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Evaluation of the progress of Salinity intrusion in the downstream area regarding the regulation of Vu Gia Thu Bon reservoir system

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Summary: *Salinization process in the VGTB downstream has been primarily affected by the upstream flow, especially since large hydropower reservoirsthat operated the downstream flow mode have changed a lot compared to the past.In recent years, the salinity of the downstream river has been complicated, especially in Vu Gia and Vinh Dien whose high salinity level seriously affected water supply of Cau Do Water Factory and water pumping constructions on Vinh Dien River. In 2015, government issued a multi-reservoir operation procedure in the VGTB 1537 / QD-TTg. This is the third change that thereservoir operation procedure in the dry season was added, which supports more reasonable regulation of water resource to adapt to the drought and salinity. In order to evaluate the effectiveness of the process in the dry season, this study calculates the salinity intrusion in the lower VGTB considering reservoirs operated by multi-reservoir operation procedure. It is a base for solutions of reducing the downstream salinity intrusion and at the same time not significantly affecting the power output of hydropower plants in the upstream.*

Keywords*: Salinity intrusion, hydropower plants, reservoir operation, catchment, Vu Gia Thu Bon River*

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I. Introduction

Since the downstream water of Vu Gia - Thu Bon river system (VGTB) flows into the sea, salinity intrusion at the estuary occurs frequently in the dry season, especially when water that flows down from the upstream decreases, salt water tides deep into the river. To overcome the effect of salinityintrusion and raise the water level for water exploitation in the downstream ofVGTB river,dam systems were built such as:An Trach Dam on Yen River, Bau Nit Dam and Ha Thanh Dam on Qua Giang River, Thanh Quyt Dam on Thanh Quyt River, Duy Thanh Dam on Ba Ren River. These dams only reduce the salinity intrusion in the upstream, while it is continuous in the downstream, whichaffects much the water use in this area, especially in the Cau Do water plantwhereserves most ofDanang citizensis always salinized with higher salinity level. The main reason for salinity intrusion is the reduction of downstream flow and sea level rise that tides deep into the estuaries. The decreasing flow of VGTB river system in the dry season is mainly due to the deforestation and the operation of hydropower plants, especially the DakMi 4 hydropower reservoir changed the flow and the effect ofclimate changein dry season as well as evaporation due to high temperature, etc. In order to propose solutions to cope with drought and salinity intrusion,the study will simulate the progress of salinity intrusion in the downstream of VGTBRiver under the scenarios of multi-reservoir operation procedure1573/QD-TTg.

Salinity intrusion has many issues that needevaluating such as from the risk of uncertain data inputs to the change of forecasting study scenarios due to climate change, the impacts of salinity intrusion on agricultural production and water supply, etc. In addition, the impact of reservoir operation mode to the downstream is assessed. Therefore, there are many approaches to solve problems of salinity intrusion in coastal estuaries accordingly.

In Vietnam, the basins of Mekong River Delta, Red River and Dong Nai River have been studied by researchers to build salinization models, improve the flow in dry season,and serve agricultural production in particularas well as meetthe requirements of socio-economic development in general. A number of research topics such as Doan Thanh Hang, the salinity forecasting program for Red River Delta - Thai Binh [2], Le Sam, Salinity intrusion research for Socio-economic development of Mekong River Delta [8] have been proposed.However, there is not many studies on salinity intrusion in the Central area except for the study on Evaluation and prediction of salinity intrusion in Tra Khuc river basin by Dang Thi Kim Dung and her partners. In the VGTB basin,since 2000 there have been studies on salinity intrusion, such as studies of Mrs. To Thuy Nga [6], applying the VRSAP model to simulate salinity intrusion in the downstream of Vu Gia Thu Bon River, Mr. Nguyen The Hung and Mr. Nguyen Huu Thiem [4], applying the MIKE 11 model for salinity intrusion progress prediction in the downstreamof Vu Gia River (Da Nang city), Mr. Nguyen Tung Phong and his partners[7] with research on salinity intrusion calculation in Vu Gia Thu Bon river system taking into account the effects of climate change,Mr. Trinh Quoc Viet [9] with the salinity intrusion simulation in the downstream of VGTB River and proposing seven measures to reduce salinity intrusion in the downstream.These studies in the VGTB basin have created the original database, as well as provided the reasons of the situation. However, they have not assessed the impact of the upstream hydroelectric reservoir system on downstream salinity intrusion, which has recently become one of the major factors.

Due to the very rapid development of hydrological and hydraulic computations, there are now many multifunctional models in the world in which modulators for pollutants and salinity dispersionthat are indispensable. Among them, many models are purchased and transferred in many forms into Vietnam.Some typical models such as ISIS (The UK), MIKE 11 (Denmark), HEC-RAS (USA), etcare modules that calculate the spread of salinity intrusion, but they are under testing.Over the past 10 years. **The MIKE 11 model** is a hydraulic model and one-way water quality (in case of salinity intrusion) and two-way with high reliability which is appropriate for various practical problems. This model has been applied popularly in the world as well as in Vietnam for calculation and flood forcast. The MIKE 11 Model is applied in this study for salinity intrusion simulation.

From the above reasons, the study on the evaluation of salinity intrusion in the downstream of VGTB River considering the operation of the reservoir system is to propose a rational operation solution to improve the downstream water supply.

Figure 1. *Scope of hydraulic calculation models*

II. Material and Methodology

2.1 Hydrological modeling

The MIKE NAM hydrological model is used to simulate the flow calculation for the basins. Construction of model parameters is based on the flow data of Nong Son and Thanh My hydrological stations together with hydrological data of Song Bung and A Vuong reservoirs.

Input data:

- Rainfall and evaporation data of the stations on the VGTBbasin: Using documents from 1980 to 2010 of Nong Son, Thanh My, Kham Duc, Tra My, Tien Phuoc and Hiep Ducstations.
- Flow data: Nong Son and Thanh My stations

Thanh My basin covers an area of 1850 km^2, using the rainfall data of Kham Duc and Thanh My stations. Nong Son basin covers an area of 3150 km^2, using rainfall data from Tra My, Tien Phuoc, Hiep Duc, Nong Son, Kham Duc and Thanh My stations.

- Model parameters found after calibrationwith 1980-1995 dataset and validationwith 1996-2010 dataset for NASH coefficient and correlation coefficient as Table 1. Compared with the result of this evaluation, it is sufficiently reliable to use flow restoration calculation for the remaining sub-basins in the Vu Gia - Thu Bon basin in comparison with the hydraulic model.

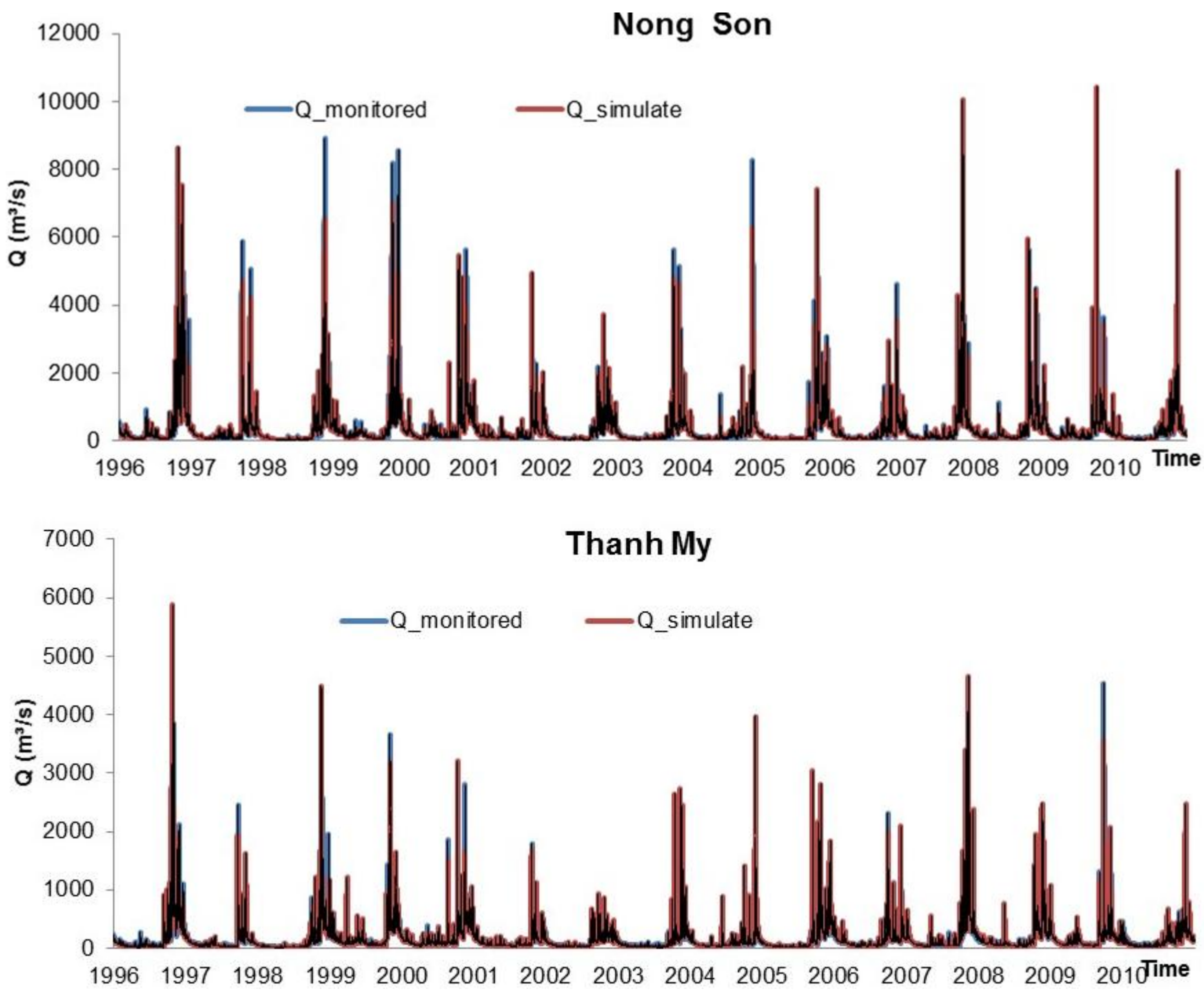

***Figure 2.** Calibrated model test in Nong Son - Thanh My basin*

Table 1. Reliability index of the NAM model in the VGTB basin

Station	Calibration (1981-1995)		Validation (1996-2010)	
	NSE	*R^2 (correlation coefficient)*	*NSE*	*R^2 (correlation coefficient)*
Nong Son	0,87	0,94	0,87	0,94
Thanh My	0,63	0,83	0,70	0,83

2.2 Establishment of multi-reservoir operating modelon the Vu Gia-Thu Bon basin

Calculation of the flow of reservoir operation on the VGTB basin by HEC-RESSIM model

For power generation reservoir system, due to the complex relationship of hydrological, irrigation and hydraulic matters and agriculture activities, the guaranteed capacity of any water storage in the system with the effective capacity V h (or working water depth h_{ct}) depends on the income flow to the reservoir, discharge flow through the turbine, upstream water level and downstream water level of the lake:

$$NPJ = f(Q_{X(j-1)(t)}, q_{tbj(t)}, Z_{j(t)}, Z_{hj(t)}) \quad (1)$$

In which:

$Q_{X(j-1)(t)}$: discharge flow process from reservoir number (j-1)

$q_{tbj(t)}$:discharge flow process from the reservoir through turbines number j

$Z_{j(t)}$:water level process in reservoir number j

$Z_{hj(t)}$:water level changing process of reservoir number j

- The model was established to operate a system of 5 large reservoirs in the VGTB river basin, namely A Vuong, Dak Mi 4a, Tranh 2 River, Bung 2 River and Bung 4 River.
- The river and reservoir system network of The VGTBriver basin is set up by HEC-RESSIM model shown as follows:

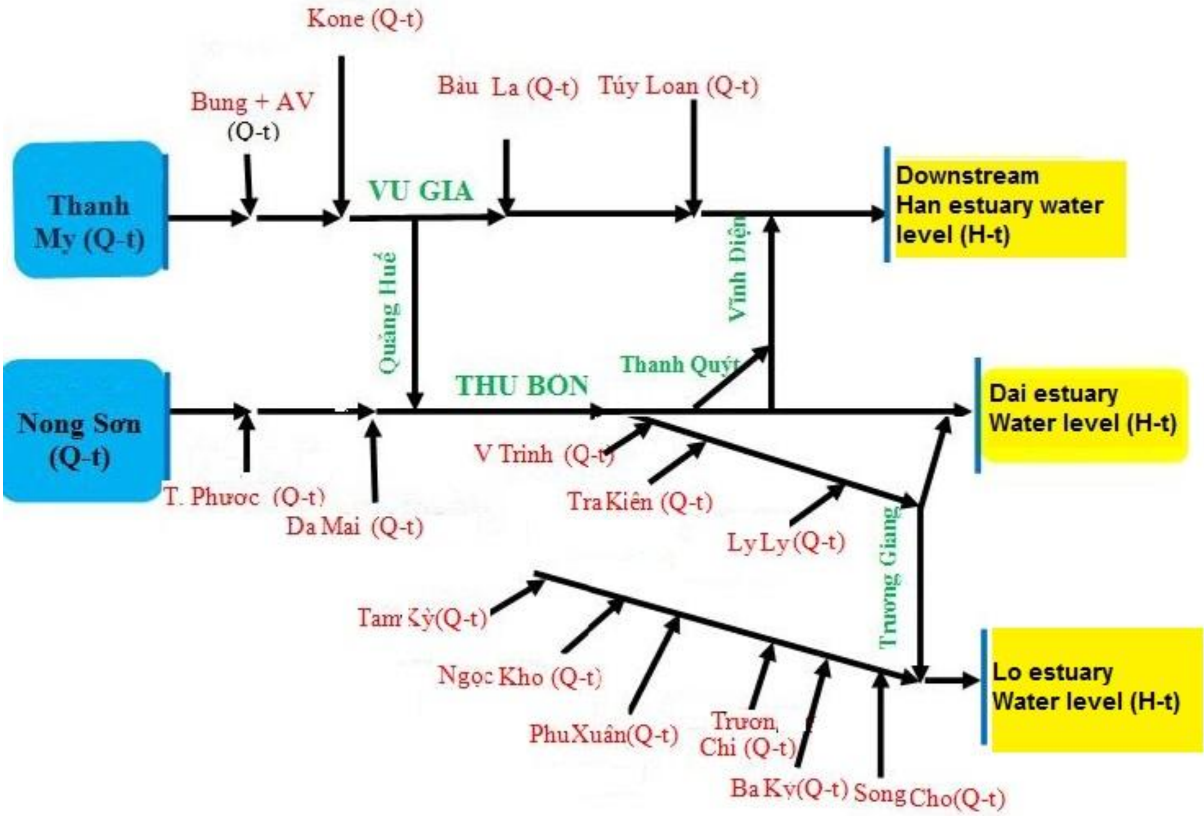

Figure 3. *Establishment of the HG-RESSIM upper reservoir network model VGTB*

Q-t: Upstream, flow data along time

H-t: Downstream, water level data along time

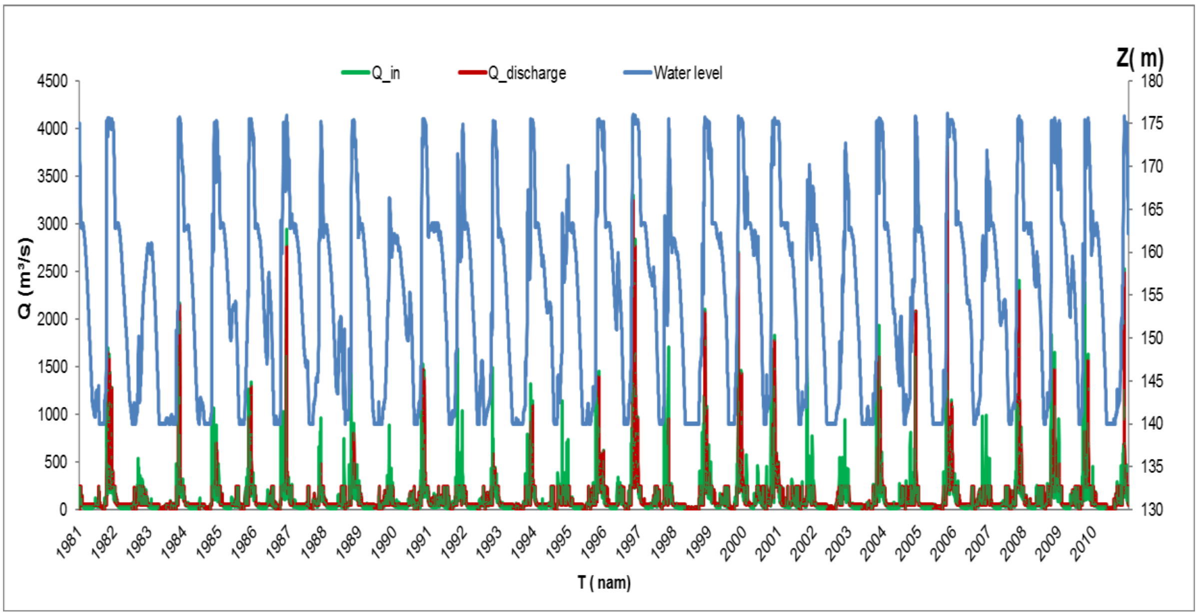

Figure 4. *Simulation result of regulation in Tranh 2 River Hydropower reservoir (1980-2010)*

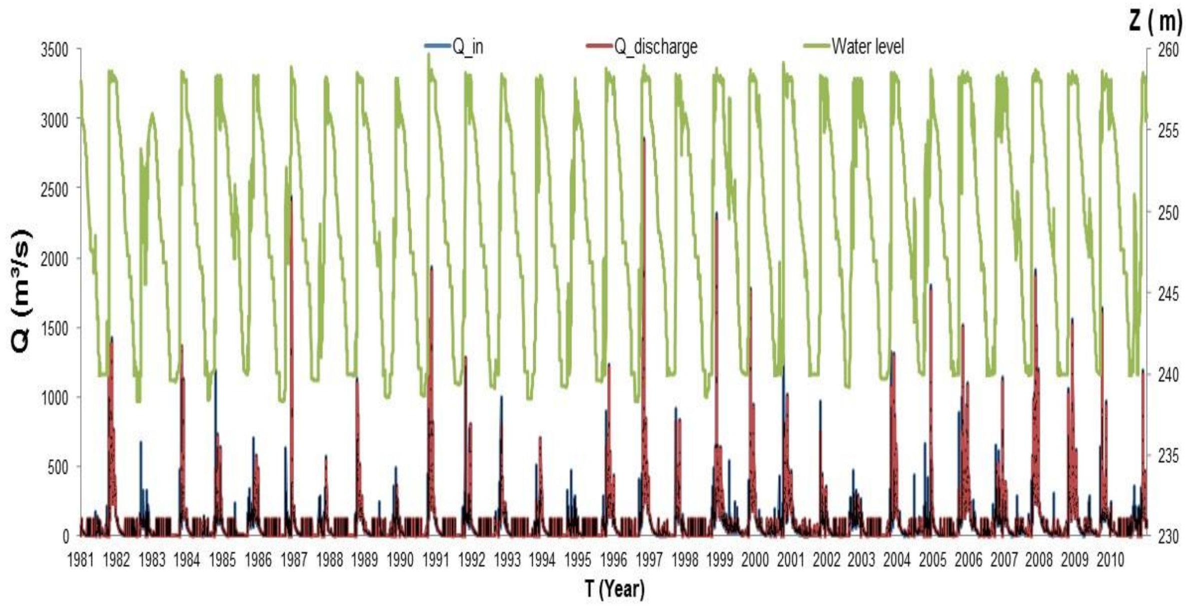

Figure 5. *Simulation result of regulation in Dak Mi 4a hydropower reservoir (1980-2010)*

2.3 Hydraulics modeling and salinity intrusion simulation

Hydraulics diagram of VGTBRiver network with length of 77465m includes 119 sections. (***Fig. 3***) Thu Bon river with the length of 65598m: 92 sections, Quang Hue River with the length of 5404m: 27 sections. Ba Ren river with the length of 29295m: 25 sections, Vinh Dien River with the length of 24130m: 40 sections. Tuy Loan river with the length of 13000m: 27 sections, Qua Giang River with the length of 14960m: 27 sections, La Tho river with 10680m in length: 18 sections, Thanh Quyt river with 51350 in length: 7 sections.

Calculated data includes:
- Upstream boundary: The flow in Nong Son and Thanh My and Bung river basin, A Vuong and Bung 4 hydropower, Con river tributaries and Tuy Loan river.
- Downstream boundary: the lower boundary data of the water level at Cua Han, Cua Dai and Lo.

Using hydraulic model MIKE 11 HD and AD, the model parameters are found through two steps:
Model parameters are set up based on the data series in dry season, 2005 and 2009, the model parameters are adjusted and inspected in 2 steps as follows:
- Calibration and validation of the hydraulic model for the dry season in 2005 and 2009.

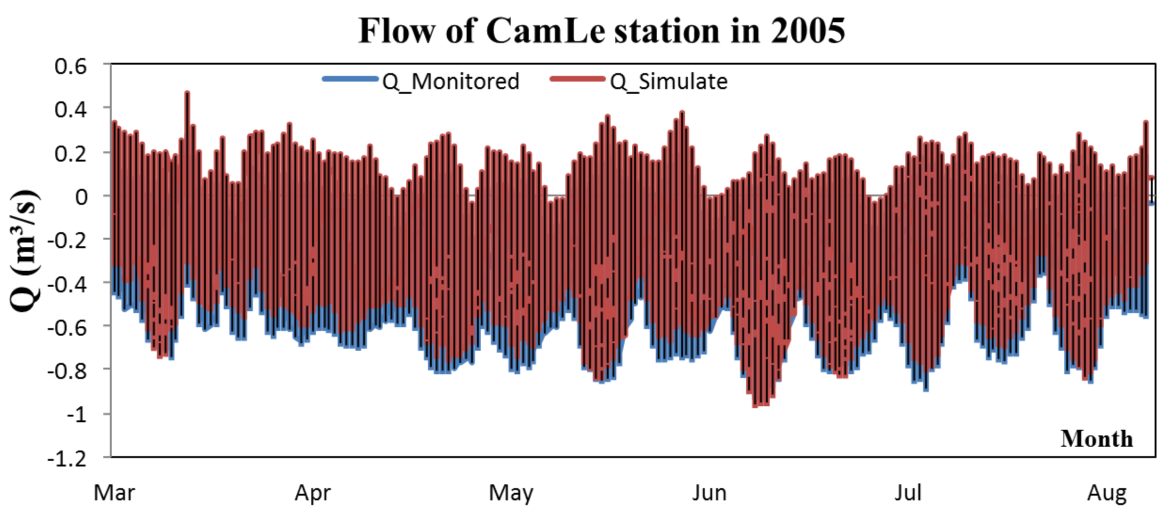

Figure 6. *Calibration result of water level at Cam Le Station from 01/03/2005 to 31/08/5*

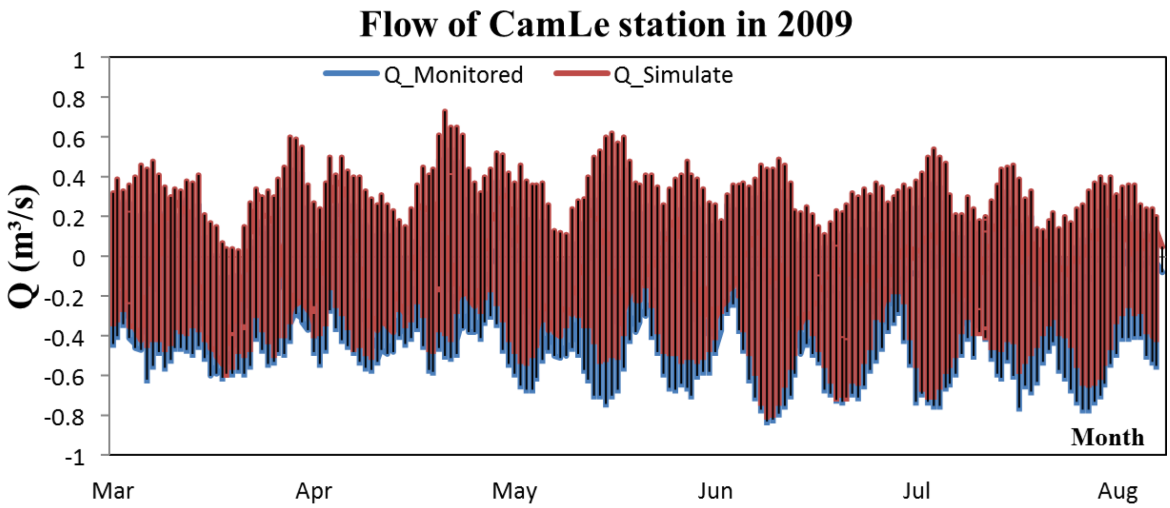

Figure 7. *Validation result of water level at Cam Le Station from 03.01.2009 to 31.08.2009*

- Calibrate and validate the salinity intrusion with 2005 and 2009 datasets.

Table 2. Actual measured data and calculation data (April-July 2005)

Time	Nguyen Van Troi		Cam Le		Tu Cau	
	Measured	*Model*	*Measured*	*Model*	*Measured*	*Model*
12am April 28	22.3	27.113	13.3	13.072	21.1	21.937
1.pmApril 28	22.2	26.755	10.6	14.176	21.5	22.159
2.pm April 28	21.3	25.539	10.5	14.948	21.6	21.94
3.pm April 28	21.1	23.757	4.7	15.84	21.3	21.013
8.am May 18	22.3	24.277	19.7	11.612	19.9	16.221
9.am May 18	21.9	23.955	18.5	11.444	19.8	16.361
10am May 18	21.8	23.121	18.7	10.949	19.5	15.83
11am May 18	21.5	22.42	19.3	10.555	19.5	15.099
11h June 24	23.3	26.86	15.7	14.845	20.4	20.173
12.am June 24	23.8	25.906	15.5	15	20.6	20.186
1pm June 24	23.6	24.124	15.3	14.231	20.3	19.518
2pm June 24	23.5	22.358	14.8	12.909	18.4	17.967
9am July 7	23	26.103	15.6	14.707	20	19.404
10am July 7	23.7	25.622	14.4	14.382	19.4	19.545
11am July 7	20.5	24.239	14.3	13.269	19.6	19.003
12am July 7	20.9	22.705	14	11.993	18.5	17.635

Data on water level and actual measured salinity that are used for calculation validation from 1st March 2009 to 31st August 2009.

Table 3. Actual measured data and calculation data (March-July 2009)

Times	Nguyen Van Troi		Cam Le		Co Man	
	Measured	*Model*	*Measured*	*Model*	*Measured*	*Model*
4am/Mar/12	21.18	22.18	11.73	12.23	15.73	16.48
6am/ Mar /12	21.75	22.55	12.48	12.98	15.90	16.55
8am/ Mar /12	21.93	22.73	12.70	13.20	16.18	16.83
8pm/ Mar /12	22.40	23.20	14.30	14.80	17.28	17.93
4pm / Mar /4	22.1	23.019	13.5	9.799	17	12.532
5pm/ Mar /4	22.1	22.965	12	9.132	17.6	12.873
6pm /Mar /4	22	22.428	13.1	8.51	17.4	12.927
7pm Mar /4	21.8	20.72	8.5	6.957	17.4	12.563
8pm/Mar /23	20.8	23.756	4.4	8.756	18.5	11.836
9pm /Mar/23	20.5	24.572	4	8.503	18.3	11.448
10pm/Mar /23	19.7	24.472	4	8.047	18.3	10.476
11pm /Mar /23	19.4	23.301	3.7	7.684	18.4	9.969
12am/April/29	21	25.63	2	11.586	17.6	14.712
1pm/April /29	21.3	25.355	1.7	10.831	18.5	15.239
2pm/April /29	19.8	23.69	1.6	9.38	17.8	15.216
3pm/April /29	19.5	20.443	0.5	7.802	17.6	14.569
9am/May/ 9	19.3	20.77	0	5.501	10.2	7.886
10am / May/ 9	19.2	20.886	0	5.04	10.1	8.732

11am / May/ 9	19.1	19.082	0	4.45	10	8.429
12am / May/ 9	18.8	16.536	0	3.407	9.7	7.356
10am /June/ 9	20.9	21.832	0	6.801	13.3	9.292
11am /June/ 9	20.8	20.888	0	6.6	13.2	9.383
12am /June/ 9	20.6	18.934	0	6.123	12.9	8.631
1pm /June/ 9	20.5	16.536	0	5.595	12.8	7.527
10am /July/ 9	22.7	24.109	6.6	10.528	18	14.791
11am /July/ 9	22.6	23.64	6.3	9.996	18	14.931
12am /July/ 9	22.4	22.38	6	9.211	17.5	14.435
1pm /July/ 9	22.2	20.725	5.3	7.922	17.3	13.52

III. Conclusion

Water level simulation at Cam Le Stationhas given good resultsof the calibration in 2005 and the validation in 2009. The reliability of the calculation model is shown as the two close lines.

For salinity simulation, the result is exact to relation between monitored and simulated dataset, but it is not as good as hydraulic result due to the variouseffects onthe downstream flow on VGTBRiver in the dry season. For simulated salinity, the result is correct in shape and trend. The reliability between simulation and measurement is not as good as that of hydraulic modeling. The reason isdue to the dry season flow, especially in the downstream area of Vu Gia-Thu Bon River, is affected by various factors, not to mention the data quality of the non-continuous salinity measurement and the salinity measurement of 3 median points for comparison of the simulation results that willimpossibly attain exact result.

The result of salinity intrusion calibration in 2005 shows the value between simulation and measurement is relative close. This is the year in which the exhaust frequency is P = 85% in the upstream. The result of calibration and validation shown highly exact result of NASH index at Cam Le. The results of salinity calibration and validation at Nguyen Van Troi Bridge, Cam Le Bridge and Tu Cau are relatively appropriate. From that, this set of model parameter can be used to simulate salinity for specific calculations.

3. Simulation of salinity intrusion when operating the reservoir system in accordance with the multi-reservoir process.

3.1. Developing scenarios for normal and increasing water demand

To evaluate the effectiveness of the current process and to propose a complementary multi-reservoir operation, this study will focus on simulating the conversion of salinity intrusion between continuous discharge and discontinuous discharge with the purpose of proposingsolutions ofde-salinity in the downstream area.

Recommended solutions: The alternating operation mode for multi-reservoir on the VGTB river system, can ensure the operation according to the current procedure while the flow can be continuously stable in the downstream of VGTB. In that case, Song Bung 2, Song Bung 4 and A Vuong hydropower plants generate from 7am to 10pm (15 hours per day), so the DakMi 4 hydropower reservoir can discharge from 22pm until 7am in the same day.

The discharge returning back to Vu Gia river of DakMi 4 will change in the period of 24 hours (average flow according to Decicion No.1537) to 9 hours (per day). Then the discharge flow for 9 hours in average day would be calculated as: $Q_{9h}=24/9Q_{tb\_\text{Đakmi 4}}$

Based on that approach, the four operating scenarios are shown in **Table 4**, and the2005 dataset is selected as basic dataset in simulation (frequency 85%), and simulating time includes 2 periods of the normal water demand and high demand from March 1st to April 30th and from May 5thto June 30th respectively.

Table 4. The scenario of simulation period with normal water consumption and increase one.

Scenario	Description scenario
KB1	Dakmai 4a reservoir dischargesinto Vu Gia with the average flow (as Decision No.1537/QD-TTg), reservoirs operate an average flow of 24 hours in the downstream.
KB2	Dakmai 4a reservoir discharges into Vu Gia with the average flow (as Decision No.1537/QD-TTg), reservoirsoperate thepower generation to the downstream from 7am to 22pm daily (current operation).
KB3	Operated as the **KB2** but DakMi 4a does not discharge onto Vu Gia river.
KB4	The multi-reservoirsoperate the power generation to the downstream from 7am to 22pm daily (current operation).DakMi4 reservoir discharges flow to Vu Gia river with the average amount according to the Decision No.1537/QĐ-TTg (same amount as 24 hours) but only operate at the time from 10pm to 7am (non-electricity generation period).

3.2. Simulation results:

The simulation results of KB1 to KB4 are shown as Figure 8 to Figure 10

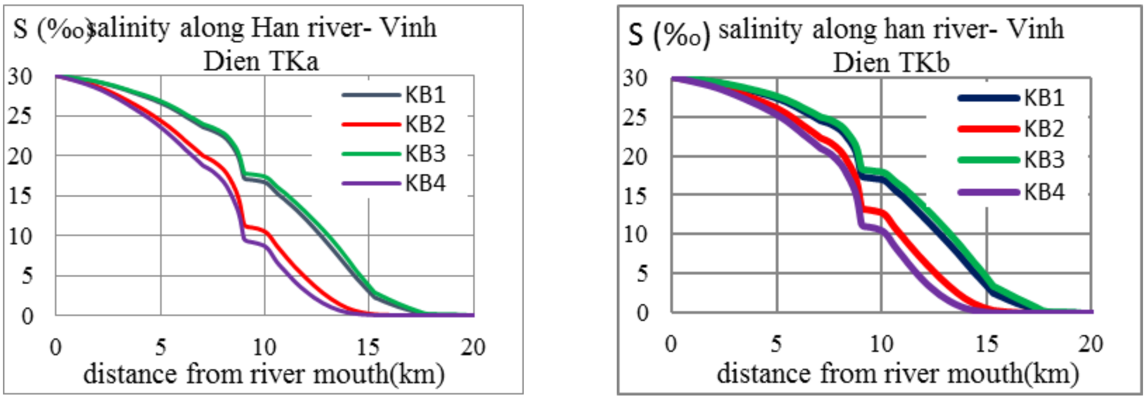

Fig. 8, a, b. Largest salinity intrusion progress on Han-Vinh Dien River. (period of normal water use from March 1 to April 30 and the period from May 11 to June 10)

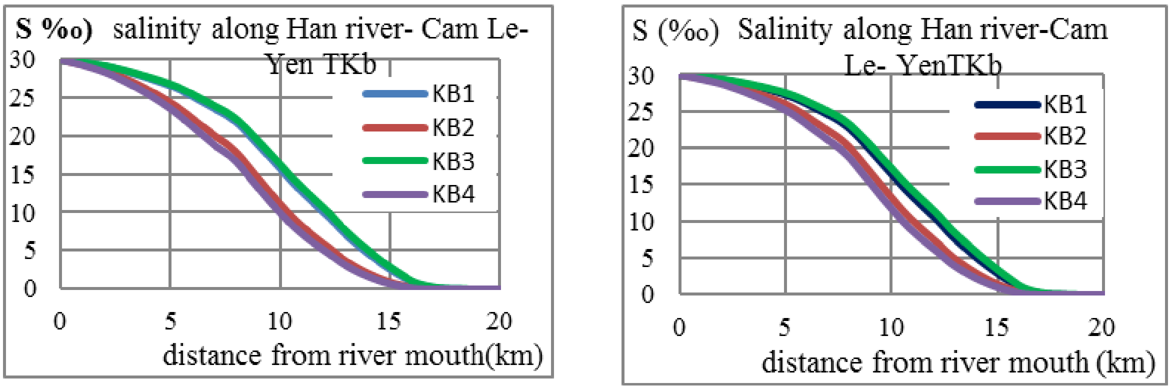

Figure 9, a, b. Largest salinity intrusion on Han-Cam Le - YenRiver (period of normal water use from March 1 to April 30 and the period from May 11 to June 10)

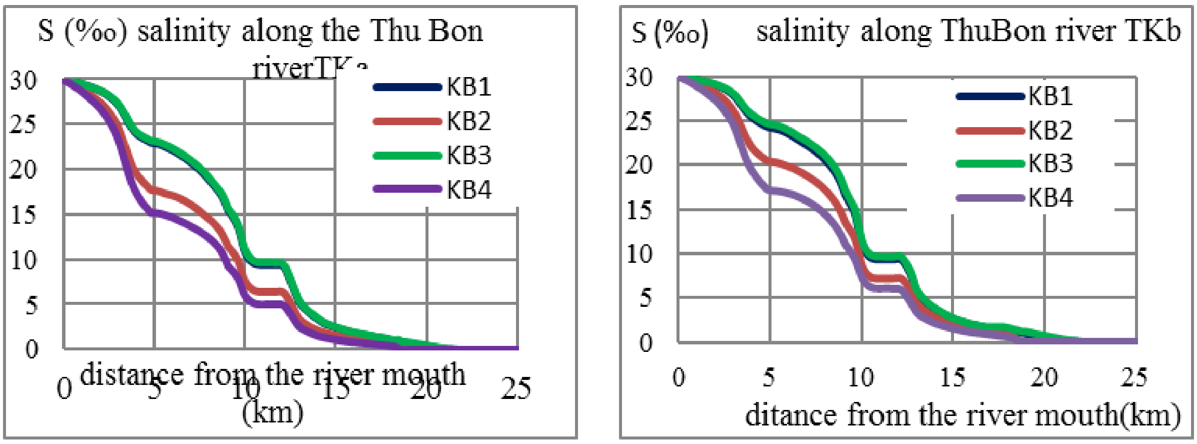

Figure 10, a, b. Largest salinity intrusion on Thu Bon River (period of normal water use from March 1 to April 30 and the period from May 11 to June 10)

The calculation results show that:

- Salinity is distributed on Yen - Han, Cam Le, Vinh Dien - Han, Thu Bon rivers corresponding to the period of normal and high water demand in salinity fluctuation along the scenarios.
- In KB3 scenario, when the reservoir Dakmi 4a does not discharge onto Vu Gia River, the salinity intrusion will reach maximum, it shows that the salinity in the downstream of Vu Gia river directly impacted onthis reservoir discharge.
- In the KB2 scenario, under the current procedure (Decision No.1537), the downstream salinityhasthe relatively large reduction in comparison with KB1 and KB3 scenarios.

- In KB4 and KB2 scenarios, the daily total discharge of Dak Mi 4a is the same. However, when Dakmi 4a dischargesonto Vu Gia river from 22pm to 7am (KB4), the salinity in the downstream decreases significantly in comparison with the case of average discharge (KB2). This could be proposed to regulate the multi-reservoir procedure Decision No.1537/QĐ-TTg to stakeholders.

IV. Conclusions and recommendations

1. The study results showed the change of salinity of Vu Gia, Thu Bon and Vinh Dien rivers operating the multi-reservoir operation process No.1537/QD-TTg,
2. The operation mode of discontinuous discharge to the downstream could increase the salinity intrusion. To reduce this inconvenientmatter, it is more effective to alternate generating discharge and returning discharge of Dakmi
4 hydropower plant. Particularly, based on the simulation results of scenario KB4, the proposed discharge operation is appropriate with the current power generation of the reservoirs and reduces the downstream salinity of the VGTB basin.
3. Authorities should propose additional procedures for operation of the Vu Gia Thu Bon reservoir in accordance with scenario 4.

Acknowledgements

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