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Simulation of Karangkates Reservoir Operation

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Abstract: The present paper describes the application of a simulation model for the operation of Karangkates reservoir in the Brantas Basin located in East Java – the largest province of Java, Indonesia. At present, the basin is experiencing considerable stress on the water resources in the basin due to huge developmental pressures. Consequently, the water resources in the Brantas basin are fast approaching their limits. The demand for potable water is increasing rapidly, and therefore it is important that the available water resources are managed in the best possible manner. Through this research, the application of simulation model for the operation of Karangkates reservoir has been demonstrated. Simulation models runs have been carried out to estimate peak and offpeak power that could be generated from the Karangkates reservoirs at different exceedence probabilities. Results have been presented for the 50%, 95% and 98% exceedence probabilities. A distinct practical advantage of the simulation model presented here is that it can be used to simulate the operation of reservoirs under various user defined operating policies.

Keywords: simulation, Karangkate, reservoir, Brantas

I. INTRODUCTION

Water resource systems are an important part of the infra-structure of every country, particularly the developing ones. In addition to the basic purpose of supporting life, they serve a multitude of water uses such as water supply, hydropower generation, recreation, irrigation, flood control, navigation and wild life maintenance. The spatial and temporal distribution of water is highly variable and is dependent upon the climatic factors that are beyond human control. Due to tremendous population growth and extensive industrial and agricultural development, the demand on water resources is increasing everywhere in the world. In some parts, the characteristics of water supply and demand pose few problems for agricultural, domestic, and industrial users. In other areas, including much of the developing world, physical, social and political factors make effective water resource management vital. In developing countries, the gap between water demand and supply has been continuously widening. This has led to an increased emphasis on the optimal management of the available resources. Rigorous planning and management of water resources is required for long term sustainable resource development. The need for optimal management of existing water resource systems as well as the optimal development of the new ones is now universally acknowledged. Optimising the economic benefits of water resource systems is a classical and persistent problem. The solution to the problem is difficult because of the large number of variables involved, the non-linearity of system dynamics, the stochastic nature of future inflows, and other uncertainties of the system. Nevertheless, a number of mathematical programming techniques have been developed to aid derivation of optimal operating strategies for water resource systems. Most of these techniques perform satisfactorily for the problems they are developed for. A generic methodology that can handle problems in their general form has not yet been identified however. For this reason, there is a continuing need to improve and extend existing optimisation techniques as well as to explore new ones.

II. LITERATURE REVIEW

During the last three decades, one of the most important advances made in the field of water resources engineering has been the development of optimisation techniques for planning, design and management of complex water resource systems. The recent rapid increase in computer technology has made the development of sophisticated mathematical models for the analysis of water resource systems possible. These models are increasingly being used by system managers to determine decision alternatives which are optimal in some defined sense. The optimisation of reservoir systems operation usually involves the search through large decision spaces for optimal parameter sets. Often, the decision space is too large for a complete search. This has motivated the development of various optimisation procedures. However, despite the extensive research carried out in the last three decades, reservoir control still remains an active research field. Most optimisation procedures are based upon some type of mathematical programming technique such as linear programming (LP), non-linear programming (NLP), or dynamic programming (DP) first reported by Bellman (1957).

Dynamic programming (DP) has long been recognized as an effective approach for optimization of multi-stage decision processes. Hall and Buras (1961) were the first to propose the application of dynamic programming (DP) to determine the optimal returns from the reservoir systems. Young (1967) developed optimal operating rules for a single reservoir using DP. Dimensionality problems associated with the conventional DP approach has motivated the development of many variants of DP notable being incremental DP (Larson, 1968) and discrete differential DP (Chow and Cortes, 1974). Another approach that overcomes the dimensionality problem is the DP successive approximation (DPSA) technique (Trott and Yeh 1973). Turgeon (1981a) has reported the use of progressive optimality algorithm (POA), which can handle large-scale systems. The implementation of POA is more complicated than that of DDDP and DPSA. None of the variants of DP are completely free from the curse of dimensionality associated with DP. Approaches based on optimal control theory (OCT) (Pontryagin et al. 1962) have also been used for reservoir systems optimisation. Wasimi and Kitanidis (1983), Papageorgiou (1985), Georgakakos and Marks (1987), Georgakakos (1989), McLaughlin and Velasco (1990), and Mizyed et al. (1992) have all reported the use of the approach. Many other optimisation techniques have been developed with their own merits and demerits.

Dimensionality problems associated with the traditional optimization approaches have motivated the development of evolutionary algorithms. Notable among these are genetic algorithm (Goldberg 1989), ant colony optimization, and particle swarm optimization. Many works (DeJong 1975; Michalewicz 1992) have established the validity of the GA technique in function optimisation. A brief review of GA applications to civil engineering problems in general and water resources problem in particular is given by Wardlaw and Sharif (1999) and Sharif and Wardlaw (2000). Meraji et al. (2011) presented particle swarm optimization for application to operation of Dez reservoir in southern Iran. Results obtained have shown that algorithm works better than the non-linear programming (NLP) model. Afshar et al. (2011) presented honey bees mating optimization algorithm for developing operating rules for multireservoir systems. A detailed review of evolutionary algorithms as applied to reservoir operation models with single as well as multiple objectives has been presented by Ayeyemo (2011). Rani and Moreira (2010) present an elaborate survey of simulation and optimization modelling approaches used in reservoir systems operation problems. Simulation models present an alternate approach for determining optimal solutions for problems that are not amenable to solutions by available techniques. Often, the time required to obtain a solution to a complex problem is too long. For such problems, the cost of obtaining an optimal solution is more than the savings obtained through applying the optimal solution. In such cases simulation models provide an effective tool for obtaining solutions that could be practically implemented.

III. THE STUDY AREA

The Brantas Basin is located in East Java, the largest province of Java, IndonesiaThe Brantas Basin lies in the Southern Hemisphere and has a tropical climate. Figure 1 shows the main features of the Brantas Basin. The mean annual rainfall over the basin is about 2000 mm varying from 1500-1800 mm in the delta area to over 3000 mm on the south western slopes of G. Kelud. The climate is monsoonal and the wet season is associated with the northwest monsoon which generally extends from November through April. During this period, 80 percent of the annual rainfall can be expected. This seasonal nature of rainfall leads to marked seasonality of streamflow in the K. Brantas. The mean daily temperature is generally around 23.80 C in Malang and around 27.50C in the Brantas Delta. Temperature varies little throughout the year. The relative humidity is high at all times at about 60-80%.

The Kali Brantas is the second largest river in Java and has a total catchment area of 12000 km2 and a main stream length of 341 km. Almost half of the total basin area is under cultivation. The main stream of the Kali Brantas irrigates 81,000 hectares (ha) of high intensity agriculture whereas the total land irrigated in the basin is about 200,000 ha. The Kali Brantas forms a spiral around the G. Batuk, G. Kelud and G. Arjuno: G. Kelud is an active volcano. Finally, Kali Brantas flows into the Indonesian Ocean south of the City of Surabaya. The primary use of water in the basin is for irrigated agriculture. The annual diversion requirement for schemes fed by the Brantas main stream alone is 1600 Mm3. The study by Mott MacDonald had put the industrial water use

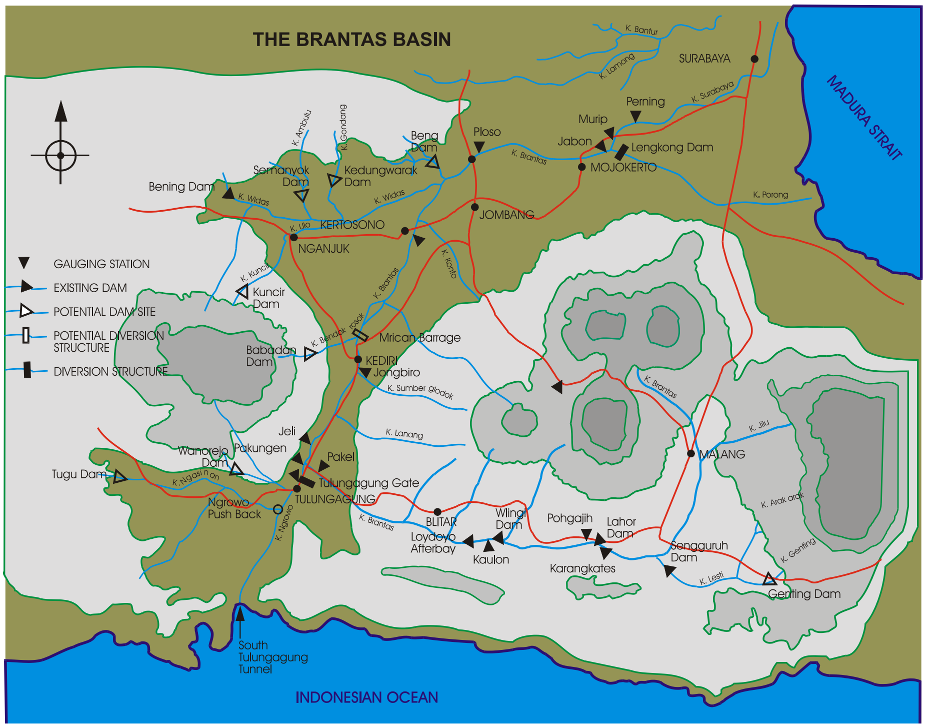

Fig. 1 The schematic of the Brantas Basin

by direct abstraction from the K. Surabaya at 1.0 m3/s after allowing for unlicensed abstractions and inaccuracies in the estimates of actual consumptive use. Surabaya is the commercial and industrial centre of East Java. The city has been expanding rapidly and so is the demand for potable water supplies. The demand projection for the City of Surabaya is shown in Figure 2. By the year 2020, the potable water demand is expected to rise to 20 m3/s. Regular Flushing of canals in the urban and the semi urban parts of Surabaya is required to maintain an acceptable level of water quality and to prevent the deposition of organic matter on the bed of the canals. The demand for flushing irrigation canals in the City of Surabaya has been estimated to be of the order of 120 Mm3 annually.

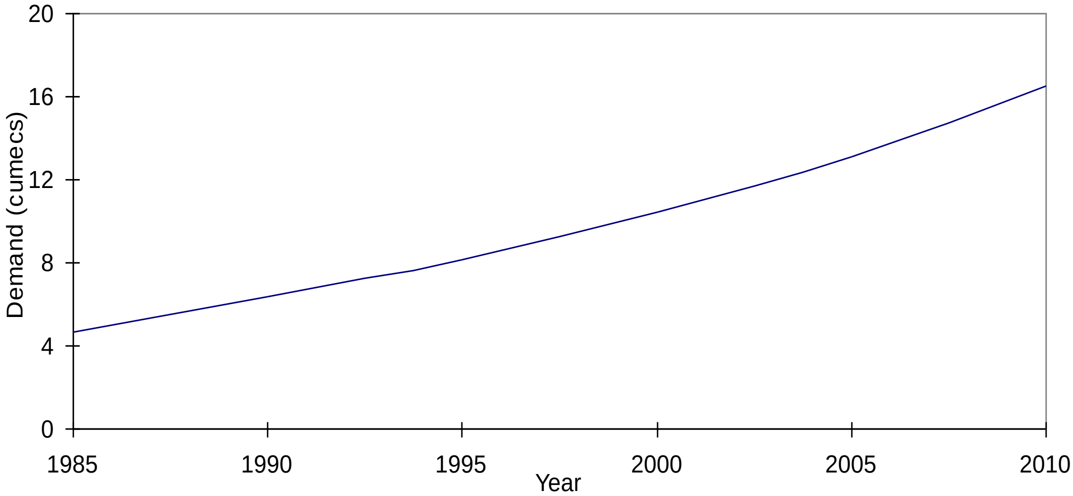

Fig. 2 Potable water demand forecasts for City of Surabaya

A comprehensive water resource availability study in the Brantas basin was carried out by Mott MacDonald (1981). The study dealt with water use in the K. Surabaya and with water resource availability for expansion of city's water treatment facilities. The study concluded that water resource development in the basin had reached its limits and recommended a revision of the operation rules of Karangkates reservoir. Japan International Co-operation Agency (1985) completed a water resource development and management plan for the basin. An action plan was prepared covering all aspects of integrated development in the basin. Mott MacDonald (1988) carried out a major water resources Master Plan study for water supply for East Java Province. As part of the project, a simulation model was developed for the Brantas Basin. Wardlaw (1993) describes the development of the model and the diverse ways in which the past developments have influenced the hydrological records in the basin.

IV. KARANGKATES RESERVOIR

Karangkates reservoir is the most important reservoir in the Brantas Basin. It was built in 1972 in the Village of Karangkates, Subdistrict of Sumber Pucung in East Java. It has a total catchment area of 2200 km2 and regulates flows during the dry season. The effective storage capacity is 253 Mm3 and although this is less than 4 percent of mean annual basin runoff, its regulating effect on dry season flows is significant. The potential surface flow from the basin is 12 billion m^3/year while the annual utilization is about 3 billion m3/year. The releases from Karangkates reservoir are used for generating hydropower, for irrigation and for supplying drinking water to the City of Surabaya. The water from the reservoir is used to irrigate 34,000 ha of agricultural land. For power production, Karangkates reservoir is very important. It has a total installed capacity of 105 mega watts (MW) and accounts for approximately 20 percent of the total installed capacity in East Java. The characteristics of Karangkates reservoir are summarised in Table 1 and the elevation versus area and storage data is presented in Table 2

TABLE I
CHARACTERISTICS OF KARANGKATES DAM AND RESERVOIR

Dam Characteristics	
Type	Rock Fill
Height	100.0 m
Crest Elevation	279.0 m
Crest Length	810.0 m
Reservoir Characteristics	
Catchment Area	2050 km2
Normal HWL	272.5 m
Normal LWL	246.0 m
Design HWL	275.5 m
Abnormal HWL	277.5 m
Surface Area (HWL)	15.0 Km2
Gross Storage Capacity	350.11 Mm3
Effective Storage Capacity	267.0 Mm3
Power Characteristics	
Type of Turbine	Vertical Francis
Installed Capacity	3 x 35 MW
Maximum Turbine Discharge	51.4 m3/s
Minimum Turbine Discharge	25.0 m3/s

TABLE IIIII
ELEVATION VERSUS STORAGE AND AREA DATA FOR KARANGKATES RESERVOIR

Elevation (masl)	**Storage**	**Area (Km2)**
215	0.922	0.37
220	4.18	1.01
225	10.40	1.62
230	20.02	2.38
235	33.76	3.30
240	52.61	4.54
245	77.34	5.78
246	83.40	5.98
250	107.67	6.80
255	143.77	8.15

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260	186.94	9.76
262.5	212.56	11.13
265	241.10	12.65
267.5	273.51	14.12
270	309.73	15.70
272.5	350.11	17.46

V. THE BRANTAS BASIN SIMULATION MODEL

General-purpose system simulation models are available (e.g., HEC-6, BTA-155 etc.) but they cannot be expected to cater to the needs of all types of river systems. A specific model for the basin was developed by Wardlaw (1993). The simulation model developed by Wardlaw (1993) has been applied for the development and application of the model for investigating alternative strategies for water resource development in the basin. The model works by effectively routing a series of inflows through the network of natural river channels and reservoirs. It uses a network comprising nodes and reaches.

Storage reservoirs are those that have a regulating influence on the river and the physical characteristics of such reservoirs must be supplied to the model. For the Brantas Basin, Karangkates, Wonorejo and Beng are treated as storage reservoirs. Of these the effect of Karangkates on the river regulation is much more significant than the other two. The model performs a water balance on storage reservoirs during each time step of the simulation. Run of river installations include Wlingi, Lodoyo Afterbay, Wangi and Sengguruh. Due to small effective storage at these installations, only single day regulation of river flows is possible. The only output from run of river hydropower nodes is peak and offpeak energy generated in each time step of the simulation. Pumping schemes like the Ngrowo Push Back Scheme and Beng dam involve large pumping stations. At these nodes the model is required to compute the pump discharge and the energy required for pumping.

The Brantas Basin simulation model was set up to run in a continuous simulation mode for the entire period of available streamflow data. It was assumed that for the existing situation in the basin, the operation of Karangkates reservoir is according to a rule curve derived in 1978 (Nippon Koei 1978). This rule curve is known as 1978 rule curve, and is shown in Figure 3. The rule curve specifies the target levels to be maintained at the end of each 10-day time step. To evaluate the existing situation in the basin, a base run employing the 1978 rule curve was carried out using the calculated theoretical irrigation requirements for present day cropping practices.

VI. SIMULATION RESULTS

The results of simulation model run under 1978 operating rule are shown in Figure 4 to Figure 6. The simulated irrigation deficits at various exceedence probabilities with the current operating rule are shown in Figure 4. The model evaluates deficits in each 10 day time-step by satisfying all demands from upstream to downstream and then comparing the demands of the Brantas Delta with the available river flow. From Figure 4 it is clear that during dry periods there are large deficits even with 80% exceedence probabilities.

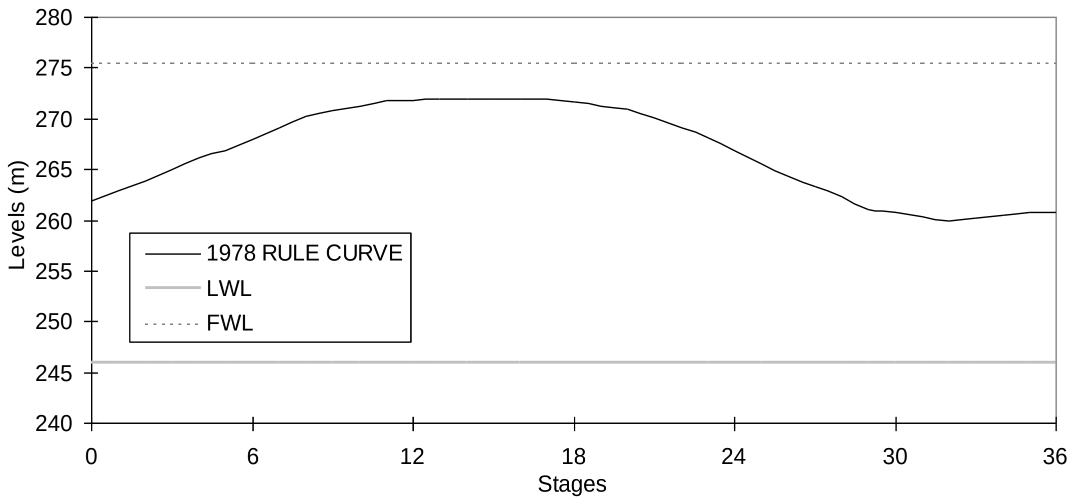

Fig. 3 The 1978 rule curve

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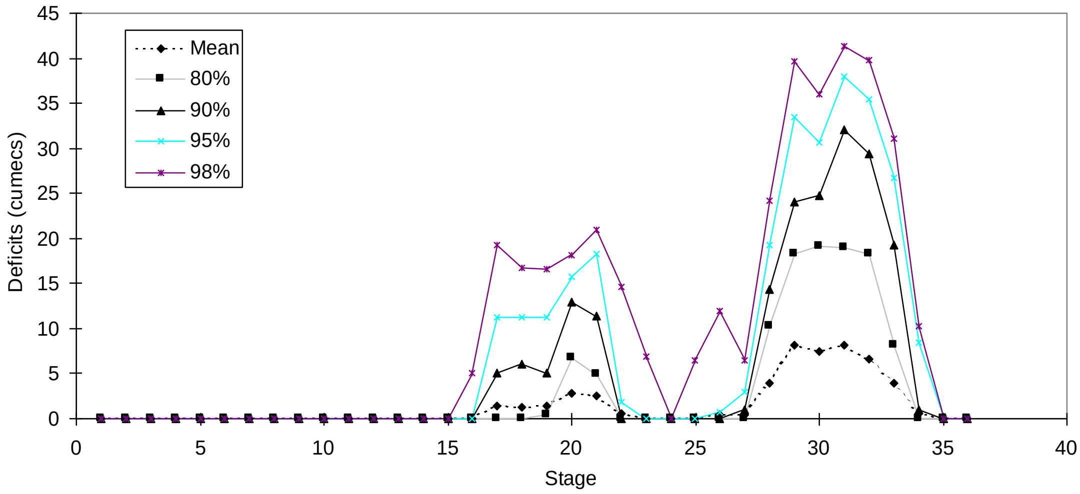

Fig. 4 Simulated irrigation deficits at different exceedence probabilities with 1978 rule curve

Figure 5 shows the simulated water levels in Karangkates reservoir with the 1978 rule curve, from which it appears that reservoir storage is not fully utilised. It was seen that with the 1978 rule curve there is a failure to realise full potential of agricultural production, and the mean annual damages are of the order of 5000 million Rupiah. The 1978 rule curve was intended primarily to stabilise power production and in that respect it has served its purpose well. Figure 6 and Figure 7show offpeak and peak power production respectively at Karangkates with the existing rule curve.

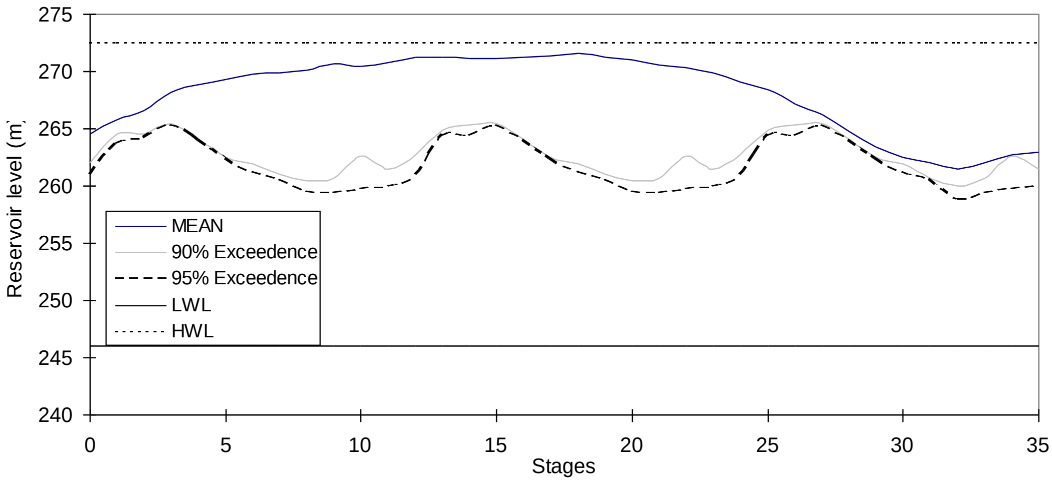

Fig. 5 Karangkates water levels , base run

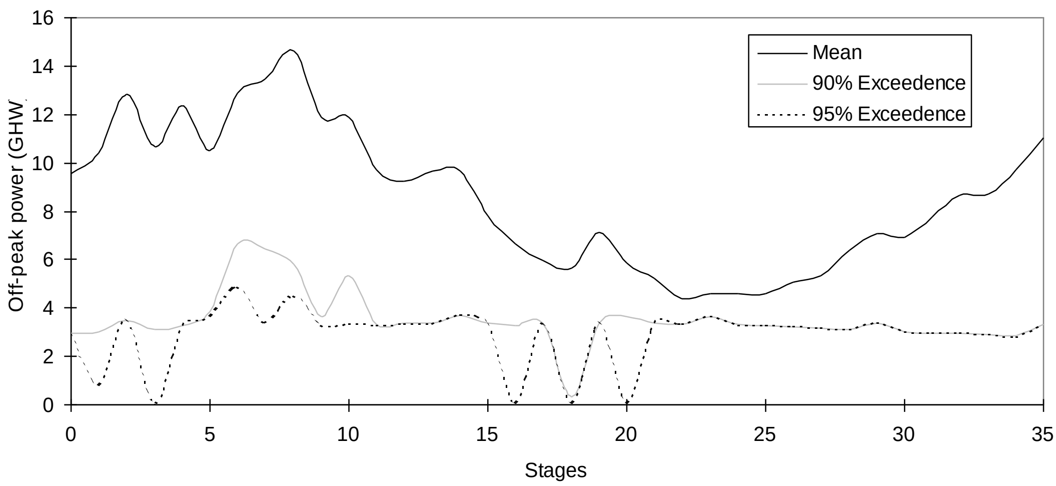

Fig. 6 Karangkates offpeak power

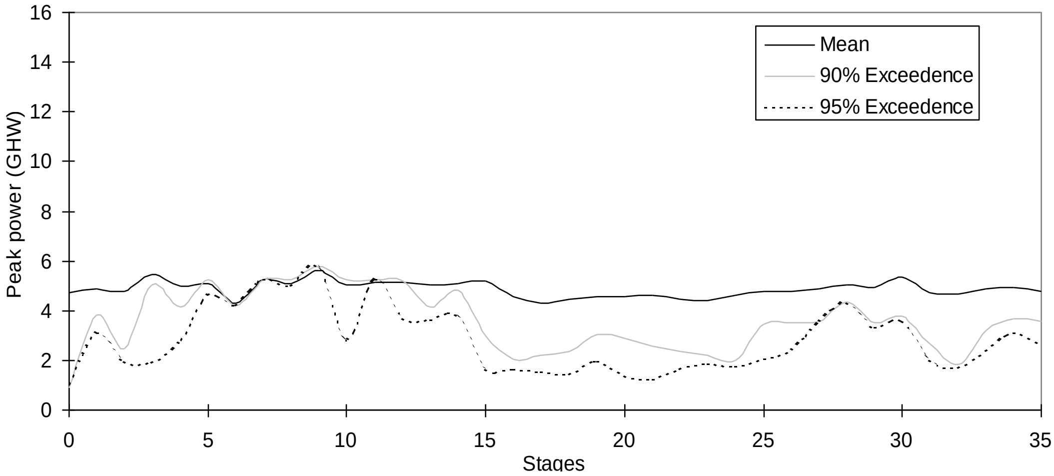

Fig. 7 Karangkates peak power

VII. CONCLUSIONS

In this paper, the characteristics of the Brantas Basin and the storage reservoirs in the basin were described. A brief survey of the past water resource development studies in the basin was also presented. The application of simulation model to the operation of Karangkates reservoir in the Brantas basin has been described. Results of simulation model indicated that large irrigation deficits cannot be avoided even at 80% exceedence probability. Upto time step of 15, the irrigation deficits were found to be zero at all levels of exceedence probabilities. Evident from the model results was the fact that with the existing rule curve there was a failure to realize full potential of agricultural potential in the basin. The existing rule curve has, however, served its purpose well with respect to the stabilization of power production from the reservoir. The simulation model has the potential for being used for assessing long term economic impacts of alternative scenarios of water resource development in the basin.

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