Estimation of Future Water Status through Water Balance Analysis in Chao Phraya river basin

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Abstract

Chao Phraya river is in charge of 30% of total Thailand area (about 513,000 km^2) and 33% of total population (about 64 million people) lives in there and 44% of total GDP is concentrated. Especially near Bangkok and Ayutthaya (70km of north of Bangkok) there are many industrial factory including Japanese automobile such as Toyota, Honda, Mitsubishi etc. and computer manufacturer such as Toshiba, Western digital etc., therefore economic activity is active. Chao Phraya river is consisted of 8 basins and area is about 158,592km^2. Considering the importance of Chao Phraya river basin, the present and future water demand has been estimated and the analysis of water balance also has been studied with cooperation between RID (Royal Irrigation Department) in Thailand and K-water in Korea.

Generally, the future water supply status should be checked with water balance between future water demand (Domestic, Industrial, Agricultural and River maintenance flow) and water supply from water source such as river, dam, reservoir and ground water in the basin. Moreover, the future water balance analysis is studied based on the target year and is possible to check water shortage amount in each sub-basin.

The present and future Water demand (Domestic, Industrial, Agricultural and River maintenance flow) of 8 sub-basins in Chao Phraya river basin is estimated. And then, the severe water shortage area is checked in the point space-time factor through water balance analysis modeling. In Chao Phraya river basin, the present water demand (2015) was checked to 30,945 MCM, and the future water demand was estimated to 34,042 MCM in 2025 and 37,157 MCM in 2035

For the water balance analysis, the domestic water shortage was considered to 97% water supply reliability and the agricultural water shortage was counted in the condition of 80% water supply reliability. Specially, the amount of water shortage was calculated based on the following criteria that 100% of water shortage was counted to the water shortage of domestic, industrial water and river maintenance flow and, agricultural water was considered to be deficient amount only when exceeded 20% of the demand.

The amount of water deficiency has been analyzed based on decadal units (2015, 2025 and 2035) for 8 sub-basins in Chao Phraya river basin. Finally, it was expected that the total water shortage will increase from 3,015 MCM in 2015 to 4,526.1 MCM in 2035. Specially, considering Gov. plans for the additional water resources, the

water shortage was estimated to 3,253 MCM/yr. The lower Chao Phraya river basin was the largest, followed by the Yom watershed and the SakaeKrang watershed. In terms of usage, agricultural water shortage was the largest, followed by domestic water and industrial water.

1. Introduction

Chao Phraya river is in charge of 30% of total Thailand area (about 513,000 km^2) and 33% of total population (about 64 million people) lives in there and 44% of total GDP is concentrated. Especially near Bangkok and Ayutthaya (70km of north of Bangkok) there are many industrial factory including Japanese automobile such as Toyota, Honda, Mitsubishi etc. and computer manufacturer such as Toshiba, Western digital etc., therefore economic activity is active and is very important area to sustain the economic development of Thailand.

Chao Phraya river is consisted of 8 basins (such as Ping, Wang, Yom, Nan, Sakeakrang, Pasak, Tachin and Lower Chaophraya) and area is about 158,592km^2. Considering the importance of Chao Phraya river basin, the present and future water demand has been estimated and the analysis of water balance also has been studied with cooperation between RID (Royal Irrigation Department) in Thailand and K-water in Korea.

Generally, the future water supply status should be checked with water balance between future water demand (Domestic, Industrial, Agricultural and River maintenance flow) and water supply from water source such as river, dam, reservoir and ground water in the basin. Moreover, the future water balance analysis is studied based on the target year and is possible to check water shortage amount in each sub-basin. Specially, on this study, K-MODSIM was used for the study for “Estimation of Future Water Demand and Analysis of Water Balance in Chao Phraya river basin”. Specially, K-MODSIM was developed based on the cooperation between K-water and CSU (Colorado State University, USA).

2. Available water resources in Chaophraya river basin

2.1 Total water resources

To check the water resources in Chaophraya river basin, monthly data were obtained from 218 rainfall stations and 138 runoff stations in Chaophraya river basin for last 30 years(1986~2015). Specially, for rainfall data, the missing data were complemented using NRM (Normal Ratio Method) and were verified by DMAM (Double Mass Analysis Method). Monthly average rainfall were estimated by Thiessen method using observation data and average rainfall of the each basin was calculated using Area Weighted Method. Moreover, the runoff during past 30 years (1986 ~ 2015) were analyzed through collecting monthly runoff data from rainfall observations inner basin which have observation records more than 10 years.

The total amount of water resources in a basin is calculated by multiplying the average precipitation (rainfall) by the basin area. The total water resources of Chaophraya river basin is estimated by multiplying the average rainfall of each basin by the basin area which are derived above, the result is shown in <Table-1>. The Total water resources of Chaophraya river basin is 173,593 MCM.

<Table-1> Total Water Resources of Chaophraya river basin

Basin	Area (㎞²)	Rainfall (mm/yr)	Water Resource (MCM/yr)
Ping	34,499	1,029.7	35,523.6
Wang	10,793	1,042.3	11,249.5
Yom	23,948	1,118.2	26,778.7
Nan	34,908	1,195.9	41,746.5
Pasak	15,623	1,117.0	17,450.9
Sakae Krang	5,055	1,133.0	5,727.3
Tha Chin	13,491	1,045.1	14,099.4
Lower Chao Phraya	20,523	1,024.1	21,017.6
Total	158,840		173,593.5

2.2 Available water resources

An available water resources in a basin is calculated by multiplying the total water resources by the runoff rate. The result of available water resources of Chaophraya river basin estimated by each basins is shown in <Table-2>, it shows that the runoff rate is 20.4% and the available water resources is estimated to 35,424 MCM per year.

<Table-2> Available water resources in Chaophraya river basin

Basin	Area (㎢)	Water Resources (MCM/yr)	Runoff (MCM/ yr)	Loss (MCM/yr)	Run off Rate (%)
Ping	34,499	35,524	9,044	26,480	25.5
Wang	10,793	11,249	1,663	9,586	14.8
Yom	23,948	26,779	4,166	22,613	15.6
Nan	34,908	41,747	12,428	29,319	29.8
Pasak	15,623	17,451	3,669	13,782	21.0
Sakae Krang	5,055	5,727	1,269	4,458	22.2
Tha Chin	13,491	14,099	1,437	12,662	10.2
Lower Chao Phraya	20,523	21,018	1,748	19,270	8.3
Total	158,840	173,594	35,424	138,170	20.4

3. Estimation of water demand in Chaophraya river basin

3.1 Domestic Water Demand

The water demand in service area was estimated based on water supply data and plan of MWA (Metropolitan Waterworks Authority) and PWA (Provincial Waterworks Authority). Recently, MWA published “Project-9” plan to supply additional water in Bangkok metropolitan area (Project Period : from 2017 to 2022, Project budget : 42,750 mil.baht). The main items of Project-9 are to install additional new water treatment plant (800,000 ㎥/day) in Mahasawat water treatment plant and to construct additional water retention tank of 360,000 ㎥. Future water demand in MWA service area was estimated to 2,693 MCM/yr based on Project-9 plan. And, it was considered that there would not be happened any additional water supply project to 2035 after Project-9. The Present and Future water demand in MWA service area is shown as <Table-3>

Location	Rowater Source	Present (MCM/yr)	2025 (MCM/yr)	2035 (MCM/yr)
East Chao Phraya	Chao Phraya river	1,498	1,630	1,630
West Chao Phraya	Maeklong river	527	876	876
Total		2,025	2,506	2,506

<Table-3> Present and Future Water Demand in MWA service area

PWA supplies water to the area out of MWA service area. Future water demand in local service area was estimated based on PWA's additional water supply plan. The result of Present and Present and Future water demand in PWA service area is shown as <Table-4>.

<Table-4> Future Water Demand in PWA service area

Code	Sub-basin	Present (MCM/yr)	2025 (MCM/yr)	2035 (MCM/yr)
0600	Ping	86.30	136.29	210.36
0700	Wang	15.32	23.72	35.34
0800	Yom	21.45	31.01	46.03
0900	Nan	18.98	28.39	38.58
1000	Lower Chao Phraya	436.19	639.02	892.02
1100	Sakae Krang	3.40	6.26	10.39
1209	Pasak	28.97	45.96	70.70
1300	Tha Chin	108.16	142.42	203.09
Total		718.77	1,053.07	1,506.51

Future water demand out of service area of MWA and PWA was estimated by using 10 years (2006 ~ 2015) population data from DLA (Department of Local Administration). At first, the future population was estimated by using exponential function. And then, the population of non-service area was calculated by the service area population excluded. Finally, the future water demand was estimated by multiplying Non-service area population and LPCD (Liter per Capita per Day). LPCD was considered to use 120 ℓ.

The total present and future water demand of service area and non-service area in Chao Phraya river basin is shown in <Table-5>.

<Table-5> Present and Future Domestic Water Demand in Chao Phraya river basin

Code	Sub-basin	Present (MCM/yr)	2025 (MCM/yr)	2035 (MCM/yr)
0600	Ping	182.85	233.78	308.46
0700	Wang	38.79	45.82	55.57
0800	Yom	90.71	95.87	105.27
0900	Nan	109.59	114.61	121.47
1000	Lower Chao Phraya	2,554.03	3,569.02	4,915.56
1100	Sakae Krang	18.97	21.33	24.11
1209	Pasak	89.01	102.18	120.59
1300	Thachin	187.68	212.45	259.27
Total		3,271.63	4,395.05	5,910.30

3.2 Agricultural Water Demand

The Present and Future agricultural water demand were estimated by using project plans of RID (Royal Irrigation Department). With deeply discussion with RID, the short-term plans was used for the agricultural water demand in 2025 and the mid-term plans was considered for the agricultural water demand in 2035. The result of future agricultural water demand is shown in <Table-6>.

<Table-6> Future Agricultural Water Demand in Chao Phraya river basin

Code	Sub-basin	Present (MCM/yr)	2025 (MCM/yr)	2035 (MCM/yr)
0600	Ping	3,412.3	3,538.8	3,837.1
0700	Wang	270.1	405.1	408.2
0800	Yom	2,025.6	2,552.3	2,654.7
0900	Nan	3,681.2	4,577.7	4,788.9
1000	Lower Chao Phraya	10,926.9	10,930.8	10,930.8
1100	Sakae Krang	561.6	561.6	1,161.4
1209	Pasak	1294.1	1416.7	1593.7
1300	Thachin	3,448.4	3,448.4	3,536.6
Total		25,305.3	27,057.6	28,419.5

3.3 River Maintenance Flow Demand

River Maintenance Flow was calculated based on 90 ~ 50% flow in each sub-basin. Moreover, the future river maintenance flow also was used to the same value as the resent river maintenance flow. The result of river maintenance flow in Chao Phraya river basin is shown in <Table-7>.

<Table-7> River Maintenance Flow Demand in Chao Phraya river basin

Code	Sub-basin	River Maintenance flow (m^3/s)
0600	Ping	5.03
0700	Wang	0.37
0800	Yom	0.31
0900	Nan	16.38
1000	Lower Chao Phraya	175.00
1100	Sakae Krang	0.04
1209	Pasak	4.85
1300	Thachin	2.59

3.4 Present and Future water demand in Chaophraya river basin

The present and future water demand considering domestic water, industrial water, agricultural water and river maintenance flow is shown in <Table-8>.

<Table-8> Presnet and Futrue Water Demand in Chao Phraya river basin

Item	Present	2025	2035
Domestic (MCM/yr)	3,271.6	4,395.1	5,910.3
Industrial (MCM/yr)	2,371.1	2,589.3	2,827.6
Agricultural (MCM/yr)	25,305.3	27,057.6	28,419.5
Total (MCM/yr)	30,948.0	34,042.0	37,157.4
River maintenance flow (Station C2, ㎥/s)	175.0	175.0	175.0

4. Water Balance Analysis by K-MODSIM

4.1 K-MODSIM

K-MODSIM, as adapted from the MODSIM generalized river basin management decision support system (DSS), has been developed based on the cooperation between CSU (Colorado State University) and K-water. The main goals to develop K-MODSIM can be defined in four focus areas such as 1) Develop both monthly and daily simulation networks of all features of the Geum River basin (in South Korea) system that are most appropriate in terms of describing the physical and operational characteristics of the river system, 2) Apply hydrologic routing in the daily river basin network model to insure water allocations are correctly considered, 3) Use the developed KMODSIM networks to test and evaluate operational scenarios being developed in other components of the DSS, 4) Develop a set of Hangul menus for the KMODSIM model to make it easier for use by K-water personnel. Particularly, K-MODSIM's optimization of the objective function essentially provides an efficient means of assuring that all system targets and guide curves are achieved according to the desired priorities, while making certain that water is allocated according to physical, hydrological, and institutional/administrative aspects of river basin management.

4.2 Analysis Process and Method

First of all, the present and future Water demand (Domestic, Industrial, Agricultural and River maintenance flow) of 8 sub-basins in Chao Phraya river basin is estimated. And then, the severe water shortage area is checked in the point space-time factor through water balance analysis modeling.

Setting up water supply network

▼

Input of Water Demand
(Domestic, Industry, Agricultural, River Maintenance flow)

▼

Input of Water Supply Source
(River, Dam, Reservoir, Diversion, Pumping)

▼

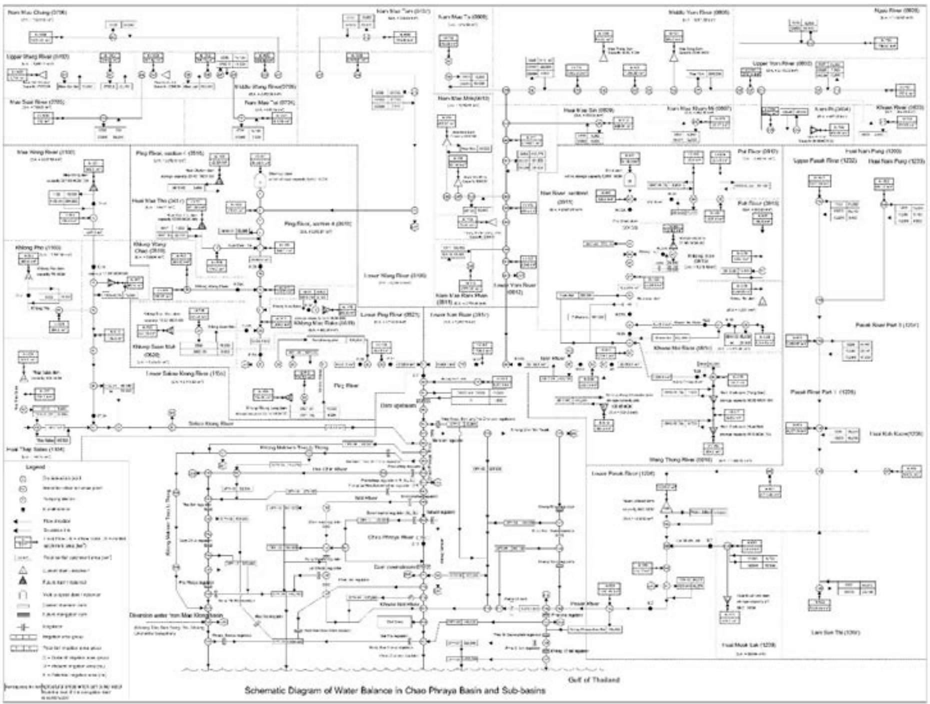
Modeling and Checking Water Shortage

<Figure-1> Process of Water Balance Analysis

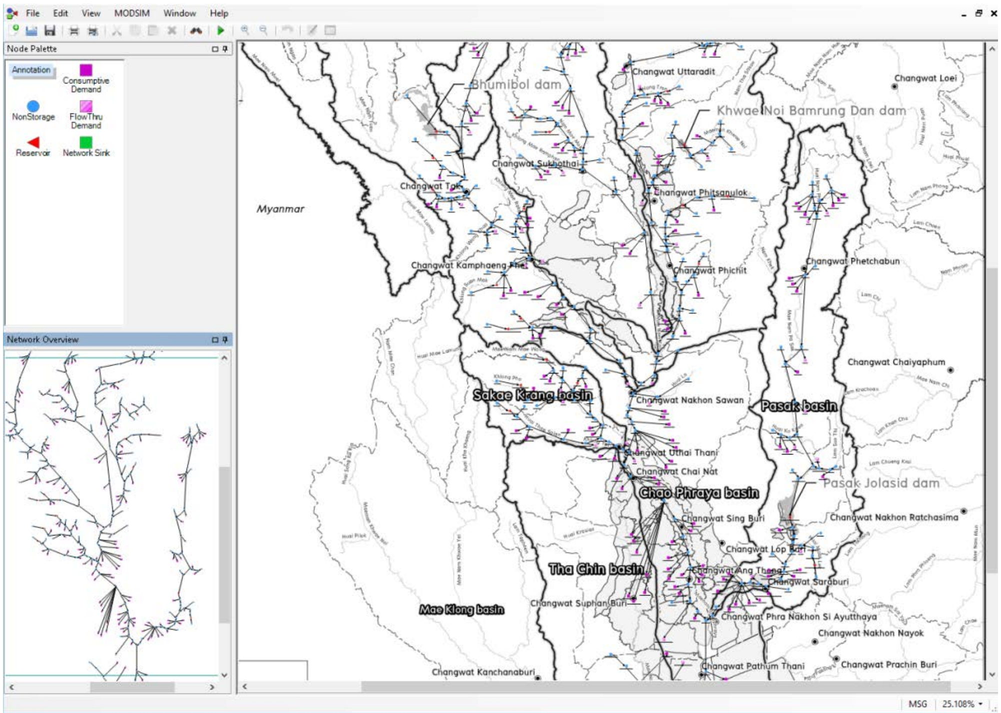
The water balance analysis was conducted by targeting to Present (2015), Future after 10 years (2025) and Future after 20 years (2035). And, the water balance modeling was simulated based on monthly time interval. The river runoff data was used for 30 years from 1986 to 2015 and the runoff condition was considered to flow in the same pattern in the 3 scenarios (2015, 2025, 2035). Domestic water and Industrial water demand was assumed to have the stable water consumption per month over all modeling years. The monthly irrigation water demand considering effective rainfall was used for Agricultural water demand of each sub-basin. River maintenance flow is considered at the ending point of each sub-basin. Moreover, the return flow rate also was considered based on Thai regulation ; Domestic water 0 %, Industrial water 0 % and Agricultural water 30%. And, the water supply priority was considered by following condition that Domestic water is the 1st, Industrial water the 2nd, River maintenance flow in the 3rd and Agricultural water is the 4th. Moreover, the domestic water shortage was considered to 97% water supply reliability and the agricultural water shortage was counted in the condition of 80% water supply reliability. Specially, the amount of water shortage was calculated based on the following criteria that 100% of water shortage was counted to the water shortage of domestic, industrial water and river maintenance flow and, agricultural water was considered to be deficient amount only when exceeded 20% of the demand.

4.3 Water Balance Analysis Modeling by K-MODSIM

By using K-MODSIM, the water balance analysis modeling was set up. For this process, the water supply and river network was surveyed and drawn based on the diagram. This network diagram is shown as Figure-2. Moreover, the result of water balance analysis modeling in Chaophraya river basin by K-MODSIM is also shown as Figure-3.



<Figure-2> Water supply and river network's diagram in Chaophraya river basin



<Figure-3> Water Balance Analysis Modeling by K-MODSIM

4.4 Result of Water Balance Analysis

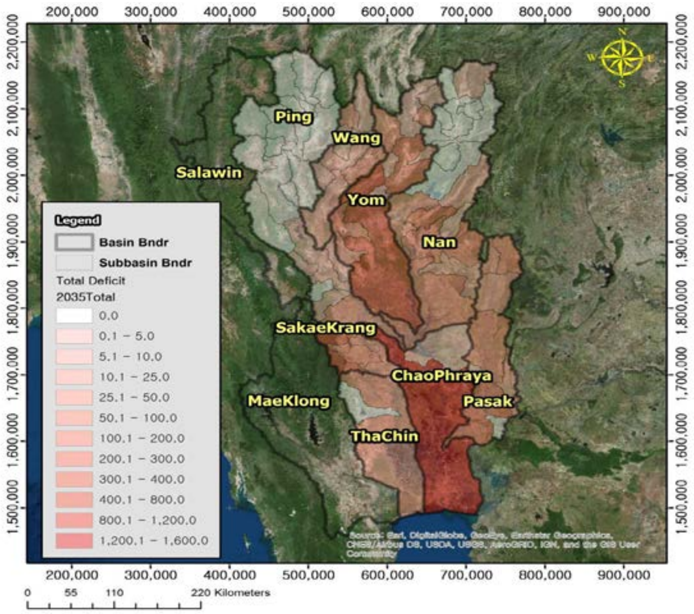
The results of water balance analysis for 8 sub-basins in Chao Phraya river basin are shown in <Table-9>. It is expected that the total water shortage will increase from 3,015 MCM in 2015 to 4,526.1 MCM in 2035. The lower Chao Phraya river basin was the most severe, followed by the Yom watershed and the SakaeKrang watershed. In terms of usage, agricultural water shortage was the largest, followed by domestic water and industrial water. Moreover, we also considered the additional water resources plans of Thai Government such as new dam construction. After considering these plans, the final water shortage in Chaophraya river basin was estimated to 3,253 MCM in 2035. And, the most severe zone was Lower Chaophraya and Thachin river basin which has the water shortage of 1,787 MCM in 2035.

<Table-9> Present and Future Water Shortage in Chaophraya river basin

Sub-Basin	Present (MCM/yr)				2025 (MCM/yr)				2035 (MCM/yr)			
	Do.	In.	Agr.	Sum	Do.	In.	Agr.	Sum	Do.	In.	Agr.	Sum
Ping (0600)	-	-	4.4	4.4	-	-	9.6	9.6	-	-	29.1	29.1
Wang (0700)	-	-	48.5	48.5	-	-	59.6	59.6	-	-	106.5	106.5
Yom (0800)	-	-	328.1	328.1	-	-	770.4	770.4	-	-	1,061.9	1,061.9
Nan (0900)	-	-	201.3	201.3	-	-	303.8	303.8	-	-	474.9	474.9
Lower Chao Phraya (1000) + Thachin (1300)	21.8	40.6	1,682.2	1,744.6	32.8	48.6,	1,783.3	1,864.7	70.9	74.4	1,794.0	1,939.3
Sakae Krang (1100)	-	-	397.2	397.2	-	-	398.1	398.1	-	-	543.2	543.2
Pasak (1209)	-	-	290.9	290.9	-	-	329.9	329.9	0.4	0.1	370.7	371.2
Total	21.8	40.6	2,952.6	3,015	32.8	48.6	3,654.7	3,736.1	71.3	74.5	4,380.3	4,526.1

<Table-10> Water Shortage considering Thai Gov. plans for additional water resources

Basin	Water Shortage (MCM)		Gov. Plan (MCM)		Expected Shortage (MCM)	
	2025	2035	2025	2035	2025	2035
Ping	10	29	170	350	-	-
Wang	60	107	18	19	42	88
Yom	770	1,062	193	252	577	810
Nan	304	475	909	1,276	-	-
L. Chao Phraya + ThaChin	1,877	1,900	36	113	1,841	1,787
Sakae Krang	398	543	70	346	328	198
Pasak	330	371	-	-	330	371
Total	3,749	4,487	1,396	2,356	3,118	3,253



<Figure-4> Water Shortage in Chaophraya river basin

5. Conclusion

The present and future Water demand (Domestic, Industrial, Agricultural and River maintenance flow) of 8 sub-basins in Chao Phraya river basin is estimated. And then, the severe water shortage area is checked in the point space-time factor through water balance analysis modeling, K-MODSIM. In Chao Phraya river basin, the present water demand (2015) was checked to 30,945 MCM, and the future water demand was estimated to 34,042 MCM in 2025 and 37,157 MCM in 2035. For the water balance analysis, the domestic water shortage was considered to 97% water supply reliability and the agricultural water shortage was counted in the condition of 80% water supply reliability. Specially, the amount of water shortage was calculated based on the following criteria that 100% of water shortage was counted to the water shortage of domestic, industrial water and river maintenance flow and, agricultural water was considered to be deficient amount only when exceeded 20% of the demand.

The amount of water deficiency has been analyzed based on decadal units (Present, 2025 and 2035) for 8 sub-basins in Chao Phraya river basin. Finally, it was expected that the total water shortage will increase from 3,015 MCM in present to 4,526.1 MCM in 2035. Specially, considering Gov. plans for the additional water resources, the water shortage was estimated to 3,253 MCM/yr. The lower Chao Phraya river basin was the largest, followed by the Yom watershed and the Sakaekrang watershed. In terms of usage, agricultural water shortage was the largest, followed by domestic water and industrial water.

In conclusion, considering the huge water shortage in Chaophraya river basin, the additional water resources plans should be studied and suggested as soon as possible, to support the water security for the sustainable water supply and the stable country development.

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