin increases from 88.18 × 10^6 m^3 to 164.22 × 10^6 m^3, nearly twice as much, the water supply reliability of the basin would slightly increase, around 1%. Furthermore, total water demand of the basin in planning condition grows up to 1.7 times compared to current situation (Table 5). This change demonstrates the general effectiveness of the WWP in allocating water to irrigation nodes, i.e., more water demand same water resources and similar water reliability. When including the regular water demand, e.g., domestic, industry and breeding (Table 6), the water reliability in WWP present a similar condition to the current water work system (89 - 90%) whereas water demand grows 1.5 times, i.e. 1455 × 10^6 m^3 comparing to 919.94 × 10^6 m^3.

Table 6. Water balance for both irrigation and regular water users in the Ba river basin

Irrigation region	Water demand (10^6 m^3)		Water deficit (10^6 m^3)		Water supply reliability (%)	
	Current	*Planning*	*Current*	*Planning*	*Current*	*Planning*
Nam Bac An Khe	52.51	146.26	0.18	22.15	100	85
Upper Ayun	55.29	123.53	6.32	9.54	89	92
Ayun Pa	113.63	136.86	26.03	25.81	77	81
Krong Pa	90.57	213.95	2.30	30.46	97	86
Krong Hnang	160.14	269.41	10.77	29.56	93	89
Upper Dong Cam	52.22	98.05	9.31	13.13	82	87
Lower Dong Cam	395.57	467.50	33.27	33.97	92	93
Total	**919.94**	**1455.57**	**88.18**	**164.61**	**90**	**89**

Among seven regions of the Ba River basin, the four regions including the Upper Ayun, Ayun Pa, Upper Dong Cam and Lower Dong Cam show an increase in water supply reliability while the three other regions show a decrease. In general, the water demand reliability in planning condition is still acceptable compared to the irrigating threshold of 85% [14]. That means the WWP is more powerful in Upper Ayun, Ayun Pa, Upper Dong Cam and Lower Dong Cam and less effective in Krong Pa and Krong Hnang.

4. Conclusion

The study evaluated the effectiveness of the WWP in the Ba River basin based on numerical method. The water balancing in irrigation and regular nodes was calculated using the MIKE HYDRO basin model. Generally, the planned water demand in the Ba River basin up to 2030 increases by 1.5 times compared to current conditions. This results higher water deficit at irrigation nodes. By implementing WWP, the water supply reliability in the future plan slightly decreases in the whole river basin and shows better water resource allocation in Upper Ayun, Ayun Pa, Upper Dong Cam and Lower Dong Cam. The change demonstrates the significant effectiveness of the WWP in the four irrigation regions and adequate efficiency in other regions.

Even though improvement of WWP is demonstrated in water allocating, the study contains uncertainties in determining WWP's components. These components were set up in the MIKE HYDRO Basin model using the collected information from irrigation plans of the basin and agricultural development plans of the provinces those only provide overall strategies and trends of water work and cropland changes. Specifying these changes in the numerical model thus is uncertain depending modeler's understanding and views.

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Annex Table 1. Crop coefficient of paddy rice in the Ba River basin

Crops	**Period**	**Nursery**	**Vegetative Early growth**	**Early - Late growth**	**Late growth - Ripening**	**Total days**
Winter-Spring paddy rice	No. days	20	30	40	30	120
	K_c	1.05	1.05	1.2	0.95	
Summer-Autumn paddy rice	No. days	25	30	30	25	110
	K_c	1.15	1.15	1.3	1	

Annex Table 2. Crop coefficient of other crops in the Ba River basin

Crops	**Period**	**Early**	**Development**	**Mid-season**	**Late season**	**Total days**
Winter-Spring maize	No. days	15	30	40	15	100
	K_c	0.6	1.15		0.8	
Summer-Autumn maize	No. days	15	30	40	15	100
	K_c	0.6	1.15		0.8	
Sugarcane	No. days	30	60	180	95	365
	K_c	0.55	1.1		0.6	
Coffee	No. days	45	70	160	90	365
	K_c	0.8	0.9		0.9	