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BUILDING THE REASONABLE OPERATION MODEL OF THE DAU TIENG HYDRAULIC WORK TO SERVE WATER SUPPLY AND FLOOD PREVENTION FOR THE DOWNSTREAM OF SAI GON RIVER

SPECIALIZATION: Water resources engineering

Code: 9-58-02-12

SUMMARY OF TECHNICAL DOCTOR THESIS

HO CHI MINH CITY, 2021

The project was completed at **Southern Institute of Water Resources Research**

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This thesis will be defended in front of the Institutional Thesis Council at: Southern Institute of Water Resources Research at ……..…. day …..month.…..year.…………

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PREAMBLE

1. Necessity of the thesis topic

The thesis topic “Building the reasonable operation model of the Dau Tieng hydraulic work to serve water supply and flood prevention for the downstream of Sai Gon River” has essential meaning for the society development, both scientific and practical significance on management, exploitation, and operation of the Dau Tieng reservoir.

2. Study purposes

The thesis is aimed to find out the solutions and tools supporting the Dau Tieng reservoir operation for storing and supplying water in the dry season; ensure the hydraulic work safety, prevents and reduces the impacts of flood on the downstream area of Sai Gon River.

3. Subject and scope of the study

The study subject is the Dau Tieng reservoir and factors relating to operation work of the Dau Tieng reservoir. The thesis also proposes non-structural solutions to support the Dau Tieng reservoir reasonable operation.

4. Methods of the study

Scientific observation, information collection; Theory analysis and synthesis; Classification, systematization theory; Assumption; Data investigation and analysis, information processing; Empirical science; Algebraic application and mathematical model.

5. Scientific and practical significance of the thesis

Contribute to developing the scientific basis of reservoir operation, water resources management, and socio-economic of localities in the beneficiary areas.

6. New contributions of the thesis

(1) Propose solutions on the Dau Tieng reservoir flow forecasting in the dry season; (2) Propose solutions for water discharge for salinity control at Hoa Phu pumping station in Sai Gon River; (3) Program rainfall data

extraction from global weather forecasting model, combined with measured data for the inflow simulation model; (4) Develop a program for flood control regulation of the Dau Tieng reservoir.

7. Structure of the thesis

In addition to preamble, conclusion and recommendations, the thesis includes 3 main chapters, are presented as follows: Chapter 1,Study overview; Chapter 2, Methodological basis for the reasonable operation of the Dau Tieng reservoir; Chapter 3, Study on solutions and applications to support the operation of the Dau Tieng reservoir.

CHAPTER 1. STUDY OVERVIEW

1.1. STUDY OVERVIEW OF RESERVOIR OPERATION

1.1.1. Study on developing procedures and tools to support operations

Method used: Approximation of random function planning; application of genetic algorithms, evolutionary algorithms, optimization of ant colonies; using Monte Carlo simulation method;...

Research objectives: Find the reasonable water release from Dau Tieng reservoirs, corresponding water release from other reservoirs to satisfy many conflicting purposes;...

1.1.2. Forecasting of inputs variables to calculate operational support

Methods used: Using many types of models such as RAMS, HEC-HMS, HECRESSIM, BOLAM, NAM., artificial neural network (ANN) to compute and predict flood….

Research characteristics: Studies in the world tend to apply artificial neural network models for flow forecasting increasingly; Studies in the country mainly apply the combination of irrigation and power generation. Reservoirs for irrigation purposes only have a small capacity and are often serving for a small scope of a province.

1.1.3. Study on the Dau Tieng reservoir operation

Remaining problems: (i) The rain and flow forecast are not really efficient. (ii) There has been no research to support the task of calculating and regulating floods reasonably. (iii) The method of reasonable water release for salinity control has not been proposed.

1.2. OVERVIEW OF THE DAU TIENG HYDRAULIC WORK

- **Operation process of Dau Tieng water reservoir:**

Inter-reservoir operation procedures in Dong Nai River basin, according to Decision No. 1895/QD-TTg. Operation procedures of the Dau Tieng reservoir, according to Decision No. 3474/QD-BNN-TCTL.

- **Practical requirements for the current operation of Dau Tieng reservoir**

With the work of inflow forecasting to lake in the dry season: *Reservoir owners must:* Organize the forecast lake inflow and water level in the next 10 days on the 1st, 11th, and 21st of every month.

With the work of water discharge for salinity control, dilute salinity on the Sai Gon River: The scientific basis for operation is uncertain. The results of this work have not satisfied the practical requirements, the amount of water needed for this mission is relatively large.

With the work of forecasting the flow to lake in the flood season: Organize the rainfall surveying according to regulations; surveying and calculating lake water level, and inflow rate, discharge flowrate through the spillway, factory, sluice at the beginning of the canal at least 4 times/day at the following times: 1, 7, 13, and 19 pm.

With the calculation and regulation of flood: Calculating the discharge volume must be such that the lake water level during flood regulation procedures does not exceed the maximum test water level (26.92 m) and after flood regulation procedures, the lake water level must be returned to the pre-flood water level [42].

1.3. STUDY ORIENTATION

1.3.1. Case study approach

- ***Theory approach:*** The ANN network model has been used to study and predict the inflow in the dry season; MIKE-NAM model has been used to simulate inflow during flood season; Besides, MIKE 11 model has been used to conduct numerical experiments to find solutions to discharge water for salinity control.
- ***The laws of nature approach:*** The ANN model has been used to detect natural laws through learning from the past statistical data series so that future predictions can be applied.
- ***Practical approach, driver:*** The flood regulation program has been built based on the provisions of Procedure 1895 and the tidal condition (or predicted tidal level) to build the flood regulation algorithms.
- ***Experimental approach:*** The MIKE 11 model has been used to conduct numerical experiments to find out the rules or instructions for the effective operation of water discharge for salinity control.

1.3.2. Study mission

(1) Study on solutions and applications of inflow forecasting in the Dau Tieng reservoir in the dry season and flood season; (2) Study on solutions and applications to discharge water for salinity control at Hoa Phu pumping station on the Sai Gon River; (3) Study on solutions and applications of flood regulation in the Dau Tieng reservoir.

CHAPTER 2. METHODOLOGY BASIS OF THE REASONABLE OPERATION OF DAU TIENG RESERVOIR

2.1. DEFINITIONS

2.1.1. The concept of the reasonable operation model of the reservoir

The model of reasonable reservoir operation is a model studied on operating methods, operating time, and operating results.

2.1.2. The concept of the real-time reasonable reservoir operation

Every decision for operation at any time has depended on the state of the system at that time and forecast information at the following times.

2.1.3. Study contents on the reasonable operation of the Dau Tieng reservoir

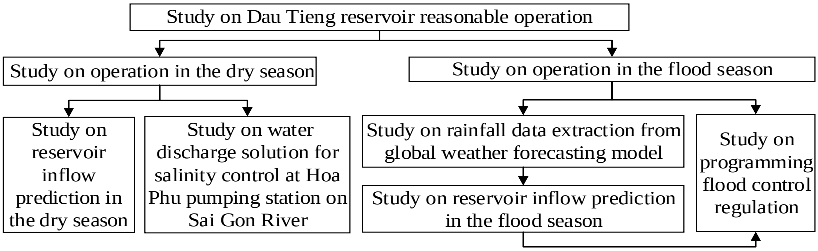

Figure 2.1: Flowchart of research content on the reasonable operation of the Dau Tieng reservoir

2.2. MODEL ASSESSMENT STANDARDS

Pearson correlation coefficient (r); Model efficiency coefficient (R^2); Mean square root error (RMSE); Mean absolute error (MAE); Residual Quantity Surplus (BIAS).

2.3. DATABASE FOR RESEARCH

Data of river sections; Topographic data of fields and infrastructure; data at the boundaries; and data base of meteorology, hydrology.

2.4. BASIS OF FORECASTING METHODS OF FLOWING TO LAKE IN THE DRY SEASON

- **Study approach basis**

As the outstanding characteristic of the ANN network is the ability to learn and find complex relationships between input and output data, the ANN approach is a suitable model in the dry season.

- **Research tools and data normalization methods**

Artificial neural network model in this study has been used through Matlab's Neural Network Toolbox (nntool) [65]. The input data of modelhas been standardized as follows:

$$X_n = 0,05 + 0,9 * \frac{(X_r - X_{Min})}{(X_{Max} - X_{Min})} \qquad (2.9)$$

Where: X_n is the value after standardization, and X_r is the input raw value; X_{max} and X_{min} are the largest and smallest value of the series.

2.5. BASIS OF METHODS OF WATER DISCHARGE FOR SALINITY CONTROL

- **Study basis:** To impact on the water quality on the Sai Gon River, if discharged from the Dau Tieng reservoir 1m^3, it must be discharged equivalent to 12 to 15 m^3 from Tri An and Phuoc Hoa reservoirs [43].
- **Some mathematical models applied for saltwater intrusion study:** Model SOGREAH, KOD, SAL, VRSAP, DUFLOW, iSIS, MIKE.

2.6. BASIS OF FORECASTING METHODS OF FLOW TO LAKE IN THE FLOOD SEASON

- **Forecast data source**

Reference website are https://freemeteo.vn/, https://www.windy.com.

- **Extract data from website freemeteo.vn**

Once you have geographic coordinates, follow these steps:

Step 1: Open the provider's website (https://freemeteo.vn/)

Step 2: Select and enter Latitude, Longitude Coordinates ▼

Step 3: Choose any day of the week MondayTuesday 11 January12 December

Step 4: Select the item 7 days and select the item List

Step 5: Record a 7-day rainfall forecast.

- **Extract data from website Windy.com**

API requests have been performed over the HTTP protocol and the data features returned either JSON or XML files. Many API features can be combined into one HTTP request. Program to extract rain data returned JSON or XML file. Some steps to analyze the returned JSON Weather chain values are as follows:

Step 1: Create a class that is similar to an object representing the location to get weather information containing attributes such as temperature, wind, ...

Step 2: Create a class to store information such as location,wind, rain,.

Step 3: Create a class to convert the data from the returned JSON data.

Step 4: Create a class that extracts the JSON value chain from the API according to desired locations.

Step 5: Build the basic interface to display the processing classes.

Step 6: Write Code (source code) for the program.

2.7. BASIS OF THE METHOD OF FLOOD REGULATION FOR THE DAU TIENG RESERVOIR

Basis for setting up the problem of flood regulation of the Dau Tieng reservoir

When the water level at Phu An is ≥1.3 m and the reservoir water level is ≤ 25.10 m, the maximum discharge flowrate is 200 m^3/s. In the remaining cases, the reservoir can be discharged with the flowrate is larger than 200 m^3/s. The maximum water level must always be 26.92 m, at the end of the flood regulation procedure, the lake water level must be returned to the pre-flood water level or a reasonable stored water level.

Diagram of flood regulation procedures of the Dau Tieng reservoir

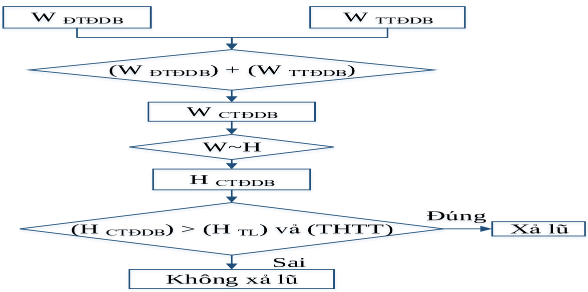

Figure 2.18: Diagram of flood regulation procedures of the Dau Tieng reservoir

In which: W_{DDTDB}: Reservoir capacity at the beginning of the forecast period; W_{TTDDB}: Capacity to the lake during the forecast period; W_{CTDDB}: Lake capacity at the end of the forecast period; H_{CCDDB}: Lake water level at the end of the forecast period; H_{TL}: Elevation of water level before flood; T_{HTT}: Weather situation after the forecast period; W~H: Relation of capacity and lake water level.

CHAPTER 3. STUDY ON SOLUTIONS AND APPLICATIONS SUPPORTING OPERATION OF THE DAU TIENG RESERVOIR

3.1. RESEARCH FOR FLOW FORECAST TO LAKE IN THE DRY SEASON

3.1.1. Document for the study

The data has been used to train the ANN network from 1990-2011 (Train phase), the data has been used to test this network from 2012-2016 (Test phase).

3.1.2. Planning options to forecast lake inflow in the dry season

Option 1: Forecast of daily flowrate to the lake:

+ Scenario 1 (KB-1): Q_{t-1}, Q_{t-2}.

+ Scenario 2 (KB-2): Q_{t-1}, Q_{t-2}, Q_{t-3}.

+ Scenario 3 (KB-3): Q_{t-1}, Q_{t-2}, Q_{t-3}, Q_{t-4}.

+ Scenario 4 (KB-4): Q_{t-1}, Q_{t-2}, Q_{t-3}, Q_{t-4}, Q_{t-5}.

In which: Q_{t-1}, Q_{t-2}, .Q_{t-n} is the flowrate to the lake in the previous days.

Option 2: Forecasting flowrate to the lake 10 following days:

+ Scenario 1 (KB-DB10-1): Q_{HT}, Q_{t-TB10}.

+ Scenario 2 (KB-DB10-2): Q_{HT}, Q_{t-TB10}, Q_{t-TB20}.

In which: Q_{HT} is the current inflow flowrate; Q_{t-TB10} is the average inflow rate 10 previous days; Q_{t-TB2} is the average inflow rate 20 previous days.

Option 3: Forecast of flowrate to the lake 30 following days:

+ Scenario 1 (KB-DB30-1): Q_{HT}, Q_{t-TB30}.

+ Scenario 2 (KB-DB30-2): Q_{HT}, Q_{t-TB30}, Q_{t-TB60}.

In which: Q_{HT} is the current inflow flowrate; Q_{t-TB30} is the average inflow rate 30 previous days; Q_{t-TB60} is the average inflow rate 60 previous days.

3.1.3. Analyze training results and test predictive scenarios

Training the dataset for KB-1 to KB-4 for the Train phase, and testing for the Test phase gives quite good results with r=80% and R^2=90%. Comparing scenarios in the Test phase, KB-2 gives good results, r=0.91 and R^2=0.82; The lowest value of MAE and RMSE errors are 22.46 and 37.32, respectively. Therefore, KB-2 is selected as input for training the daily inflow network prediction.

Training the dataset for KB-DB10-1 and KB-DB10-2 for the Train phase, and retesting the Test phase gives satisfactory results, $70\% \geq R^2 \geq 50\%$. Comparing the scenarios in the Test phase, KB-DB10-2 has a better R^2 and lower RMSE error value than KB-DB10-1. Therefore, KB-DB10-2 is selected as the input fortraining the inflow network prediction of an average of 10 following days.

Training the dataset for KB-DB30-1 and KB-DB30-2 for the Train phase, and retesting for the Test phase gave satisfactory results, $70\% \geq R^2 \geq 50\%$. Comparing scenarios in the Test phase, KB-DB30-1 has R^2=0.57 better than KB-DB30-2 (R^2 =0.50), and RMSE error of 45.63 is lower than KB-DB30-2 is 51.88. Therefore, KB-DB30-1 is selected as input for training the inflow network prediction of an average of 30 following days.

3.1.4. Analyze model testing results

The validation results of the predictive daily flowrate model to the Dau Tieng reservoir are quite good with $R^2 \geq 70\%$. The validation results of the predictive average flowrate model to the Dau Tieng reservoir after 10 days are quite good with the coefficient $R^2 \geq 70\%$. The results of validation results of the predictive average flowrate model to the Dau Tieng reservoir 30 days later are quite good with the coefficient $R^2 \geq 70\%$.

3.2. STUDY ON WATER DISCHARGE FOR SALINITY CONTROL AT HOA PHU PUMPING STATION ON SAI GON RIVER

3.2.1. Establishing a study model for water discharge work

The thesis topic has been inherited the diagram of river and canal network from previous projects [5], [6], [47], [53], and updated, supplemented, calibrated and tested for a 3-year operation model, including 2010, 2011 and 2013.

3.2.2. Calibration and testing of the research

The results of calibration and testing show that the model ensures reliability for the study on the saline intrusion in the downstream area of the Dong Nai basin.

3.2.3. Study on determining the relationship between tidal level and salinity

3.2.3.1. Study methods

Select the times when tides appear with salinity ≥ 150 mg/l Cl^- in March and April of 2006, 2007, 2010, 2013 and 2015 for study.

3.2.3.2. Summary and analysis results

The average phase difference between the tidal peak at Vung Tau and Sai Gon Port is 4 hours; between the tidal peak at Sai Gon Port and the salinity peak at Hoa Phu pumping station is 5 hours; between the tidal peak at Vung Tau and the salinity peak at Hoa Phu pumping station is 8 hours.

3.2.4. Study on determining the relationship between discharge time and salinity

3.2.4.1. Study methods

Case 1: Discharge according to flowrate fluctuation from 20 m^3/s to 70 m^3/s, with the same starting time of discharge (discharge from 06 am of March 27, 2010).

Case 2: Change the discharge starting time, do not change the discharge flowrate, specifically select a test discharge with a flowrate of 60 m^3/s.

3.2.4.2. Study results

In both cases, after only 01 to 02 hours of discharge, the salinity in Hoa Phu pumping station has changed, however, the salinity decreased significantly low compared to before discharge.

3.2.5. Studyon determining the reasonable time to discharge water at the Dau Tieng reservoir

3.2.5.1. Study methods

Step 1: Experiment with the model with the case of no water discharge.

Step 2: Experiment with the model of water discharge in a day with each flowrate fluctuation (from 20 to 70 m^3/s), according to different starting times of discharge, calculate the percentage of salinity reduction at the salinity peaks when changing the discharge time.

3.2.5.2. Study results

Table 3.11: Results of the percentage of salinity reduction at the peaks when changing the discharge time, corresponding to the case of the continuous discharge of 60 m^3/s

No	Peak salinity (mg/l CL^-)	Time starting salinity	Time starting water discharge for 4th peak salinity						
			24	28	34	38	**48**	72	96
1	365.21	2am 26/3/2010	0.00	0.00	0.00	0.00	4.53	24,81	23,62
2	379.84	6pm 26/3/2010	0.00	0.17	4.07	7.89	17.81	23,32	22,77
3	416.87	4am 27/3/2010	0.00	9.26	15.04	18.83	23.77	21,90	21,55
4	401.48	6pm 27/3/2010	5.81	21.31	23.92	**24.28**	**24.05**	**22,18**	21,76
5	463.10	5am 28/3/2010	16.12	22.36	22.16	22.04	21.80	20,36	20,09
6	437.04	7pm 28/3/2010	23.55	23.13	22.87	22.72	22.41	20,84	20,50
7	485.00	6am 29/3/2010	21.95	21.47	21.29	21.20	20.96	19,59	19,31
8	469.53	7pm29/3/2010	22.27	21.74	21.55	21.45	21.19	19,77	19,45
9	476.73	7am 30/3/2010	21.84	21.36	21.18	21.08	20.83	19,44	19,11
10	478.36	7pm 30/3/2010	21.59	21.13	20.96	20.87	20.62	19,23	18,89
11	464.60	8am 31/3/2010	21.67	21.21	21.05	20.95	20.70	19,29	18,93
12	497.59	8pm31/3/2010	20.68	20.28	20.14	20.05	19.82	18,48	18,12
13	444.22	10am 01/4/2010	21.23	20.81	20.65	20.56	20.31	18,93	18,55
Average			16.39	18.69	19.57	**20.16**	**21.19**	**20.28**	20.04

From the results of Table 3.11, to reduce the 4th salinity peak, it must be discharged before 38 hours to reduce salinity by 24.28%, discharged before 48 hours to reduce salinity by 24.05 %, and reduce salinity by 22.18% for discharging before 72 hours. Overall, discharge 48 hours before, the salinity peaks decreased by an average of 21.19%.

3.2.6. Study on determining the relationship between time and discharge flowrate

3.2.6.1. Study methods

Step 1: Prepare discharge options, see Table 3.12.

Table 3.12: 48-hour pre-discharge options

Discharge option	Starting time	Ending time	Total time	Total days	Q_{dis} (m^3/s)	$W_{đis}$ ($10^6 m^3$)
Scenerio 1 (PA1)	6pm 25/3/2010	6pm 31/3/2010	144	6	20	10.368
Scenerio 2 (PA2)	6pm 25/3/2010	6pm 29/3/2010	96	4	30	10.368
Scenerio 3 (PA3)	6pm 25/3/2010	6pm 28/3/2010	72	3	40	10.368
Scenerio 4 (PA4)	6pm 25/3/2010	6pm 27/3/2010	48	2	60	10.368
Scenerio 5 (PA5)	6pm 25/3/2010	6pm 26/3/2010	24	1	120	10.368
Scenerio 6 (PA6)	6pm 25/3/2010	6am 26/3/2010	12	0.5	240	10.368

Step 2: It is predicted that from 6pm on March 27, 2010, salinity is likely to exceed the threshold at Hoa Phu pumping station, so it is decided to discharge from 6 pm on March 25, 2010.

3.2.6.2. Study methods

Table 3.13: Average % salinity reduction at the peaks according to the scenarios

Peak salinity	Average % salinity reduction at the peaks					
	PA1	PA2	PA3	PA4	PA5	PA6
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1st Salinity peak	1,54	2,30	3,05	4,53	8,83	16,94
2nd Salinity peak	5,93	8,90	11,86	17,81	35,70	44,66
3rd Salinity peak	9,55	14,22	18,82	27,80	45,23	42,78
4th Salinity peak	13,69	20,30	26,72	**38,92**	**45,11**	**42,89**
5th Salinity peak	16,01	23,67	31,05	41,26	41,21	39,28
6th Salinity peak	20,65	30,28	39,35	42,19	41,99	40,06
7th Salinity peak	22,46	32,84	39,88	39,45	39,47	37,71
8th Salinity peak	26,55	38,47	40,30	39,74	39,73	37,98
9th Salinity peak	29,43	40,08	39,51	39,02	39,06	37,35
10th Salinity peak	32,59	39,67	39,02	38,57	38,63	36,95
11thSalinity peak	36,18	39,67	39,05	38,63	38,68	37,01
12thSalinity peak	37,92	37,93	37,43	37,08	37,17	35,55
13thSalinity peak	40.10	38.76	38.24	37.87	37.95	36.30
Average % salinity reduction	22.51	28.24	31.10	**34.07**	**37.60**	**37.34**

From Table 3.13, at the 4th salinity peak, shows that: PA4 has a rate of salinity reduction of 38.92%, and an average reduction of salinity peaks of 34.07 %; PA5 has a salinity reduction rate of 45.11%, and an average reduction of salinity peaks of 37.60%; PA6 has a salinity reduction rate of 42.89%, and an average salinity reduction rate of 37.34%.

3.2.7. Study on determining reasonable flowrate, discharge time

3.2.7.1. Study methods

Case 1: Discontinuous discharge according to levels from 20 m^3/s to 240 m^3/s in batches (4 hours/batch).

Case 2: Continuous discharge according to levels from 20 m^3/s to 240 m^3/s in batches (4 hours/batch).

3.2.7.2. Study results

Case 1: The flowrate at Hoa Phu pumping station changes mainly in the first 106 hours. After 8 hours of discharging 240 m^3/s, the largest change was 195.276 m^3/s.

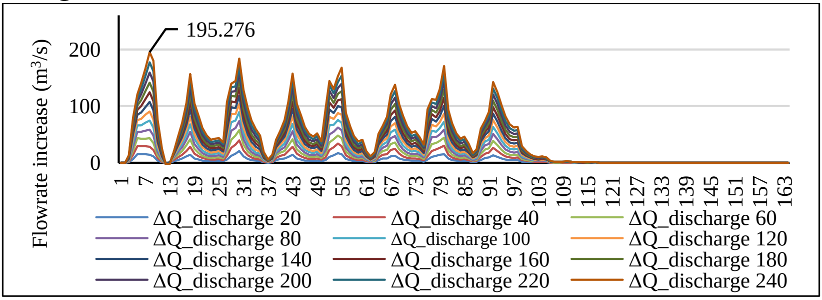

Figure 3.23: Change of flowrate increases according to different discharge flowrate with discontinuous discharge case of the 8-cycle stage (32 hours of discharge)

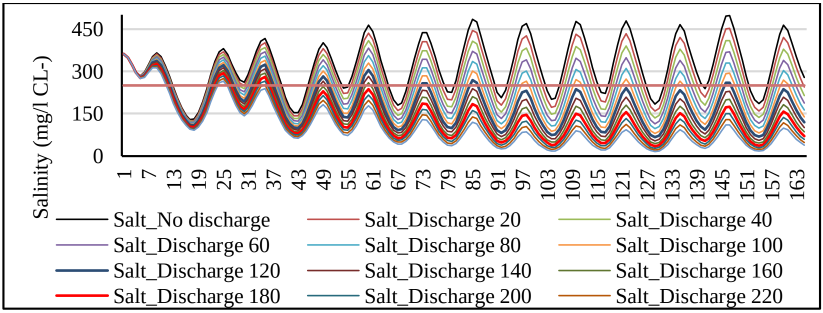

Figure 3.24: Change of salinity according to different discharge flowrate with discontinuous discharge case of the 8-cycle stage (32 hours of discharge)

To bring from the 4th salinity peak to the allowable threshold, the flowrate of 180 m^3/s must be discharged. If discharging 120 m^3/s (13.824 million m^3), bringing the 8th, 9th, 10th, 11th, and 13th salinity peaks to the allowable threshold, the remaining saline peaks are higher than the allowable threshold.

Case 2: The flowrate at Hoa Phu pumping station changes mainly in the first 48 hours. After 25 hours of discharging 120 m^3/s, the biggest change was 207,768 m^3/s, and the biggest change was 488,212 m^3/s when discharging 240 m^3/s.

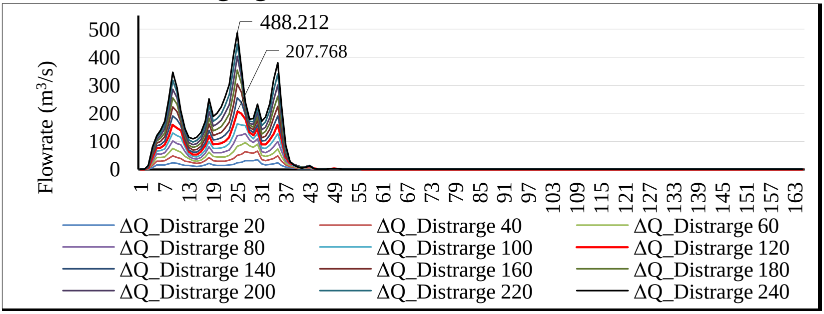

Figure 3.25: Change of flowrate increases according to different discharge flowrate with continuous discharge case of the 8-cycle stage (32 hours of discharge)

Figure 3.26 shows that just 120 m^3/s in 32 hours (13.824 million m^3) can bring from the 2nd salinity peak onwards to the allowable threshold.

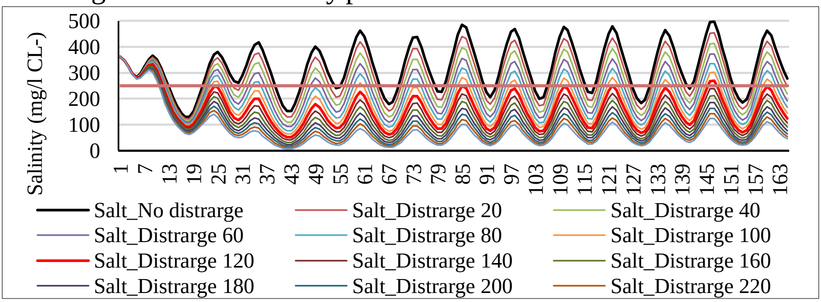

Figure 3.26: Change of salinity according to different discharge flowrate with continuous discharge case

3.2.8. Analyze and evaluate the effectiveness of applying research results

3.2.8.1. Analytical and evaluation methods

Case 1: Testing the model with the case that the Dau Tieng lake with no discharge.

Case 2: Discharging with real-time and flowrate.

Case 3: Discharging 120 m^3/s in 32 hours.

For each case, calculate the total number of hours where the salinity exceeds the allowable threshold.

3.2.8.2. Analysis and evaluation results

Table 3.18: Results of discharge for salinity reduction by cases

Case	The total number of hours of salinity exceeds the allowable threshold	The total amount of water used for salt suppression ($10^6 m^3$)	Note
1	931	0	No discharging
2	83	73,152	Discharging according actual condition
3	29	55,296	Discharging according new method

Applying the new method results to save 17.86 million m^3 (fallen by 24.41% compared to discharge according the actual condition), reducing the number of hours when the salinity exceeds the threshold is 54 hours.

3.2.8.3. The procedure of water discharge for salinity control at Hoa Phu pumping station

Table 3.19:Instructions for discharging at Hoa Phu pumping station on the Sai Gon River

Content	Discharge according to contact	Discharge in the dry season	Maximum discharge in the dry season	The remaining time in the dry season	Tidal level reach a espeak at Sai Gon Port station	Salinity starts to peak at Hoa Phu pumping station	Time for starting discharge at the Dau Tieng spillway
					(**T**=dd/mm/yyyyhh:mm)		
Annual required time for discharge	12 months	January to Jully	March to 15 May	January to February and 16 May to 30 June			
Discharge flowrate	According regulation $\leq 36\ m^3/s$	According regulation $\leq 36\ m^3/s$	≥ 120	≥ 100			
Discharge time	Daily	Daily	32 hours/ discharging time continously	32 hours/ discharging time continously			
At time					$\mathbf{T}_{TrSG} = \mathbf{T}$	**T**+ (5 hours)	**T**- (43 hours)
Required salinity	≤ 250 mg/l CL-	≤ 250 mg/l CL-	≤ 250 mg/l CL-	≤ 250 mg/l CL-			

3.2.9. Applying the study results of the 8th and 9th batches of water discharge for salinity control in 2016

Determining the time when the salinity exceeds the threshold at Hoa Phu pumping station

From the tide table [45], it is determined that from April 18 to May 10, 2016, there are 2 high tides, it is possible to predict the time when the saline peak will appear at Hoa Phu pumping station.

Select the water release option

Option 1 discharges 120 m^3/s per day, option 2 discharges 60 m^3/s per 2 days, option 3 discharges 120 m^3/s per 32 hours. All three options were discharged from 6pm on April 18, 2016. Since this is the first experiment, the lake owner chooses option 2.

Results of the 8h water realse application in 2016

The maximum salinity surveying result at 20h 20/4/2016 is 332 mg/l Cl-, higher than the predicted salinity value under option 2 is 54,086 mg/l Cl-, salinity on 22/4/2016 has reached 188 mg/l Cl-. The 8th water discharge ended at 6pm 23/4/2016, the surveying results showed that the salinity change at Hoa Phu pumping station was the highest at 166 mg/l Cl-.

Results of the 9th water realse application in 2016

The actual discharge with option 2 (from 4 am 4/5/2016 to 4am6/5/2016). Salinity monitoring results showed that: On May 4 and May 5, 2016, the highest salinity was 252 mg/l Cl-, continuing to discharge 60 m^3/s for the following day. Surveying results show that salinity changes from May 6 to May 10, 2016 are quite low.

Analysis of the results of the 8th and 9th water release phase

The 7th discharge totally used 24.70 million m^3, the total number of hours of salinity exceeding the threshold is 76 hours; the 8th discharge used 22.46 million m^3, the total number of hours of salinity exceeding the threshold is 10 hours; The 9th discharge used 15.55 million m^3, the total number of hours of salinity exceeding the threshold is only 2 hours.

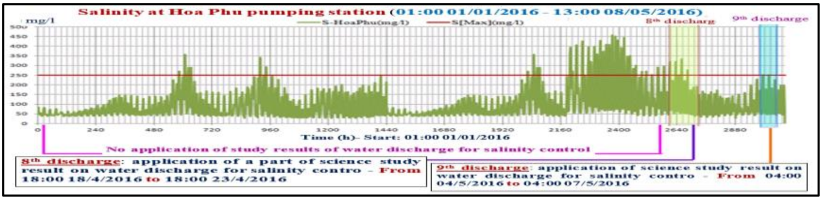

Figure 3.29:Salinity at Hoa Phu pumping station on Sai Gon River after discharging from the Dau Tieng reservoir, from 1am January 1, 2016 to 1pm May 8, 2016

3.3. STUDY ON FLOW FORECASTING TO LAKE IN THE FLOOD SEASON

3.3.1. Study to extract data from weather forecasting models

3.3.1.1. Program to extract forecast weather data

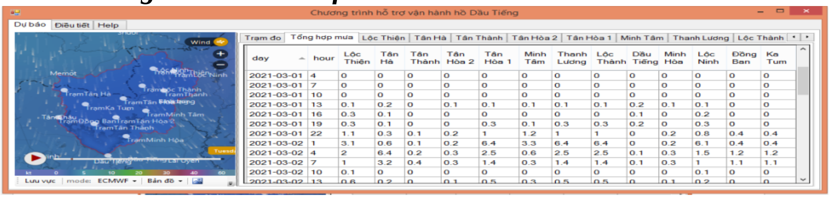

Figure 3.31: Summary of rainfall forecast at 13 rain gauge stations in the basin

The program is built in C# language, based on the website Windy.com. Weather data is stored on the computer as *.csv files.

3.3.1.2. Analysis and selection of predictive models for the Dau Tieng reservoir basin

a. Document for the study

From the website windy.com, it was predicted that from November 24, 2018 onwards, the storm will cause heavy rain on the Dau Tieng reservoir basin on November 25th or November 26th,2018.

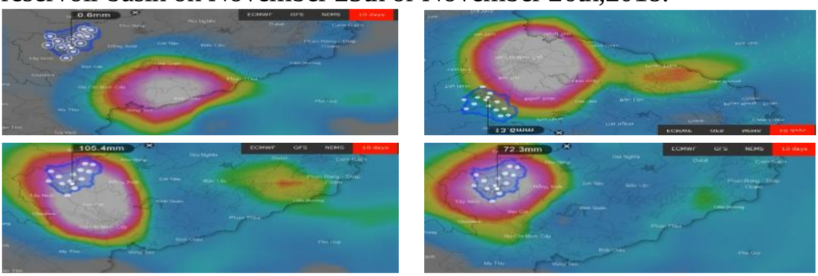

Figure 3.33: Some images of moving the center of rain from Storm No. 9 in 2018

Using data extracted on November 22th, 23th, 24th, and 25th, 2018 to evaluaterain forecast from November 25th to 27th, 2018. Rain forecasthas been used to analyze and compare with the actual rain measured from November 25 to 27, 2018.

b. Study methods

Based on correlation coefficient (r), mean absolute error (MAE), and total average rainfall in the basin during the survey to determine and evaluate the relationship between measured rain and forecasted rain.

Table 3.24:Total average rainfall (mm) in measured and forecasted basins for 3 days, from November 25, 2018 to November 27, 2018

Meaure (mm)	Predictive model	Forecast news according to models					% error
		22 Nov	23 Nov	24 Nov	25 Nov	Daily average	
141.66	ECMWF	115.06	133.98	161.26	118.52	136.87	3.38
141.66	GFS	205.11		211.34	126.01	180.82	27.64
141.66	NEMS	55.97	47.95	79.32	102.59	71.46	49.56

The forecasted rain tends to be small compared with the actual rain. The analysis results according to the **r** and **MAE** indexes, the **ECMWF** model gives better results, there is a small difference between the total average rainfall forecast for 3 days (136.87 mm) and the total average rainfall measuredfor 3 days (141.66 mm).

3.3.1.3. Set up the regression equation

With measured data and forecasted data, after calculating the average rainfall of the basin, using Excel software to set up the regression equation.

With the average rainfall of the basin in 3 hours and the average of the 4-day forecast period, the R^2 index is very low ($R^2 = 0.1322$). With the average rainfall in the basin for 1 day and the sum of 4 forecast days, the R^2 index is quite good (R^2=0.8524). Therefore, using the 1-day cumulative forecast rain to interpolate to the ground gauge station, the correlation equation (3.6) can be used: $\mathbf{Y = 1.1106*X}$ (3.6)

In which: X: The forecasted rainfall from the ECMWF model has not been interpolated; Y: Rainfall forecast from the interpolated ECMWF model.

3.3.1.4. Recommendations to use forecast rain data

Data extracted from the Dau Tieng reservoir monitoring system can be used and combined with forecast rain data to simulate flood flow to the lake.

3.3.2. Set up a simulation tool for flood flow to the Dau Tieng lake

3.3.2.1. Determine the weights of rain gauge stations

The weights of rain gauge stations in the basin are shown in Table 3.27.

Table 3.27: Theissen weights of rain gauge stations

Name of station	Tan Thanh	Minh Tam	Thanh Luong	Ka Tum	Don Ban	Minh Hoa	Dau Tieng
F(km^2)	225.21	297.81	222.14	209.15	78.66	209.35	86.68
Weight	0.089	0.117	0.087	0.082	0.031	0.082	0.034
Name of station	Tan Hoa 1	Loc Ninh	Loc Thien	Loc Thanh	Tan Hoa 2	Tan Ha	
F(km^2)	228.22	167.01	227.01	225.02	152.20	215.64	
Weight	0.090	0.066	0.089	0.088	0.060	0.085	

3.3.2.1. Input document

Basic inputs include rainfall, evaporation, and flowrate. The initial model parameters are determined during calibration and validation.

3.3.2.2. Calibration and validation of the model

Calibration and validation results of the model give quite good value. Calibrating the for the 2017 gives R^2 = 0.798 andtesting the 2018 gives R^2 = 0.703 for flood season model.

3.3.3. Proposal to use the results of flow forecasting to the lake in the flood season

Measured data combined with forecasted data to predict the flow to the lake, as the basis for operating decisions according to articles 39 and 40 of Procedure 1895.

3.3.4. Applying flood simulation study results to the Dau Tieng reservoir

3.3.4.1. Document for the study

a. Measured evaporation and rainfall data: Rainfall and evaporation data were measured in the study area in 2017 and 2018.

b. Rain forecast document: Extract data from 22th November 2018 to get forecasted rain data from 23th November to 27th November 2018. Extract data from 23th November 2018 to get forecasted rain data from 24th November to 27th November 2018. Extract data from 24th November 2018 to get forecasted rain data from 25th November to 27th November 2018. Extract data from 25th November 2018 to get forecast rain data from 26th November to 27th November 2018.

3.3.4.2. Analyze calculated results

The analysis results have shown that the amount of water to the lake from the model is more accurate the closer it is to the time of the flood occurrence (15.13% deviation from the data on November 22th, 2018, 2.43% deviation from the data on November23th, 2018).

3.3.4.3. Determine the operating plan

Table 3.35: Calculation results of lake water level at the end of the forecast period

Date	Lake capacity at the beginning of the forecast period ($10^6 m^3$)	Lake capacity at the forecast period ($10^6 m^3$)	Lake capacity at the ending of the forecast period ($10^6 m^3$)	Lake water level at theending of the forecast period (m)
22/11/2018	1,312.90	110.263	1,423.163	23.69
23/11/2018	1,312.90	129.615	1,442.515	23.78
24/11/2018	1,314.96	158.903	1,473.863	23.93
25/11/2018	1,366.46	93.039	1,459.499	23.86

Since the lake water level at the end of the forecast period is higher than the water level before the flood, it is necessary to discharge to ensure the regulation of Operation Procedure. However, based on Article 17 of Process 471 on water storage at the end of the flood season, ***the lake owner decided not to release flood to regulate the flood before and during the occurrence of Storm No. 9.***

3.4. STUDY ON FLOOD REGULATION OF THE DAU TIENG RESERVOIR

3.4.1. Document for the study

Document of flow to the Dau Tieng reservoir, document predicting tidal level in the downstream area, document the relationship between water level and reservoir capacity.

3.4.2. Diagrams of the program to calculate and regulate floods in the Dau Tieng reservoir

3.4.2.1. LOGIC diagram

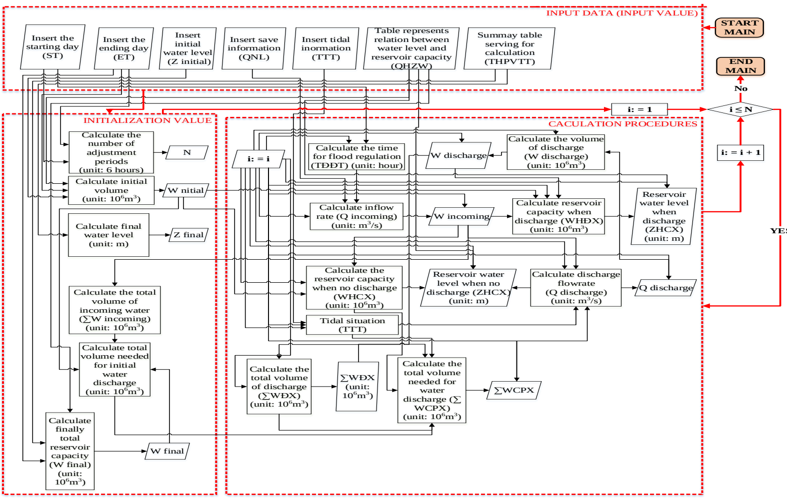

Figure 3.40: LOGIC diagram of flood regulation program

3.4.2.2. Schematic diagram of flood regulation algorithm

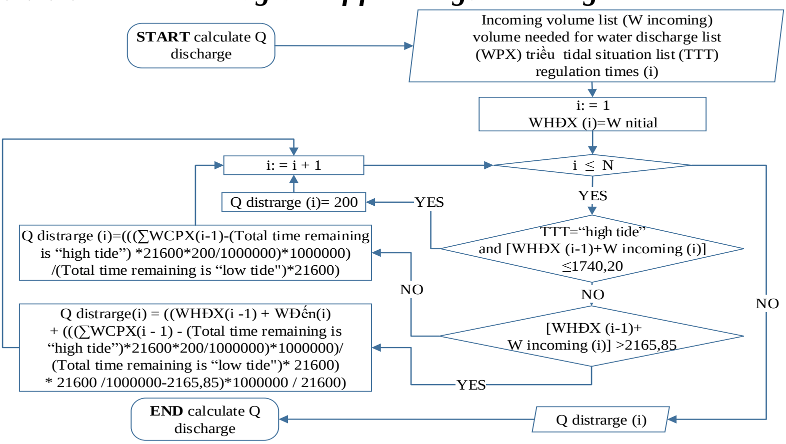

Figure 3.41: Algorithm diagram for flood regulation

3.4.3. Program to calculate and regulate floods in the Dau Tieng reservoir

Build a program using the C# programming language.

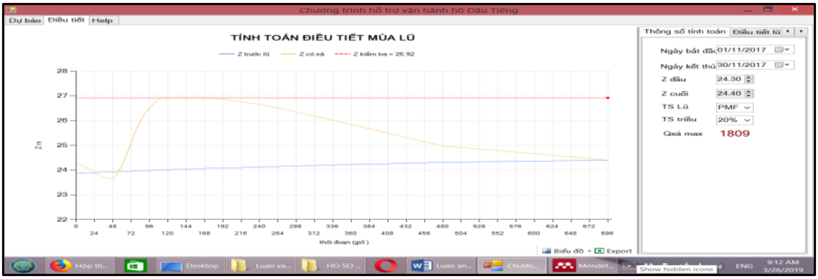

Figure 3.42: Input data for flood regulation calculation

3.4.4. Applying study to calculate flood regulation of the Dau Tieng reservoir

3.4.4.1. Setting up the flood regulation problem

Assuming that at 6am on November 1st, 2017, the lake water level is at 24.30m, the flood flow forecast to the lake in the next 10 days is approximately the frequency of PMF floods. The forecasted tidal water level at Phu An pumping station is 1.68 m (P_{tide}=20%).

3.4.4.2. Requirements when calculating flood regulation

Use maximize flood prevention capacity to regulate floods. During high tide ($H_{PhuAn} \geq 1.3$ m) and when lake water level $\leq$ 25.10 m, discharge $\leq$ 200 m^3/s. When the lake water level is >25.10 m, discharged >200 m^3/s, the lake water level must always be $\leq$26.92 m, at the end of the flood regulation procedure, the lake water level must be brought back to a reasonable integrated water level (Z= +24.40m) to ensure the task of storing water in the lake.

3.4.4.3. Calculation results for flood regulation

To return the lake water level to a level of 24.40 m on November 30th, 2017, then: $Q_{\text{max discharge on high tide}}$=2,102.87 m^3/s; $Q_{\text{min discharge on high tide}}$=200 m^3/s; $Q_{\text{max discharge on low tide}}$=1,117.51 m^3/s; $Q_{\text{min discharge on low tide}}$=506.44 m^3/s.

CONCLUSIONS AND RECOMMENDATIONS

The results of the thesis:

(1) The study has applied the ANN model to forecast the flow to the Dau Tieng reservoir in the dry season, the model test results are quite good with $R^2 \geq 70\%$, suitable for daily, an average of 10 following days, and an average of 30 following daysinflow forecast.

(2) The study has proposed a basis for forecasting the time of occurrence of the maximum salinity at Hoa Phu pumping station (*Between the tidal peak at Sai Gon Port and the salinity peak at Hoa Phu is 5 hours, between the tidal peak at Vung Tau and salinity peak at Hoa Phu is 8 hours*); reasonable time to discharge at the Dau Tieng reservoir (*Discharge 48 hours before the expected time when salinity starts to peak at Hoa Phu pumping station will bring the best salinity reduction effect*); Time and flow required for effective water discharge for salinity control for a high tide (*It is necessary to discharge continuously for 32 hours with a discharge flowrate of 120 m^3/s, which can bring salinity peaks to be lowered to the allowable threshold*).

(3) The study proposed a method of extracting forecast rain data from the website https://freemeteo.vn, setting up a program to extract rain data from global weather forecasting models, analyzing and selectinga reasonable model for the Dau Tieng reservoir (ECMWF); establish a correlation equation to convert forecast rain data suitable to the Dau Tieng reservoir basin ($Y = 1.1106*X$); established, calibrated and tested the NAM model to ensure reliability and used it as a flow forecasting tool to the lake (*calibrating the model with Nash coefficient = 0.798 and testing the model with Nash coefficient = 0.703*); The study used measured and forecasted rainfall data to simulate the flood flowto the Dau Tieng reservoir from the Storm No. 9 in 2018, the results can be used to forecast the change of lake water level to give

decision whether to store or discharge water.

(4) Study has built a program to calculate flood regulation ensuring the scientific logic and current legal basis (*ensure the binding conditions of the 1895 Procedure, system inputs and outputs, and tidal conditions in the downstream of Sai Gon river*).

Recommendations for outgoing study:

(1) When rainfall data is sufficientlyprovided for the Dau Tieng reservoir basin, the study applies the ANN method to forecast the flowrate to the reservoir in the rainy season, then add more rainfall data into the input layer (*INPUT Layer*) of the ANN model; and compare this result with the rain forecast results from the NAM model, and measured data.

(2) With the study of solutions of water discharge for salinity control, it is important to study and predict the salinity and time of saline intrusion at Hoa Phu pumping station during high tides to save discharge flowrate at the Dau Tieng reservoir. It is expected that applyingthe ANN modeling method to study this issue will cause great attentionfrom researchers.

(3) Continue to collect measured rainfall data, and forecast from ECMWF, GFS, and NEMS models to analyze, evaluate and strengthen the scientific basis to improve the quality of exploiting data serving for flood flow forecast to the Dau Tieng reservoir. The study also established the regression correlation equation to calibrate the forecasted rainfall data to suit the conditions of the Dau Tieng reservoir basin, however, due to the limited data used for correlation regression analysis, provided data are not enough for building correlation equations according to the levels of rainfall. Hence, the correlation equation proposed in the thesis should only be used as a reference.

PUBLISHED ARTICLES

1. Nguyen Tran Quan, Le Thi Khuyen, Nguyen Van Lanh, Le The Huy, Trieu Anh Ngoc, Le Viet Thang, Nguyen Hong Quan, 2015. *Applications of MDSS software for reservoir operation: a case study in the Dau Tieng*, Journal of Science Mr. Technology No. 53 (3A) (2015);
2. Nguyen Van Lanh, Le Van Duc, 2015. *Initially evaluating the effectiveness of the water discharge for salinity control from the Dau Tieng reservoir on the Sai Gon River and posing problems for the future researches*, Collection of results on Science and Technology 2015, Southern Institute Of Water Resources Research;
3. Nguyen Van Lanh Le Van Duc, 2016. *The current situation of water sources to the lake and proposals for the reasonable operation solutions for the water supply task of the Dau Tieng reservoir,* Agriculture and Rural Development Journal, No.6, 2016, p. 79-89;
4. Nguyen Van Lanh, Le Van Duc, 2016. *Study on a scientific basis to support reasonable flood management to ensure the absolute safety of the Dau Tieng reservoir, flood prevention and reduction for the downstream of Sai Gon River*, Collection of results on Science and Technology 2016, Southern Institute Of Water Resources Research;
5. Nguyen Van Lanh, Le Van Duc,2016. *Study on a scientific basis to support reasonable water storage management and ensure the absolute safety of the Dau Tieng Hydraulic Works*, Collection of results on Science and Technology 2016, Southern Institute Of Water Resources Research;
6. Le Van Duc, Nguyen Van Lanh,2016. *Study on a scientific basis to support reasonable management of water discharge on Sai Gon River to dilute salinity in service of water supply for Tan Hiep water plant operating continuously in the dry season*, Collection of

Works - The 19th National Conference of Hydraulic Mechanics in 2016, Hanoi Polytechnic Publishing House;

7. Nguyen Van Lanh, Le Van Duc, 2016. *Applying scientific study results to the management of water discharge for salinity control on the Sai Gon River for Tan Hiep water plant to operate continuously in the dry season*, Recruitment Workbook - The 19th National Conference of Hydraulic Mechanics in 2016, Hanoi Polytechnic Publishing House in 2016;
8. Nguyen Van Lanh, Le Van Duc, 2017. *Study on a scientific basis and develop a program to support the operation of the Dau Tieng reservoir for water supply in the dry season*, Collection of results on Science and Technology 2017, Southern Institute Of Water Resources Research;
9. Nguyen Van Lanh, Le Van Duc, 2018. *Study and develop a reasonable flood regulation program to ensure the safety of the Dau Tieng reservoir work, prevent and reduce floods for the downstream of Sai Gon River*, Scientific journal of rural development in Vietnam, No. 39-2018;
10. Dinh Cong San, Luu Ngoc Thanh, Nguyen Van Lanh, 2019. *Predicting rain in the Dau Tieng reservoir basin from global weather forecasting documents for forecasting flood flows and reservoir regulation during the flood season*, Journal of Irrigation Science and Technology-Vietnam Institute of Hydrology, No. 56, 10-2019.