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STUDY ON SCIENTIFIC BASES TO DEVELOP INTER-RESERVOIR OPERATION PROCEDURES FOR FLOOD CONTROL IN THE BA RIVER BASIN

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INTRODUCTION

1. Thesis statement

In 2010, the Vietnam Government issued Decision No. 1879/QĐ-TTg approving the list of reservoirs in the river basins to develop inter-reservoir operating procedures [28]. Accordingly, there are 61 large reservoirs on the 11 watersheds would be built and operated following the inter-reservoir operating procedures, the river basins are: Red, Ma, Ca, Huong, Vu Gia Thu Bon, Tra Khuc, Kon - Ha Thanh, Ba, Dong Nai, Sesan and Srepok. Currently, Ministry of Natural Resources and Environment (MONRE) has completed the construction of inter-reservoir operating procedures of the 11 watersheds that the author of this thesis is one of members who carried out the inter-reservoir operating procedures in Ba and Red River. In reality, the operation of inter-reservoir procedures faces with many difficulties because of the limited capacity of the hydrological and water resources forecasting, which is crucial for the proper operation of the reservoirs. Thus, since 2014 all operating procedures have flood control capacity for cutting off flood volume during flooding season. This capacity requires to maintain low water level could result in inefficient operation of reservoirs during flooding season because of not enough water end of flood season to supply in dry season. In late 2015, the shortage of flow and reservoir storage in flood season occurs on most rivers in Quang Nam, Gia Lai, Kon Tum, Phu Yen and Da Nang provinces [55], the Ministry of Natural Resources and Environment has sent an official dispatch to the provinces and other relevant offices to require ensuring water supply for downstream during the dry season in 2016 [53]. Thus, the maintenance of the flood control capacity during the flood season for all the reservoirs would lead to the ineffective water use for each reservoir or the whole iner-reservoir system. The thesis aims to develop a scientific method for inter-reservoir operation procedures which guarantee both an effective flood control and efficient water use in the Ba river basin.

2. Objectives of the study

- Develop the scientific and practical bases to build the operation rules for reservoir systems to reduce flood damages in downstream of the Ba River basin considering downstream flood protection and water use efficiency;

- Propose inter-reservoirs operation procedures for downstream flood prevention in the Ba River basin.

3. Scope of the study

Subjects and scope of the dissertation are a system of 6 reservoirs (Ka Nak, An Khe, Ayun Ha, H'nang, Ba Ha and Hinh) and the flood flow regime on the Ba River basin. The thesis focuses on developing inter-reservoir operation principles to mitigate flood damages, protect downstream area, and ensure efficiency of water use.

4. The scientific and practical significances of the study

4.1. Scientific significance: Establishing a scientific basis of the inter-reservoir operation procedures for flood control purpose in the Ba river basin which includes:

- Determining the flow regime of tributaries and regulation role of upstream reservoirs for downstream flood control supporting integrated operation rules of inter-reservoir for flood control at downstream of the Ba river basin;

- Proposing operation procedure that integrates flood cutting ability of each reservoir in the system to control downstream flooding and ensure water use efficiency;

- Determining the flood control capacity of each reservoir participating in downstream flood reduction.

4.2. Practical significances of the study are:

- Identifying the role of each reservoir as well as reservoir system in inter-reservoir operating procedures for flood control in the Ba river basin;

- Proposing water discharging rule to provide flood control capacity without causing negative impacts on downstream;

- Supporting to adjust the operation rules of inter-reservoir in the Ba river basin.

5. The contributions of the study

- Develop the operation problem of flood control for multiple reservoirs in Ba River basin based on adjustment of the flooding control role of the reservoirs in the system while ensuring the other functions of the inter-reservoir system including power generation and water supply for downstream;

- Establish scientific and practical bases for determining the flood storage capacity and coordination mechanism of reservoir system to mitigate downstream flood damages in the Ba River basin;

- Propose the adjustment of inter-reservoir operation rules in flood season in the Ba River basin.

CHAPTER 1. OVERVIEW OF RESERVOIR OPERATION

Recently, mathematical modelling and optimization techniques have been intensively empoloyed for developing real time reservoir operation [56, 58, 60, 61, 64, 71-73], and multi-purpose reservoir operation [57, 59, 60, 62, 64-70, 73]. When the multi-purpose reservoir operation procedure is developed, storage capacity of each of the individual reservoir in the inter-reservoir system is determined for each water use purpose. In the developed countries, the water use data bases are well and comprehensively constructed. Furthermore, water resources management is also efficiently implemented with the negotiation among water users as well as stakeholders. Therefore, the analysis of water use has been studied for both temporal and spatial scales ensuring highly accurate short-, medium-, and long-range forecasts for reservoir operation. Multi-purpose reservoir operation is thus feasible in these developed countries. The current situation in Vietnam is quite in contrary, where both the water use database and hydromet and hydrologic monitoring facilities are not yet adequately developed which has posed many difficulties and challenges for the development and operation of multi-purpose inter-reservoir operation.

In Vietnam, in particular, the Ba river basin, most of studies related to hydrology and water resources is developed and adopted upon the existing tools, models and methods in the world considering local conditions. Recently, studies in hydrology and water resources science and has been more concerned. The works carried out by the Institute for Water Resources Planning [14], Water Resources University [4, 9, 25, 35, 44], University of Natural Sciences [40], Institute of Geography [10], Institute of Mechanics [20, 24], Department of Water Resources Management [18, 23], National Center of Water Resources Planning and Investigation, and [41], National Centre for Hydro-Meteorological Forecasting [46], and Viet Nam Institute of Meteorology, Hydrology and Climate change [21] focus on solving problems such as: water balance, water resources allocation, water use conflicts, flood forecasting, impact of climate change on water resources, and so on in order to make plans and scenarios for the sustainable development of the river basins. In these studies, reservoir operation is considered under certain assumptions and existing regulations without comprehensive and practical concerns and efficient assessments as well. The studies related to reservoir operation in various river basins [4, 7, 12, 17, 20, 22, 25] interest in developing flood identification technology, assessing reservoirs' role in flood control, and optimizing reservoir operation. The works done for reservoirs operation in the Ba river basin such as [30, 33, 34, 47] have neither presented the combined operation rule of reservoir systems in flood mitigation purpose nor provided highly effective operation procedures for both water supply and power generation.

In reality, the development and operation of inter-reservoir system is a complicated problem involving the determination of many variables and for multi-purposes including flood control, electricity generation, irrigation, and navigation with various constraints of economy, environment and social aspects. Therefore, the inter-reservoir operation problem should be comprehensively considered taking into account the interests of all water users and stakeholders. Recently, long-term forecasting with time span from 3-5 days (or even 1-day ahead) with acceptable errors on rivers in Central part has faced huge difficulties. Thus, the study will focus to assess the roles of reservoir system in the spatial scale of flood mitigation and to propose regulation rules for flood reduction of reservoir system in the Ba river basin while considering water supply role of the system.

CHAPTER 2. DEVELOPEMENT OF INTER-RESERVOIR OPERATION PROCEDURES FOR FLOOD CONTROL IN THE BA RIVER BASIN

2.1. Meteo-hydrological characteristics of the Ba river basin

The Ba river basin is one of the nine largest river basins in Vietnam with a total area of about 13,4170 km^2 [33], the basin occupies the western and the eastern sides of Truong Son mountain range, located in Kontum, Gia Lai, Dak Lak provinces in the Central Highlands and Phu Yen province in the South Central of Vietnam. The basin is located from 12^0 35' to 14^0 38' North latitude 180^0 00 'to 190^0 55' East longitude (Fig. 2.1).

The basin is strongly influenced by two climate conditions, namely East and West Truong Son monsoon. The climate condition in the West Truong Son is the moisture-southwest monsoon that blows through the Bengal Gulf lasting from May to October and resulting thunderstorms with plentiful rainfall amount annually. The dry season lasts from November to June, with little rainfall amount. The climate in the East Truong Son is impacted by the weather disturbances from the East Sea associated with the northeast monsoon. From September to December, the late storms from the East Sea are weakened by the Truong Son range from tropical depressions and then combine with the northeast monsoon that causes heavy rain in the upper of the Ba river mainstream and influences on Hinh watershed and apart of Krong Hnang watershed in downstream. During winter season, in the area from upstream to An Khe and from Son Hoa and Song Hinh to the river mouth, because of northeast monsoon and late storms from the East Sea, rainfall occurrs with small amount.

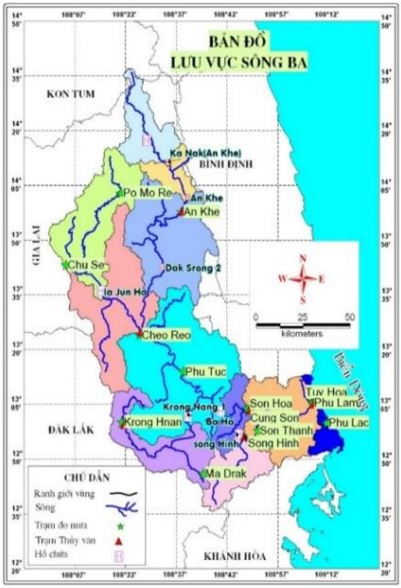

Fig. 2.1. The Ba river basin

2.2. Current situation of water use and flood control in the Ba river basin

The Ba river basin is one of the earliest basins with water works built in the Central of Vietnam. Over time, there are many water infrastructures that have been constructed for major purposes such as power generation, water supply, and flood reduction. Thus, most of river branches have been regulated by irrigation works and reservoirs. The water users in this basin are: domestic water supply, irrigation, and water uses in industry and service. The water supply systems include pumping stations, gravitational weirs (Ayun Ha weir), spillway (Dong Cam weir), irrigation reservoirs, and hydropower reservoirs (some of them transfer water to other catchments such as An Khe, Ayun Ha and Song Hinh).

2.2.1. The infrastructure systems for irrigation and hydropower

The Ba River is one of the basins with high potential of irrigation and hydropower among the major river basins in Vietnam. The irrigation system in the

Ba River was firstly developed in the Central for power generation, water supply and flood control. There are around 329 head water works in the river basin including 147 reservoirs, 121 spillways, and 61 pump stations operating for domestic, agricultural, industrial and service water supplies. Among them, water works including An Khe - Ka nak, Ayun Ha, Krong H'nang, Hinh and Ba Ha are selected as study objects in the thesis, in which An Khe, Ayun Ha and Hinh reservoirs are water-transferring constructions to Kon river, irrigation channels, and Con river, respectively [29].

2.2.2. Operational activities of the irrigation and hydropower works in the Ba river basin

The reservoirs mainly focus on power generation, which results in no release to downstream during low-load hours. The Krong H'nang and Ba Ha reservoirs have been not properly been operated according the operation rules, which often breaks the regulation charts. Ka Nak reservoir is operated for water supply while An Khe reservoirs generates electric power and transfers water to Con River. Therefore, the return flow to downstream is small in dry season, sometimes causing dry-bed condition on rivers in downstream.

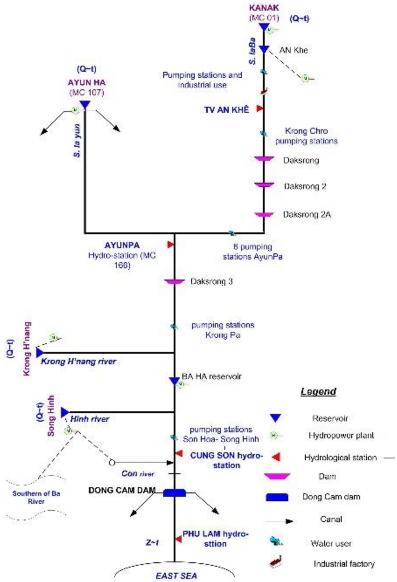

Fig. 2.2: Schematic presentation of the Ba river system

2.2.3. Flood control requirement in the Ba river basin

In the Ba river basin, flood is seen as one of the most threatening disasters resulting in huge damages for domestic residents and socio-economics. Beside the local inundations caused by heavy rains, there are three regions that are often affected by river flooding causing extreme damages to the livelihood and socio-economic development in the region [30]:

- An Khe downtown: located near the Highway No.19 from Binh Dinh (An Nhon) to Pleiku, and between the two passes An Khe (border of Tay Son district, Binh Dinh province) and Mang Yang (border of Mang Yang district, Gia Lai province). When flood water level at An Khe hydrological stations rises, water flows in the area and causes flooding. The area is at downstream of An Khe reservoir 8.5km and of Ka Nak reservoir 33km, the flood control thus depends on upstream reservoir operations. The analysis of relationship between effective storages of the two reservoirs An Khe and Ka Nak and flood water volume revealed that the total volume of 10-day floods were 1.0 and 0.6 times higher than the total storage capacity of the two reservoirs of An Khe and Ka Nak in 12 years and 11 years out of 32 years that have recorded data. This indicates that, when extreme floods occur, even with fully operation of the two reservoirs, it is not possible to effectively reduce flood damages. These reservoirs are thus taken into account in a flood control system.

- Floodplain area from Ayun Pa valley - Cheo Reo to Phu Tuc: this area is a separated valley, fairly flat with low elevation difference between the agricultural land and the river, and is divided by mountain ranges forming narrow terrain types at To Na pass. So the area is often inundated up to the elevation of 160 m during flood events in October and November. The joint area of Ayun branch to main stream is inundated under around 1m in 2-6 days. This area is located at downstream of Ayun Ha and An Khe reservoirs about 34.5km and 105km, respectively, thus the flood control is affected by operation of Ayun Ha reservoir.

- The flood plains in the Ba river delta: The area located in the downstream of the Ba River, mostly located in Phu Yen province, has a low terrain and heavy rain from the sea, resulting more frequent floods than the upstream areas. The inundation depth in Tuy Hoa downtown is in between 0.3-0.5 m during 10 days. The area is around 25km and 22.3km downstream of Ba Ha and Hinh reservoirs. The flood control features of the area are controlled by the two reservoirs operation rules. Regarding the relationship between useful storages and total flood water volume to Cung Son station, the 10-day total flood volume is greater than total useful storages of three reservoirs Krong H’nang, Hinh and Ba Ha in most of years (3 and 2 times higher in 15 and 20 years out of 32 data years). Therefore, the reservoirs could only be a part of reservoir system for flood control.

The reservoirs in the Ba river basins were designed without surcharge storage, and they are are allowed to maintain the normal water level during flood season following the single reservoir operating procedures, and this operation would bring higher power generation efficiency. For inter-reservoir operating procedures, the reservoirs need to have flood control capacity from the early flood season and continue to lower water level when floods are predicted to occur. The latter operation procedures would increase flood control efficiency but decrease water supply. There is a high possibility that the reservoirs may not adequately store water during flood season or they need to cut off electricity generation capacity during flood season [3, 11, 19, 31, 38, 48].

2.3. Development of inter-reservoir operating procedures for flood control in the Ba river basin

2.3.1. The inter-reservoir operating principles for flood mitigation in the Ba river basin

The reservoir operation system is a fairly complex problem involving multivariate control that needs to meet multi-objectives including flood control, power generation, irrigiation, and navigation.

The single reservoir operation procedures only consider independent role of each reservoir in the system. The Ba Ha, Krong H'Nang, Hinh and Ka Nak reservoirs are maintained at normal water level during flood season and are operated according to the provisions of Decree No. 112/2008 / ND-CP of October 20, 2008 in dry season. The inter-reservoir operating procedures in flood season built in 2009 had good operating principles, however, involved several drawbacks such as allowing to lower the water level in the reservoir if the water level at control point is high (approximately II level alert), which is helpful to create flood control capacity but risky for downstream protection; no further assessment of the flood water releasing to maintain flood control storage(all reservoirs are allowed to maintain at a high level, and only discharge if forecasted water level reaches limiting level). By 2014, the inter-reservoir operating procedures for both flood and dry season in order to effectively control flooding were developed, all reservoirs should have flood control capacity since the early flood season and successively release to spend more storage for future floods. This new operation rules help improve the flood control efficiency, by the contrast, it would affect electricity generation capacity fo the reservoir because of high probability of lacking water in the end of flood season.

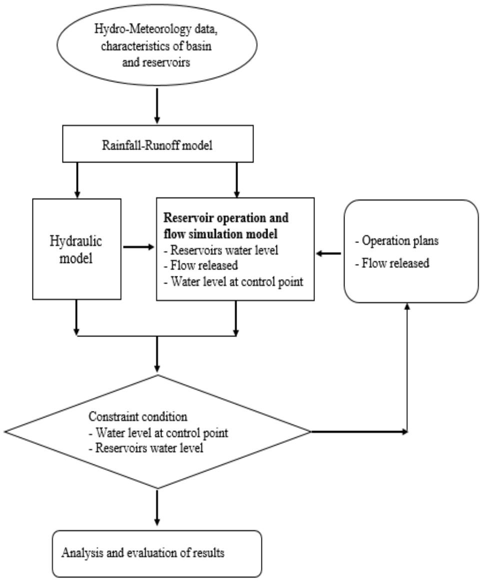

Fig.2.3: Flowchart of inter-reservoir operation in the Ba river basin

Similar to other river basins in Vietnam, currently, a comprehensive water use and hydromet and hydrological database is yet developed for the Ba river basin. There are overlappings, and a clearly defined responsibilities of relevant stakeholders involved in water resources management are yet put in place. Also, there are no temporal and spatial analyses in water use in the river basin. The ineffective management system coupled with a lack of a comprehensive study of the water usage have posed significant challenges for the optimal reservoirs operation. Moreover, the short- and medium-range forecasts of flood flow to the reservoirs and river water level for reservoir operation with low accuracy would affect the efficiency of flood control.

With the above-mentioned issues, the inter-reservoir operation rules are determined based on principles defined as follows:

1. To coordinate the reservoirs’ operation in the system based on the adjustment of role for each reservoir to mitigate flood damages;

2. The water level at downstream and flood flow into reservoirs serve as basis for the determination of effective flood control storages;

3. To efficiently operate the reservoir system to mitigate flooding while ensuring that the purposes of power generation and water supply as designed are not affected.

The key contents need to be identified and studied for the proposal of the scientific and practical bases for reservoir operation for downstream flood control are presented as Figs.2.3 and 2.4:

- Segmentation of reservoirs operation periods;

- Determination of control points and constraints in operation procedure;

- Identification of the roles of reservoirs and coordination mechanism of reservoir system in flood control operation;

- Determination of releasing time and lowering water levels before floods coming;

- Determination of the time for flood regulation and flood mitigation efficiency;

- Operating reservoirs for flood mitigation ensuring downstream safety;

- Determination of an efficient water usage during flooing season;

- Study of water storing in the late flood season.

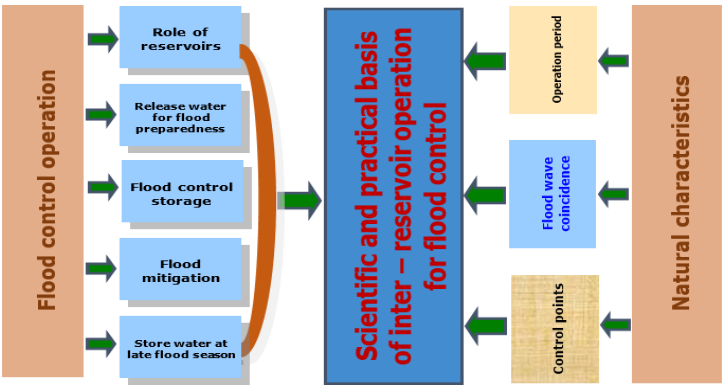

Fig.2.4: Block diagram of identification of the scientific and practical bases for flood mitigation in the Ba river basin

2.3.2. Development of inter-reservoir operation model package for downstream flood control

A model package is proposed to simulate the water resource system and to support decision making in water resources management. In order to achieve the thesis objectives, the author employed the following simulation tools:

- The hydrologic modelling so called MIKE-Nam is applied to fill the missing data of flood flows to the reservoirs and to the subcatchment outlets in the Ba river basin including reservoirs: Ka Nak, Ayun Ha, Krong H'nang; and lateral subcatchments: Ka Nak-An Khe, An Khe-Ayun Pa, Ayun Ha-Ayun Pa, Ayun Pa-Ba Ha reservoir, Krong H'nang reservoir- Ba Ha reservoir, Ba Ha reservoir -Cung Son, Hinh reservoir-Cung Son and Cung Son-Phu Lam. The simulated flows are extracted from the projects [30,47].

- The reservoir operation model: Although there are existing models which are widely used in reservoir operation, they are mainly ultilized for simple systems and for water balance studies. For the inter-reservoir operation problem, the esixting model could not satisfy the practical requirements. The author thus originally develops a module for inter-reservoir operation procedures for flood control in the Ba river basin.

- The hydraulic model MIKE11-HD is used to simulate the water depths and discharge flow at control points along the main river from Cung Son station to the river mouth.

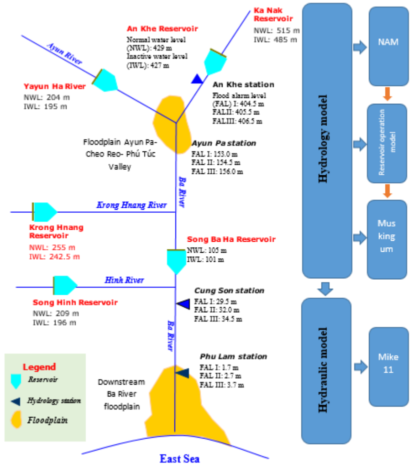

Fig.2.5. Diagram of mathematical model application

2.4. Conclusion of Chapter 2

In the Ba river basin, there are two reservoir operation procedures approved by the Government namely single- and inter-reservoir operation. The single-reservoir operation procedures proposed the ambiguous operation rules for both flood and dry seasons in terms of coordination among reservoir system. For inter-reservoir operation procedures, the determination of flood control storages (water level at the beginning of flood season and release discharge during flood season) would improve flood reduction efficiency but this affects the water supply and hydropower efficiency due to a possible lack of water at the end of flood season.

The Ba River is known as a high flood-potential river. Severe flood events occurr along the basin from upstream to downstream. The total event flood volume is further greater than useful capacity of reservoirs, the flooding thus could not successfully be reduced and the single reservoir only plays a role in the flood mitigation system. In the whole the Ba river basin, rainfall patterns dramatically vary over time and space, in particular the upstream area in West Truong Son mountain range is in rainy season while the downstream area is still in dry season, and when the upper area is the end of rainy season the downstream surfers from heavy rainfall. These features are challenges in effectively operating reservoir for flood control.

The water works in the Ba river basin includes various types with different scales and purposes as well. However, there are only 6 large reservoirs which significantly have impacts on flow regimes and water use in the basins. These works will be the main targets of this study.

Reservoir systems in the Ba river basins are located in the zone with complicated rainfall distribution influenced by the monsoons from both East and West sides of Truong Son mountain range. Thus, oriented operating principle of the study is to find the coordination of operation for flood mitigation based on the analysis of natural and hydrological characteristics of the Ba river basins ensuring water use efficiency and downstream safety. The model operating flood routing and reservoir operation is developed to achieve this overall objective.

CHAPTER 3. SCIENTIFIC AND PRACITAL BASES OF INTER-RESERVOIR OPERATION PROCEDURES TO MITIGATE FLOOD IN THE BA RIVER BASIN

3.1. Determination of control points for the inter-reservoirs operation procedure

3.1.1. Control points selection

The control points for inter-reservoirs operation include control points of inflow of reservoirs and discharged flow at downstream reservoirs:

- Control points of inflow could be hydrology station or water level measuring points which used for estimating total water volume flow into reservoirs. At the moment, most of hydrology stations in the Ba River basin were installed before the construction of reservoirs, thus there is no station represents for inflow to reservoirs. Instead of that is water level measured at upstream of dams to observe the changing reservoirs water level.

- Control points of water released from reservoirs are hydrology stations at downstream reservoirs or operation stage of reservoirs (working number of bottom gates, spillways or turbines) and points which are allow to measure water discharged from reservoirs. At the moment in the Ba River basin, all downstream of reservoirs exit hydrology station. For instant, downstream An Khe reservoir has hydrology station An Khe; hydrology station AyunPa is located downstream of junctions of the Ba River and Ayun River, far from Ayun Ha to downstream 34km. Cung Son station is located at downstream Ba Ha and Hinh reservoirs. Phu Lam station is located further downstream near outlet of the river, far from Cung Son station 41.7km. These hydrology stations are working with completed database as well as oficial flood warning levels [27].

During the flood season, when extreme flood in the Ba River basin occurs, 3 regions often flooded including An Khe Town, Ayun Pa - Cheo Reo - Phu Tuc Valley and plain of the Ba River. There are 5 main large reservoirs: An Khe - Ka Nak reservoir system is located at upstream of An Khe town, Ayun Ha is located upstream - Cheo Reo - Phu Tuc valley; Krong H'Nang, Ba Ha and Hinh reservoirs are located upstream of the floodplain in the Ba river delta.

Therefore, the control points for inter-reservoir operation in the Ba River basin are at four hydrological stations named An Khe, Ayun Pa, Cung Son and Phu Lam (see Fig.2.5).

3.1.2. Flow charateritics at control points in flood season

Water arlam level represents the level of flood danger that influences on the residential areas and the important cities or towns. Therefore, the water levels corresponding to the alarm statuses at hydrological stations are used as the basis for flood control operation. In the Central part of Vietnam, the water alarm levels for each station basin are shown in Table 3.1.

Table 3.1: The water levels corresponding to the alarm statuses at hydrological stations on the Ba River

No	River	Station	Water level corresponds to the water alarm state (m)		
			I	II	III
1	Ba	An Khe	404.5	405.5	406.5
2	Ba	Ayun Pa	153.0	154.5	156.0
3	Ba	Cung Son	29.5	32.0	34.5
4	Da Rang	Tuy Hoa (Phu Lam)	1.7	2.7	3.7

3.2. Segmenttation study of reservoir operation periods

The segmentation of operation period of multi-reservoirs, in fact, is to determine the probability of flood occurrence at different levels (slight, moderate and severe) in different time periods and is indentified by flood season segmentation at hydrological stations into early, main, and late floods [20, 28]. This division is based on the classification of levels and occurrence and peaks at the control points.

At present, in river basins in Vietnam as well as the Ba river basin, study on flood classification at hydrology station is calcualted based on frequency curve [14] (Decision No. 18/2008/QĐ-BTNMT promulgating the naitonal standards for flood forecast) and average value of flood peak [48] (Decision No. 46/QĐ-TTg, Promulgation of regulations on flood forecasting and warning in disaster communications). These methods rely on a purely observed water level, average observed flood peak water level and water levels corresponding to different frequencies are calculated at hydrological stations. These clasification do not consider specific hydrologic - hydraulics conditions of each region and effect at each flood level to the river bank, dike erosion, related lowlands, township, towns and cities.

In 2006, the Ministry of Natural Resources and Environment commissioned the Viet Nam Institute of Meteorology, Hydrology (now is the Viet Nam Institute of Meteorology, Hydrology and Climate Change) to conduct a study on "Proposal for a regulation of water alarm states on main rivers of Vietnam". The result of the study was the water alarm states of 131 hydrological stations on the river basins in Vietnam, and was approved by the Government Decision No. 632/QĐ-TTg of May 10, 2010 [25]. Accordingly, the water level corresponding to water alarm state allows us to know the status of flood danger levels and potential impact level on residential areas, city town. Since then, the thesis chosed flood levels classification method by using flood water level corresponding to alert stage level I, II and III. 3 floods level are divided as follows:

- Slight flood: $H_{BDI} \leq H_{maxi}$
- Moderate flood: $H_{BDII} \leq H_{maxflood} \leq H_{BDIII}$
- Severe flood: $H_{BDIII} \leq H_{maxflood}$

Where, H_{maxi}= peak flood water level of flood event i; $H_{BDI,}$ $H_{BDII,}$ H_{BDIII}= water levels correpond to water alarm state 1, 2 and 3, respectively;

Criterial of flood classification are defined as follows:

- Main period is the time of flood season when most of floods with peak flood water level over water alarm state II occur. Historical data shown that most of big and extreme floods occur in this period.

- Early period lasts from the starting time of flood season or the time where water level over water alarm state 1 to the starting time of main period;

- Late period lasts from the ending time of the main period to the ending time of flood season or when small floods occur more frequently.

Table 3.2: Flood season segmentation

Station	Early period	Main period	Late period
An Khe	1/9-30/9	1/10-3/12	4/12-31/12
Ayun Pa	3/8-5/9	6/9-5/12	6/12-31/12
Cung Son	1/9-24/9	25/9-15/12	14/12-31/12
Phu Lam	1/9-20/9	21/9-15/12	14/12-31/12

The 5 hydrology stations in the basin (Po Mo Re, An Khe, Ayun Pa, Cung Son and Phu Lam) are opearting and has fullly observed water level data. An Khe station represents for the Ba river upstream with Ka Nak - An Khe reservoir system; Ayun Pa station represents for Ayun Ha reservoir in Ayun River, big tributary of the Ba River. Cung Son station represents the middle part and Phu Lam station represents downstream and Krong H'nang, Ba Ha and Hinh reservoir will be selected to determine the period of operation of the reservoir.

Based on flood season divergence of hydrological station and the location of reservoirs in the Ba river basin, operation period is determined as follows:

- The Krong H'nang, Ba Ha and Hinh reservoirs' operation period based on Cung Son station (early flood period lasts from September 1 to September 24, the main flood period lasts from September 25 to December 13 and late flood period from December 14 to December 31).

- An Khe - Ka Nak system operatation period based An Khe stations (early flood period lasts from September 1 to September 30, main flood period lasts from

October 1 to December 3 and late flood period lasts from December 4 to December 31).

- Ayun Ha reservoirs operatation period based on Ayunpa stations (early flood period lasts from August 3 to September 5; main flood period lasts from September 6 to December 5 and late flood period lasts from December 6 to December 31).

Operatation procedure of reservoirs is divided into 3 periods allows researchers to determine the scale of flood reduction process for individual reservoir - reservoirs system. For early and late flood periods, target of system is completely flood control for downstream while in main period, reservoirs has a support function only to reduce one part of flood in downstream.

3.3. Coincidence of flood flow in tributaries of the Ba River

Rainfall and flood flows at middle part and downstream of the Ba River basin are mostly coincidence:

- When flood occurs at Cung Son, other tributaries also have flood at different magnitude;

- At Cung Son, when extreme flood occurs, the severe flood also occurs at the same time in the other tributaries, except 1988 when flood occured mainly in the middle and downstream. Therefore, when extreme flood is recorded at Cung Son, on the other streams its occurrence is highly probable;

- When extreme floods occur on the AyunPa station branch, they also probably occur on Ayun tributary;

- Flooding in Hinh and Krong H'nang tributaries are synchronized with the floods in Cung Son station. When flood in Cung Son is from moderate to extreme levels, it also occurs on the two other tributaries.

3.4. The study of role adjustment of reservoir and coordination of inter-reservoir for flood control in the Ba River

Reservoir operation procedure in flood season includes the following objectives: To ensure the safety of construction, contributing to reduce downstream flooding and ensure efficient electricity generation [48]. However, safety issues related to the structures of hydropower plants, reservoirs and flood design should not set as a research objective in this thesis. Therefore, the flood control operational objectives in this thesis are reducing downstream flooding, to ensure safety for downstream (not increase flood), ensuring efficiency of power generation and storing water in late flood season to ensure water supply in the dry season.

3.4.1. Determination of principles for flood control reservoir operation

To effectively control flooding in downstream, the reservoir system must create flood control capacity from active storage. The problem is that flood control capacity need to be created when and how much for each reservoirs and how to use this capacity when participating to regulate flood for downstream. There are two ways to create flood control capacity: reservoirs release water to create flood control capacity before the flood season or before each flood events. Depending on the characteristics of each reservoir as well as characteristics of flood in the basins, flood control storage capacity can be determined in different ways. Water released from An Khe-Ka Nak reservoirs system directly affects water levels at An Khe station; Ayun Ha reservoirs directly affects water levels at Ayun Pa station; Ba Ha and Hinh reservoirs directly affect water levels at Cung Son and Phu Lam stations. Therefore, in order to dertermine the volume of water released from reservoirs without causing affects on the downstream, the water level at the control points lowering water alarm state I needs to be determined and controlled (floods do not have apparent impact on residential areas).

The combination of different floods (by selecting floods has the same duration from 1 to 3 days) appeared in the month (September, October, November and December) for analyzing water level fluctuations from the lowest water level of flood to water alarm state I would help to proposesolution of water release operation for an effective flood control of the reservoirs. The results of the analysis and evaluation are as follows:

- To increase water level from current stage to alarm state I at An Khe and Ayunpa stations, An Khê-Ka Nak and Ayun Hạ resrevoirs could be relaese a quite large additional water volume. So the releasing processes for creating the flood control capacity of these reservoir are meaningful and feasible before a flood coming.

- The additional discharge from Ba Ha and Hinh reservoir quickly lead to water level at control poits in downstream reaching alarm state I. Therefore, these reservoirs can not releas water to create flood control capacity for each flood event. Krong H'nang, Ba Ha and Hinh reservoirs have to save flood control capacity during flood season.

Thus, in the operation in the flood season, reservoir systems are proposed to create control flood capacity by 2 different methods: Ka Nak and Ayun Ha reservoirs can maintain high water level during flood season and release only when flood is forecasted occuring in the basin; Krong H'nang, Ba Ha and Hinh reservoirs have to save flood control capacity before flood season.

3.4.2. Recommendation of flood control capacity of reservoirs

The value of water level before rising limb and the difference between this value with water alarm state 1 at the control points is the basis for determining the flood control capacity of reservoirs. Release flow of reservoirs and the rating curve at the station will determine the allowed water level and increasing release flow without affecting downstream. To avoid affects on downstream from the processes of water release/ increasing water release, the thesis proposed the reservoirs release sequentially in first period (6 -12 hours) to reaches the flood aler stage 1 at control point. After that, released flow is maintained to create flood control capacity during next 12-18 hours. The results of analysis and evaluation are as follows:

1. An Khe - Ka Nak reservoir system: At An Khe station: In order to increase the water level from 401,69m, 402,27m and 402,86m (corresponding to low, medium and high flood base) to water alarm state 1, additionally released flows correspondingly are 467m^3/s, 452m^3/s and 391m^3/s. Analyzing the relationship between release alternatives and flood base to determine lowering water level of the reservoir for different flood base:

- With low flood base, lowering the volume of the Ka Nak reservoirs ranged from approximately 48 to 51 million m^3. The reservoir water level can be lowered to 511,8m.

- With medium flood base, lowering volume of Ka Nak reservoirs ranges from about 47 million m^3 to 50 million m^3. The maximum reservoir water level is lowered to 512m.

- With high flood base, lowering volume of Ka Nak reservoirs ranges from approximately 38 million m^3 to 43 million m^3. The reservoir water level can be lowered to 513 m.

2. Ayun Ha Reservoirs: At Ayunpa station, to increase the water level from 150.62m, 151.39m and 152m (low, medium and high flood base) to the water alarm state 1, the additionional release flow are 1014m^3/s, 794m^3/s and 549m^3/s, respectively. Analyzing the relationship between release alternatives and flood base to determine lowering water level of the reservoir for different flood base:

- With low flood base, lowering the volume of the Ayun Ha reservoirs ranges from approximately 31.8 to 34.7 million m^3. The water level can be lowered to 203m.

- With medium flood base, lowering the volume of the Ayun Ha reservoirs ranges from 25 to 27 million m^3. The water level can be lowered to 203,2m.

- With high flood base, lowering the volume of the Ayun Ha reservoirs ranges from 16.8 to 18.3 million m^3. The water level can be lowered to 203,5m.

3. Ba Ha, Hinh and Krong H'nang reservoirs

In principle, the larger of reservoir capacity the the higher flood control efficiency. But in order to avoid significant affects on water use during flood season, the hydro-power plan should generate electricity with the highest flow through turbine.

In fact, lead time flood forecasting is 24 hours, 48 hours for assessment and within 7-10 days for water use planning. Therefore, depending on the characteristics of each reservoirs, the author proposes a minimum volume to ensure that reservoirs can generate electricity for at least 1-10 days. Flood control capacity equal the different between active capacity and minimum capacity.

To propose flood control capacity of the reservoir, the thesis based on the characteristics of storage capacity, inflow and hydro-power generation of each reservoir. Based on the required capacity for power generation and flood control capacity of the three reservoirs under different schemes and considering the possibility of refilling volume after electricity generation through the comparison and evaluation of total inflow volume with capacity requirements for generator. Calculation results and the analysis as showin Table 3.3 indicate:

- For Krong H'nang reservoirs: When considering the requirment for power generation with the highest flow from 1 to 5 days, the capacity for flood control is very large accounts from 74% to 95% of active capacity. Krong H'nang River is tributary of the Ba River, flows directly into the Ba Ha reservoir causing the effective of flood relief is small. Further inflow in duration of 1 to 10 days compared to the amount of water for power generation from 7 to 10 days is very small (they are much smaller in most years). For that reason, the thesis proposed flood control capacity of the reservoir is from 54 to 71 million m^3.

- For Ba Ha reservoir: Demand for electricity generation is relatively high, active capacity only meet the demand generator from 1 to nearly 5 days, respectively, the flood control capcity is accounted for 39% to 80% of active capacity. This reservoir is located in the downstream of the Ba River causing inflow to reservoir is quite large compared to the demand for electricity generation and it will play a major role in flood control. Hence the thesis proposed flood control capacity of the reservoir from 98 to 132 million m^3.

- For Hinh reservoir: Located in Hinh River, main tributaries of the Ba River, the reservoir, together with Ba Ha reservoir, serves as a flood control tool. Further, according to the analysis of coincidence of floods, the ability appearing big flood at the same time with Cung Son is very high. Therfore, this reservoir also has significant role as Ba Ha in reduce flood for downstream. Reservoir with the largest active capacity can be used to generate electricity for more than 2 months, while the amount of inflow to reservoir in the flood season is relatively large compared to the total amount of requirement water for electricity generation . Therefore, flood control capacity of the Hinh reservoir is be selected in large ranges, from 100 to 318 million m^3.

Table 3.3: Capacities for electricity generation and flood control of reservoirs

Number of day	1	2	3	4,8	5	7	10	19	30	45	65
KrongH'nang Reservoirs											
Storage capacity for power generation (million m3)	5,9	11,8	17,6	28,2	29,4	41,1	58,8	111,6			
Flood control capacity (million m3)	106,4	100,5	94,7	84,1	82,9	71,2	53,5	0,7			
Ratio of flood control capacity with active capacity (%)	94,8	89,5	84,3	74,9	73,8	63,4	47,7	0,6			
Ba Ha Reservoir											
Storage capacity for power generation (million m3)	34,0	67,9	101,9	163,0							
Flood control capacity (million m3)	131,9	98,0	64,0	2,9							
Ratio of flood control capacity with active capacity (%)	79,5	59,1	38,6	1,8							
Hinh Reservoir											
Storage capacity for power generation (million m3)	5,0	9,9	14,9	23,8	24,8	34,7	49,5	94,1	148,5	222,8	321,8
Flood control capacity (million m3)	318,0	313,1	308,1	299,2	298,2	288,3	273,5	228,9	174,5	100,2	1,2
Ratio of flood control capacity with active capacity (%)	98,5	96,9	95,4	92,6	92,3	89,3	84,7	70,9	54,0	31,0	0,4

3.4.3. Determination of flood control capacity for reservoirs

1. Ka Nak and Ayun Ha reservoirs

In the study on releasing flow for creating flood control capacity of the reservoirs, water level at control point is lower than water alarm state I considering the constraint. This is the safety condition for downstream in the process of releasing water to create flood control capacity. The thesis proposed minimum lowering of the water level in the Ayun Ha and Ka Nak reservoirs is the releasing scenarios corresponding to low flood base condition. Thus, Ka Nak reservoir is allowed to release water to reach the water level of 511,8m (corresponding to flood control capacity of 48 million m^3), for water level of Ayun Ha reservoir can reduce to 203m (at flood control capacity of 32 million m^3). Further assessment of the ability refilling reservoir in December showed that:

- The total amount of inflow to the Ayun Ha reservoir in December is higher than the proposed flood control capacity. Wit this, the reservoir can retain maximum waer volume at the end of the flood season and the proposed lowering water level values is appropriate.

- The total amount of inflow to Ka Nak reservoir in December is much smaller than proposed flood control capacity in 10/32 years of time series data (accounting for 31%, and the reservoir can not retain completetly at the end of flood season), but Ka Nak is multi-year regulation reservoir and only release water when forecasting floods occur, so it can be acceptable.

2. Ba Ha, Hinh and Krong H'nang reservoirs

- Krong H'nang reservoir: there are 30/32 years (94%) has inflow to the reservoir in December were larger than the value of 50 million m^3. Thus, in alternatives identifying flood control capacity, thesis suggested chosing flood control capacity for the reservoir about 53.5 million m^3. In order to create a flood control capacity as specified before the flood season, it is needed to generate electricity with the highest flow before 12 days including 3 days of releasing all inflow to reservoir.

- Ba Ha reservoir: total amount of inflow to the reservoir in December were always higher than the value of 100 million m^3. Thus, flood control capacity of the Ba Ha reservoir about 98 million m^3 is chosen in the thesis. To create a flood control capacity before the flood season, reservoir needs to generate with the largest flow before 8 days including 5 days of releasing inflow volume.

- Hinh reservoir: there are 2/32 years (6%) that has inflow to the reservoir in December were smaller than the value of 125 million m^3. On the other hand, the proposed flood control capacity of reservoir can not regulate effectively most of the floods and Hinh river is not the main tributary causing flood in downstream areas. Therefore, in order to get water use efficiency, thesis proposed the value of flood control capacity required during the flood season is 100 million m^3. To create the flood control capacity at the beginning of the flood season, reservoir need generate with the largest flow before 22 days including 2 days releasing inflow to reservoir.

In summary, in the principles of 5 reservoir participating to flood relief, Krong H'nang, Ba Ha and Hinh reservoirs will not reduce the water level to create the flood control capacity when forecasting floods is recorded, but they have to save flood control capacity throuhout flood season, different with Ka Nak and Ayun Ha reservoir. This is the principle of multi-reservoir operation to ensure efficiency of water use and electricity generation, especially reservoir Ka Nak has 48 million m^3 and Ayun Ha have 32.0 million m^3 for hydro-power and water supply. Minimum lowering water level of the reservoir as possible of main flood control reservoirs (Ka Nak and Ayun Ha reservoir) and supplemental reservoirs (Krong H'nang, Ba Ha and Hinh) show in Table 3.4. Total capacity for flood relief of system was 331.5 million m^3.

Table 3.4: The maximum water level and proposed flood control of reservoir

Feature	**Ka Nak**	**Ayun Ha**	**Krong H'nang**	**Ba Ha**	**Hinh**
Flood control capacity (million m^3)	50.5	35	53.5	98	273.5
Lowering water value for flood control (m)	511.7	202.9	250.2	103.1	199.5

3.4.4. Recommendation of operation stages for downstream flood control

Operation tasks for flood reduction include the following steps:

- Releasing water to creat flood control capacity;
- Switching wait status to flood control status;
- Regulating floods (flood control);
- Refilling reservoirs to allowed flood preparedness water level after completing flood control process.

Ba Ha, Krong H'nang and Hinh reservoirs have to save flood control capacity at the begining of the flood season when the water level at the control points is quite low, thus it will not affect downstream, while Ka Nak, Ayun Ha reservoirs need maintain high water level for power generation and water supply during flood season and only create flood control capacity when flood occurs.

Floods in Cung Son have direct and strong impacts on floods in Phu Lam, however, release operation reduce floods at the reservoir Ka Nak, Auyn Ha impacts on flood at Ba Ha negligible. Flood peak of inflow to the reservoir Ba Ha changed no more than 3%. This implies that the operation of Kanak and Auyn Ha servoirs are independent from the operation of other reservoirs of Ba Ha, Krong Hnang, and Hinh in downstream.

In the Ba River basin in particular and the central coastal area in general, extreme floods are often formed rain storms, tropical depressions, cold air, tropical convergence zone or combination of factors [45, 51]. The rain patterns are generally forecasted, updated. Mechanism of forecast, warning, and disaster communications [45, 48, 51] storm forecast procedue have to be done in 24 hours, and 48 and 72 hours. Therefore, the reservoirs can be based on the above scheduled time to release for flood control. Ka Nak-An Khe and Ayun Ha reservoir will release for flood preparedness when it has a large flood forecasted in Basin.

Reservoirs will stop releasing water for flood preparedness when when water levels at control point in excess water alarm state 1. Based on the forecast the next step: If the flood continues rising, reservoirs will remain operation to switch to flood relief stage; if flood forecasts down, Ayun Ha, Ka Nak reservoir will move retain stage.

Flood control is the process to store water in reservoir at the specific time to regulate the flow and reduce water level at downstream. In the Ba River, flood control capacity of reservoir is very small compared with incoming flood, and the reservoir system could only partially reduce the flood when a big flood occurs. In reality, the system could effectively control flood with with small-intensity floods. Therefore, the author proposes the time of reservoirs regulating flood for downstream in 2 ways:

- When the water level at the control point reaches water alarm state II.

- In 6-12 hours next, forecasting flood will reach the peak.

3.5. Conclusion of Chapter 3

From the analysis of the relationship between reservoir operations with flooding characteristics in the Ba River basin, thesis selected An Khe, Ayun Pa, Cung Son and Phu Lam stations as control points for flood control reservoir operation of the Ba River basin. On the basis of flood segmentation at these hydrological stations, operating periods of the reservoirs are divided into 3 periods, namely early, main and late periods.

The results obtained from the analyses of the possibility of flood coincidence on different tributaries, relationship between release discharge and flood levels, and relationship between the total inflow volume amount end of flood season and flood control capacity of the reservoirs are used to propose operation procedures for flood control as well as to determine flood control capacity of each reservoir. The detailed procedures are presented as follows:

- The analysis of the flood affected downstream is utilized to adjust reservoir function for flood prevention task and to determine the operation rules for releasing flood water to downstream.

- The process of releasing operation to create flood control capacity is controlled by water levels at control points which are lower than water alarm state I. This regulation would not cause man-made flooding and flood coincidence for downstream.

- Ka Nak and Ayun Ha reservoirs play main role in flood water capturing and they are allowed to maintain high water level during operation procedure and only need to be lowered if large flood is forecasted. Thus, the water use efficiency is represented by the using actively flood control capacity of reservoirs;

- Krong H'nang, Ba Ha and Hinh reservoir is used as supporter for flood control; the reservoirs should have free storage for flood capturing in the early flood season. Flood control capacity of the reservoir is determined through analysis of maximum electricity generation demand in flood season and the correlation between the capacity of the reservoir and the ability to reach to normal level at the end of flood season while generating power during the season. Thus, the water use efficiency is assessed by the success of power generation in flood season and water supply in dry season which will occur right after the flood season.

Extreme floods in Ayun Pa is mainly caused by floods in Ayun tributary, on the other hand An Khe reservoir is far from Ayun Pa station, so An Khe- Ka Nak reservoir system operates independently and flood control efficiency at Ayun Pa station is strongly dominated by Ayun Ha reservoir. In the downstream, when extreme flood occurs at Cung Son, flood also occurs on the Hinh tributary. Thus, the flood reduction efficiency at downstream is achieved if reservoirs participate for flood control; and this regulation is impacted by the upstream reservoirs operation.

CHAPTER 4. ANALYSIS OF PERFORMANCES OF INTER-RESERVOIR OPERATION PROCEDURES, AND PROPOSAL OF RECOMMENDATIONS

4.1. Analisis of inter-reservoir operation's performances for flood reduction in typical flood events

4.1.1. The operation scheme for downstream flood reduction

For the operation in flood season, Krong H'nang, Ba Ha and Song Hinh reservoirs release water for saving flood control capacity at the beginning of flood season. Whereas, Ayun Ha and Ka Nak reservoirs only release when future flood are predicted. During the operation periods, if water level reaches the normal level, the resevoirs adjust the releasing schedule to maintain normal water level. If the forecasted flood could reach maximum water level or exceed BDII the reservoirs are operated for downstream flood control. Until 1st of December, since severe flood rarely occur in the basin, the reservoirs are allowed to store water or reduce electricity generation in order to achieve normal water level. The efficiency of these operation rules in typical flood events are shown in the Fig. 4.1.

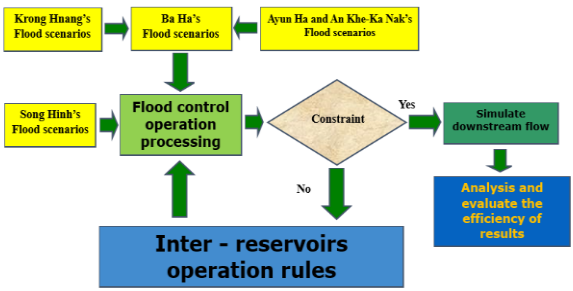

Fig. 4.1. Diagram of inter-reservoirs operation procedure

4.1.2. Performances of inter-reservoir operation procedure

In the Ba River basin, the four typical floods occurred in 1981, 1988, 1993 and 2009. The simulated inflow to reservoirs and lateral flow obtained from the project "Development of operation rule in flood season" are used for flood regulating in the dissertation. The results show that:

- Because the criteria of releasing flow to create flood preparedness capacity without causing Water Alarm II in downstream, both Ka Nak and Ayun Ha reservoirs cannot release enough to reduce water volume to allowable storage capacity in 24 hours (for Ka Nak, the largest discharge in 4 typically floods was 34.8 million m^3, equal to 60.4% capacity allowed to reduce; for Ayun Ha, the largest discharge was 18.31 million m^3, equal to 40.6% of allowable capacity) (Table 4.1).

- Most of the reservoirs cannot successfully control flood in order to reduce water level below water alarm state 1or 2, but only to support to partially reduce flood: Ka Nak reservoir regulates flood water level at An Khe station by 4.15m; Ayun Ha reservoir cuts flood water level at Ayun Pa station by 1.14m; Ba Ha and Song Hinh reservoirs can reduce flood water level at Cung Son station by 0.56m (Table 4.2).

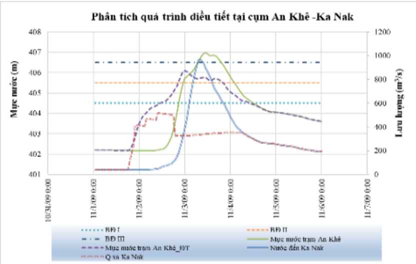

Fig. 4.2a: Results of flood control operation An Khe - Ka Nak - 2009

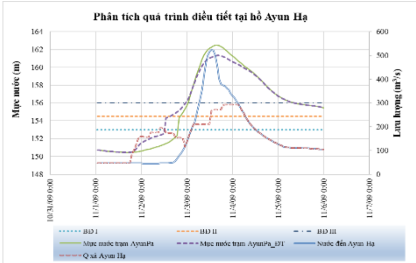

Fig. 4.2b: Results of flood control operation Ayun Ha - 2009

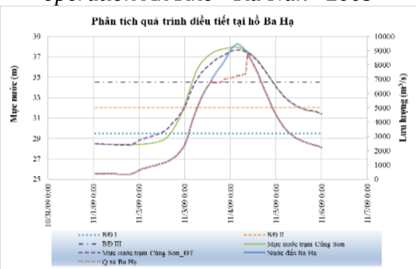

Fig. 4.2c: Results of flood control operation Ba Ha-2009

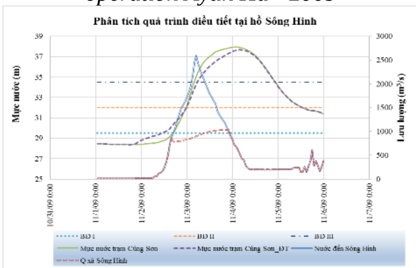

Fig. 4.2d: Results of flood control operation Song Hinh-2009

Table 4.1: Flood control capacity of reservoirs (million m^3)

Reservoir	Features	1981	1988	1993	2009
Ka Nak	Allowed lowering capacity	57.6	57.6	57.6	57.6
	Reality lowering capacity	16.14	6.99	11.69	34.80
	Flood control capacity	15.86	6.86	11.49	35.08
Ayun Ha	Allowed lowering capacity	44.00	44	44	44
	Reality lowering capacity	17.99	5.58	18.31	10.87
	Flood control capacity	15.84	5.27	17.32	10.77
Krong H'nang	Allowed lowering capacity	56.6	56.6	56.6	56.6
	Flood control capacity	57.80	57.31	55.46	57.45

Reservoir	Features	1981	1988	1993	2009
Song Ba Ha	Allowed lowering capacity	98.9	98.9	98.9	98.9
	Flood control capacity	96.59	77.59	100.29	100.09
Song Hinh	Allowed lowering capacity	262.4	262.4	262.4	262.4
	Flood control capacity	148.05	143.92	186.03	80.94

Table 4.2: Flood control efficiency at control stations (m)

Station	1981	1988	1993	2009
An Khe	4.15	0.60	0.38	0.88
Ayun Pa	0.41	0.26	0.32	1.14
Cung Son	0.45	0.56	0.48	0.27

4.2. The recomendations of inter-reservoir operation for flood control

The following improvements are recommended for the multi-reservoir operation rules:

1. Adjust the flood prevention roles: Ka Nak and Ayun Ha receive flood water; Krong H'nang, Ba Ha and Hinh regulate flood.

2. Rules need to be obeyed in operation:

- Water level at the beginning of flood season: Reservoirs are allowed to release water in flood season if the water level at downstream control point is lower or equal to Water Alarm I.

- Allowable water level of reservoirs at the beginning of flood season are:

Table 4.3: Water level for flood lowering at the beginning of flood season

Reservoir	Ba Ha river	Hinh river	Krong H'nang	Ka Nak	Ayun Ha
Water level (m)	103.1	206.2	250.2	511.8	203.0

- When water level at control point exceeds Water Alarm I, the reservoirs release discharge lower or equal to the inflow rate to the reservoir to maintain water level downstream under the Water Alarm I.

- When water level in the reservoirs reach the normal level, to ensure reservoir safety, the reservoirs are required to release discharge greater than or equal to the inflow rate to the reservoir to maintain water level lower than the normal water level.

-When water level at control points is lower than Water Alarm 1, the reservoirs operate with releasing discharge greater than inflow to the reservoirs to lower reservoir water level to the required water level.

3. Time for water compound in the late flood season: From 1st December, based on hydro-meteorological forecast reported by the National Center of Hydro-meteorological Forecasting, if flood would not occur further, the reservoirs are allowed to capture water reaching normal water level.

4.4. Conclusion of Chapter 4

The Chapter 4 proposed the inter-reservoir operation procedures and provided an assessment of the scientific and practical bases for that operation rules by evaluating proposed operation in typical flood events. To effectively use water in flood season and reserve adequate water resources for dry season, the reservoirs need to annually capture inflow water from the beginning of December..

CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

1. The inter-reservoir operation is a complicated problem determining multi-variables and for multi-purposes including flood control, electricity generation, irrigation, and navigation with various constraints of economy, environment and social aspects… In the world, optimization techniques have been employed to develop effective inter-reservoir operation in both dry and flood seasons. However, in Vietnam, due to the considerations of political-social benefits, databases of water users have not been comprehensively developed, in addition, the operation purposes have not been analyzed in real time and space. These aspects cause challenges in application of optimization techniques for inter-reservoir operation. Therefore, instead of using optimization techniques the author focused on determining the scientific and practical bases for inter-reservoir operation for flood control considering power generation and downstream safety as defined in the design phase.

2. From the analyses of probability of flow coincidence of tributaries and relationship between releasing periods of reservoirs and flood states (slight, moderate, and severe), the author determined roles of reservoir as well as inter-reservoirs for flood control and then estimated flood control capacity of reservoirs. The author thus also proposed the operation principles as follows: maintain the high water level Ka Nak - Ayun Ha reservoirs during operation periods and only lowering the water level when floods are predicted to occur in the drainage area, the reservoirs thus spend storage capacity for flood water; maintain flood control storage in Ba Ha and Hinh reservoirs at the beginning of flood season.

The operation procedure is proposed that the water level at control points (at downstream of each reservoir and reservoir system) is constrained to be lower than Water Alarm I, the floods thus would not coincided at downstream. This is the major scientific base for the inter-reservoir operation for flood control in the Ba River.

3. The proposed improvements of operation rules would ensure safety for downstream by maintaining water level at control points lower than Water Alarm I while releasing water from reservoirs to achieve flood control capacity at the beginning of flood season. The study gained the efficiency of water using through improved operation rules as following: 1. The aforementioned operation procedures of An Khe – Ka Nak give 48 million m^3 and 32 million m^3 of storage capacity of An Khe and Ka Nak reservoirs, respectively, for flood water; 2. The improved operation

rules of Ba Ha, Krong H'nang and Hinh reservoirs ensure power generation capacity in flood season as well as water supply in next dry season.

4. Nowadays, in the climate change context, severe droughts causing dried rivers and reservoirs have been occurred widely and frequently. As mentioned above, even the reservoirs in the Ba River are at dead level, they would still failed to cut off flood water. The proposed operation procedures therefore significantly contribute to increase water use efficiency and mitigate droughts in the basin.

5. The recommendations of the thesis are need to be verified by practical application and adopted for different reservoir systems.

B. Recommendations

1. The effectiveness of flood reduction depends significantly on the forecast of the flow to the reservoirs and water level in rivers. Currently, however, the accuracy of the results of these forecasting systems is not very high. Therefore, strengthening accuracy of flow forecast has been become essential for inter-reservoirs operation those include setting monitoring stations, comprehensively modernizing facilities, utilizing new tools for rainfall and flow forecast, and building capacity for technical staffs. The inter-reservoir operation is then adjusted for flood control and downstream water supply.

2. The thesis provided analyses and calculations to determine quantitative parameters for adjustment of inter-reservoirs operation procedures in the Ba river basin. The author strongly recommends these results to management agencies for practical applications.

3. There are numerous reservoirs built in the river basins in Central Part and Central Highlands of Vietnam for water supply and downstream flood safety. These river basins share similarities in geographical characteristics, current water supply status, and water users with the Ba river basin. The developed operation procedure is proposed to apply for reservoirs in these river basins.

4. To ensure water supply, apart from the requirements of conformance with the operation rules, it is necessary to get the socio-political system involved in the operation of inter-reservoir l system to solve the problem.

LIST OF PUBLISHED WORKS OF THE AUTHOR

1. Duong Thi Thanh Huong, Nguyen Tien Cuong, Nguyen Tien Giang, **Luong Huu Dung** (2010), "Supporting tool for multi-reservoirs operations in Ba river system", A collection of works for the national scientific conference on Fluid Mechanics in 2010.

2. **Luong Huu Dung** (2011), "Characteristics of precipitation and floods in Ba riverbasin for multi-reservoirs operations and flood control downstream," Hydro-meteorology magazine.

3. **Luong Huu Dung** (2013), "Scientific and practical basis for developing operation rules for reservoir system on Ba River", Organizing Committee of the fourteenth Asian Congress of Fluid Mechanics (14th ACFM).

4. **Luong Huu Dung** (2013), "Assessment of effectiveness of downstream flood reduction of multi-reservoirs in Ba riverbasin", a collection of works for the 9th national conference on Fluid Mechanics.

5. Ngo Dinh Tuan, **Luong Huu Dung**, Nguyen Van Sy (2015), "Characteristics of Ba riverbasin for reservoir operations and EIA", Water irrigation and environmental engineering Magazine.

6. **Luong Huu Dung** (2016), "Determining period for operations and flood control in Ba river basin", Water resources magazine.

7. **Luong Huu Dung**, Trinh Thu Phuong, Nguyen Le Giang (2016), "Droughts in 2015-2016 in 2 main riverbasin in Central Highlands", Vietnam Science and Technology magazine.