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STUDY ON ALLOCATION OF WATER RESOURCES AND RATIONAL OPERATION OF RESERVOIRS SYSTEM IN VU GIA – THU BON RIVER BASIN IN DRY SEASON

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LIST OF PUBLICATIONS

1. Tô Việt Thắng, Ngô Lê Long, Nguyễn Tùng Phong (2018), *Research on contribution ratio of large upstream reservoirs for minimum flow in Vu Gia – Thu Bon river system*, Hội thảo quốc tế: Water Security and Climate Change (Nairobi, Kenya 12/2018);

2. Tô Việt Thắng (2018), *Nghiên cứu tính toán vận hành hệ thống liên hồ chứa lưu vực sông Vu Gia – Thu Bồn trong mùa cạn bằng mô hình HEC-RESSIM*, Tạp chí Khoa học kỹ thuật thủy lợi và Môi trường 09/2018;

3. Tô Việt Thắng (2018), *Method for optimal water allocation of reservoirs system – a casestudy of Vu Gia – Thu Bon River basin, Vietnam***,** Hội thảo quốc tế: IWA World Water Congress & Exhibition, (Tokyo, Nhật Bản 9/2018);

4. Tô Việt Thắng, Ngô Lê Long, Nguyễn Tùng Phong, Lars Ribbe (2017), *Nghiên cứu tạo chuỗi số liệu dòng chảy với mô phỏng Monte Carlo phục vụ bài toán phân bổ hợp lý nguồn nước lưu vực sông Vu Gia – Thu Bồn*, Tạp chí khoa học và công nghệ Thủy lợi 02/2017;

5. Tô Việt Thắng, Ngô Lê Long, Nguyễn Tùng Phong (2017), *Nghiên cứu xây dựng mô hình tối ưu phát điện, cấp nước các hồ chứa trên lưu vực sông Vu Gia – Thu Bồn trong mùa cạn*, Tuyển tập hội nghị khoa học Thủy lợi toàn quốc 2017 *(có trình bày trước hội nghị);*

6. Tô Việt Thắng, Ngô Lê Long, Nguyễn Tùng Phong (2017), *Nghiên cứu mô phỏng chuỗi dòng chảy ngẫu nhiên đến hồ chứa đảm bảo tính đồng bộ thủy văn hệ thống sông Vu Gia – Thu Bồn*, Tuyển tập hội nghị khoa học thường niên 2017 – Đại học Thủy lợi *(có trình bày trước hội nghị);*

7. Tô Việt Thắng, Ngô Lê Long Nguyễn Tùng Phong (2016), *Nghiên cứu thiết lập bài toán phân bổ nguồn nước hợp lý hệ thống hồ chứa đáp ứng nhu cầu sử dụng nước lưu vực sông Vu Gia – Thu Bồn trong mùa cạn*, Tuyển tập hội nghị khoa học thường niên 11/2016 – Đại học Thủy lợi *(có trình bày trước hội nghị).*

INTRODUCTION

1. Rationale of the thesis

Nowaday, the allocation of water resources among households using water is not a simple problem in many river basins (Harou, Paredes, Solera, & Andreu, 2012). When water demand is low compared to the supply capacity of the system, all water users can coexist without conflict or dispute. However, as water demand increases among water users such as households, agriculture, industry, hydropower, etc., conflicts of interest will increase, especially in the dry season (Liu, Chen, & Lou, 2009), leading to difficulties in managing water resource allocation effectively.

The Vu Gia-Thu Bon river system (VGTB) is the largest inter-provincial river system in the central coast of Vietnam. The construction of a system of hydroelectric reservoirs on the river has made the management and allocation of water resources to different water users in the river basin become complicated and difficult. Conflicts between water use goals become more profound, especially in the dry season requiring a solution of "compromise" between objectives to improve the efficiency of water resource allocation for river basins.

Therefore, the PhD student has chosen the topic of "Research on allocation of water resources and proper operation of reservoir system in Vu Gia - Thu Bon river basin in dry season" as a doctoral thesis research topic.

The research content of the thesis will focus on solving the problem of combining simulation and optimization of reservoir system operation, especially in the dry season as a basis to serve the allocation of water from hydropower reservoirs. The thesis will focus on researching the scientific basis, setting up the problem, the approach from which to propose simulation-optimal model of inter-

reservoir regulation for multi-purpose uses. The study will be applied to large reservoirs on the VGTB river system.

2. Objective the thesis

- Establishing a scientific basis for rational water allocation of reservoir system to meet the needs of VGTB river basin in dry season;
- Propose a plan to coordinate the operation of the reservoir system, ensuring intergrated economic efficiency (highest).

3. Subject and scope of the research

- Subject of research: Reasonable allocation of water sources for reservoirs A Vuong, Song Bung 4, Dak Mi 4 and Song Tranh 2 on VGTB river basin.
- Scope of the research: VGTB river basin system in dry season.

4. Methodology

- The thesis uses the following methods: (i) Method of field investigation; (ii) Methods of statistical analysis; (iii) System analysis method using simulation model and optimization of use in inter-reservoirs operation; (iv) Expert method and community participation; (v) Method of hydrological and hydraulic modeling.

5. New contribution of the thesis

- Building a scientific basis for operating the reservoir system in rational allocation of VGTB river basin water resources in the dry season;
- Proposing the optimal operation rule of the four largest reservoirs in the VGTB river basin, including (A Vuong, Song Bung 4, Dak Mi 4 and Song Tranh 2 reservoirs) to ensure maximum electricity production volume from power generation and harmonization target reservoirs to meet downstream water supply requirements;

6. Structure of the thesis

The thesis consists of 130 pages, 17 tables, 54 figures and 55 references. In addition to the introduction and conclusion, the thesis consists of 3 chapters:

Chapter 1: Overview of related research and methods for reservoir operation and allocation of river basin water sources

Chapter 2: Research on scientific basis to build a model of water allocation and rational operation of VGTB river basin reservoir system in dry season.

Chapter 3: Results of calculation and operation of reservoir system in VGTB river basin to improve the efficiency of water resources allocation.

CHAPTER 1: OVERVIEW OF RELATED RESEARCH AND METHODS OF RESERVOIR OPERATION FOR WATER RESOURCES IN RIVER BASIN

1.1. Overview of research on distribution of river basin water resources in the world and in Vietnam

The methods of operation, management and allocation of reservoir in the river basin according to the system operation model can be mentioned as the method of using simulation models, optimization methods and tissue combination methods simulation and optimization (Louck and Eelco van Beek, 2005), (Liu et al., 2009), (Husain, 2012), (Fayaed, El-Shafie, & Jaafar, 2013) and (Ahmad, El-Shafie, Razali, & Mohamad, 2014)...

1.1.1. Literature review of reservoir water allocation using simulation method

In the field of integrated water resources management, the first simulation method was used by the US Army Engineers Association (USACE) to plan and manage Missouri River water resources in 1962 (Rani & Moreira, 2010).

Subsequently, the Harvard Water Program applies a technique to simulate the economic designs that apply to water resources (Rani & Moreira, 2010), (Mckinney, Cai, Rosegrant, Ringler, & Scott, 1999).

Gradually, complete simulation models were developed and introduced as HEC family models (HEC3, HEC5, HEC RESIM) - developed at the Hydrologic Engineering Center (HEC) of US military, serving for reservoir simulation (Rani & Moreira, 2010), (Fayaed et al., 2013).

Some other basin simulation models are MITSIM, WUS, MIKE-BASIN WEAP. These are models that can be capable of simulating complex river basin systems.

However, although widely used in field of integrated water resources management in general and in simulation of water allocation from reservoir systems in river basins in particular, the simulation method still has a limited point when only provide the best operation plan in simulation scenarios. Therefore, in parallel with the simulation method, the optimisation method has been developed and applied in many studies.

1.1.2. Literature review of reservoir water allocation using optimization methods

Optimization is a method of finding the best option in possible alternatives. The most important component in optimization is the objective functions, through which to determine the optimal solutions - the target solution satisfies all the assumptions and constraints.

John W. Labadie (2004) summarized the optimal techniques used in the problem of water allocation from reservoirs and multi-purpose reservoir systems on the same river basin, including a group of implicit stochatic optimization methods and explicit stochatic methods.

In the past two decades, heuristic algorithms (self-experimental algorithms) have been developed to solve the optimal problem of water allocation, especially the optimal reservoir operation. The important benefit of this approach compared to traditional methods is: it can approach the global optimization for a practical problem rather than global optimization for the simplified problem (Maier, 2014).

Some newly developed algorithms include genetic algorithms (GA), fuzzy set theory algorithms (FUZZY SET THEORY), Neural network algorithm (ANN).

Young (1967) proposed for the first time to use linear regression method to outline general operating rules from defined optimization.

After that, many authors in the world such as Yakowiz (1982), Teh (1985), Simonovic (1992), Wurbs (1993), Oliveira and Loucks (1997), Chen (2003), Kumphon (2013), Robin (2012), Mohsen Ahmadi et al. (2015) ... applied the optimal technique for simulating reservoir system operation to build adaptive operating procedures for reservoirs. However:

- Although optimization and simulation are two different modeling approaches on characteristics, the clear distinction between these two directions is difficult because most models contain components of two above directions.
- It is necessary to have a simulation model in order to check the optimal procedure in the water reservoirs allocation process.
- Therefore, the simulation-optimization combination method has been formed to solve the problem of operating and distributing water sources of reservoir systems.

1.1.3. Literarute review of reservoir water allocation using simulation-optimization method

Carson and Maria (1997) presented a simple diagram of the optimal simulation model in reservoir water allocation (Figure 1.1). Under

this model, the simulation model will generate data and this data will be used for optimization strategies to find the best solution for water allocation. This optimal solution on the contrary will provide better input to the simulation model.

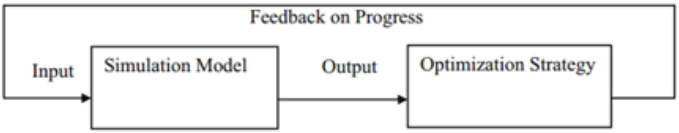


Figure 1.1. Simulation-optimal model diagram

This method has been used by some scientists in the world and Vietnam such as Fereidoon & Koch (2003), Alzali et al. (2010), Hoang Thanh Tung, Vu Minh Cat and Robeto Ranzi (2010), Hoang Thanh Tung, Ha Van Block Nguyen Thanh Hai (2013), Le Xuan Cau and colleagues (2014) ... developed, applied for operation of reservoir system and allocation of river basin water sources.

1.2. Literature review of reservoirs in Vu Gia - Thu Bon river basin

In Vietnam, since about 2000, there have been a number of studies on reservoir operation in the VGTB river basin. A number of studies on water resource allocation in the river basin VGTB use simulation and optimization techniques, which can be mentioned as follows:

Hoang Minh Hieu (2013) used genetic algorithms to calculate long-term optimal operation of A Vuong hydropower plant on VGTB river system.

Nguyen The Hung and Le Hung (2011) [3] did research and propose mathematical models to solve the problem of optimal regulation of multi-purpose reservoir operation in VGTB river basin. The program has been applied for Dinh Binh and A Vuong reservoirs.

To Thuy Nga and Nguyen The Hung (2013) [7] studied the approach to the operation of the VGTB river system of real-time flood control reservoirs, combining ideas between HEC-HMS and HEC-RESSIM to overcome problems and took advantages of these two models.

1.3. Summary of the Rule of inter-reservoir operation (Rule 1537) on the VGTB river basin

On September 7, 2015, the Prime Minister (TTCP) signed Decision No. 1537 / QD-TTg on the issuance of the QLDHH on the river basin of VGTB (Rule 1537). The Rule regulates inter-reservoir operation of A Vuong, Dak Mi 4, Song Bung 4, and Song Tranh 2 reservoirs during the flood season (from September 1 to December 15) and dry season (from December 16 to August 31).

1.4. Limitations and gaps in the studies of inter-reservoir operation and allocation of water resources at VGTB river basin

The research on distribution of reservoir water in the VGTB river basin has received much attention from managers and scientists. However, most of the studies are mainly focused on indivisual reservoir. Research on optimal water resource allocation and especially research using optimal simulation-matching techniques to solve inter-reservoirs water allocation, multi-purpose use or calculation for dry season with very short steps (less than 1 month) in the VGTB river basin are very few.

Currently, the Prime Minister has issued Inter-reservoirs Operation Procedures for river basins of VGTB (Rule 1537), however, the reality shows that more intensive research is needed to solve some problems. There still exists in the management and operation of the system, that is:

- Research to extend the inflow data to reservoirs
- Research on reasonable discharge flow of each reservoir to ensure objectives

- Optimize electricity production from hydroelectric reservoirs and ensuring downstream water supply requirements

These are 03 issues that the PhD student chooses to consider and solve in this thesis.

1.5. Conclusion Chapter 1: Approach and orientation of the research steps of the thesis

The thesis has synthesized and analyzed the studies on the distribution of water reservoirs in the world, Vietnam and in the Vu Gia Thu Bon river basin. The review study is organized according to methods of reservoir water allocation system, including simulation method, optimization method and combination method of simulation and optimization. The review study has shown the basic contents, advantages as well as limitations of the studies and then indicate approach and research steps such as in Figure 1.2.

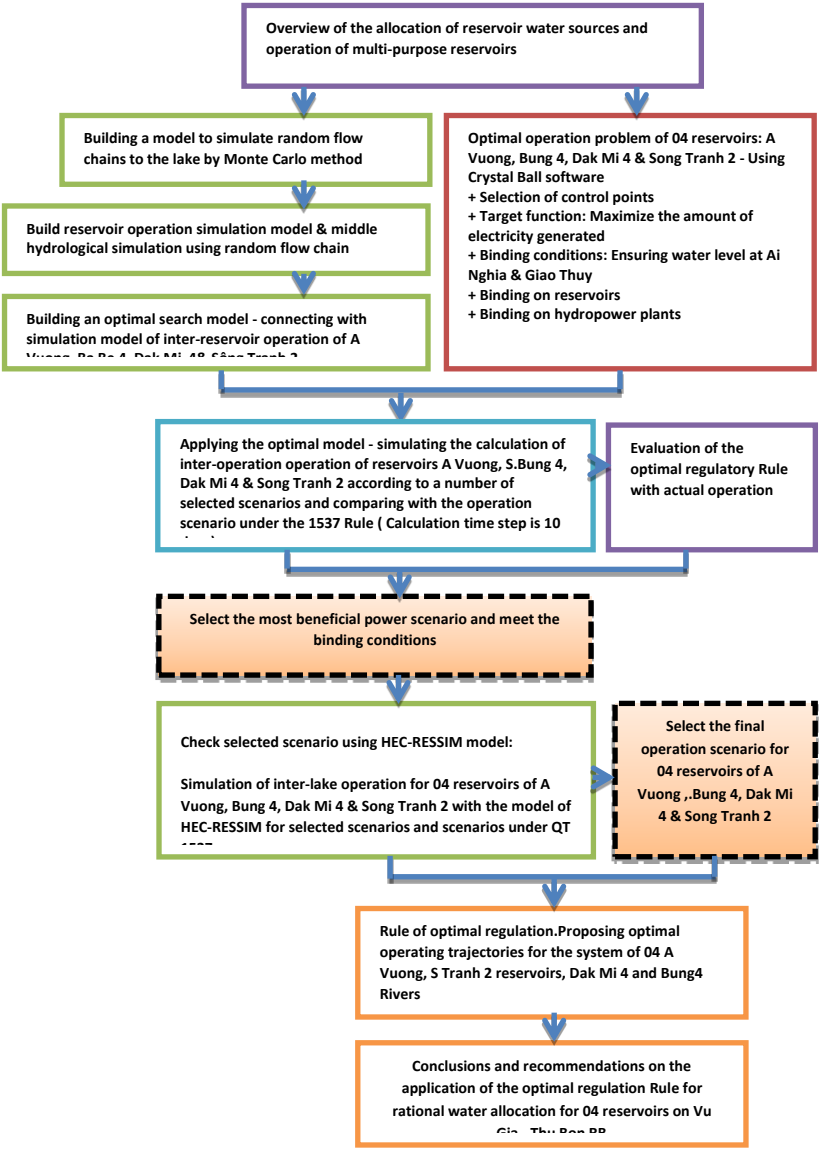


Figure 1.2. Diagram for the research steps of the thesis

CHAPTER 2: RESEARCH ON SCIENTIFIC BASIS FOR MODELS OF SUPPLYING WATER RESOURCES AND OPERATING THE SYSTEM OF RESERVOIRS FOR VU GIA THU BON RIVER BASIN - IN THE DRY SEASON

2.1. Introduction of reservoir system in Vu Gia - Thu Bon river basin and select reservoirs for research

In the VGTB river basin currently there has asystem of reservoirs that were already built and put into operation. The thesis selected 04 reservoirs of A Vuong, Song Bung4, Dak Mi 4 and Song Tranh 2 for studying of coordinating operation and allocation of water sources for electricity generation and water supply in the basin. These are also four reservoirs that greatly affect the allocation of water resources for different purposes in the VGTB basin and the reservoirs are mentoned in the inter-reservoir opeartion rule of VGTB river system.

In this study, to conduct the calculation and allocation of water resources for 04 A Vuong, Song Bung 4, Dak Mi 4 and Song Tranh 2 reservoirs, the thesis has simulate inflow to 04 above reservoirs following three steps:

1) Analyzing to find out the appropriate form of probability distribution for the monthly inflow to each reservoirs (for all 4 reservoirs);
2) Establishing hydrological correlation between river branches to ensure uniformity of flow regime in the same river system;
3) Generating random flow data to the above reservoirs using MonteCarlo method - to model random flow of 10-day average period based on real data series measured up to 4 reservoirs.

2.2. Establishing a random simulation model of inflow to the reservoirs taken into account the hydrological correlation in the system

2.2.1. Determine the type of probability distribution for the inflow data to 04 reservoirs

By analyzing historical data to establish and select probability distribution functions for inflow data, the thesis has determined the most appropriate probability distribution for each 10-day period for the inflow data to 04 reservoirs of A Vuong, Song Bung 4, Dak Mi 4 and Song Tranh 2.

2.2.2. Set up hydrological correlation among river branches

In order to ensure uniformity of flow regime in a river system, the study analyzed hydrological correlations by month (January to December) and analyzed the relationship between adjacent months for actual inflow of all 4 reservoirs. These actual hydrological correlation coefficients will be used in the model as the limits of the range of values of each random simulation series.

Table 2.1. Results of calculation of flow correlation coefficients among 04 reservoirs in VGTB river basin

Month / Reservoir	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
AV-ST2	0.118	0.126	0.031	0.027	0.080	0.215	0.153	0.248	0.041	0.777	0.885	0.798
AV-SB4	0.740	0.449	0.498	0.725	0.621	0.565	0.274	0.598	0.668	0.863	0.966	0.872
AV-DM4	0.969	0.923	0.892	0.905	0.803	0.889	0.635	0.702	0.686	0.784	0.574	0.718
SB4-DM4	0.752	0.527	0.584	0.746	0.786	0.673	0.561	0.776	0.742	0.758	0.681	0.594
ST2-DM4	0.162	0.105	0.058	0.039	0.174	0.149	0.133	0.250	0.175	0.797	0.603	0.763
ST2-SB4	0.243	0.159	0.161	0.093	0.013	0.023	0.019	0.123	0.027	0.730	0.889	0.750

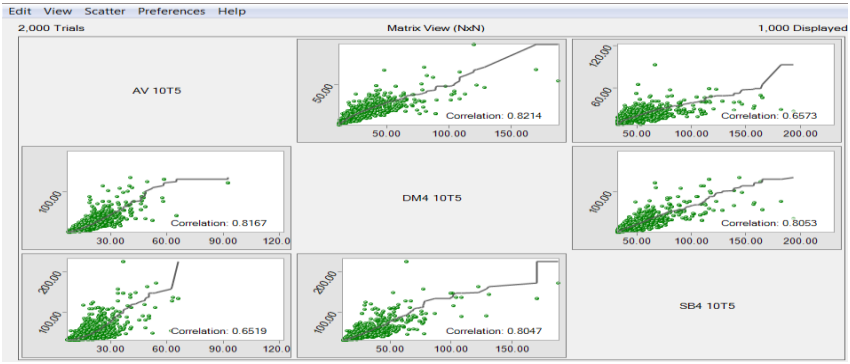


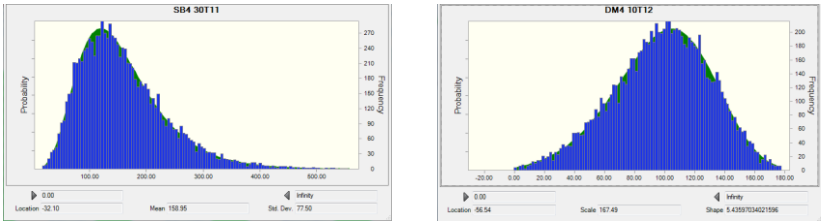
Figure 2.1. Illustrate the correlation of the inflow among reservoirs

Checking the results of the caculation of random inflow to 04 reservoirs in 10-day periods through the correlation matrix (Figure 2.1) shows that the coefficient of the inflow (among reservoirs) is close coefficients of actual data. This help eliminate the difference of flow regime between branches in the same river system.

2.2.3. Creating random inflow data to 04 reservoirs

After calculating the probability distribution function of the incoming flow chain and the hydrological correlation between the river branches, the study applied the Monte Carlo method to create the average random flow to the reservoirs. Conduct a test with 10,000 random random flow values for each period according to the probability distribution form defined above.

The results show that, with a large number of random inflow data created, random data sets have covered the possible combinations of random variables, statistical parameters of random number sequences. The output does not change compared to the series of monitoring data.



Legend: The blue column chart is the randomly generated data and the green part is the actual flow distribution

Figure 2.2. The comparison of the actual flow probability distribution pattern and the random flow is generated by Monte Carlo simulation

Thus, the generated random number sequence can be used in the optimization problem of reservoir operation, distribution of reservoir water appropriately in the river basin VGTB.

2.3. Develop a model of operating multi-purposes reservoir system

Steps to develop the optimization - simulation model in the thesis include:

1) Establish optimal issues in reservoir system operation;
2) Develop simulation model in reservoirs operation;
3) Develop an optimization model of search and connect with the simulation model of operating A Vuong, Song Bung 4, DakMi 4 and Song Tranh 2 reservoirs;

2.3.1. Study establishment

Downstream control points

Two hydrological stations of Ai Nghia and Giao Thuy were selected as two control points for water level / flow in the study.

The thesis uses the results of calculation of downstream water demand of the Ministry of Natural Resources and Environment in the Rule of inter-reservoir operation in the VGTB river basin No. 1537 / QD-TTg dated 07/9/2015. Accordingly, ensuring the demand for

downstream water uses is shown through the assurance of water level in Ai Nghia (Ai Nghia ≥ 2.67m) and in Giao Thuy (Giao Thuy ≥ 1.02m).

Objective and objective function

The objective of the study:

To reasonable allocate water sources of VGTB river basins for various water-uses in order to maximize the electricity generation from hydropower plants, as well as ensuring the demand for water supply for economic sectors, livelihood and services in the dry season in VGTB river basin.

Objective function:

The objective function of operating 04 reservoirs is displayed as:

$$F = \mathrm{Max}\left(\frac{1}{n}\sum_{i=1}^{4}\sum_{j=1}^{n}\sum_{t=1}^{25} 9{,}81 * \beta_{i,j} * Q_{i,j,t} * H_{i,j,t} * \Delta t\right)$$

Where:

F : Objective function to maximize electricity generated from A Vuong and Song Bung 4, Dak Mi 4 and Song Tranh 2 hydropower plants

Qi,j,t : Average discharge of plant i, year j, at period t

Hi,j,t: Average water column of plant i, in year j, at period t

βi,j: Total efficiency of turbine and generator of plant i in year j

Δt: Time step = 10 days; dry season includes 25 periods (from 16/12 previous years to 31/8 continuous year)

n: number of years to simulated (10,000 years)

i: number of hydropower plants, only 04 plants are focused as A Vuong, Song Bung 4, Song Tranh 2 and Dak Mi 4.

Ei,t: electrical power of plant i at the period of "t" (kwh)

Constraints on reservoirs and hydropower plants as: Constraints on water balance at reservoir node; Constraints on water balance at the flow node; Constraints on the smallest and largest storage volumes of reservoirs; Constraints on actual discharge for generation;

Constraints on power generation capacity; Constraints on the relationship of bed reservoir topography; Constraints on discharge ~ downstream water levels;

Constraints on demand of water supply at downstream: Ensuring water level at control points: $H_{Ai\ Nghia} \geq 2.67m$; $H_{Giao\ Thuy} \geq 1.02m$

2.3.2. Develop optimization searching model and connect to reservoir operation simulation model

The study uses OptQuest optimal module under the Crystal Ball model to develop the optimisation model then connected to the random inflow simulation model and reservoir operation simulation model to form the optimal operation model of A Vuong, Song Tranh 2, Song Bung 4, Dakmil 4 reservoirs.

The objective function in the study is to optimize the power generation in dry season of 04 hydropower plants of A Vuong, Song Bung 4 and DakMil 4 and Song Tranh 2. The thesis has searched for the optimal options (based on thousands scenarios to simulate electricity generation from hydropower plants, comply with defined constraints) to determine the most optional plan of power generation in dry season (December 16 to August 31 of the following year) in the system.

The opimisation search is applied as follows:

- The inflow to each reservoir is randomly generated by Monte Carlo method and complies with the predefined hydrological correlation; Flow through turbines is used as a decision variable; The objective function is to maximize the total output of electricity, calculated according to the equation in Section 2.3.1.
- Optquest module will conduct searching in multiple simulations to determine the maximum value of the objective function.

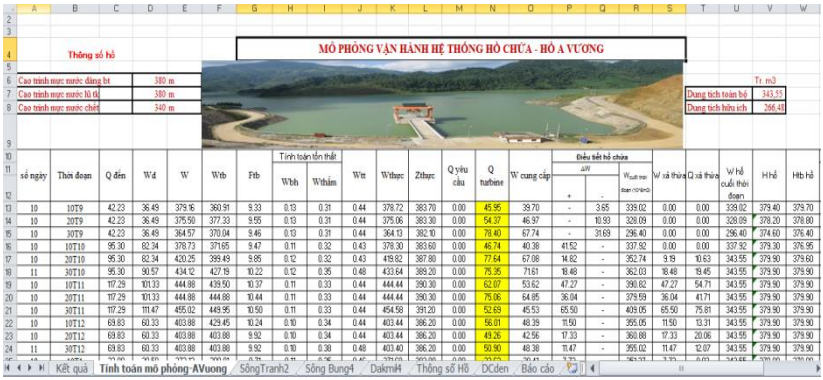


Figure 2.3. Simulation - optimization operation reservoir model of VGTB river basin

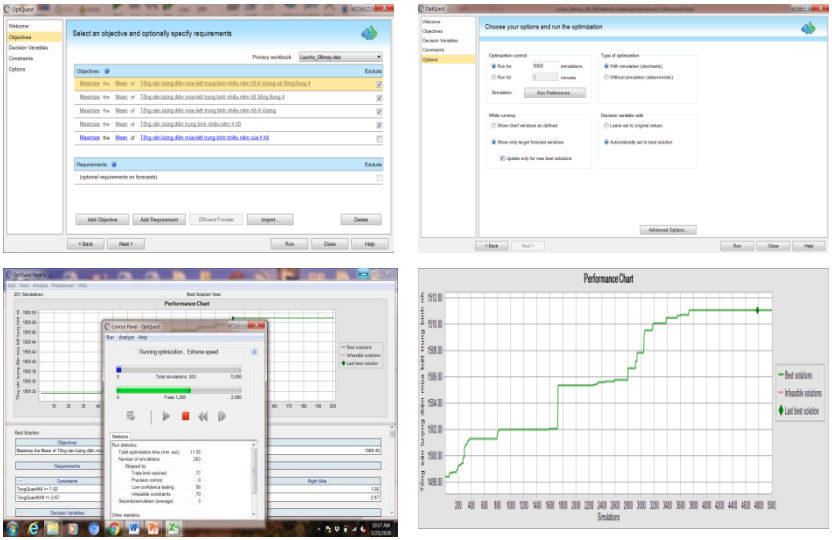


Figure 2.4. optimization searching in the study

2.4. Develop a simulation model of inter-reservoirs operation with HEC-RESSIM

Although the simulation-optimization reservoir operation model of Vu Gia - Thu Bon has been developted with many advantages in combining optimization and simulation

techniques but there are still certain limitations includig: (1) it cannot confirm that the result is optimal or not because the model runs thousands of random options and selects the best option; (2) The simulation time step is 10 days, which makes it difficult to follow the Rule of inter-reservoir operation or actual operation.

Therefore, the PhD student select the model HEC-RESSIM to re-simulate the river reservoir system in the short time (1 hour). The purpose of the calculation is to re-examine the selected option, the objective function of the problem as well as the controlled water levels points in the downstream.

The HEC-RESSIM model has been set up with the following parameters:

Up Border:

- Vu Gia River: release discharge from reservoirs A Vuong, Song Bung 4, Dak Mi 4 .

- Thu Bon river: release discharge to reservoirs Song Tranh 2 and Dak Mi 4 reservoirs.

Border for joint branches: the flow of middle areas of Bung, A Vuong, Cai, and Thu Bon rivers is taken according to the ratio of areas.

Calibration and verification of models: The data used to calibrate and verify the model are measured data of Nong Son, Thanh My (flow) hydrological stations in 2015 and 2016.

Table 2.2. Result of Calibration and verification of models

Location	Calibration	verification
Thanh My	0,9305	0,9762
Nong Son	0,7514	0,8246

2.5. Conclusion of chapter 2

The thesis has conducted research steps to establish a scientific basis for the coordination of water resource allocation for the system of 04 reservoirs, including:

(1) Develop a random simulation model of the flow to reservoir which is considered the hydrological correlation in the system.
(2) Establish optimal study for operating reservoirs of A Vuong, Song Bung 4, Dak Mi 4 and Song Tranh 2.
(3) Develop simulation model for operating 04 reservoirs.
(4) Optimal calculation and development of the optimization searching model in connection with the reservoir operation simulation model to determine the optimal operation process for power generation of A Vuong and Song Bung 4 reservoir systems. Dak Mi 4 and Song Tranh 2.
(5) Develop the HEC-RESSIM model to simulate inter-reservoir operation systems of A Vuong, Song Bung 4, Dak Mi 4 and Song Tranh 2. The model has been calibrated and verified.

CHAPTER 3: CALCULATION RESULTS OF SYSTEM OPERATION IN VU GIA THU BON RIVER BASIN – TO IMPROVE EFFICIENCY OF WATER ALLOCATION

3.1. Identify scenarios to operate 04 reservoirs

The study on operation of reservoirs system A Vuong, Song Bung 4, Dak Mi 4, Song Tranh 2 is using the simulation - optimal operation model which will be having 10 scenarios, divided into 03 group as follows:

Group 01: Calculated scenario under Rule No. 1537

1. Base scenario: The release discharge rates of A Vuong, Song Bung 4 and Dak Mi 4 reservoirs comply with the provisions in Rule No. 1537.

Group 02: defined according to reservoir characteristics

2. Scenario 1: Release discharge rates of A Vuong, Song Bung 4 and Dak Mi 4 reservoirs are equal to the ratioes of catchment area in the system
3. Scenario 2: Release discharge rate of A Vuong reservoir is equal to release discharge rate of Song Bung 4 reservoir (50% -50%).
4. Scenario 3: The release discharge rates of reservoirs A Vuong, Song Bung 4 and Dak Mi 4 are equal to the ratio of yearly inflows to reservoirs.

5. Scenario 4: The discharge rates of reservoirs A Vuong, Song Bung 4 and Dak Mi 4 are equal to the ratio of inflows to reservoirs in dry season.
6. Scenario 5: The release discharge rates of reservoirs A Vuong, Song Bung 4 and Dak Mi 4 are equal to the proportion of the volume of corresponding reservoirs.

Group 03: Group of scenario defined according to reservoir characteristics with discharge rate of Dak Mi 4 reservoir defined according to Rule No. 1537

7. Scenario 6: The release discharge rate of reservoirs A Vuong and Song Bung 4 are equal to the ratioes of catchment area in the system, one of reservoir Dak Mi 4 is taken according to the Rule No. 1537
8. Scenario 7: The release discharge rate of reservoir A Vuong and Song Bung 4 are equal to the ratio of yearly inflows to reservoirs, the release discharge rate of reservoir Dak Mi 4 is taken according to the Rule No. 1537.
9. Scenario 8: The release discharge rate of reservoir A Vuong and Song Bung 4 are equal to the ratio of inflows to reservoirs in dry season, the release discharge rate of reservoir Dak Mi 4 is taken according to the Rule No. 1537.
10. Scenario 9: The release discharge rate of A Vuong and Song Bung 4 reservoirs are equal to the proportion of the volume of corresponding reservoirs, the release discharge rate of reservoir Dak Mi 4 is taken according to the Rule No. 1537.

Each scenario is calculated with:

+ 25 random variables corresponding to each reservoir flow in each period in the dry season. There are 100 random variables for four reservoirs in the system.
+ 25 decision variables corresponding to discharge flow through each plant in each period in the dry season. There are 100 decision variables.
+ The main predictor variable is the total annual electrical output of 04 reservoirs in dry season
+ The constraint of water level at Giao Thuy is not less than 1.02m and at Ai Nghia is not less than 2.67m and constraints on reservoirs and hydropower.

+ Each scenario is carried out through 5000 simulations with each simulation will conduct 2000 trials.

3.2. Summary of calculation results of all scenarios

Summary of calculation results using simulation - optimization model to operate 04 reservoirs with 10 scenarios can sum up with some conclusions:

1) All scenarios have total power output in dry season is greater than the actual one in 2015 and 2016.
2) The highest power output is in scenario 5, reaching 1570.0 million kWh, higher 10.2 million kWh (0.6%) than base scenario; higher 88 million kwh (5.9%) and 170.1 million kwh (12.1%) compared to the actual electricity output of the reservoirs in 2015 and 2016 respectively,.

   Compare among 04 reservoirs:

3) Power output in the dry season of A Vuong Reservoir is the largest, followed by Song Bung 4, Song Tranh 2 and Dak Mi 4

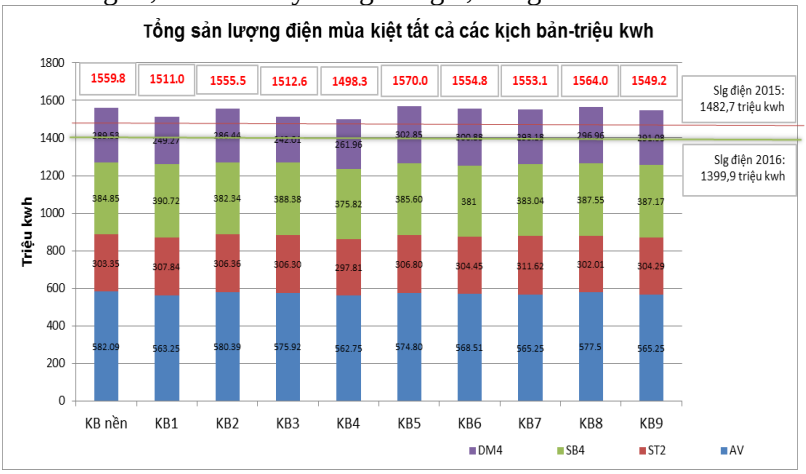


Figure 3.1. Power output in the dry season

In terms of power output, scenario 5 is selected as the optimal scenario.

Group of Scenario 2 Group of scenario 3

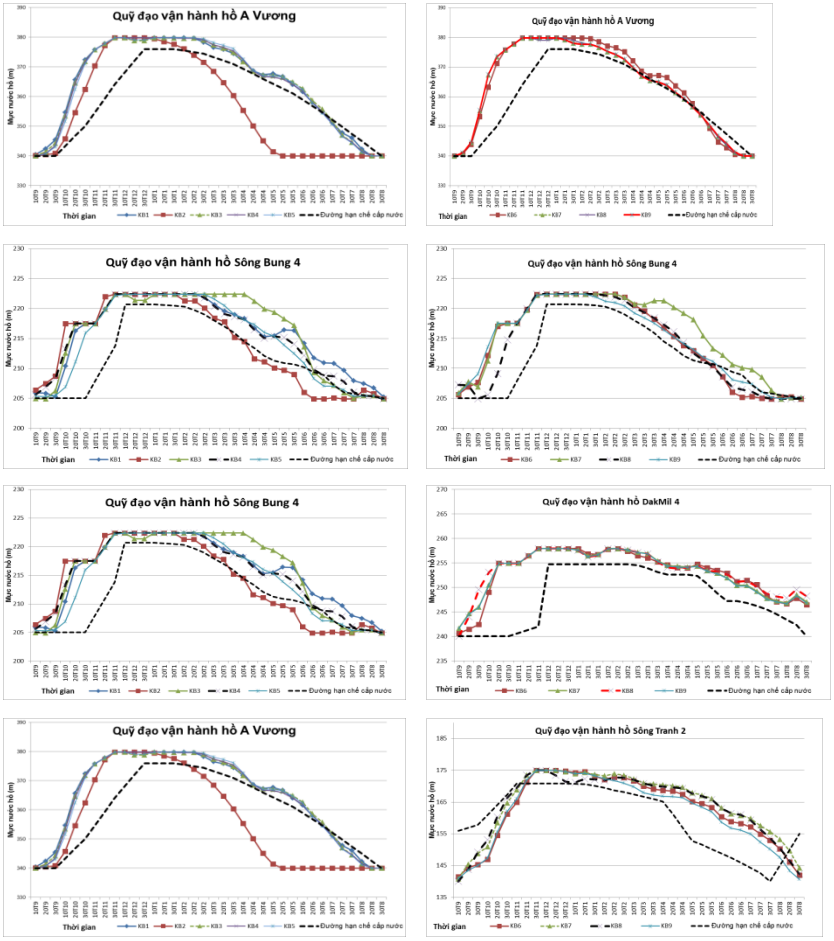


Figure 3.2. Optimal operation curve by all scenarios

Sum up with the operation curve of reservoirs of A Vuong, Song Bung 4, Song Tranh 2 and Dak Mi 4 for 10 scenarios, some conclusions can be showed as follows:

1) Most operating curves of 04 reservoirs violate the regulated restriction water supply curves of each reservoir according to the Rule No. 1537.

2) The inter-reservoir operation curve under Scenario 5 is less violation compared to others .

*In terms of inter-*reservoir *operation curve, it is proposed to select scenario 5 (The discharge rate of A Vuong, Song Bung 4 and Dak Mi 4 reservoirs is equal to the proportion of the corresponding reservoirs' volumes) is the optimal scenario.*

Therefore, PhD student proposed to select scenario 5 for detailed calculation by HEC-RESSIM model, because this scenario is more optimal in production power and operating trajectory than the other scenarios.

3.3. Using HEC-RESSIM model to details calculate selected scenarioes

In order to evaluate the effectiveness of the optimal operation plan, the PhD student use the HEC-RESSIM model to calculate and analyze options for operating the reservoir system in dry season from December 16 prevous year to December 31 next year:

1) Option 1: Minimum release discharge from 04 reservoirs according to the Rule No. 1537;

2) Option 2: Minimum release discharge from 04 reservoirs according to the selected Scenario 5;

Each option is calculated with 2 cases: 1) inflow data is according to the actual measured data in 2015, 2016 (after all 4 reservoirs have entered electricity generation); and 2) inflow data is for the period 1981-2008 (before building 04 reservoirs on Vu Gia - Thu Bon river).

3.3.1. Simulation of operation in 2015 and 2016

Figure 3.3 illustrates the results of the operation simulation of 04 reservoirs with inflow data according to the actual measured data of 2015 and 2016.

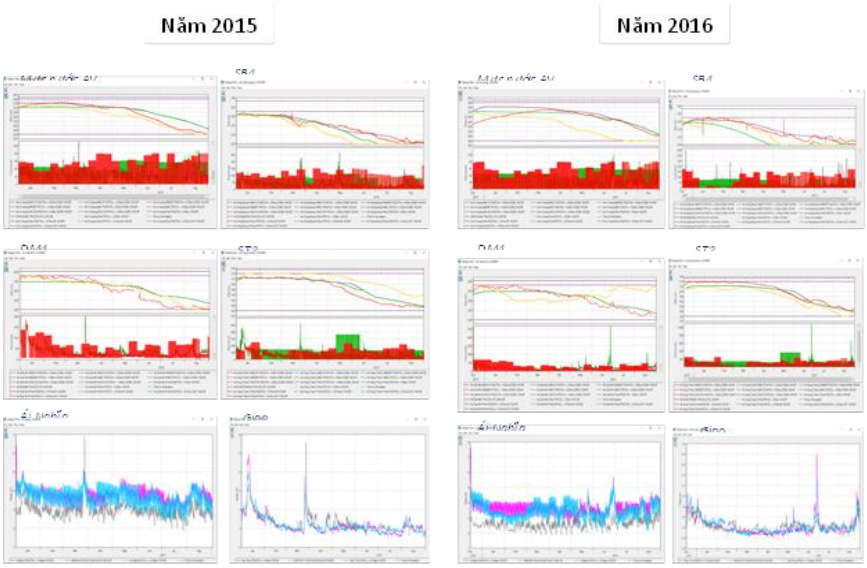


Figure 3.3. The results of operation simulation of 04 reservoirs with flow data according to the actual data of 2015 and 2016.

Table 3.1. Summary of calculation results of electricity output by each reservoir

Resevour	power generated in dry seasons 2015 (MWh)		power generated in dry seasons 2016 (MWh)	
	Option 1	**Option 2**	**Option 1**	**Option 2**
A Vương	435.915	448.083	427.508	416.455
Bung 4 River	260.518	257.371	192.646	164.063
Đăk Mi 4	158.301	212.726	162.982	210.654
Tranh 2 River	305.211	322.985	229.839	231.639
Total 04 resevours	**1.159.945**	**1.241.165**	**1.012.975**	**1.042.811**

Comment: Electricity output of alternative 1 in the dry season of reservoirs A Vuong, Song Bung 4, Dak Mi 4 and Song Tranh 2 is greater than the option 1 for both years 2015 and 2016. The corresponding difference for each year is 7.00% (2015), equivalent

to 81,220 MWh and 2.94% (2016) equivalent to 29,836 MWh in the dry season.

Considering water level at downstream, the results of water level calculation at Ai Nghia and Giao Thuy show that the water level at Ai Nghia and Giao Thuy is higher than the control water level of 2.67m and 1.02m respectively.

3.3.2. Simulation of operation in 1981-2008

This is the period before the operation of reservoirs in the system. The author has calculated the annual regulation for each year, comparing the electricity output of each year in the period 1982-2008. and follow Options 1 and 2.

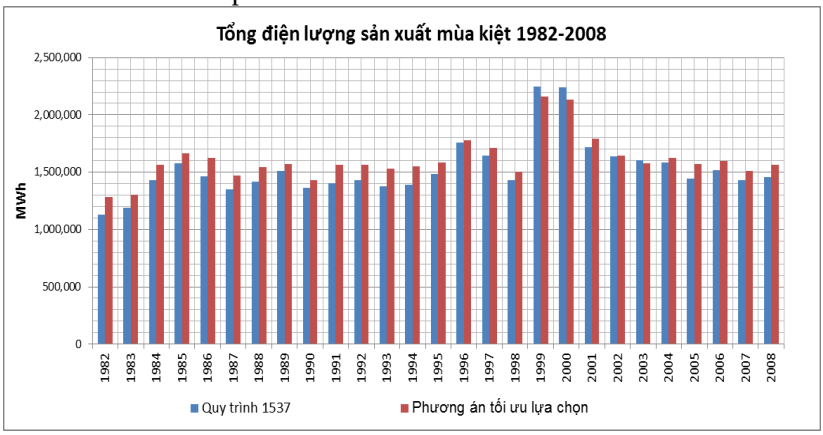


Figure 3.4. Total power generated in dry seasons 1981-2008

Comment: Electricity production in the dry season of each year in the period 1982-2008 of reservoirs A Vuong, Song Bung 4, Dak Mi 4 and Song Tranh 2 according to option 2 is greater than the power output of 04 reservoirs operated by Procees No.1537 (Option 1). The lowest difference was 1.12% (1996), equivalent to 20,067 MWh and 11.20% (1994), equivalent to 157,145 MWh in the dry season.

Therefore, it can be concluded once again that the inter-reservoirs operated under Scenario 5 (with release discharge rates of

reservoirs A Vuong, Song Bung 4 and Dak Mi 4 is equal to the proportion of the corresponding reservoirs' volumes) has advantages regarding the electricity generation, compared to the Rule No 1537 and still ensures water demand at downstream.

CONCLUSIONS AND RECOMMENDATIONS

The study has developed the random simulation model of inflow to the reservoirs considering the hydrological correlation in the system. The model includes components such as: Analyzing to find out the probability distribution for each month's flow to each reservoir; Generate a random inflow to the above reservoirs using the Monte Carlo method which taken into account the uniformity of the flow regime based on the hydrological correlation among the river branches from the actua data. This is an important baseline calculation providing input data for simulation and optimization models.

The optimization searching model with connection to reservoir operation simulation model to determine the optimal operation plan of the reservoirs system of A Vuong, Song Bung 4, Dak Mi 4 and Song Picture 2 is developed in the thesis. Based on the combining model of simulation and optimization techniques, the inter-reservoir operation process is selected, analyzed, established and calculated according to 10 scenarios. Results of the inter-reservoir operation are feasible when all 10 scenarios have a higher power productions than actual ones in 2015 and 2016. The calculation results show that the largest power output is in the scenario 5 reached 1570.0 million kwh, 10.2 million kwh (0.6%) higher than the baseline scenario calculated under Rule No.1537; which is 88 million kwh (5.9%) higher and 170.1 million kwh (12.1%) higher than the actual operating of those reservoirs in 2015

and 2016. This is also an orbital scenario of inter-reservoir under water supply curve.

The optimal inter-reservoir operation Rule is identified in the thesis (the release discharge rate of reservoirs A Vuong, Song Bung 4 and Dak Mi 4 is equal to the proportion of reservoir's volumes - Scenario 5). The the selected operation process is tested by the HEC-RESSIM model.

The scientific research is completed when integrating reservoir operation simulation model of HEC-RESSIM for the optimal Rule from simulation-optimal model. The results of operation calculation for the 27 years from 1982 to 2008 (the period before the reservoirs' operation) and the period of years 2015-2016 (after all 4 reservoirs have been operated) shows the power production of optimal Rule is greater than operated according to the inter-reservoir operation Rule of the Ministry of Natural Resources and Environment (Rule No. 1537), the difference is from 1.12 % (1996) equivalent to 20,067 MWh to 11.2% (1994) equivalent to 157,145 MWh. With the above results, the thesis identifies two new contributions, including:

- Develop a scientific basis for operating the reservoir system in water allocation of VGTB river basin in dry season;
- Initially, propose the optimal operation Rule of the four largest reservoirs in the VGTB river basin including (A Vuong, Song Bung 4, Dak Mi 4 and Song Tranh 2 reservoirs) to ensure maximum electricity production and harmonization with water demand at downstream;

Recommendation

The study of the thesis is quite detailed with many different operating scenarios applying simulation - optimizing operation of inter-reservoir system. In order to reduce time in calculation, the evaluation of the downstream water level assurance is based only on hydrological models through consideration of the relationship

between flow and water level at the control points. To be able to assess more accurately, it is possible to use a hydraulic model to consider the effect of water level fluctuations due to the operation of discharging water from upstream reservoirs to the water level at the control points.

Applied to other river basins has similar conditions, in particular in ones in central Vietnam.