International Conference "Water, Environment, Energy and Society" (WEES–2009)
New Delhi, 12–16 January 2009

Water Balance Assessment of a River Basin through System Simulation

N.S.R.K. Reddy
NWDA, New Delhi, INDIA

S.K. Jain
NIH, Roorkee, INDIA

ABSTRACT: Assessment of overall water resources as well as surplus (or shortage) in a river basin considering the current and future needs is the key in water resources planning. This exercise is normally done through water balance studies which estimate annual water availability in a 75% dependable year and projected needs for different purposes. By the use of computer simulation models, the outcome of these preliminary studies can be refined by evaluating the performance reliability of a river basin system over a long period. Such studies need to take into cognizance the effect of carryover capacities and operation policies of major reservoirs in making up the water shortage or augmenting the surplus.

The present paper assesses the surface water balance of Godavari basin in Peninsular India in the ultimate water development scenario. Since the interest is to assess such a balance at the terminal storage/diversion structures, multi-reservoir simulation has been carried out for 30 years for 2 proposed storage projects viz. Inchampalli and Polavaram at the tail end of the basin and an existing barrage at Dowlaiswaram just before the confluence of the Godavari with the Sea. A multi-reservoir simulation model has been used for the study.

The present study envisages long term solution for integrated operation of both the reservoirs and the barrage in the basin to find out their operational reliability. Thereafter, their performances have been refined through simulation considering different priorities of use (irrigation/power) and downstream committed releases, based on which appropriate firm power and release pattern has been fixed. Finally, quantification of surplus surface water in the basin has been done according to the derived optimal reservoirs operation policy.

INTRODUCTION

Of late, there has been considerable emphasis for river basin planning instead of individual project based planning, hitherto being practiced in the country, in order to strike an amicable balance between limited water resources vis-à-vis conflicting water needs. The first step towards this is a realistic assessment of water resources of the concerned basin. One preliminary way of estimating a basin's water resources is by carrying out water balance studies which assess the annual yield at certain dependability (usually 75%) from long term yield series (either observed or generated through rainfall-runoff relationship) and estimate the present and future water needs for various purposes adopting appropriate norms. These broad studies serve as primary indicators of the water position of a basin. Such studies, however, do not consider the effect of carryover capacities and operation policies of the major reservoirs in the system in making up the deficit or augmenting the surplus.

Clearly, the system studies are required to evaluate the performance of the system over a long period, duly considering the storage capacities and operation policies of major reservoirs for meeting various demands at desired degrees of reliability. Computer simulation models and systems analysis provide more refined and realistic studies compared to the dependable year water balance studies and are required for intelligent and coordinated operation of a number of storage reservoirs already built or under construction in each basin.

The present paper reports water balance assessment of the Godavari basin, a major river basin in peninsular India, through simulation of two reservoirs and one terminal barrage and demonstrates the effectiveness of system analysis and simulation models in the assessment and planning of water resources of a river basin.

THE GODAVARI BASIN

The Godavari is the largest river in Peninsular India. It rises in the Sahyadris near Triambakeswar in the Nasik district of Maharashtra. It flows for a total length of 1465 km through the States of Maharashtra and Andhra Pradesh before joining the Bay of Bengal. The

Fig. 1: Map of Godavari Basin

basin lies between latitudes 16° 16′ N and 23° 43′ N and longitudes 73° 26′ E and 83° 07′ E. The basin extends over an area of 312813 km^2, which is nearly 10% of the total geographical area of the country. The percentages of the areas of the basin in the States of Maharashtra, Madhya Pradesh, Chattisgarh, Karnataka, Andhra Pradesh and Orissa are 48.6, 8.4, 12.5, 1.4, 23.4 and 5.7 respectively. Important tributaries of the Godavari are the Pravara, the Purna, the Manjra, the Maner, the Penganga, the Wardha, the Pranhita, the Indravati and the Sabari. Jayakwadi project, Sriramsagar project and Cotton barrage (Dowlaiswaram) are the important projects existing in the basin. The proposed major projects are Bhopalpatnam, Inchampalli and Polavaram. The basin map is presented at Figure 1.

In the present study reservoir simulation has been carried out at the Inchampalli and the Polavaram reservoirs and the existing Cotton barrage.

Inchampalli

The Inchampalli project is proposed on the river Godavari about 12 km downstream of the confluence of Indravati with the Godavari river in Andhra Pradesh. It is a joint project among the States of Maharashtra, Madhya Pradesh and Andhra Pradesh. It is a multi purpose project envisaging irrigation benefit for the upland areas, generation of hydropower, navigation facilities in the river, development of pisciculture and providing recreation benefits besides mitigating flood hazards.

Polavaram

The Polavaram project is planned d/s of Inchampalli after the confluence of another major tributary 'the Sabari' with the Godavari River. It is a multi purpose project for irrigation, hydropower and water supply to Vizag city. The project has been planned for utilizing the significant quantum of flows that would be received from Sabari and power releases and spills from Inchampalli for its own uses and also for regulating releases for Godavari delta.

Dowlaiswaram Barrage (Cotton Barrage)

The Dowlaiswaram Barrage is the terminal project on Godavari, located downstream of Polavaram, catering to the needs of Godavari delta. It is named after Sir Arthur Cotton, who built the barrage in regard to his yeoman services to the upliftment of the people in the area.

THE SRA MODEL

The Software for Reservoir Analysis (SRA) developed by the National Institute of Hydrology (NIH), Roorkee is used for the study. In the model, highest priority is given to the water supply demand for domestic purposes and the minimum flow requirement in the d/s channel. Priority between hydropower or irrigation can be specified by the user and may change from one period to another. Five rule curve levels have been specified viz., the upper rule level, the first middle rule level, the second middle rule level, the lower rule level and the link rule level; the upper rule level for the highest level up to which a reservoir should be filled, the middle and lower rule levels for situations when water is scarce and full supply to various demands can not be made and the link rule level to incorporate water transfer component from a surplus node to a deficit one.

The model considers four possibilities of water releases through power plant. For this purpose, irrigation demand has been bifurcated into two parts, one, which passes through the power plant and the other, which does not. In the first case, all the releases from the reservoir including irrigation (partial or full), water supply and minimum flow pass through power plant. In the second case, the domestic water supply bypass the power plant, while in the third case, irrigation releases bypass it. In the fourth case, only minimum downstream flow requirement passes through the power plant, while all the other releases bypass it. The detailed information on the concept and capabilities of the model is available in its user's manual (NIH 1996–97).

APPROACH

The study has been carried out in 2 stages. Stage-I envisages to study performance of the basin in the ultimate water development scenario through simulation of the considered reservoirs and barrage in meeting their requirements at desired operational reliabilities. In stage-II, optimization of the basin performance is carried out considering different priorities and release patterns from the reservoirs. In case of Inchampalli and Polavaram, simulation runs are taken for two cases, viz., irrigation priority and hydropower priority. In both the cases, firm power demand has been varied and the reliabilities are observed. The option, which yields the best performance, has been chosen. Further, in case of Polavaram which caters to the requirements of downstream Dowlaiswaram barrage, the releases have been enhanced to improve the performance of the barrage, while ensuring desired reliabilities for its own needs. In case of Dowlaiswaram barrage, the option of net demand has been introduced. With this option, the net requirement at the barrage in excess of its local inflows will only be drawn from Polavaram. This will not only ensure drawl of water when necessary but also minimize wastage of water at the barrage, if the water would have been released from Polavaram reservoir in a fixed released pattern. After optimization, the firm power generation at both Inchampalli and Polavaram hydropower plants has been fixed and the surplus/deficit position of the basin has been ascertained.

Multi-reservoir simulation is carried out for a common period of 30 years. Since the present study is for a future scenario, the inflow data used are not the observed inflows at a reservoir but are estimated inflows after considering full upstream development. The peculiarity of the basin is such that the water resources in its upper catchment are not enough to meet its various needs while there are abundant flows in the lower part of the basin after confluence of Pranhita and Indravati rivers to cater to its present and projected needs. Therefore, Sri Ram Sagar Project (SRSP) situated in Middle Godavari has been considered as the starting point for the present study. Further, while working out the inflows at a project/reservoir in some deficit years, the situation is such that the water available in an upstream sub-basin may not be enough to meet its own projected requirements. The net annual inflows from that sub-basin into the reservoir in such years are considered to be 'nil'. The annual inflows have been distributed into monthly inflows on an average proportion based on the available observed discharge data at the project site/ nearest G&D site.

Project Demands

The various demands considered for the reservoirs/ barrage are given in Table 1.

Table 1: Project Demands in the Godavari Basin

Sl. No.	*Project*	*Firm Power (MW)*	*Irrigation (Mm^3)*		*Water Supply (Mm^3)*		*Downstream Requirement (Mm^3)*
			LBC	*RBC*	*LBC*	*RBC*	
1.	Inchampalli*	117	150	470	–	–	–
2.	Polavaram#	60	1881	1402	664	162	7423
3.	Dowlaiswaram#	–	7774		–		–

Source: * NWDA (2004) # NWDA (1999).

ANALYSIS AND RESULTS

The analysis carried out for both the reservoirs and barrage indicates the following findings.

Inchampalli Reservoir

Long term simulation of the operation of this project (Stage-I) shows that it can generate its planned firm power of 117 MW with 92.5% reliability. Besides, it can meet its irrigation demands in full (620 Mm^3) in 80% of the years providing 99.4% of the volumetric requirement.

Under optimization (Stage-II), the performance of the reservoir has been analyzed for two cases, one with irrigation priority and the other with power priority.

Case-I: Irrigation Priority

A number of simulation runs were taken with varying firm power demands. About 58 MW of firm power can be generated with 100% irrigation reliability while the planned firm power of 117 MW by the project authorities is possible with 92.5% reliability and corresponding annual irrigation reliability of 80%. On further optimization, firm power corresponding to 90% time reliability is found to be 127 MW with comfortable annual reliability of 80% for irrigation (Figure 2).

Case-II: Power Priority

In this case also, it is seen that a firm power of 127 MW can be generated but with annual irrigation reliability of only 63.3%. The deficit range for irrigation is 16 Mm^3 to 44 Mm^3 in 9 years.

Since the firm power generation is the same in both cases, Case I has been chosen as it provides higher irrigation reliability. The monthly firm power before (117 MW) and after (127 MW) optimization is shown in Figure 3.

Polavaram Reservoir

The project can comfortably meet its irrigation requirement of 3283 Mm^3 with 80% annual reliability and 99.5% volume reliability. Besides, it can also generate its planned firm power of 60 MW at 98.1% time reliability.

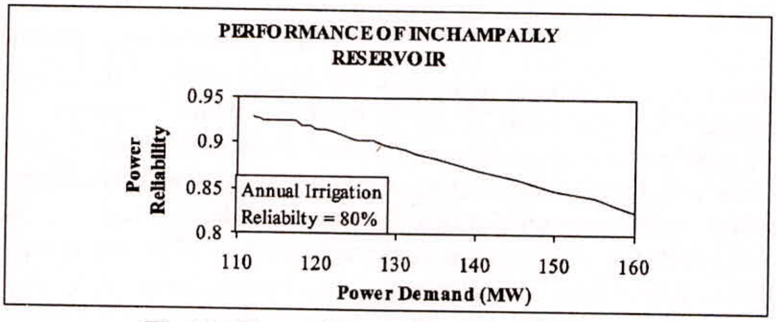

Fig. 2: Power demand *vs* Power reliability

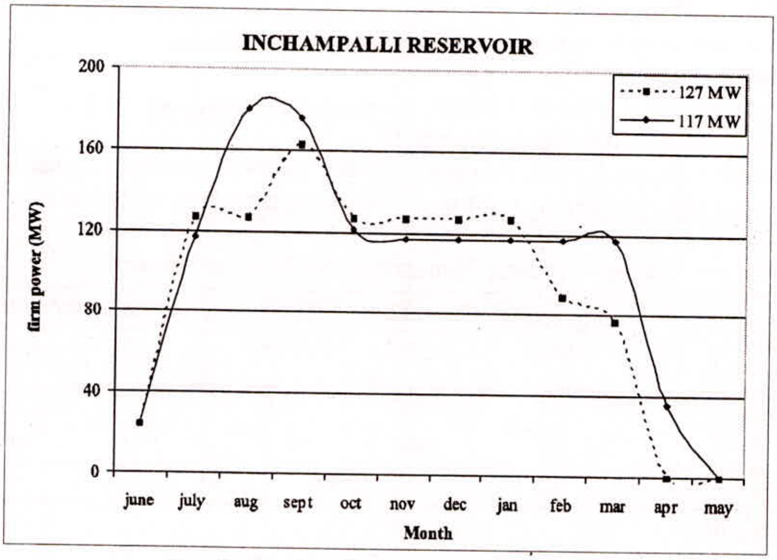

Fig. 3: Monthly firm power at Inchampalli

Then, under optimization two cases corresponding to power generation of 117 MW and 127 MW at Inchampalli have been taken up. In each case again, irrigation and power priorities are specified for simulation and performance of the reservoir is studied.

Case I: Inchampalli Firm Power (117 MW)

This case has been taken up to ascertain how much firm power is possible at Polavaram beyond 60 MW in the case it receives power releases from Inchampalli with planned firm power generation of 117 MW.

Irrigation Priority: A firm power of 105 MW can be generated at Polavaram while ensuring the irrigation reliability of 76.7% for its irrigation.

Power Priority: A firm power of 77 MW is possible at 97.2% of time reliability. Further increase in power demand will affect the irrigation reliability to below 76.7%. Therefore under case I, irrigation priority will be the better option in view of higher firm power along with desired irrigation reliability.

Case II: Inchampalli Firm Power (127 MW)

In this case, the improvement in firm power generation at Polavaram in the optimized case of firm power generation of 127 MW at Inchampalli is studied.

Irrigation Priority: It is seen that firm power generation can be enhanced to 112 MW while maintaining the irrigation reliability at 76.7%.

Power Priority: Only 69 MW of firm power demand can be met with as further increase will reduce the irrigation reliability to 73.3%. The power reliability, is however, as high as 97.5%. On comparison of the both the cases, Case II with irrigation priority was found to be the better option as it yields higher firm power with high reliability for irrigation. The average annual power generation has improved from 2029 MU to 2039 MU after optimization. The monthly firm power before and after optimization is given in Figure 4.

Dowlaiswaram Barrage

Dowlaiswaram will have an annual irrigation reliability of 70% in both the cases considered as above at Polavaram. This situation is not due to the deficit of water at Polavaram, as the time (95%) and volume (97.5%) reliabilities at Dowlaiswaram indicate. Since Polavaram is optimized for maximum power generation, the power releases and the irrigation needs are mismatching. It is, however, seen that the average annual irrigation release is 7608 Mm^3 (98% of the target demand of 7774 Mm^3) and the deficits in two years are very marginal (1.5%), which can be made up by reducing the power releases in other periods in such years during real time reservoir operation. It may perhaps be not appropriate in the planning stage itself to reduce firm power at Polavaram considerably (to 95 MW) to obtain 76.7% reliability for irrigation needs at Dowlaiswaram.

The final performance indices for each of the reservoirs/barrages after optimization are presented in Table 2.

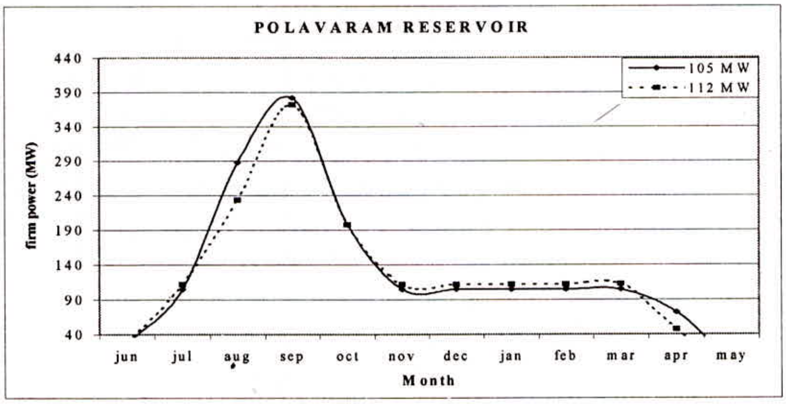

Fig. 4: Monthly firm power at Polavaram

Table 2: Final Performance Indices of Reservoirs and Barrage after Optimization

Units : Power – MW; Irrigation – Mm^3;										
Sl. No.	*Reservoir*	*Criteria/ Priority*	*Power*		*Irrigation Reliabilities*				*Water Supply*	
			Demand	*Reliability*	*Demand*	*Time*	*Volume*	*Annual*	*Demand*	*Reliability*
1.	Inchampalli	Irrigation	127	0.9	620	0.961	0.993	0.8	–	–
2.	Polavaram	Irrigation	112	0.908	3283	0.964	0.994	0.767	826	0.975
3.	Dowlaiswaram	–	–	–	7774	0.95	0.979	0.7	–	–

Surface Water Balance

After optimization, the surface water position at Dowlaiswaram has been assessed from the model studies. Reliability concept has been adopted to assess the balance in the basin at 76.7% reliability. The spills at Dowlaiswaram have been arranged in descending order from which the Godavari basin is found to contain about 19354 Mm^3 of surplus at 76.7% reliability (Table 3).

Table 3: Monthly Surplus in Godavari Basin (at 75% reliability)

Month	*Surplus (Mm^3)*
July	205
August	6243
September	5660
October	2256
November	555
December	557
January	529
February	645
March	737
April	841
May	1126
Total	**19354**

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based on the present system study, the following conclusions could be drawn.

1. Multi reservoir simulation modeling can be used to optimize the reservoir performance through simulation. The kind of trade-off studies conducted in the present study enable a decision-maker to analyze alternate scenarios for development of multi-purpose reservoir projects.
2. The within year and carry-over storage capacities of the reservoir and their impact in storing the excess water when available and releasing it in times of need has been considered in the present study. The storage impact coupled with appropriate operation policies for power generation not only ensures supplies for project utilization at desired reliability but also helps in making downstream releases in accordance with the optimized firm power demand/committed downstream requirement. Thus, supplies more than those estimated in conventional water balance studies would be available at the subsequent sites for utilization.
3. Water balance situation arrived at by the system study (19534 Mm^3) is considered to be more realistic as (i) it is based on long term simulation (30 years) and (ii) inflows at reservoir sites take into account only the surplus yields from tributaries.

Recommendations

This study has considered only those projects in Godavari river basin which pertain to the inter basin link system under National Perspective Plan (NPP). A long-term water balance simulation study with all major reservoirs in the basin will give a more realistic picture which will interalia enable the planner to identify intra basin transfer links to overcome temporal and spatial imbalance within the basin itself.

REFERENCES

National Institute of Hydrology, User's Manuel on "Software for Reservoir Analysis (SRA)", Roorkee, 1996–97.

National Water Development Agency (NWDA). "Feasibility report of Inchampalli—Pulichintala link", Volume II, New Delhi, December, 2004.

National Water Development Agency (NWDA). "Feasibility report of Polavaram—Vijayawada link" Volume II, New Delhi, September, 1999.