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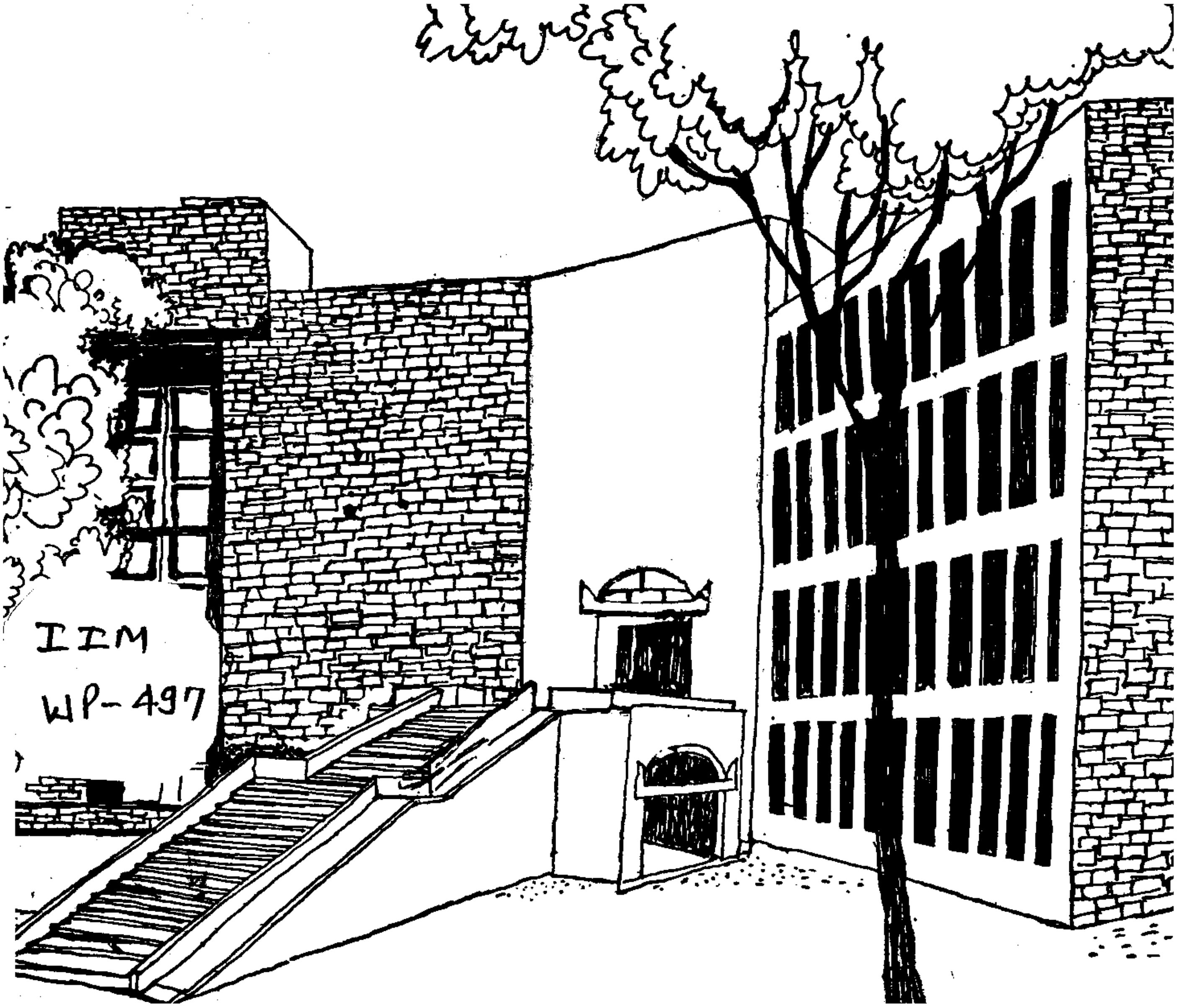

A SIMULATION MODEL FOR SIZING DECISION IN A LARGE IRRIGATION/POWER PROJECT IN INDIA

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ABSTRACT

This paper describes our experience with construction and use of a simulation model for a large Irrigation and Power Project in a state in India. The project has an estimated outlay of Rs. 5000 million (U.S. $ 5 billion) and a project construction time of thirty years. The model was used by decision makers to fix key project parameters such as the main canal capacity and the capacity of the power plant.

It integrates a variety of uncertain factors, such as upstream withdrawals, effect of rain-fall and use of ground water. The model has also been instrumental in a qualitative re-design of the project, by indicating substantial benefits from creation of additional storage in the command area. This project is now being actively investigated by the project authorities.

A SIMULATION MODEL FOR SIZING DECISION IN A LARGE IRRIGATION/POWER PROJECT IN INDIA*

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1. INTRODUCTION

This paper describes the design and use of a simulation model for answering certain basic questions regarding a major irrigation-power project in India. The project envisages the development of a large irrigation-power system in State A using the waters of a large river which flows almost directly west across central India. Its drainage area lies for the most part in two States A and B, with a small portion in another State C. Despite having a mean annual flow exceeding the sum of flows in three of the five famous rivers of the Punjab (Rabi, Beas and Sutlej) its development potential has not been tapped so far because of inter-state disputes on sharing of water. However, after the report and decisions of the river water disputes tribunal was finalised in December 1979, the stage was set for harnessing the river waters.

As a result of the tribunal's report, State A geared up to implement the ambitious irrigation-power project. This project envisages construction of a large concrete gravity dam (the second largest - after the Hoover dam in the world), which would be the most downstream dam in a series of dams of which all others will be in State B. The dam would have a power house in the river bed (RBPH) as well as a power house at the head of the main canal (CHPH). The main canal as planned

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would be the largest lined irrigation canal in the world. It would be 440 Km. in length and feed a gross command area of 2.1 million hectares comprising one fifth of the gross cropped area of the state. Whereas water flowing through the CHPH would be available for irrigation from the main canal, all the water sent through RBPH would be lost to the project command area. The cost of the project at 1981/82 prices is estimated to be Rs. 50,000 million (US $ 5 billion) of which roughly one third is the cost of the main canal. The potential benefits are also large. It is envisaged that the annual increase in value of agricultural production alone would be Rs. 6,000 million (US $ 600 million).

Some of the key judgements regarding the project as handed down by the tribunal are as follows:

i. The utilizable flow of water of 28 Million Acre-feet (MAF) at the 75% reliability level* was to be shared as follows:

State A	9.00 MAF
State B	18.25 MAF
State C	0.25 MAF
State D	0.50 MAF

ii. To achieve this utilizable quantum, a carry-over requirement during good years was stipulated. For a year in which utilizable flow (UF) was in excess of 28 MAF, amount to be carried over to the next year would be Min (8.291, UF-28) MAF. The reservoir in State A would be required to hold 19/56 of this amount. The rest would be carried over in reservoirs of State B.

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* This is the level that will be exceeded in 75% of years.

iii. The tribunal recognized the need to co-ordinate the construction of project in State A with construction of upstream projects in State B. Accordingly, it laid down an implementation schedule for the two states summarized in Table I.

Table I: Implementation Schedule for Projects

	State A		State B	
	Irrigation Requirement (MAF)	Live Storage Capacity (MAF)	Irrigation Requirement (MAF)	Live Storage Capacity (MAF)
Stage I (10 years from start of construction)	2.55	4.72	5.00	12.73
Stage II (30 years from start of construction)	9.00	4.72	13.00	17.06
Stage III (45 years from start of construction)	9.00	4.72	18.25	17.77

iv. The Full Reservoir Level (FRL) for the project was to be 455', the maximum water level was to be 460' and the Full Supply Level (FSL) at the head of the main canal was to be at 300'. State B's share of water would be delivered at the tail of the main canal.

v. In view of the long time that it would take for States A and B to fully develop their irrigation delivery systems, a river bed power house (RBPH) with a capacity of 750 MW was recommended in State A to generate power upto this time. After full development in the two states, it would operate purely on spills.

vi. The RBPH must be operated at full capacity during periods of spills. Any additional water available from spills, after operating the RBPH at full capacity, could be used by State A, and such spill water extraction would not be counted towards the state's share.

vii. State A's share of the power generated in both RBPH and CHPH would be 16%.

2. RESEARCH OBJECTIVES

The two studies which preceded our work were screening models developed by Operations Research Group (ORG), Baroda, and by the Irrigation Department of State A. ORG developed linear programming model for the main canal sizing decision. The study by the irrigation department used a simulation model in which the reservoir operations were simulated with ten daily historical inflow data. The power generation in the river-bed power house was maximized subject to meeting a fixed irrigation demand and carry-over requirements. Both models had the following limitations:

i. The operating decision at any point in time was made with perfect knowledge of all future inflows.

ii. The possibility of utilizing spills at State A for irrigation was not considered.

iii. Possible correlations between the demand for water and the utilizable inflows were not considered.

Our work was concerned with overcoming the above limitations in order to determine more realistically the quantum of water that could be extracted from the system for irrigation by a good operating policy under different sizes of main canal and RBPH capacity. To begin with, a pure supply - side model was developed to answer this question with no regard to demand. Subsequently, this model was enlarged to accommodate demand-side factors such as cropping patterns, distribution losses, rainfall and groundwater ousage effects.

3. THE SUPPLY MODEL

This model was developed to assess the amount of water that could be extracted for irrigation with a good reservoir operating policy. The major aspects kept in mind while building such a model were:

i. The flow in the river is highly seasonal. Measurements over the period 1948-1970 show that out of an average total flow of 30.5 MAF, the flow in the period July-October is 28.1 MAF. As the storage in the project is very small relative to the share of State A, a poor operating policy may result in spills which may make it impossible to draw the state's share of water for agriculture.

ii. As it would take State B a long time to build up its total agricultural demand, and as the power releases in State B would be into the river, for the first two stages it may be possible through a good operating policy to use spill water to increase the amount of water extracted beyond the share amount.

Our first effort was to make some rough assessments regarding the short-term predictability of 10-day flows under virgin conditions. We found very erratic and low correlations from simple time-series forecasts. We therefore, decided to use a conservative approach by employing a simple policy which did not make any forecasts of future inflow.

The only significant uncertainty is during the monsoon or kharif season (July-October). For the remaining eight months of the rabi (winter, November-February) and summer (March-June) seasons, there is virtually no spillage possibility and little uncertainty in inflows. Thus, the key problem is reservoir operation in the kharif. At the end of the kharif, for the rest of the year, one can deterministically calculate how much water will be available for agriculture, given the requirement of carry-over. For power generation, we have used operating curves which specified upper limits for each period for water to be released into the RBPH (these limits would, of course, be overridden during times of spillage). These curves were exogenously specified, based on the irrigation department study mentioned earlier.

The model used a 10-day period based on the 10-day historical data and inflows available for 31 years. The reservoir operating policy OP1 was as follows:

Kharif Season

a. If there is no spillage condition at the reservoir then,

   i. Calculate amount available for use in period t = opening storage for period t + inflow during period t.

   ii. Generate as much power as possible subject to the operating curve limit for the period.

   iii. Calculate State A's share based on total river flow upto end of period t*. Subtract from this the cumulative amount extracted so far.

b. If the balance exceeds the canal capacity, then extract at the canal capacity rate, otherwise extract the full amount of the balance.

If spillage conditions exist then,

   i. Generate as much power as possible upto full RBPH capacity using spills alone.

   ii. If the power operating curve limit is not reached, generate upto this limit.

   iii. If there is still spillage, extract the spillage amount (subject to the canal capacity limit).

   iv. If there is still canal capacity available, extract according to step (iii)(a) above.

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* Since the total river flows was certain to exceed 8 MAF, this was used as a lower limit for total river flow instead of zero.

Rabi and Summer Seasons

Extract as much water as possible for agriculture, ensuring that the carry-over amount is always left behind at the end of the period.

This policy is simple to operate and ensures that at all times the state does not violate the tribunal's rulings. As noted earlier, the policy OP1 is conservative in that it provides estimates which may be improved with more sophisticated forecasting schemes. In order to test how far it may be below more sophisticated policies, we examined two other policies. Each one is an 'extreme' policy - policy OP2 seeks to maximize the extraction against share of state A, while policy OP3 maximizes the quantum of spills diverted into the main canal. Both OP2 and OP3 differ from OP1 only in kharif. Policy OP2 assumes perfect knowledge about the total annual flow, and hence the annual share of State A. Thus, unlike OP1 which uses cumulative flows, OP2 uses the annual flow to limit withdrawals against share of State A. Policy OP3 makes no withdrawls until the reservoir is full, and all subsequent withdrawls in kharif are purely from spills. Clearly no policy can improve on OP3 in maximization of spill withdrawls. The sum of regular withdrawals for OP2 and spill withdrawls for OP3 for any year, gives an upper bound on the quantum that can be extracted during the year. It is thus possible to bound both the average and the 75% reliable annual withdrawal under any operating policy. The results of this analysis for two canal capacities: 40,000 cusecs and 48,000 cusecs (the range considered worth investigating) are presented in Table II.

TABLE II: Comparison of OP1 with OP2 and OP3

Policy	Canal Capacity	RBPH Capacity	Water Abstracted*		Power Generated
			75% Reliability	Average	
	(000 cusecs)	(MW)	(MAF)		(000 MWH)
OP1	40	750	10.70	12.15	1427
OP2	40	750	6.40	7.54	1431
OP3	40	750	4.39	5.89	1431
Upper bounds for OP1			11.97	13.43	1431
OP1	48	750	11.37	13.19	1424
OP2	48	750	7.03	7.94	1431
OP3	48	750	5.03	6.81	1431
Upper bounds for OP1			12.77	14.75	1431

* Figures are for total withdrawals in the case of OP1, Gujarat Share withdrawals for OP2 and spill withdrawals for OP3.

From the results we see that OP1 is not unduly conservative since no other policy can improve the water abstracted by more than 10% beyond OP1. The performance of OP1 is very interesting. The average share of State A for the simulation period is 10.51 MAF. We observe that OP1 is able to substantially improve on this by spill extraction; for main canal capacity of 40,000 cusecs and 48,000 cusecs, it draws additional amounts of 1.64 MAF and 2.68 MAF. This led us to conclude that there is a good possibility for utilizing spill waters in State A.

To confirm this we examined the performance of OP1 for inflow sequences which reflect Stage I, Stage II and Stage III development in the upstream area. These inflows were worked out using logic employed by department studies. In brief, these inflows clubbed all upstream reservoirs into one upstream reservoir and computed releases into the river so as to ensure 75% reliability of meeting fixed agriculture requirements in the upstream command areas. The results as shown in Table III suggest that substantial extra water is available to State A in the form of spills in the earlier stages of development in State B.

TABLE III: Abstraction Using OP1 in Stages I, II & III

Stage	Canal Capacity (000 cusecs)	RBPH Capacity (MW)	Gujarat's Share Avg. (MAF)	Gujarat's Share .75 Rel. (MAF)	Abstraction OP1 Avg. (MAF)	Abstraction OP1 .75 Rel. (MAF)
I	40	750	11.85	9.75	12.86	9.75
	48	750	11.85	9.75	13.08	9.75
II	40	750	12.56	9.75	12.79	9.75
	48	750	12.56	9.75	13.11	9.75
III	40	750	12.29	9.75	11.15	7.81
	48	750	12.25	9.75	11.40	7.81

4. THE DEMAND MODEL

The supply side model clearly indicated the possibility of extracting water in excess of State A's share in the early stages of development. The next step was to examine the possibility of extracting more water when supply and demand were taken together. This step required determination of periodwise irrigation requirement, and modelling the impact of groundwater and rainfall in the command area on the system.

The requirement for irrigation water depends on the cropping pattern and the climatic factors in the command area. These data for all the six zones comprising the command area were provided by the agricultural department of State A. The modified Penman's Method [1] was used to compute the ten-day periodwise requirement of water for irrigation. The net irrigation requirement was determined by subtracting the effective rainfall [2] from the gross requirement for irrigation.

In most of the studies on reservoir operations the impact of rainfall is taken into account somewhat crudely. An average availability of water from rainfall is assumed, and this amount is subtracted from the gross requirement to arrive at the net irrigation requirement. Such a method is inadequate when there is high variability in rainfall, particularly since rainfall may be positively correlated to river flow.

For this project it was necessary to ensure a reliability of 75% for supplies to irrigation. The computation of reliability is influenced by the manner rainfall is accounted for. If average rainfall is used then reliability could be grossly over-estimated. Period-wise actual rainfall obtained from historical data gives a better picture of reliability of supply by automatically accounting for the negative correlation between irrigation requirement and rainfall in the command area.

The groundwater in the command area was modelled as a safety stock that provides protection in poor inflow years. The higher the level of groundwater, the greater would be the protection. This positive aspect though has to be weighed against the increased possibility of water-logging. The desired level of groundwater as safety stock was determined by simulating the reservoir operations for prespecified levels and then examining the impact of these levels on the reliability of supply for irrigation and the maximum level of groundwater during the year.

The Operating Policy

The reservoir operating policy was similar to OP1 for the supply model. It assumed no information about the future inflows and was based on the premise that the annual flow would be at least 8 MAF. The policy attempted to ensure a reliability of 75% to the supply for irrigation. This reliability was computed by classifying a year as a 'failure' year if the availability of water in any two successive periods in the year fell short of the requirement for agriculture in these periods by more than 50%. The policy also incorporated the possibility of a feedback to upstream reservoirs. If spillage conditions prevailed at State A in any period in rabi or summer season, then the power releases at the upstream reservoirs could be reduced to prevent/reduce loss of water due to spills.

In the kharif season, surface water was used first to meet the irrigation requirement. Groundwater was used only when the surface water available fell short of the requirement. The use of surface water was limited by the balance share of State A, while the use of groundwater was limited by the pumping capacity expected to be installed in the command area. The releases for power generation were governed by a prespecified capacity utilization curve on the basis of studies done earlier. This ceiling on capacity utilization of RBPH was disregarded in periods of spills, and in such periods the power house was operated at maximum possible capacity. Water available from spills, after operating the RBPH at full capacity, was abstracted for agriculture. This water would not be counted towards State A's share.

In the rabi and summer seasons, the order in which ground water and surface water were used in meeting the irrigation needs depended upon the availability of groundwater. If the availability was greater than the desired safety stock, then groundwater was used first to meet the irrigation needs. Surface water was used first in case the groundwater available was below the desired safety stock. Such a policy would control the chances of water-logging and yet provide protection in poor inflow years. The usage of surface water was limited by the balance share of State A, while the use of groundwater was limited by the pumping capacity. Releases for power generation were made only when the surface water available exceeded the balance share of State A. The carry-over restrictions specified by the tribunal were adhered to in every period.

5. DISCUSSION OF RESULTS

The above policy was used for simulating the reservoir operations for various stages of development. Since a decision to construct a canal with a capacity of 40,000 cusecs had been taken, we used only one level of canal capacity for the simulation runs. The decision on the RBPH capacity had not been taken, and hence we simulated the reservoir operations for two levels of capacity, 800 MW and 1200 MW. The results are summarised in Table IV. It was apparent that a fair amount of water in excess of demand would be available throughout the life of the project. This possibility initiated a search for locations to store the extra water. A storage was necessary since this extra water was available from spills in the kharif season. As no natural storage was available within the command area, the possibility of taking this water to a perennially water scarce area adjoining the command of the project was explored. A storage of about 2 MAF has been located in the adjacent area and this would feed the existing reservoir systems in the region.

The analysis thus helped in not only developing a reasonable operating policy for the reservoir, within the framework of tribunal's stipulation, but it also opened up a possibility of further benefiting the people of a water scarce region.

TABLE IV: Excess Water Available in Stages I, II, & III

Stage	Canal Capacity (000 cusecs)	RBPH Capacity (MW)	Power Generated Average (000 MWH)	Abstraction in Excess of Demand (MAF) Avg.	Abstraction in Excess of Demand (MAF) .75 Rel.
I	40	800	3766	8.32	6.97
	40	1200	4247	7.44	6.61
II	40	800	2559	2.06	0.00
	40	1200	2870	1.69	0.00
III	40	800	1569	1.48	0.00
	40	1200	1732	1.30	0.00

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