Application of MIKE 11 in managing reservoir operation

LONG LE NGO
Institute of Environment & Resources, Technical University of Denmark, Building 115,
DK-2800 Kongens Lyngby, Denmark, e-mail: lln@er.dtu.dk

HENRIK MADSEN
DHI Water & Environment, Agern Allé 5, DK-2970 Hørsholm, Denmark,
e-mail: hem@dhi.dk

DAN ROSBJERG
Institute of Environment & Resources, Technical University of Denmark, Building 115,
DK-2800 Kongens Lyngby, Denmark, e-mail: dr@er.dtu.dk

CLAUS B. PEDERSEN
DHI Water & Environment, Agern Allé 5, DK-2970 Hørsholm, Denmark,
e-mail: cbp@dhi.dk

Abstract: Hoa Binh is the largest reservoir in Vietnam. It has been operated since 1990 with the main purposes of flood control in the Red River basin and hydropower generation. Because these different purposes always cause conflicts and disputes during the flood season, it is desirable to improve the current operational regulations of the reservoir. In this paper, the operation rules of the reservoir are adjusted by applying the MIKE 11 river modelling tool. The model set-up includes the main rivers and tributaries of the Red River basin and a logical decision tree defining the reservoir regulation. These strategies define the reservoir release as function of the time of the year, the actual reservoir stage, and the water level forecast at Hanoi. A data set consisting of ten years of flood season data was used to evaluate the control strategies with respect to flood control and hydropower generation. The reservoir operation using the complete control system and the current as well as alternative regulation strategies has been evaluated. Results showed that the operation rules perform well under different hydrological scenarios and, therefore, can be effectively used for short-term reservoir operation.

Key words: reservoir operation; flood control; hydropower generation; MIKE 11 river model.

1 INTRODUCTION

The operation of a reservoir system for flood control and hydropower generation is a complex decision making-process involving many variables and objectives, as well as considerable risk and uncertainty (Oliveira and Loucks, 1997). In addition, the conflicting objectives lead to significal challenges for operators when making operational decisions. Most reservoir systems are still managed based on fixed rule curves. These rules are usually presented in the form of graphs or tables (Yeh, 1985) and guide the release of the reservoir systems according to the current storage level, the hydro-meteorological conditions, and the time of the year. Operators, however, also apply personal judgment to decide on the target value, and thus the selected target becomes subjective (TVA, 2005).

In recent years, the problem of ineffective operation of existing reservoirs using outdated technology and highly subjective management practices has been pointed out by many specialists. Therefore, it is necessary to establish a more analytical and systematic approach to reservoir operation. This requires the assistance of computer modelling tools to provide information for rational operational decisions. One effective tool is a simulation model that includes decision rules to enable a decision-maker to examine the consequences of various scenarios of an existing reservoir system (Yeh, 1985).

In this paper, reservoir operation rules for the Hoa Binh reservoir are integrated with the MIKE 11 river modelling tool (DHI, 2004). The MIKE 11 model set-up includes the main rivers and tributaries of the Red River basin. A decision tree made up of more than one hundred logical statements is supplied to the model in order to define the present reservoir regulation policy. The intention is to investigate the possibilities for improved flood control during the flood season (1 June - 1 Oct.) by changing the reservoir control strategies in terms of reservoir stages and the water level forecast at Hanoi. At the same time, the energy production must be at the highest level possible.

2 DATA

A six-hourly hydrometric data set comprising ten years of data during the flood season (1 June – 1 Oct.) was used. The General Department of Hydrometeorological Service (GDHS) is responsible for collection, processing and management of these data. The cross-sections and longitudinal bed profiles were measured in 2000 under the flood-control programme for the Red and Thai Binh rivers. In addition, elevation and geographical (e.g. river network) data have been used to set-up and calibrate the model.

3 SHORT DESCRIPTION OF THE MIKE 11 MODEL

MIKE 11 is a professional engineering software package for simulation of one-dimensional flows in estuaries, rivers, irrigation systems, channels and other water bodies. The Hydrodynamic Module (HD), which is the core component of the model, contains an implicit finite-difference 6-point Abbott-Ionescu scheme for solving the Saint-Venant’s equations. The formulation can be applied to branched and looped networks and flood plains. A number of add-on modules such as the Structure Operation Module (SO) exist for the Hydrodynamic Module.

The SO module consists of a number of different standard structures with user-defined operating strategies such as sluice gates, overflow gates, radial gates, pumps, reservoir releases etc. Using the interface of the SO module, reservoirs may be controlled by choosing among an arbitrary number of different control strategies, and any number of conditions can be specified for each strategy. For a given control strategy all the conditions must be satisfied, if the strategy in question is to be executed. The use of several control strategies makes it possible to simulate multi-purpose reservoirs, which take into account a large number of objectives such as flood protection, energy production and water supply (DHI, 2004).

4 MODEL SET-UP

4.1 MIKE 11 hydrodynamic model

The model includes a subset of rivers that belong to the Red River system with the following main tributaries: Da, Thao, Lo, Duong (see Figure 1).

The upstream boundary conditions are discharge boundaries at Ta Bu on Da, Phu Tho on Thao, and Vu Quang on Lo. The downstream boundary conditions are rating curve (discharge vs. water level) boundaries at Hung Yen on the Red River and Thuong Cat on Duong. The data used for model calibration are discharge and water level at Son Tay and Hanoi on the Red River.

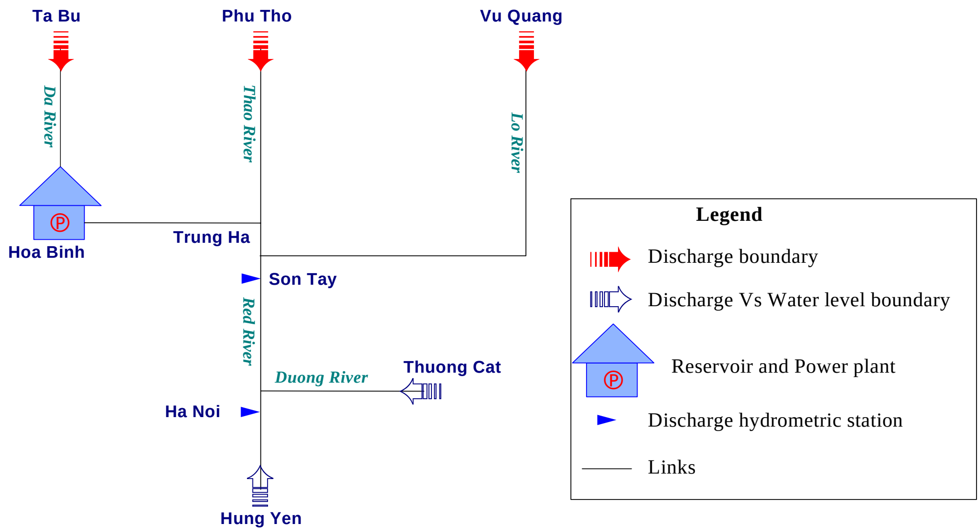


Figure 1: Description of the Red River basin system

The river network for the Red River system, including the Hoa Binh reservoir, is schematised in 436 chainages and 15 branches. The Hoa Binh dam has been placed in the reservoir branch of the network, and the 6 spillways and 12 bottom gates of the dam have been included in the control structure of the model. The discharges through spillways and bottom gates are specified for different water levels, when all the gates are fully open. A total of 311 cross sections located in 15 branches of the system are included in MIKE 11, and 66 cross sections are used to define the Hoa Binh reservoir. The Manning's roughness coefficient has been taken as 0.033, 0.034 and 0.036 for Da, Thao, and Lo, respectively. For the upstream part of the Red River the Manning's roughness coefficient is set to 0.038, whereas 0.040 is used for the rest of the river.

4.2 Hoa Binh reservoir operation

The Hoa Binh reservoir, which was completed in 1989, has a storage capacity of 9.5 billion m3, and an active storage of 5.6 billion m3. It is expected to reduce the peak flood level of 1971 by 1.5 metres at Hanoi (from 14.8 m to 13.3 m). The hydropower plant at Hoa Binh has a power generating capacity of 1920 MW and an energy production of 7.8 billion KWh per year (40 percent of Vietnam's electricity) (Tinh, 2001). It is a multipurpose reservoir providing flood control, hydroelectric power generation, and water supply. The Central Committee for Flood and Storm Control takes responsibility for operation of the reservoir during the flood season by regulating the outflow as appropriate.

In order to ensure both flood protection and electric efficiency improvement, three regulation periods have been defined (CCFSC, 2005):

a) Subordinate floods: From 15 June to 15 July;
b) Main floods: From 16 July to 20 August;
c) Final floods: From 21 August to 15 September.

The staged water levels in the reservoir before storing water for flood cutting commences are shown in Figure 2 (flood control curve). In the final flood period, operation is reviewed in consideration of rainfall forecasts with the goal of ensuring a full reservoir and maximum power generation before the dry season begins in October.

4.2.1 Regulation for flood control

Reducing downstream flood damage is the primary objective of the reservoir. To reduce the risk of flooding, the Hoa Binh reservoir implements the following actions:

Operational procedures for reducing regular floods: If it is predicted that the water level in Red River at Hanoi exceeds +11.50 m within the next 24 hours, flood-reducing operations will be initiated for the Hoa Binh reservoir. The aim is to keep the water level at Hanoi below +11.50 m, while at the same time keeping the water level in the reservoir below +100 m.

Operational procedures for reducing a major downstream flood in the Red River: Given that the water level is +11.50 m at Hanoi station, the water level +100.00 m at Hoa Binh reservoir (i.e. the maximum level for regular flood regulation), and the predicted water level in the Red River in the next 24 hours rapidly increases, then the normal operational procedures will be changed to procedures for reducing a major flooding in the downstream part of the Red River. These procedures are based on the water level at Hanoi being below +13.10m and the reservoir level being below +120m..

Operational procedures for safe protection of the Hoa Binh reservoir: In the case where the water level at Hanoi reaches +13.10 m, the reservoir level is +120 m, and there is a flooding in Da that is rapidly increasing (which can become harmful for operations of the Hoa Binh reservoir), the procedures are changed to reservoir protection. Based on predicted water levels for the Da and the Red River, a step-by-step opening of bottom and spillway gates is commenced to reach a situation where the release through the reservoir and the turbines is not larger than the inflow.

Water releases are usually accomplished by operating the turbines at maximum capacity until the necessary quantity of water has been discharged from the reservoir. At other times, additional water must be released through the bottom gates or spillways to lower the reservoir level more quickly and regain the needed storage capacity for future flood events. For a detailed description of the regulation, refer to CCFSC (2005).

4.2.2 Regulation for hydropower generation

Because hydropower generation is the second objective of the reservoir in the flood season, the reservoir is operated to get as much hydropower as possible within the contraints of the flood mitigation rules. A 10-day rule curve assumption is used to define how much water is supplied in the model for hydropower generation. It consists of three curves (upper, lower, and critical limit) as shown in Figure 2. The operations are as follows:

1) When the water level is above the upper limit, hydropower generation is maximized.
2) When the water level is between the upper and lower limits, hydropower generation is operated with a discharge through turbines corresponding to maximum capacity to the minimum downstream discharge requirement.
3) When the water level is between the lower and critical limits, hydropower generation is operated with the discharge through turbines to meet the minimum demand of agriculture (680 m^3/s).
4) When the water level is below the critical limit, hydropower generation is halted.

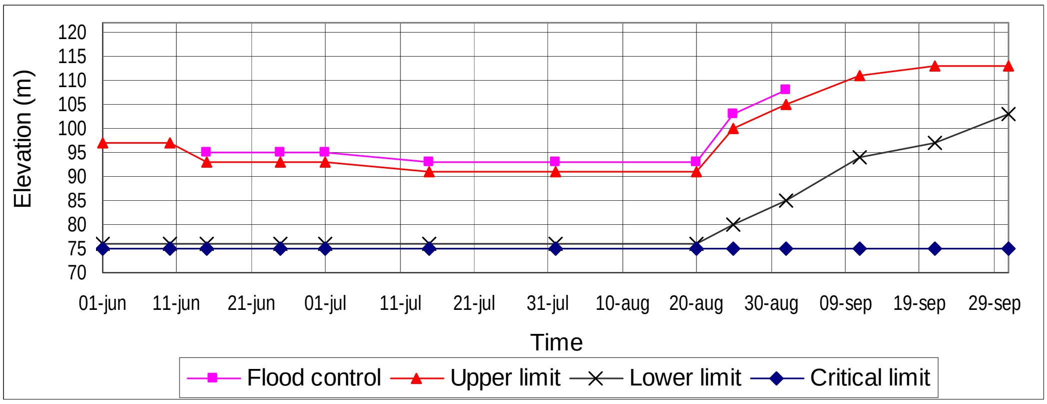


Figure 2: Rule curves of the Hoa Binh reservoir

5 APPLICATION SCENARIOS

After developing and calibrating the model, it is possible to study various options for flood control. Three alternative cases have been analysed:

a. The Hoa Binh reservoir starts its operation for regular flood cutting when the 24 hour forecast of the water level in the Red River at Hanoi exceeds + 10.50 m.
b. The Hoa Binh reservoir starts its operation for regular flood cutting when the 24 hour forecast of the water level in Red River at Hanoi exceeds + 11.50m.
c. The same situation as case A. However, the water level in the reservoir in the main flood period is + 95 m before storing water for flood cutting (2 m higher than in the original regulation).

Table 1 Maximum discharge and water level in the Hoa Binh reservoir and at Hanoi station.

No	Year	Date	Q_{max} at Hoa Binh (m^3/s)	H_{max} at Hanoi (m)
1	1996	18 August	22600	12.43 (12.90)
2	1964	9 July	17200	11.58
3	1971	20 August	16200	14.05 (14.67)
4	1969	17 August	15800	13.20
5	1995	18 August	13400	11.73 (12.28)
6	1991	12 August	13000	11.49 (11.47)
7	1966	30 July	12800	11.77
8	1983	4 August	12600	12.07
9	1986	26 July	12000	12.35
10	1990	29 July	11000	11.94 (12.05)

Note: The value in the brackets shows the data estimated by Hoa et al. (1997) without reservoir regulation and dyke break.

In order to evaluate the control strategies, historical data of ten flood seasons with very large floods are selected. They are sorted in descending order of maximum discharge at the Hoa Binh station on Da (see Table 1). All of these events caused the water level at Hanoi exceeding the alarm level III (11.50 m).

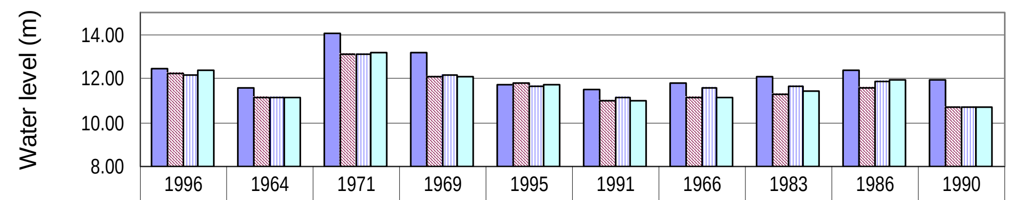
The reservoir operation has been evaluated with respect to flood control and hydropower generation using the actual regulation and the implemented control system with the three alternative operation strategies.

6 RESULTS AND DISCUSSIONS

When applying these strategies to Hoa Binh reservoir operation, the following questions arise: How will the reservoir work and how much does the reservoir reduce the water level at Hanoi? How much does it shorten the duration of high water level (the water level at Hanoi greater than the alarm level III corresponding to a water surface elevation above 11.50 m)? And how much does it increase hydropower generation? In order to answer these questions the obtained results are presented below in terms of flood control and hydropower generation.

6.1 Flood control

One of the most important issues of flood control for the downstream part of the Red River basin is peak flood level reduction. It is obtained by designating a volume of storage in the reservoir. By using the MIKE 11 model the effects of alternatives reservoir operation policies on flood control are evaluated quantitatively. Figure 3 gives the peak flood levels at Hanoi that would occur in the ten years of flood seasons corresponding to, respectively, Case A, Case B and Case C reservoir operation policy compared to the observed water level (Reality). It should be mentioned that the water levels that occurred after 1990 have been obtained with the actual regulation of the Hoa Binh reservoir.



	1996	1964	1971	1969	1995	1991	1966	1983	1986	1990
Reality	12.43	11.58	14.05	13.20	11.73	11.49	11.77	12.07	12.35	11.94
Case A	12.26	11.17	13.14	12.09	11.77	10.98	11.15	11.26	11.59	10.69
Case B	12.19	11.17	13.12	12.15	11.67	11.10	11.58	11.64	11.86	10.69
Case C	12.34	11.17	13.17	12.10	11.70	10.99	11.15	11.41	11.94	10.69

Year

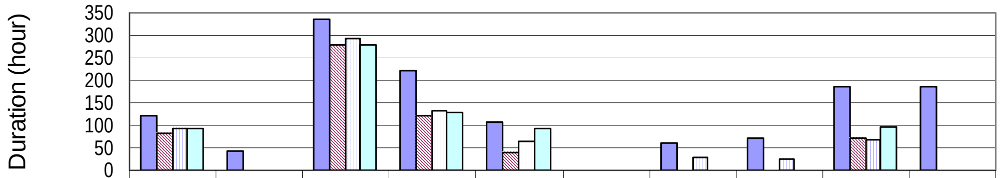
Figure 3: Maximum water level at Hanoi

From this figure, it can be seen that regulation of the Hoa Binh reservoir decreases the peak water levels at Hanoi. For example, in 1971 (the largest flood observed at Hanoi), the water level at Hanoi would be reduced from 14.05 m (without a dike break, the peak water level at Hanoi would have been 14.67 m) to 13.14 m, 13.12 m, and 13.17 m corresponding to, respectively, Case A, Case B, and Case C. At these stages, the peak water level at Hanoi is below the design level of the dike. The Case A, Case B, and Case C strategies for reservoir operation are more effective in reducing the flood peak at Hanoi than the actual operation practice. In the 1996 flood, the maximum water level at Hanoi has been estimated to be 12.90

m (Hoa et al., 1997). It was reduced by 0.47 m under the existing reservoir regulation, whereas it would be reduced by 0.64 m, 0.71 m, and 0.56 m under the alternative reservoir operation strategies (Case A, Case B, and Case C, respectively). According to Hoa et al. (1997), when applying good forecasting and operation rules, the reduction can be as much as 1.27 m (i.e. a reduction of the peak water level at Hanoi from 12.90 m to 11.63 m). During other floods, the effect of reservoir regulation on flood cutting can also become significant.

HHhh have to

To combat flooding, the city of Hanoi is protected by river dikes. Due to the fact that the dikes are built by earth material and considered to be of low quality, the time during which the dikes are able to resist high water levels has become an issue of concern (Tuan, 2002).



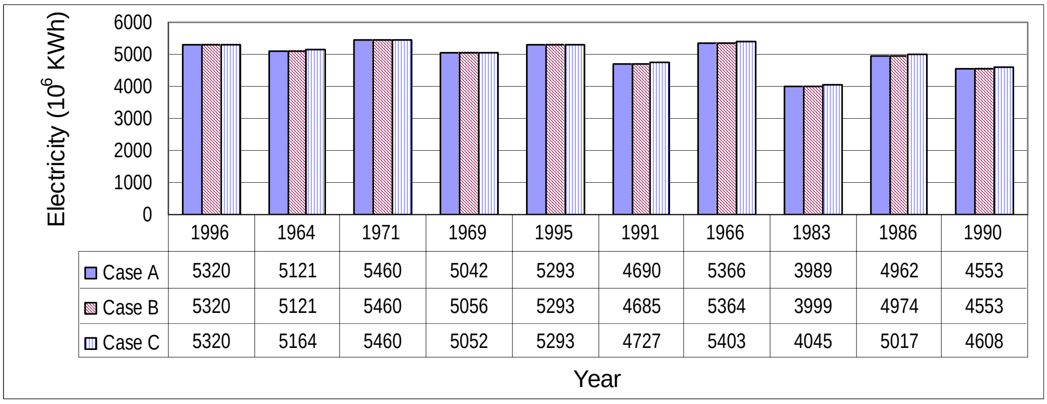
Year	1996	1964	1971	1969	1995	1991	1966	1983	1986	1990
Reality	120	42	336	222	108	0	60	72	186	186
Case A	83	0	277	120	40	0	0	0	72	0
Case B	93	0	292	131	64	0	28	24	69	0
Case C	93	0	279	127	92	0	0	0	97	0

Figure 4: Duration of high water level at Hanoi

Figure 4 shows that, there is a significant contribution from the Hoa Binh reservoir to shortening the period of high water level at Hanoi. From this figure, it can be seen that, for most of the years, the Case A reservoir operation can ensure the shortest duration of high water level at Hanoi. From the data of Hoa et al. (1997), it can be seen that in 55 out of the average of 100 years the water level at Hanoi has risen above + 11.00 m. Therefore, adopting the Case A reservoir operation policy will increase the number of times that the Hoa Binh regular flood cutting operation is started, which will be an advantage for hydropower generation in terms of discharge and reservoir level.

6.2 Hydropower generation

The second primary objective of the reservoir is the production of power for energy users. The Hoa Binh reservoir has 8 turbines with a maximum capacity of each turbine of 240 MW. The existing data of hydropower generation is not available, so in this paper the three alternatives will be used to compare electricity production. The MIKE 11 model was used to simulate the hydropower production for each alternative.



	1996	1964	1971	1969	1995	1991	1966	1983	1986	1990
Case A	5320	5121	5460	5042	5293	4690	5366	3989	4962	4553
Case B	5320	5121	5460	5056	5293	4685	5364	3999	4974	4553
Case C	5320	5164	5460	5052	5293	4727	5403	4045	5017	4608

Figure 5: Hydropower generation

Figure 5 presents the total hydropower generation that could be obtained from the 10 flood seasons. From this figure, it can be seen that the effect on hydropower generation under the three alternative strategies are quite similar. This can be explained by the fact that the flow in these flood seasons was abundant, so during most of the time the turbines could work with maximum capacity. The difference only arises in the final flood period when, beside flood control, the reservoir has to operate for two conflicting purposes, which are hydropower generation and storing of water for the dry season beginning in October. In this case, the Case C alternative seems to be predominating. However, with higher water levels in the reservoir before storage of water for flood cutting in the main flood season commences, this alternative strategy (Case C) will reduce the potential for flood control of the Hoa Binh reservoir.

7 CONCLUSIONS

The study implements a rule curve for the Hoa Binh reservoir in the MIKE 11 simulation model and demonstrates that it can be used efficiently to regulate the reservoir under different hydrological scenarios. These rules define reservoir releases (through bottom gates, turbines and spillways) in terms of the reservoir stages, the time of the year, and the water level forecast at Hanoi. They can be used to help the operators' decision-making.

In this study, a data set that comprises ten years of flood seasons has been analysed. The results show that the reservoir operation using the complete control system can lower the maximum water level and shorten the duration of high water level at Hanoi compared to the actual operation. With respect to hydropower generation, releases can be scheduled so that hydropower turbines are operated to maximize their value to the power supply system.

The study provides the basis for further research in improving the effectiveness of Hoa Binh reservoir in terms of flood control and hydropower generation. In the next phase, optimisation of the reservoir operation will be carried out, in which the decision parameters for generation of rule curves will be determined by using the Shuffled Complex Evolution (SCE) optimisation algorithm.

REFERENCES

CCFSC (Central Committee for Flood and Storm Control, 2005) Regulation on operation of HoaBinh hydroelectric power reservoir and flood cutting constructions for Red River in annual flood seasons, Drafted version, (in Vietnamese, unpublished).

DHI (2004) MIKE 11 – A modelling system for Rivers and Channels. DHI – Water & Environment, Hørsholm, Denmark.

Hoa, T.Q. et al. (1997) Study on establishment of a technique for flood estimation in the upstream region of Red River basin using Hoa Binh reservoir's operation (Final report). Hanoi Water Resources University, Hanoi, Vietnam (in Vietnamese).

Oliveira, R. and Loucks, D.P. (1997) Operating rules for multi-reservoir systems. Water Resources Research 33(4): 839-852.

Tinh, D.Q. (2001) Participatory planning and management for flood mitigation and preparedness and trends in the Red River Basin, Vietnam. Available at the website: http://www.unescap.org/esd/water/disaster/2001/vietnam.doc by June 2005.

Tuan, N.L. (2002) Dynamic flood routing in river networks and applications in flood control for the Red River basin. PhD dissertation, Miyazaki University, Miyazaki, Japan.

TVA (2005) Reservoir Operation Study, Final Programmatic EIS, Report of Tennessee Valley Authority, Homepage of TVA http://www.tva.gov/environment/reports/ros_eis/ (Available in June 2005)

Yeh, W (1985) Reservoir management and operations models: A state-of-the-art review. Water Resources Research 21(12): 1797-1818.