Application of HEC-ResSim In Qingjiang Cascade Reservoirs

A.D. Ampitiyawatta
Department of Export Agriculture
Faculty of Agricultural Sciences
Sabaragamuwa University of Sri Lanka
Belihuloya, Sri Lanka
ada@agri.sab.ac.lk

Abstract— **This paper evaluates currently practicing operation method of Qingjiang cascade reservoirs system with recently introduced HEC-ResSim model. Suitable operation rules for cascade reservoirs operation were derived using HEC-ResSim model. Considering 1955-2015 runoff records, three representative years (wet, normal and dry) were selected and 3-hour time interval simulation was carried out. A parallel simulation and comparative study was performed. Simulation results show that the HEC-ResSim model is significant over conventional method during wet and normal years and flooding seasons in all aspects and no significant difference in dry year and non-flooding seasons. It can be concluded that HEC-ResSim is a better tool for Qingjiang cascade reservoirs operation than the conventional method to increase hydropower generation and reduce water spill.**

Keywords—cascade reservoirs; hydropower generation; HEC-ResSim; conventional

I. INTRODUCTION

Owing to rapid growth in the world economy and population, the need for the optimum utilization of water resources has become more urgent than ever. Water is becoming a scarce resource as a result of the growing demand for its use in various purposes such as hydropower, irrigation, water supply, etc. Reservoir is one of the major storages of surface water and optimally operating single or multi-reservoir network system forms an integral part of water resources management. Number of successful applications of simulation and optimization techniques to reservoir operation problem has been reported in the past few decades. However, it reveals that no general technique is available to grasp whole water resources optimally. Most of the reservoirs in the world still manage on predefined operating rules based on different simulation models [1]. Simulation is a modeling technique that is used to approximate the behavior of a system on the computer, representing all the characteristics of the system largely by a mathematical or algebraic description [2]. It provides the response of the system for certain inputs, which includes decision rules, and enables decision makers to examine the consequences of various scenarios of an existing or a new system without actually building it [3]. In a pure simulation model, reservoir releases are determined by a set of predetermined operating rules. Through a series of simulation these rules can be modified and improved until model results are judged acceptable. The earliest simulation model appearing in the literature seems to be the study performed by the U.S. Army Corps of Engineers in 1953 for operational study of six reservoirs on the Missouri River [3]. Since then, simulation models have been widely used for planning and managing complex water resources systems. Among the wide range of simulation models, HEC-3 [4] and HEC-5 [5] models which were developed by U.S. Army Corps of Engineers can be considered as some of the best simulation models in the history. HEC-3 model is specific for reservoir system analysis for conservation purpose while HEC-5 is for simulation of flood control and conservation of systems. HEC-5 model has been updated as HEC-ResSim to include Windows-based graphical user interface by US Army Corps of Engineers for reservoir system simulation and released in 2003 [6].

Conventional simulation method is used in Qingjiang cascade reservoirs system in China for its operational purposes. However, it is used in independent reservoir operation and therefore, poor storage distribution can be seen among cascade reservoirs. Hence, much of floodwater resources are wasted during flooding seasons. Instead, recently introduced HEC-ResSim model can be applied directly for the whole cascade. The purpose of this study is to ascertain the suitability of HEC-ResSim model in Qingjinag cascade reservoirs

II. QINJIANG CASCADE RESERVOIRS AND OPERATION PLANS

A. *Qingjiang Cascade Reservoir System*

The Qingjiang basin is situated at southwest Hubei province in China and located between the east longitude 108°35 ' ~ 111°35 ' and the north latitude 29°33 ' ~ 30°50 ' in subtropical area. It is mountainous and has multi karsts land form with basin area of 17600 km^2. Abundant rainfall can be found in the basin and mean annual rainfall is approximately 1460mm. Mean annual runoff depth in the basin is 876mm and mean annual runoff is 423m^3/s. Qingjiang River is one of the main tributaries of Yangtze River in

China and winding from west to east. The total length of the mainstream is 423km with a hydraulic drop of 1430m. Along the Qingjiang River a three-step cascade reservoirs development scheme can be found from upstream to downstream which are called Shuibuya, Geheyan and Gaobazhou. Main purposes of these cascade reservoirs are power generation and flood prevention while improving navigation and fisheries facilities are the other benefits. Basic physical parameters of three reservoirs are listed in Table 1.

Table 1: Basic physical parameters of the Qingjiang cascade reservoirs

Reservoir	Normal pool level (m)	Flood prevention water level (m)	Dead water level (m)	Total storage (10^8m^3)	Dead storage (10^8m^3)	Installed capacity (MW)	Firm capacity (MW)	Regulation ability
Shuibuya	400	391.8	350	43.45	19.41	1600	310	Multiyear
Geheyan	200	193.6	160	31.2	16.42	1200	241.5	Annual
Gaobazhou	80	78.5	78	3.56	3.05	270	77.3	Daily

Since the effective storage capacity of Gaobazhou reservoir is very small comparing to other two reservoirs in Qingjiang cascade, it is using as a daily run-off-river hydropower plant and the water level is retained at 78.5m elevation at all the time.

B. Conventional Operation Plan

The conventional method carries on runoff adjustment computations by taking the reservoir characteristic water levels as the boundary conditions and obtains reservoir water storage guide curves corresponding to various hydrological processes using design installed capacity of the hydroelectric power station and the historical actual runoff data.Then separately choose upward and downward enveloping curves and gets upper and lower basic guide curves.

Thus, whole water storage space of the reservoir is divided into three zones naming (1) higher capacity zone (2) firm capacity zone and (3) lower capacity zone. The individual conventional operation charts of Shuibuya and Geheyan reservoirs are shown in Figures 1 and 2, respectively. According to the Shuibuya reservoir conventional operation chart as shown in Figure 1, the whole storage space is divided into five operational zones. Accordingly, following generation parameters are used in the operation process. When the reservoir water level is between upper and lower basic guide curves, the hydropower plant is working under its firm capacity (310MW). If the water level falls into operation zone 3, which is between upper basic guide curve and 800MW guide curve, the power plant capacity is 800MW. If the reservoir water level lies in operation zone 2, the capacity is 1600MW, which is similar to the installed capacity. When the reservoir's water level rises to flood prevention limit or enters into the flood prevention zone, the reservoir adjusts according to designed flood control rules and power plant works under the installed capacity (1600MW). If the water level falls below the lower basic guide curve, the power plant capacity is 250MW.

Six operational zones are found in the Geheyan reservoir conventional operation chart as shown in Figure 2. When the reservoir water levels are in different operation zones, respective generation parameters of the Geheyan reservoir are shown in Table 2. If the water level rises to flood prevention limit or into flood prevention zone, the reservoir adjusts according to designed flood control rules and power lant works under the installed capacity (1200MW).

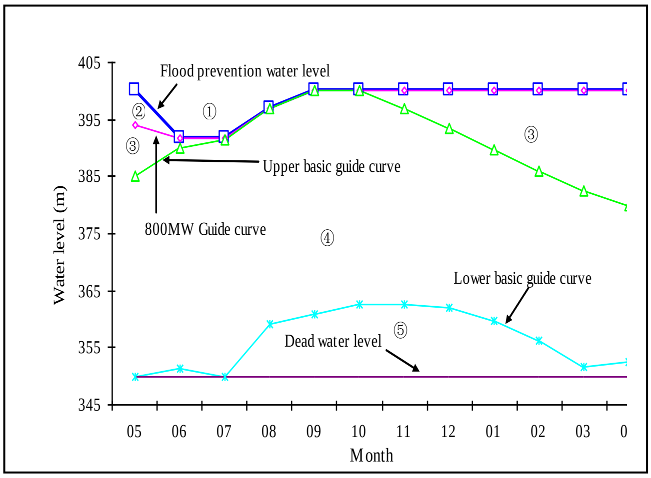

Figure 1: Conventional operational chart of Shuibuya reservoir

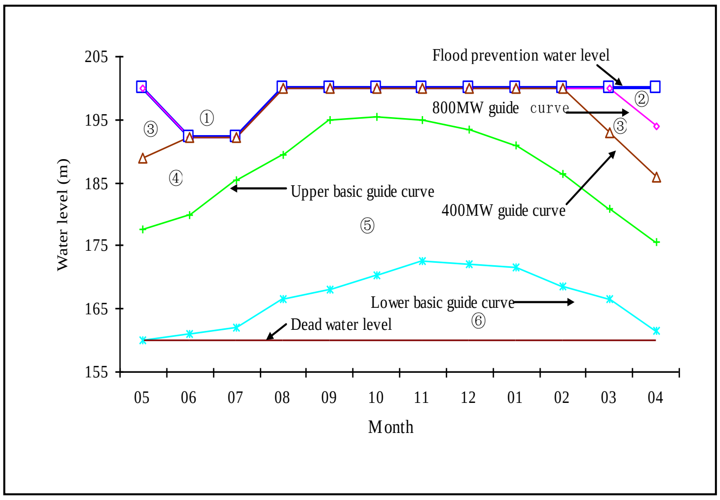

Figure 2: Conventional operational chart of Geheyan reservoir

Table 2: Generation parameters of Geheyan reservoir conventional operation chart

Operation zone	Area	Generation capacity
①	Above the flood prevention water level	1200MW (Installed
②	Flood prevention water level ~ 800MW guide	1200MW (Installed
③	800MW guide curve ~ 400MW guide curve	800MW
④	400MW guide curve ~ Upper basic guide	400MW
⑤	Upper basic guide curve ~ Lower basic guide	241.5MW (Firm capacity)
⑥	Below the lower basic guide curve	73MW

III. HEC-ResSim and its application

A.HEC-ResSim Model

HEC-ResSim is a computer based simulation model which can be used to simulate reservoir system operations. It is comprised of a Windows-based Graphical User Interface (GUI). In addition, it has capability of data storage and management and graphics and reporting facilities. The Data Storage System, HEC-DSS is used for storage and retrieval of input and output time-series data.

HEC-ResSim model offers three basic separate sets of functions called modules that provide access to specific types of data within a watershed. These modules are watershed setup, reservoir network and simulation. Each module has a unique purpose and associated set of functions accessible through menus, toolbars and schematic elements. The purpose of watershed setup module is to provide a common framework for watershed creation and definition among different modeling applications.

A watershed is associated with a geographical region for which multiple models and area coverage can be configured. A watershed may include all of the streams, projects (eg., reservoirs, levees), gage locations, impact areas, time-series locations and hydrologic and hydraulic data for specific area. After creating a new watershed, it has the ability to import maps from external sources, specify the units of measuring, add layers containing additional information about the watershed and configure elements. Moreover, it has the ability of adding projects and time-series icons within the watershed module. The purpose of the reservoir network module is to isolate the development of the reservoir model from the output analysis. Using the configurations that are created in the watershed setup module as template, it can create the reservoir network. Here, it can build river schematic, describe the physical and operational elements of the reservoir model and develop the alternatives that require analyzing. Furthermore, it can add routing reaches and other network elements to complete the connectivity of network schematic. Once the schematic is complete, physical and operational data can be defined. Also, alternatives are created that specify the reservoir network, operation sets, initial condition and data storage system path names. HEC-ResSim model has the ability of defining reservoir systems for storage balancing between tandem reservoirs and reservoirs in parallel. The purpose of the simulation module is to isolate output analysis from the model development process. Once the reservoir model is complete and alternatives have been defined, the simulation model is used to configure the simulation. The computations are performed and results are viewed within the simulation module. Results of the simulation can be viewed as plots and tabular form. Instead of that, numbers of summery reports are available after simulation is performed [6].

B.Mdoel Application

Application process of the HEC-ResSim has three steps. As the first step, Qingjiang watershed was created on the watershed setup module by defining pre-requisite parameters. Qingjiang main stream with sub streams was drawn by using the model tools and Shuibuya, Geheyan and Gaobazhou reservoirs were built on the stream subsequently. According to the application characteristics, required configurations were made. Secondly, reservoir connectivity was developed by making routing reaches between Shuibuya and Geheyan, Geheyan and Gaobazhou and downstream of Gaobazhou. As the main junctions of the reservoir network, inflow to Shuibuya, intermediate flow between Shuibuya and Geheyan, Geheyan and Gaobazhou were defined by using junction editor. Coefficient routing was selected as the routing method for all reaches in the reservoir network. Physical components were added and edited according to basic physical parameters of Qingjiang cascade reservoirs (Table 1). Two controlled outlets were defined for each reservoir and one was named as power outlet and other one as dam controlled outlet. Power plants were added to the power outlet and tail water elevation was added to both controlled outlets. For controlled release outlets of three reservoirs, maximum rate of increase and decrease were defined as $2000m^3/h$. Suitable guide curves, rules and operation data were defined according to current operation practice of the Qingjiang cascade reservoirs.

C. Deriving Reservoir Operation Rules

The period from 1^{st}, May to 30^{th}, September has been identified as the whole flood season for the Qingjiang catchment. Again, it can be divided into three sub-seasons which are rising flood season, peak flood season and recession food season. Peak flood season falls in between 1^{st}, June to 31^{st}, July. Therefore, this is an important period for reservoir

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operation and it is selected for deriving suitable operation rules for HEC-ResSim model.

Considering the previous records of 3-hour time series inflow data from 1955-2015 to Qingjiang cascade reservoirs, three representative years, wet year (1998), normal year (1987) and dry year (1992), were selected for simulation purposes. Using the selected data set, required data storage system files and alternatives were created. Finally, simulations were performed on created alternatives for deriving operation rules. Derived operation rules for Qingjiang cascade reservoirs for HEC-ResSim operations are listed in Table 3.

Table 3: Derived operation rules for Qingjiang cascade reservoirs

Reservoir	Zone	Rule	Release location	Limit	Rate (m^3/s)
Shuibuya	Flood control	Induce Surcharge	Dam	-	15000
		Maximum release	Dam	Max.	13000
		Minimum release	Power	Min.	1000
	Conservation	Minimum release	Power	Min.	230
		Controlled power release	Power	Max.	0
		Tandem operation	Shuibuya	-	-
		Controlled release	Dam	Max.	0
Geheyan	Flood control	Induce Surcharge	Dam	-	15000
		Maximum release	Dam	Max.	13000
	Conservation	Minimum release	Power	Min.	190
		Controlled power release	Power	Max.	0
		Tandem operation	Geheyan	-	-
		Controlled release	Dam	Max.	0
Gaobazhou	Flood control	Induce Surcharge	Dam	-	25000
		Maximum release	Dam	Max.	15000
	Conservation	Minimum release	Power	Min.	22
		Controlled power release	Power	Max.	0
		Down stream control	Gaobazhou	-	11000
		Controlled release	Dam	Max.	0

IV. SIMILUATION RESULTS ANALYSIS

3-hour time series inflow records to Shuibuya reservoir with intermediate flows between Shuibuya and Geheyan and Geheyan to Gaobazhou of three representative years, wet year (1998), normal year (1987) and dry year (1992), were used for cascade reservoir simulations. Using previously defined reservoir network and derived operation rules, 3-hour time interval simulation for one year period was carried out with HEC-ResSim model for selected years. A parallel simulation was also done with the conventional method for comparison purpose. All the physical and operational conditions were very similar in both methods. Finally, annual and seasonal results were compared. Resulted annual power generation abilities and spill releases from both methods are listed in Table 4. The floodwater resources utilization efficiency (η_f) of the Qingjiang cascade reservoirs can be calculated by

$$\eta_f = (1 - \sum_{i=1}^{3} W_i^S \Big/ \sum_{i=1}^{3} W_i) \times 100 \qquad (1)$$

where W_i^S 、 W_i are annual spill release and inflow discharge volumes of reservoir i. The calculated floodwater resources utilization efficiencies of these three representative years are also shown in Table 4.

Table 4: Annual power generation, spill releases and flood water resources utilization in Qingjiang cascade reservoirs

Parameter	Comparing parameter	Year		
		Wet	Normal	Dry
Annual electricity generation (10^6 KW.h)	Conventional	9068.82	7997.32	5656.84
	HEC-ResSim	9416.64	8038.55	5652.65
	Increment of	347.82	41.23	-4.19
	Increasing rate(%)	3.84	0.52	-0.07
Annual spill release (10^9 m^3)	Conventional	14.99	3.45	0.22
	HEC-ResSim	12.54	2.51	0.47
	Reduced spill	2.45	0.94	-0.25
	Reducing	16.32	27.37	-113.64
Flood water resources	Conventional	69.81	90.04	99.07
	Hec-ResSim	74.77	92.77	97.96

Table 5: Seasonal power generation and spill releases of Qingjiang cascade reservoirs

Parameter	Comparing parameter	Flooding season			Non-flooding season		
		Wet	Normal	Dry	Wet	Normal	Dry
Annual electricity generation (10^6 KW.h)	Conventional	5478.5	4536.9	2721.8	3590.3	3460.4	2935.1
	HEC-ResSim	5893.8	4641.8	2718.0	3586.4	3456.0	2929.3
	Increment of	415.3	104.91	-3.8	-3.9	-4.4	-5.8
	Increasing rate(%)	7.58	2.31	-0.14	-0.11	-0.13	-0.2
Annual spill release (10^9 m^3)	Conventional	14.91	3.44	0.22	0.067	0.013	0
	HEC-ResSim	12.52	2.51	0.47	0.017	0	0
	Reduced spill release	2.39	0.93	-0.25	0.049	0.013	0
	Reducing rate(%)	16.06	27.11	-113.64	74.78	100	na

Results reveal that HEC-ResSim works better in all the aspects of cascade simulation during wet year and normal year. Though the HEC-ResSim results are slightly less than conventional method during dry year, it cannot be seen a significant difference. Accordingly, HEC-ResSim method can increase 41.23×10^6 KW.h (or 0.52%) hydropower output and reduces 0.94×$10^9$$m^3$ (or 27.37%) spill release in the Qingjiang cascade reservoirs during the normal year. In wet year, it can be seen a great enhancement of the power generation ability. It is mainly depending on the higher inflow scenario during the wet year. HEC-ResSim acts very efficiently when controlling higher inflows to the cascade by making better storage distribution between upstream and downstream reservoirs and saving excess flood water. According to the flood water resources utilization results, HEC-ResSim shows 2.73% increment of η_f during the normal year. It also reveals the suitability of HEC-ResSim model in using Qingjiang cascade reservoirs operation.

Flooding and non-flooding seasonal simulation results are shown in Table 5. Similar to the annual results, HEC-ResSim shows superior results during flooding seasons of wet year and normal year on the aspects of power generation and water utilization. But in the seasonal case, it is very clear that the differences between HEC-ResSim and conventional method are very prominent. Therefore it is noticeable that the beneficial effects of simulation have been achieved during flooding seasons. Anyhow, here also conventional method shows slightly elevated power generation and slightly lowered spill release results over HEC-ResSim during the dry year.

When consider about non-flooding season simulation results, conventional method has slightly elevated power generation abilities in all the years. It is mainly due to poor inflow scenario during non-flooding season. Floodwater resources saving by HEC-ResSim is excellent in wet and normal years while both methods show similar results during dry year non-flooding season. During the wet year (1998), Qingjiang cascade has received some what higher inflows during off-flooding season. It is an evident that HEC works well whenever there are higher inflows to Qingjiang cascade either flooding or non-flooding season.

V. Conclusion

HEC-ResSim show significant results over conventional method during wet and normal years and flooding seasons in all aspects. In dry year and non-flooding seasons, there is no significant difference between power generation results in both methods. However, HEC-ResSim shows results on floodwater saving. Therefore, this research work reveals that HEC-ResSim is a better tool for Qingjiang River cascade reservoirs operation than the currently practicing conventional method to increase hydropower generation and reduce water wastage by spill.

References

[1] Oliveira, R. and Loucks, D.P., "Operating Rules for Multireservoir Systems" Water Resources ResearchVol. 33, No. 4, 1997, pp 839-852.

[2] Maass, A., Hufschimidt, R., Dorfman, H.A., Thomas, Jr., Marglin, S.A, and Fair, G.M., , "Design of Water Resources Systems" 1962 Harvard University Press, Cambridge, MA.

[3] Yeh, W.W-G. "Reservoir Management and Optimization Models: A state-of-the-art review" Water Resources Research Vol. 21 No. 12, 1985. pp1797-1818.

[4] Hydrologic Engineering Center (HEC), "HEC-3: Reservoir System Analysis, Technical Report" 1971, US Army Corps of Engineers, Davis, CA.

[5] Hydrologic Engineering Center (HEC), "HEC-5: Simulation of Flood Control and Conservation Systems, Documentation and User's Manual" 1989, US Army Corps of Engineers, Davis, CA.

[6] Klipsch, J.D., 2003, "HEC-ResSim: Reservoir System Simulation, User's manual" US 2003, Army Corps of Engineers, Hydrologic Engineering Centre, Davis, CA.