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RESERVOIR OPERATION STUDY FOR BHAKRA-BEAS SYSTEM

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

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ABSTRACT

Bhakra-Beas complex is a multipurpose-multireservoir system comprising Bhakra Nangal project, (with Gobind Sagar Reservoir and power plants at the dam) Nangal Dam and Nangal Hydel channels with its power plants, canal diversions at Ropar and Harike, Beas-Sutlej Link project (with diversion dam at Pandoh, Beas-Sutlej link Canal and Dehar Power plant at its tail) and Beas Project with Pong Dam and Power Plant. It is a complex system which requires integrated operation policy in the context of increasing irrigation and power demands.

In order to study the consequences of different operational policies to meet both irrigation and power demands, a simulation model PISIM-1 is developed from previously existing models. A core model is selected from these models, and modified so as to conform to the attributes and capabilities that considered desirable for the present study. An advantage of this model is its optimizing capability with respect to reservoiroperating rules for the time period under consideration. Also PISIM-1 is able to simulate power generation in the system.

The system is simulated on a 10-daily basis using eighteen years of hydrologic data and the demands in the recent years. Various feasible alternative operating policies were considered and the best policy which utilizes the available water in the system to its maximum (by reducing the spills) is presented. The new policy gave due consideration to fully exploit the existing available waters on the downstream side of

the reservoirs. This policy besides meeting the systems' irrigation requirements and the stipulated firm power for the project, can also generate additional power (Secondary power).

1.0 INTRODUCTION

1.1 Reservoir Operation

The conventional practice in planning,design and operation of Water Resources Project has been to consider a number of alternatives that would satisfy demand and select the best out of them. The project may fulfil the purpose of national economic development improvement of environment quality or enhancement of social well being. It is well recognised that there has been distinct advancement in the technology to plan and operate projects more effectively than was possible some twenty years ago. It should,therefore, be a logical corollary that there is a scope to obtain target benefits from the projects planned and executed a couple of decades ago by choosing an appropriate operation policy. This is possible,more so, in multiple reservoirs systems, serving more than one purpose.

This can be accomplished by manipulating the releases from storages in different reservoirs in a manner that the aggregate potential head of stored waters is at its maximum while meeting a certain set pattern of demands. The system should be so operated by devising a suitable operating policy in a manner that it can use the available water resources optimally and the flow of benefit is such that the objective is maximized. While doing so the limitations and constraints of the system should be well understood and due consideration should be given to the changed conditions. Some of the constraints, which require due consideration may be; transfer of water water from or to the basin; a new system component being added; a new type of demand being added or a purpose being releqated in priority or given higher priority over other purposes etc. Also, there may be institutional changes in the framework of administration and operation of the system or the change in value concept of the purposes or change in the estimate of availability of water resource or change in the pattern of demand. The above time variant constraints may necessitate changes in systm configuration or in operation of the system, which were not considered originally while planning. Also the losses must be minimized, and the net benefits over a period of time must be maximized with proper resource allocation policy against competing users.

1.2 Objective and Scope of the study

In order to study the implications of the time variant constraints while developing a suitable operating policy, a case study was undertaken. The Bhakra-Beas complex was chosen for this study since, it has all the complexitities and the project was planned two decades ago. It is planned to devise a suitable operating policy for this complex for meeting irrigation demands, while analysing the various aspects concerning the power generation of the individual hydroplants.

The object of the study is to consider a number of feasible policies of operation of the Bhakra-Beas complex and to select few operating policies that enhance the irrigation and power benefits and increases the water resource use in the system by reduction of spill at Harike to the extent possible.

For this study, a simulation cum optimization model which uses different hydrologic states(viz., dry,average and wet) for the purpose of obtaining working rule curves have been used. No water is sacrificed in the interest of power but operation rules are so chosen to meet the firm power requirement for larger times periods allowing for secondary power generation after studying a number of alternatives.

2.0 REVIEW

Streamflow regulation during planning stage by a reservoir refers to the use of the reservoirs' storage volume and physical appurtenances to modify streamflows. Inflows to the reservoirs are stored, diverted from the reservoirs and released down stream. Schedules for diversion and release and detailed operation procedures, provide for beneficial purposes while maintaining the integrity of the dam and other structures. The reservoir system is operated to handle extreme flows as well as normal flows.

Operating rules are based on availability of streamflows with respect to the demand. Sequences of streamflows can be available from historical record if the stream has a flow gauge station or may be estimated by analysis of hydrological data for other streams. Out-flows depend on hydraulic characteristics of the release facilities, the way in which these facilities are operated, storage characteristics of the storage reservoir and the height of water behind the dam. For water supply studies monthly or 10-daily intervals may be suitable.

When a dam is placed on a stream, it receives the stream flow that originates in the drainage area upstream of the dam. The reservoir often occupies only a small portion of the drainage area. If the reservoir is very large it may be used to regulate the inflows to achieve outflows according to a desired pattern. Because of topographic and economic limitations, however, it is not usual for a reservoir to be constructed large enough to provide regulation of entire flow. To take advantage of good site for construction of the dam, reservoirs are often located upstream in a basin and the reservoir controls the flows originating from only a portion of the drainage area. The regulated flow may be estimated based on studies of reservoir operation and considering the flows from the controlled, and uncontrolled areas. When a stream has more than one dam, the downstream reservoir operation considers the release from the upstream reservoir and the flows from the uncontrolled intermediate area.

A set of operating rules established for the reservoirs takes into account of inflows, needs for water withdrawals and releases, storage volumes and reservoir elevation. During the planning stage the designs of the spillway and other outlet works are dependent on these rules. The ability to provide release for water supplies and other conservation uses requires that water be held in storage at certain times to augment low inflows. In addition to the releases of water that are desirable, the maintenance of reservoir elevation within defined limits may be important. Also, if the reservoir is drawn down too far, there may be a serious reduction of hydroelectric power. For flood control, on the other hand the pool elevation must be kept low enough to provide space for containing flood flows during period of high inflows. For this reason the maximum water level of many of the reservoirs are not permitted to rise above specific levels at different periods of high flood, care being taken that sufficient storage above the dead storage level is maintained always to augment low flow and generate hydroelectric power.

The rules are initially assumed and are tested with historical or synthetic inflow records to determine the effectiveness. In a complex system involving many reservoirs in a river system assumptions concerning the operation rules of the project may be tested with the aid of simulation model. Depending on the results from the computer runs, the planner can adjust the operating rules. Thus, by successive simulation with modified rules a set of acceptable rule is derived. Mathematical optimization technique may be used to the extent possible in the simulation study. By a number of iterations sastisfactory selections are established. The efficiency by which the scales and operation rules are determined to a large extent depends on the experience and judgement of the planners. The operating rules obtained in this manner during the planning stage are considered tentative as changes in the system by way of controlled storage may be felt latter on actual operation of the project. It is possible to improve the rules based on experience and available additional data. Thus, it is necessary to update the working rules during the post planning stage.

In view of the latest development in this specific field of system engineering, an attempt is made here to introduce its application to the Indian river basins. Though this idea is not new to the Indian Reservoir Managers, many times due to various constraint and consideration they could not implement it with overall optimal operation policy in view. With advanced technology, now it is possible to include more constraints in the operation study.

3.0 STATEMENT OF PROBLEM

Bhakra-Beas complex is a multipurpose-multireservoir system comprising Bhakra Nangal Project with Gobind Sagar reservoir and Power Plants at the dam, Nangal Dam and Hydel channels with its power plants and canal diversions at Ropar and Harike, Beas-Sutlej Link Project with a diversion dam at Pandoh, Beas-Sutlej link canal and Dehar Power Plant at its tail and Beas Project with Pong Dam and Power Plant. It is designed and operated since two decades primarily for irrigation and with secondary importance for power generation. With the completion of the above system, the fury of flood has been completely eliminated.

"Method of Operation of a System of Reservoirs taking into consideration the effect of irrigation, flood control and power generation" has been considered as one of the priority areas of research at this Institute. The ninth Governing Body recommended that the reservoir operation studies of various reservoir systems in the country like Bhakra-Beas systems, Damodar Valley Corporation system, Chambal System etc. be taken up in the order mentioned. Thus, the reservoir operation study of Bhakra-Beas system was taken up at the first instance and the relevant hydrological and other data had been collected from Bhakra-Beas Management Board (BBMB), Ministry of Irrigation, Govt. of India, Government of Punjab and other concerned agencies.

Reservoir system operations are dependent on river behaviour , reservoir storage characteristics and demands. Water management programmes either encompass or form a part of a overall plan. When change is evolutionary, however, the future derives from and builds on the past, thus requiring protection of benefits to individual groups that derive from the traditional system operation. While seeking an improvement in the operational policy, one must not only increase the quality and/or the availability of system products(like power and water supply) but also provide the user communities at least as much benefits from the new operation as they used to get from the old one.

Bhakra-Beas is one of the largest system in the country and deserve attention in this direction. Keeping in mind the guidelines mentioned above, an attempt is made to suggest the modification of operation policies which will result in improvement in the performance of the Bhakra-Beas system while protecting the interests of the groups concerned.

Thus, the problem studied here is to increase the irrigation potential by minimising the spill that goes out as a waste by way of selection of better operation policy and to narrow down the shortages during the critical period of the years guided by a factor known as 'Reservoir Factor' that controls the reservoir releases proportional to the available storage position during the session. The study also includes analysis of the impact of the reservoir operation policy on the power generation of individual and overall system elements.

4.0 DESCRIPTION OF THE SYSTEM

4.1 The System

The Indus water treaty between India and Pakistan permits the utilisation of supplies of the eastern rivers i.e. Ravi, Beas and Sutlej exclusively by India. The topography of the region through which these three rivers flow permits the link amongst them. The Bhakra-Beas system details are given in Figure 1. The proposal envisaged to the storage works for these reservoirs for integrated operation have been drawn up and extended in a phased manner. The schematic diagram of the Bhakra-Beas system is given in Figure 2.

Bhakra project was planned for utilising irrigation and power potential of the river sutlej. Beas project, comprising of two units; unit I-Beas-Sutlej link of 212.5 cumecs(7,500 cusecs) capacity to divert Beas river supplies into Bhakra reservoir and Unit II- Beas Dam at Pong, to harness the irrigation and power potential of Beas river supplies.

The river Ravi and Beas are connected by Madhopur-Beas Link with a capacity of 283 cumecs (10,000 cusecs) and with the construction of unit I of Beas Project all the three eastern rivers have been interlinked. Since it is of great advantage to coordinate the functioning of Bhakra and Pong reservoirs an integrated irrigation and power management, the Bhakra Beas Management Board (BBMB) has been established.

The flow availability at Beas Dam reservoir is 0.6069

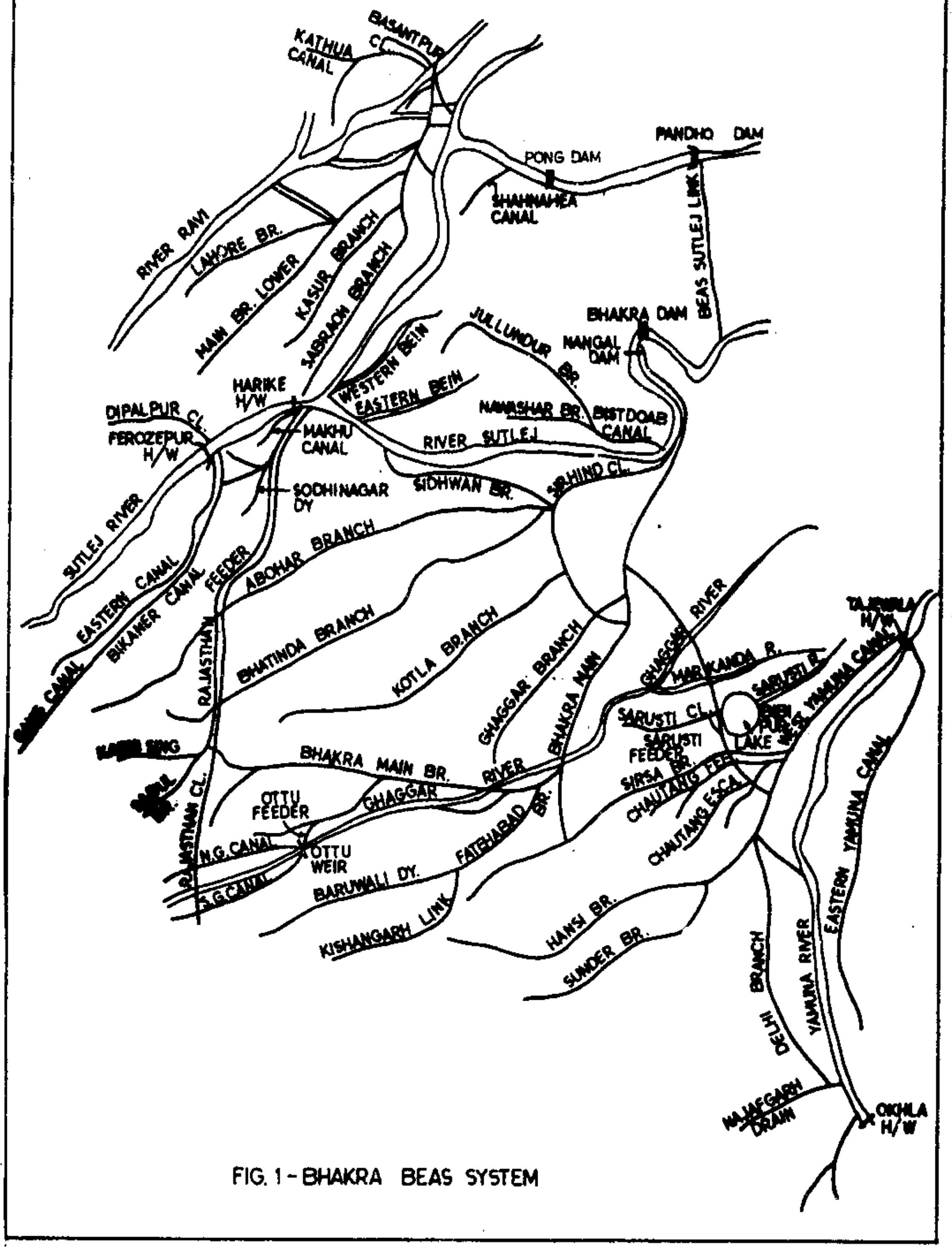


FIG. 1 - BHAKRA BEAS SYSTEM

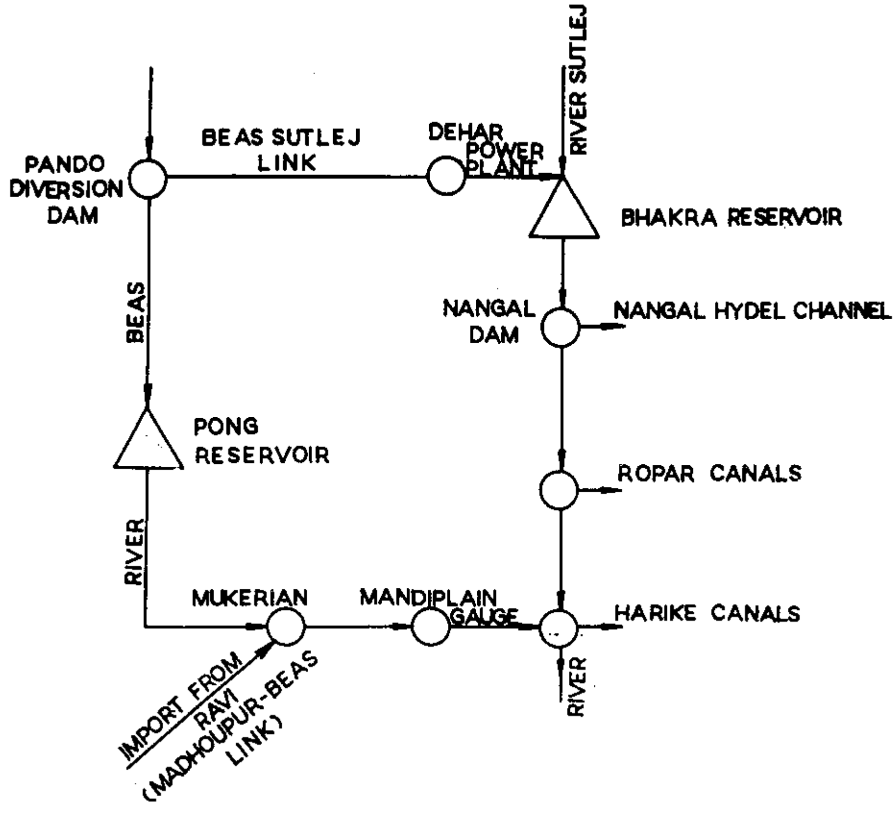


FIG. 2 SCHEMATIC DIAGRAM OF BHAKRA BEAS SYSTEM

m.ha.m is (4.92 MAF) in a mean year. But the live storage capacity is 0.690 m.ha.m.(5.6 MAF). This allows for additional storage during the surplus supplies in good years which can be carried over and used during succeeding dry years. The total annual flow in rivers Beas and Sutlej in the mean year is 3.320 m.ha.m(26.92 MAF) while maximum being 4.5467 m.ha.m(36.86 MAF). The individual systemelements are described briefly in the subsequent paragraphs.

4.2 Bhakra -Nangal Project

The composite Bhakra-Nangal project was initially designed for meeting irrigation demands of Punjab,Haryana and Rajasthan. However, subsequently, the project operating rules have been modified to cater to the needs of power generation also, in view of the additional water availability as well as increased demand for power. This project combines the Bhakra dam constructed on River Sutlej, located in the State of Himachal Pradesh and Nangal reservoir constructed on the same river on the downstream of Bhakra Dam but located in the State of Punjab, separated by a distance of around 13 kms. The details with regard to these two reservoirs are discussed below:

4.2.1 Bhakra dam

The Bhakra dam is a concrete gravity dam with a total height of 225.55 m(740 ft) above the deepest bed level. The upstream face of the cross section of the dam is vertical from the top at 518.16 m (EL 1700 ft.) to 411.48 m (EL 1350 ft) and subsequently has a slope of 0.36 to 1.0 upto the bottom. It creates an upstream lake called Gobind Sagar lake with total storage capacity of 0.9159 m.ha.m.(7.4255 MAF) at 515.11 m (1690 ft) and having a surface spread of 16,868 hectare (41, 680 acre). An ogeee type of spillway is provided at the centre of the dam with its crest at EL 501.4 m(1645 ft) and has a width of 79.25 m (260 ft) to negotiate the floods. The spillway discharge is controlled by four 15.24 m(50 ft) long radial gates. Facilities for release of water for irrigation and power production consist of sixteen numbers of 2.64 m(8'8")horse show type river outlets and 4.572 m (15 ft) diameter steel penstocks respectively. The river outlets are arranged in two tiers of eight each in the central spillway section. Generally water for irrigation is provided through discharges meant for power generation. However, either when the irrigation demand or when the demand at Nangal pond is more than the power releases then the river outlets are operated. The overflow spillway and river outlets together can take care of around 11327 cumces(4,00,000 cusecs) of flood waters.

4.2.2 Bhakra power plants

The storage of Bhakra dam is essentially for irrigation and power purposes. The flow of river Sutlej is supplemented by diversion of Beas Water through Beas-Sutlej link, which takes off from Pondoh dam acrosss Beas River. The Bhakra Power Plants are being operated in conjunction with Gungawal and Kotla Power Houses on the Nangal Hydel channel. Together the system is designed to generate 407 M.W. of firm power and lot of secondary power. There are two power plants; one on the left bank and another on the right bank.

The left bank power plants consists of five 90 M.W. vertical type generating units. Each unit comprises 1,50,000 H.P. Francis turbines designed to run at variable head from 525 to 268 feet coupled to 11,00,000 KVA (90 MW) Generators. The water for driving the turbines is led from the reservoir through 15 feet diameter steel pipes. The right bank power plant houses five generating units of 120 MW capacity each. The last unit of this series was commissioned in April,1969.

4.2.3 Nangal dam

Nangal dam is situated on the river Sutlej about 13 kms. downstream of the Bhakra dam site. The dam diverts the waters of Sutlej river into the Nangal Hydel Channel(NHC) for power generation and irrigation purposes. It acts as a balancing reservoir with storage about 1974 ha.m.(16,000 acre feet) for smoothening the variations in releases from the Bhakra power plants supplying regulated flow to Nangal Hydel Channel. There are two power houses on the NHC. The first power house is located at Ganguwal, a place about 19 km. from Nangal and second power house is situated at Kotla at a distance of 9.6 km. below Gungulwal on the NHC. A head of about 28.4 m(93 feet) is available at each of these two power houses. The two power plants generate an aggregate power of 154 MW. The tail reach water from Kotla power house is let out to Bhakra Main line canal.

4.2.4 Bhakra command area

In order to achieve the different crop pattern in preference to spreading the water over the maximum area regardless of the adequacy of supplies, the project command was classified into the following three zones on the basis of the climatical,hydrogeological and geological classification.

a) Zone no.1 (Restricted perennial)

This zone includes the Bist doab, Samrala,Rajpura south of Patiala, tracts of Punjab State and Kaithal Pehowa tracts of Haryana State. The area being nearer to the hills receives good rainfall during the winter months. The tracts are densely populated. The rainfall being deficient during the sowing and maturing periods, irrigation is definitely needed. In order to avoid the possible, water logging in the area as well as to conserve water for tracts, restricted perennial supply was proposed for canals in this region. A flow intensity of 45 percent was fixed for this area and number of full supply days were restricted to 203 days. A kharif-rabi ratio of 44.5 : 55.5 was adopted.

b) Zone no.2 (non perennial)

This zone comprises of areas with high spring levels situated close to the river. It includes the areas north of Abohar,Grey canals, situated between Kotla and Bhatinda branch and the area North of Bhatinda branch. After the construction of Bhakra Dam, a regular irrigation is provided but an intensity of 35 percent with water allowance of 0.10 cumecs(3.5 cusecs) per 404.7 ha (1000 acres) for 158 days in a year. The Kharif rabi ratio is stipulated at 52:48. These areas were originally irrigated even prior to the construction of Bhakra dam, but the supplies were limited to only during excess periods of flow in the river.

c) Zone no.3 (perennial)

This zone consists of the dry and arid areas of Hissar and Rohtak districts of Haryana State and boundary areas of Rajasthan. The rainfall in these areas is very uncertain and low varying from 250 to 380 mm. The spring level is very low and the depth to water table is around 30 to 40 meters below the natural surface. The tract was subject to frequent devasting famines. Perennial irrigation with an annual intensity of 62 percent and water allowance of 0.078 cumecs(2.75 cusecs) per 404.7 hectares (1000 acres) at distributory head for 278 days in a year were adopted for these areas. Kharif Rabi ratio is the same as for restricted perennial areas i.e. 44.5 : 55.5.

4.2.5 Bhakra canal systems

a) Bhakra canals: Bhakra Main Link(BML) takes off from the tail end of the Nangal Hydel Channel at Ropar and is aligned towards Tohana in the Hissar District. It is a lined channel of 108 miles long with a full supply capacity of 354 cumecs (12500 cusecs). The Narwana,Fatehabad and the Bhakra main branches take off from the Bhakra Main Line and through further branches and distributories these channels irrigate areas of Punjab, Haryana and Rajasthan.

b) Bist Doab Canal: It takes off from the right bank of

River Sutlej at Ropar just upstream of Ropar Head Works with full supply discharge of 45.3 cumecs (1600 cusecs). This canal serves a gross area of 2.5577 lakhs hecatares(6.32 lakh acres) in the Jullunder and Kapurthala districts of Punjab.

c) Sirhind Canal: In the pre-Bhakra state the Sirhind canal was fed from the river Sutlej at Ropar and likewise, it has the first claim on the free flow of river Sutlej. The authorised full supply discharge of the canal was 244 cumecs(8500 cusecs). There was ample supply available during summer period but during Rabi, the branches were run by rotation. Subsequent to the construction of Bhakra dam, supply of water to the Sirhind canal posed problem and it was decided that the Bhakra canals and the Sirhind canals should run as one system sharing the shortage and the excess in the ratio of their authorised full supply discharges.

4.2.6 Bhakra reservoir regulation

The regulation policy for the Bhakra reservoir is defined by the Bhakra Beas Management Board based on the indents submitted by the respective Executive Engineers on the downstream of the project. The working details of the operational policy is described below:-

The Executive Engineer, Nangal receives the consolidated indents from the concerned authorities of Bist Doab Canal,Sirhind Canal, Bhakra main line through,Executive Engineer, Ropar for irrigation purposes as well as from the Executive Engineer - Incharge for power houses at Ganguwal and Kotla. He,in turn, places an indent on Executive Engineer, Bhakra dam for the release of water from Bhakra Dam considering the maximum of the two indents.

The Executive Engineer, Ropar while placing his indent on Executive Engineer, Nangal shall consider the inflows of Sona,Sirsha tributories which join river Sutlej between Nangal and Ropar. The inflows of these tributories are,however, to be informed by Executive Engineer, Nangal twice daily during floods and once daily during normal season. Whenever it becomes necessary to release water in the river preference should be given to release the same through escape channel rather than reducing the head at Nangal hydel channel (NHC).

The construction of Bhakra dam has eliminated the occurrence of devastating floods in the downstream. The floods, whenever they occur, are absorbed and routed without causing any undesirable flow conditions along the river course down-stream of the dam. The worst flood which occurred after the construction of Bhakra Dam is on the 6th Aug,1971 which rose from 3398 cumecs (1.2 lakhs cusecs) to 17217 cumecs(6.08 lakh cusecs) in five hours and fell to 5664 cumecs(2 lakh cusecs) in the next five hours as against the design flood of 1947 pattern which rose from 3115 cumecs to 11328 cumecs in 30 hours and fell to 5664 cumecs in the subsequent 30 hours. This unprece-dented flood in 1971 resulted in a maximum rise of 3.96 m(13 ft) in Bhakra reservoir during a brief period of 24 hours from 6th August to 7th August,1971 and a total rise of 10.54 m (34.57 ft) in a 6 day period. Thus, even a flood of such a magnitude was safely absorbed and routed without causing any damage to downstream of Bhakra Dam.

4.3 Beas-Sutlej Link

A link between Beas and Sutlej rivers could be doubly beneficial for the production of Hydro power at Dehar Power Plant for augmenting storage in Bhakra reservoir for generation of power at Bhakra and for meeting irrigation demands for part of Haryana, which otherwise could not be commanded from the Beas at Pong. A fall of about 335.3 m(1000 ft) is available at the tail of the link for generating power. Also this additional diversion into the Sutlej augments the firm power at Bhakra where two sets of power plants of 1050 MW installed capacity are in operation.

Beas-Sutlej link known as Beas Unit-I consists of 76.2 m (250 ft) high rockfill diversion dam at Pondoh on river beas. The conveyance system comprises of 13.2 km.long 7.62 meter(25 ft) diameter tunnel from Pondoh to Baggi and 11.4 km. long hydel channel from Boggi to Sundher-Nagar with a maximum capacity of 212.5 cumecs(7500 cusecs). The penstock is taken from the tail of the canal and leads water to the Sutlej power plant near Dehar. There are six turbines to generate power with 165 MW of installed capacity each.

4.4 Beas Project-Pong Dam

On the downstream of Pondoh dam Pong reservoir was constructed with a water spread of about 260 sq.km. at full reservoir level of 426.7 m (1400 ft) across river Beas. When the water level reaches 426.7 m the spillway radial gates shall be raised. From irrigation and power generation considerations, the minimum level of permissible water level has been fixed at EL 384 m (1260 ft) MSL. Between the FRL at 426.7 m (1400 ft) and the dead storage level of 384 m a capacity of 0.729 m.ha.m (5.91 MAF) for controlled irrigation and power generation is available. An overflow spillway with six bays of 14.4 m(47.5 ft) each has been provided on the left abutment of the dam with the crest at EL 416 m (1365 ft). The discharge over the spillway is controlled by six 14.5 m (47.5 ft) wide and 12.34 m (40.5 ft) high radial gates with discharging facility of 1237.5 cumecs (43,700 cusecs) at the highest flood level of 433.12 m (1421 ft).

4.4.1 Pong dam power house

Steel penstocks of 7280 mm inner diameter have been installed in three tunnels of 9.14 m (30 ft) dimater each with downstream emergency gates. At the downstream portals of tunnels each penstock header is bifurcated into two penstock branches of 5205 mm. These penstock branches feed the six generating units of pong power plant of 60 MW capacity each. The maximum discharge through one penstock header is about 215.2 cumecs(7,600 cusecs) at rated head of 65.5 m (215 ft) and 158.5 cumecs(5600 cusecs) at maximum net head of 95.1 m(312 ft).

In addition, irrigation outlets have also been provided for providing releases during heavy demand for irrigation purposes. There are four outlet conduits of size 2.13 x 3.2 m (7 x 10.5 ft). Two slide gates are installed in each outlet conduits.

4.4.2 Irrigation releases from Pong dam

Pong reservoir can meet the irrigation requirements of canals of Punjab and Rajasthan which take off from Harike head works. The releases at Bhakra Dam and Pong Dam alongwith the available water through Madhopur-Beas link are to be shared between Punjab,Haryana,Rajasthan and Delhi.

Full utilisation of Ravi-Beas surplus supplies can be made only with storage on river Ravi. In the absence of such storage canal requirements of upper Bari doab canal(UBDC) cannot be fully met and the diversion through Madhopur-Beas link which joins Beas at Mukerian would fluctuate with pattern of flood peaks during the flood period. Storage of appropriate capacity is planned according to the Thein Dam proposal and is likely to contribute in the near future. As the three rivers will be completely interlinked and runoff will be fully exploited any additional storage capacity provided over and above that required for mean year could be utilised to cover shortage on any of the three rivers in succeeding dry years. But , as on today, the Madhopur-Beas link contribution to the canals at Harike is very small and seasonal.

5.0 AVAILABILITY OF DATA

The data required for the model are the system description, the maximum and minimum capacities of rivers and canals, historical ten-daily flow data, demand data and individual reservoir evaporation data. This model uses the virgin flow data as the input. During the allocation process, water released from the reservoir will be accounted alongwith the virgin flow from the downstream location.

5.1 Inflow Data

All pertinent flow data have been collected from both the Bhakra Beas Management Board and the Ministry of Irrigation,Government of India. The ten-daily flow data for the following stations have been collected for the period between 1964 to 1981.

1) Pandoh
2) Bhakra Dam
3) Nangal
4) Ropar
5) Bhakra main canal
6) Beas Dam
7) Madhopur Diversion
8) Harike

5.2 Evaporation Data

Evaporation occurs from the reservoirs, channels and irrigated areas. Evaporation from irrigated areas is included in irrigation demands and channel evaporation losses are considered while placing the indents for rivers, but the losses from reservoir shortage due to evaporation is not accounted directly. Hence, they are to be estimated for Bhakra and Pong reservoirs depending upon the water spread area and are to be given as inputs(demands). Mahandiratta and Hoon(1973) measured the Pan evaporation at Bhakra from April 1966 to March 1971 and estimated the evaporation rates using the inflow, outflow and storage data. They estimated an average pan coefficient of 0.7 for Bhakra reservoir. Using meteorological data, the average monthly evaporation rates have been calculated. The average annual evaporation is taken as 1.46 m (4.8 ft) and the monthly values from January to December are given below:

Months	Evaporation
January	48.8
February	64.0
March	112.8
April	192.0
May	228.7
June	198.2
July	152.0
August	103.6
September	118.8
October	103.7
November	76.3
December	51.8

As the operation is scheduled on a 10 daily basis, one third of the respective monthly evaporation coefficients are used to calculate the evaporation losses. Same rates are used for Pong reservoir also.

5.3 Power Data

As stated earlier, power is generated in the system at Bhakra, Pong,Dehar and Nangal including Ganguwal and Kotla power houses. Energy generated through Nangal Hydel Channel (NHC) is considered to be constant (154 MW) and the releases at Bhakra are always more than the design capacity of NHC. Also, the Nangal Hydel Channel's demand of 354 cumecs is assigned highest priority in the system. The computation of power generation in the existing system provides little freedom to use any standard procedures due to differential characteristics of individual units and their interactions.

5.3.1 Dehar power generation

The installed capacity of Dehar Power Plant is 990 MW (6 units of 165 MW). The head is almost constant. The tail water level depends upon the Gobind Sagar reservoir level formed by Bhakra Dam. For the calculation of head, tail water level of Dehar Power Plant has to be considered as Gobind Sagar level plus five feet (for stilling basin) subjected to a maximum of EL 502.9 m (1650 ft). The other detail steps are as given below:

Step-I : Head loss in tunnel in meters = $950.27 \times 10^{-6} Q^2$

Q : flow in cumecs

Step-II : Penstock losses = 7.62 m for 212.5 cumecs discharge and 4.6 m for 113.3 cumecs and below.

Between 113.3 to 212.5 cumecs the loss is linearly interpolated.

$$\text{Power in MW} = \frac{QHe}{101.87}$$

where,

H = net head (after losses)

e = efficiency

5.3.2 Bhakra power generation

There are two power plants at Bhakra Dam. They are known as left Bank and right bank power plants. The left bank power plant consists of five vertical type generating units of 90 MW each. Each unit comprises 1,50,000 horse power Francis turbines designed to run at a head varying from 79.25 to 156.05 M.

The right bank power plant consists of five generating units of 120 MW each. The maximum and minimum head available for these turbines are 158.5 and 81.95 m as against the left bank turbine heads of 156.05 m and 79.25 m respectively.

Tail race elevations are available for Bhakra Dam downstream and are given in Table 1 for various discharges. Penstock loss of 1.22 m (4 ft) is suggested by Bhakra Beas Management Board. But different heads for the two sets of turbines for the same water level in the reservoir pose problem for the power computation. However,Bhakra Beas Management Board has made a exclusive study for the determination of optimal schedule for the operation of turbines for different heads and different discharges, making use of characteristics of the two turbines (left bank and right bank). The optimized schedule for different heads and discharges are furnished in Table 2.

5.3.3 Pong power generation

Pong Power Plant comprises six units of 60 MW each. The maximum and minimum head available to the turbines are 94.5 and 45.72 m (310 and 150 ft) respectively, considering water level will not be depleted below 1260 ft. Tail race elevation for different discharges to the downstream of Pong is given in Table 1. Curves for power generation vs head and discharges as supplied by the turbine manufacturers are given in Figure 3.

TABLE 1 TAIL RACE ELEVATION DISCHARGE TABLE

BHAKRA		PONG	
ELEVATION IN FEET	DISCHARGE IN CUSECS	ELEVATION IN FEET	DISCHARGE CUSECS
355.70	283.17	330.70	79.30
355.85	330.00	330.86	113.30
356.00	372.40	331.01	147.30
356.16	410.60	331.16	184.06
356.31	456.00	331.31	218.04
356.46	497.00	331.47	252.02
356.61	536.00	331.62	288.83
356.77	580.50	331.77	322.82
356.92	623.00	331.93	356.80
357.07	665.50	332.08	396.61
357.23	696.60	332.23	427.60
		332.38	461.60
		332.54	498.40
		332.69	532.36
		332.84	566.34
		333.00	603.16
		333.15	637.14

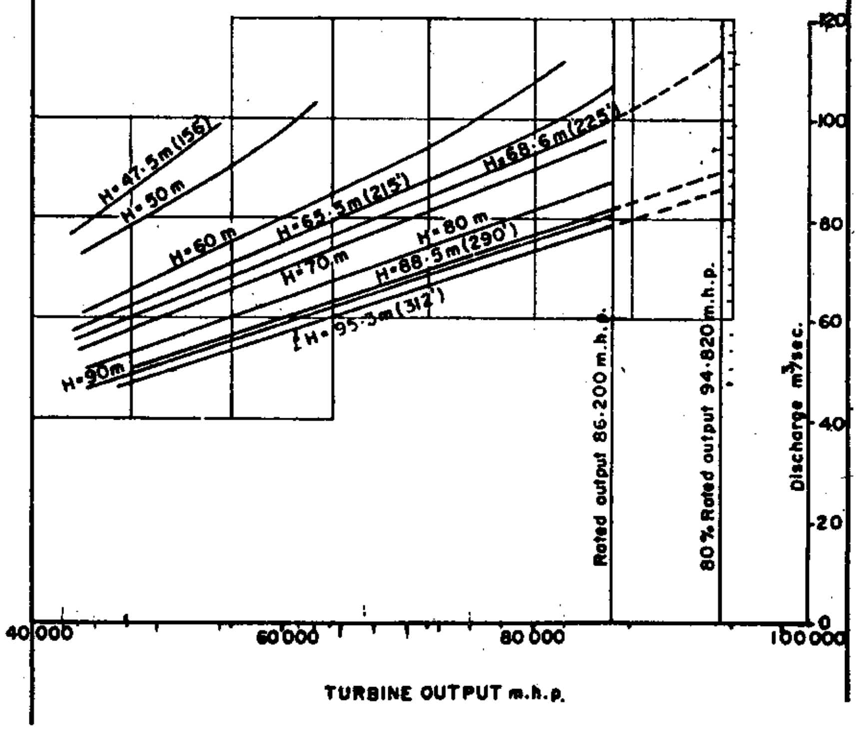
TABLE 2 - BHAKRA POWER TABLE FOR VARIOUS HEADS AND DISCHARGES
(POWER IN MW)

HEADS IN METRE

DISCHARGES IN CUMECS	81.686	97.536	109.728	121.920	134.112	146.304	152.400	158.496
141.587	200.000	200.000	200.000	200.000	200.000	200.000	200.000	200.000
212.380	200.000	200.000	206.300	226.800	244.000	250.000	265.400	265.400
255.564	200.000	219.700	241.400	274.600	300.000	310.000	326.100	326.100
276.094	200.000	240.400	266.800	300.000	311.200	336.600	347.800	347.800
295.917	209.300	258.000	300.000	319.600	344.300	359.600	376.600	376.600
349.748	296.700	300.000	336.550	375.600	406.500	429.900	445.000	445.000
409.186	300.000	349.700	400.000	442.400	469.500	500.900	525.800	525.800
477.431	350.000	415.500	464.620	515.170	558.400	590.600	609.300	609.300
518.038	376.600	450.000	515.000	556.900	607.000	640.600	654.800	654.800
558.985	422.400	488.400	550.000	606.200	648.400	694.000	718.700	718.700
607.125	456.200	523.200	593.900	650.000	655.400	749.200	781.600	781.600
639.973	473.000	544.500	626.000	692.000	750.000	797.000	822.400	822.400
679.957	493.400	561.600	669.300	731.100	797.800	850.000	869.400	869.400
710.058	511.300	610.500	704.000	761.200	829.200	878.900	900.000	900.000
763.805	596.700	656.600	797.400	824.300	883.600	950.000	979.600	979.600
819.090	599.000	699.800	799.750	891.900	950.000	1024.400	1035.000	1035.000
865.946	600.000	735.400	850.000	930.400	1010.200	1035.000	1035.000	1035.000
929.461	600.000	800.000	911.900	999.200	1035.000	1035.000	1035.000	1035.000
968.086	600.000	829.600	964.900	1035.000	1035.000	1035.000	1035.000	1035.000
992.864	600.000	830.000	950.000	1035.000	1035.000	1035.000	1035.000	1035.000
1023.673	600.000	830.000	1000.000	1035.000	1035.000	1035.000	1035.000	1035.000

PONG PROJECT

FIG. 3 - CURVES OF TURBINE DISCHARGE



6.0 METHODOLOGY

6.1 Simulation technique

Simulation of natural and man made systems is well known to water resources engineers. The importance of studying system operating characteristics by simulation lies in the fact that different system like geometrical configuration, operational constraints, etc. can be explored without actually building the system or waiting for particular scenario to occur before making decisions. In most water resource management studies the inputs are principally hydrological precipitation, streamflow, etc. Variability in these inputs could be accommodated by using an observed record from the past (deterministic simulation). Most of the simulations are generally made presuming that some particular observed hydrological time series is representative of future conditions which is not far from the truth.

Simulation is one of the many approaches that might be useful in analysing a particular water resources system. As a working definition, simulation is a technique for describing system interactions and fluxes when particular inputs derive the system while it is operated under a specific set of procedures. Most of the simulations are affected by programming elementary mathematical descriptions for solution by a digital computer.

6.2 Model Used

In this study, a core model based on the Texas Water Development Board's (TWDB) River basin simulation model(SIMYLD-II) which is a quasi optimization model employing Out-of-Kilter Algorithm has been used. The Out-of-Kilter algorithm is the back-bone of SIMYLD-II. The other structures of the programme can be altered to the desired extent depending on the specific basin conditions with required additions and commisions The original structure of the model does not have the capability of energy computations. Here the model is modified suitably to cope up with the 10-daily operation schedule using reservoir factor as well as to cater to the needs of system power generation. The modified Model is designated as PISIM-I and the flow chart is given in Figure 4.

The Out-of-Kilter Algorithm is a special purpose linear programming algorithm designed for the solution of simple network allocation problems. It is an integer arithmetic method that will converge to the minimal cost solution for any feasible problem. This algorithm requires a network definition (configuration) consisting of nodes and arcs. A node represents a storage (may be even zero capacity) location, inflow location or diversion point. An arc represents a physical flow element (river,canal etc.) of the system or a change in storage over time. For each arc it is necessary to specify.

a) source node number

b) sink node number

c) lower bound for flow in the arc

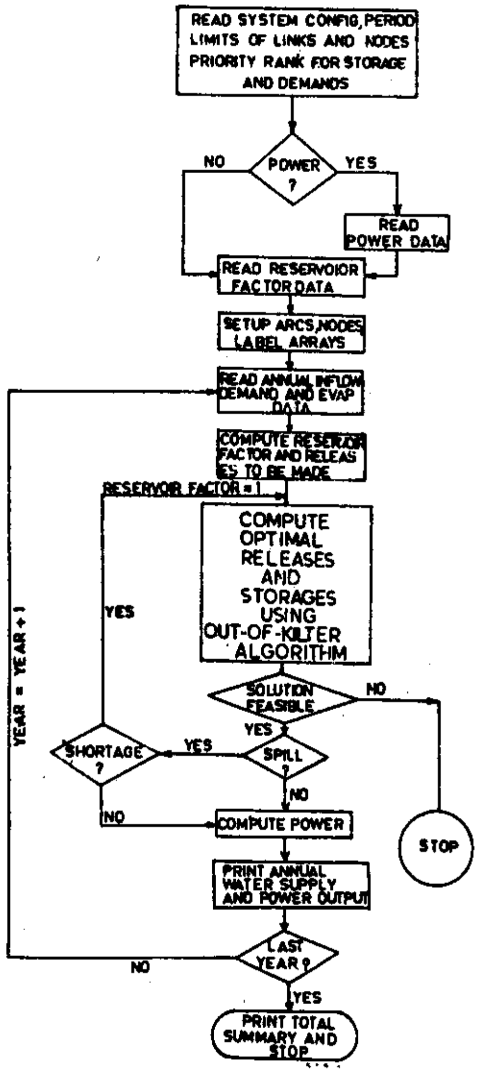


FIG. 4–FLOW CHART OF PISIM-I

Minimize:

$$Z = \Sigma_{ij} q_{ij} C_{ij} \qquad \ldots(1)$$

Subject to:

$$\Sigma_i q_{ij} - \Sigma_i q_{ji} = 0 \qquad j=1.....n \qquad \ldots(2)$$

$$L_{ij} \leq q_{ij} \leq U_{ij} , \text{ all } i,j \quad \ldots \qquad \ldots(3)$$

where,

q_{ij} = Flow from node i to node j for time t

C_{ij} = Cost of flow from node i to node j for time t

L_{ij} = Lower bound of the arc from node i to node j,and

U_{ij} = Upper bound of the arc from node i to node j

The first set of constraints (Equation 2) satisfies continuity of mass at all nodes in the network. Equation 3, describes the upper and lower limits on flow in all arcs in the network. The objective function to be minimized is expressed by Equation 1.

iv) All necessary state variables have now been determined and the status of the system at the conclusion of the current time step becomes the status at the beginning of the next time step.

The operation of the system depends on whether storage and inflow in a given period indicates the water available to be below, at or above average conditions referred to respectively as dry, average and wet states. The three states are determined as follows:-

A specific group of reservoirs or all the reservoirs are used to identify the system state.

let

$S'_{I,t+1}$ = Unit R.F.capacity of i^{th} reservoir for $t+1^{th}$ time period

N = Number of reservoirs used in identifying the state of the system

t = The period under operation

$X_{i,t}$ = end-of-period (10-daily)storage for the i^{th} reservoir in the t^{th} time frame

$Y_{i,t+1}$ = Average inflow to the i^{th} reservoir in the $(t+1)^{th}$ time frame (derived from historical record)

W_{t+1} = Total unit storage capacity of reservoirs for the $t+1^{th}$ time defining the state

$$= \sum_{i=1}^{N} S'_{i,t+1}$$

$$R = \sum_{i=1}^{N} X_{i,t} + \sum_{i=1}^{N} Y_{i,t+1} \qquad \ldots(4)$$

Let X_1 and X_2 be fractions of the subsystem maximum capacity used to determine the limits of the hydrologic state with $X_1 \leq X_2$.

Define

$$L_B = X_1 \cdot W_{t+1} \text{ and}$$

$$U_B = X_2 \cdot W_{t+1}$$

Where the hydrologic state is determined by

$$R < L_B = \text{dry}$$

$$L_B \leq R \leq U_B = \text{Average and}$$

$$R > U_B = \text{Wet}$$

Associated with each one of the hydrologic states there is a corresponding set of operating rules and ranking priorities for meeting demands. Priority indicates the order of preference in which this demand should be met in reference to other demand and storage priorities in the system. It simulates the movement of water in a system of reservoirs, and rivers on a monthly basis while trying to meet a set of specified demands in a given order of priority. If a shortage occurs (i.e. not all demands can be met for a particular time period) during the operation, they are spatially located at the lowest priority demand nodes. The desired storages are given as a percentage of the unit reservoir factor storage of each time period.

The level of demand satisfaction is a function of the storage position of the controlling reservoir. In India where ground water pumping is practiced to certain extent to augment surface water supply, minor shocks by way of reduction in irrigation supply through surface water sources are absorbed without much agitation. Therefore, reduction in releases are suggested here whenever the storage goes down below the normal expected level, rather than facing a total cut in supply towards the end of the critical period. Thus, in order to work out the proportional reduction in supply corresponding to the controlling reservoir storage a factor known as ' Reservoir factor' (R.F.) is used here.

$$R.F. = \frac{S_t + F_{(36-t)}}{I_{(36-t)}}$$

S_t = Available storage of the reservoir under consideration during the end of month t

$F_{(36-t)}$ = Cumulative inflow during the remaining period of the year, including loss or gain between and at the controlling reservoir and the demand point.

$I_{(36-t)}$ = Cumulative indent during the remaining period of the year, on the reservoir

MAX.RELEASE = DEMAND x R.F.

For this purpose the inflow during the rest of the period either dependable or mean flow depending upon the judgement on the basin character may be used.

However, whenever there is surplus reach in flow available and is likely to spillout of the system the demand is increased irrespective of the prevailing reservoir factor of the controlling reservoir, subjected to a maximum of unit reservoir factor demand. This happens mostly during the beginning of monsoon.

6.4 Assumptions

1. Evaporation losses for all reservoirs are calculated by the product of the 10 daily evaporation rate and the average 10-daily reservoir surface area.

2. Demands for water are known for the period being

simulated.

3. Reservoir storage contents are allowed to fluctuate between the maximum and minimum capacities specified by the user.

4. Spill occurs only at specified nodes and is the most expensive alternative.

5. The flow in all links ranges between the maximum and minimum capacity specified by the user.

Thus, the Out-of-Kilter Algorithm, originally used in SIMYLD-II, was adopted with a restructured out fit to suit to the conditions of the present study. The new terminology known as ' Reservoir Factor' is used here to regulate the releases at critical period of the year.

6.5 Data requirement

The data requirement of the model is as follows:
System description:

The junctions or nodes of the reservoir shall be described by name and number. A node may be a storage or a diversion point with out any storage. Diversion point also will be considered as a reservoir but with zero storage. For the computational time saving point of view,reservoirs are to be numbered first and other nodes are to be followed. Their minimum and maximum storage must be given. The minimum storage must be given. The minimum storage may be the dead storage that has to be maintained considering power and low flow augmentation. The maximum storage will change with time unless the reservoir is over designed or there is no flood cushion storage provision.

Any of the reservoir may be designated as spill reservoir. But it is better to designate the downstream most reservoir in the system as spill reservoir to analyse the seasonal loss from the system unless serious problems arised in the carrying capacity of the upstream river reaches. For reservoirs it is required to give the area-capacity and elevation tables for power and evaporation loss computations.

In order to furnish the system configuration completely, links connecting various nodes have to be numbered. Whie numbering links river reaches should be numbered first and then canals. It is to be strictly allowed because in the minimization problem the cost assigned for unit volume of flow in river reaches in less than that of canals. But this can be wisely utilized by the user depending upon his preference by even mentioning the physical system vice-versa.

Operation rules are provided as the relative priority ranks of meeting the demands and desirable storage levels in terms of unit reservoir factor storage of each time period of various nodes to decide upon the optimal releases for the time period under consideration through the Out-of-Kilter algorithm Since the optimization technique is a minimization one, lower the rank number higher will the priority assumed. The operation rule used in this simulation is ten-daily operating criteria in terms of the multiples of unit storage capacity that is desired to be in the reservoir at the end of the ten-daily for each of the dry, wet and average states.

6.5.1 Average reservoir inflow data

In the reservoir system state identification average inflow data is used alongwith the beginning storage. In the absence of any forecasting it is felt that the average flow of the simulation period is required for the above purpose.

6.5.2 Reservoir factor data

The expected cumulative inflow as per mean year or dependable year and indent during the rest of the water year in storage volume unit are to be furnished for those reservoirs which control/command the demand requirement of the down nodes. The expected cumulative inflow includes the loss or gain on the reservoir and the reach between the reservoir and its demand point.

For any reservoir the cumulative available flow may be calculated as follows:

a) Calculate the average/dependable ten-daily flows from the available record.

b) Calculate the average losses or gains between the point of release and the point where a desired indent is required.

c) Calculate the estimated evaporation losses from the reservoir. The evaporation is a function of water spread area and the evaporation rate during that time. As such it is necessary to find out the average or probable elevation during each time period of the year. Thus, it may not be possible to estimate the average evaporation loss unless it is operated for the entire simulation period. Hence, during the first iteration the system is simulated without considering the evaporation loss. Subsequently corrections are made considering the computed losses and updating the same at each stage of iteration.

d) Substract/add the above two items of losses and gains from the available average flows as these losses or gains will be there whatever be the reservoir factor adopted.

e) Convert this available average flow into volume units for each ten-daily period and find out successive totals starting from the end of the water year and working backwards to the beginning. This is the cumulative available flow.

Similarly cumulative indent on any reservoir may be worked out. The balance storage available after releasing the indent is known as the unit reservoir factor storage of the time period.

6.5.3 Power data

There are two options provided for the power computation. If power computation has to be performed on the basis of conventional methods as it happens during planning stage the installed turbine capacity in M.W. is required to be given as input. If power production calibration has been done on the turbine (which is generally done for systems under operation) head discharge power table may be given. Thus for any head Vs discharge a double interpolation is made to pickup the power generated. But both the cases require the tail race elevation versus discharge.

6.5.4 Ten-daily simulation period data

The inflow and demand data for all the junctions for the entire simulation period shall be given as input in the ascending order of nodes. These data may be in any unit but conversion factor to the storage volume shall be provided. Evaporation rate during the simulation period has to be given for the storage nodes in the ascending order of the nodes. The unit shall be in such a way that evaporation rate multiplied by area given in the area-elevation-capacity table should yield the capacity (storage volume) unit.

7.0 ANALYSIS

In the present study, discharge data of the system from 1964 to 1981 are used. It was found that there was significant deviation of reach inflow between the pre and post reservoir conditions. It is seen that the loss/gain between various control points during the post reservoir condition is almost stabilised. This is mainly altributed to the controlled releases of the reservoirs irrespective of the upstream lean or high flows. Thus, it is assumed that the data between the above period is most realistic.

7.1 Discharge

Earlier studies during the planning stage for integrated operation of the Bhakra-Beas reservoir systems have used the losses or gains between various locations as constants over a particular time period of the year. Analysis of data shows that atleast for some period, approximately for about one and a half to 2 months (worked out on the basis of 10 daily data) mainly during the monsoon season,there is substantial flow termed as reachinflow (virgin-flow) available in the intermittant catchment of the system which can almost meet the downstream demand. This is accrued because of Chakki River western and eastern Bein Rivers join in the main river, in between Pong and Harike. The present operational policy of Bhakra Beas Management Board, however, considers this additional flow calculated on daily basis though originally an average value of inflow was adopted during planning stages of the system.

Hence, as a first step of the study, the virgin-flow between the following reaches have been computed:

a) Pongdam - Mandi Plain (upstream of Harike)

b) Nangal dam - Ropar

c) Mandi Plain - Harike

d) Ropar - Harike

While, the reach inflow between Pongdam and Mandiplain includes diversion from river Ravi through Madhopur-Beas link, besides the contributions from the tributories, its value between Nangal dam and Ropar includes the flows from Nangal Hydel Channel's escapes,Soan and Sirsa Rivers. These calculations show that both losses as well as gains within these reaches are significantly different from those consideration in the planning studies. This necessitated to review the operational policies which have been institutionalised at the time of planning and operation of the system.

7.1.1 Cumulative inflows

Cumulative available inflows and indents required for the reservoir factor computation is worked out as follows. The inflow at Bhakra (Gobind Sagar) is considered as the sum of Sutlej inflows and diversion from Pandoh through the Sutlej-Beas link limited by its capacity of 212.5 m. Thus the eighteen years data at Pondoh were processed and the ten-daily average flow available thorough the link were obtained. These flows together with Sutlej inflows and the loss or gain(reach inflow/

loss)between Bhakra Dam and Ropar diversion were summed up and assumed as the available flow to the Bhakra system. Evaporation loss was estimated later on during the simulation analysis for each time period of the eighteen years and their ten-daily average was substracted from the available inflow. The indent between Bhakra Dam and Pong reservoir and that between Pong reservoir and Harike and Ropar and Harike were considered as inflow available in the Beas system. Evaporation losses are estimated as explained in Methodology. Table-3 and 4 shows the average inflow, indent and the unit reservoir factor storage for Gobind Sagar (Bhakra) and Pong respectively.

7.2 Irrigation Demand Pattern and releases for various canals

Generally, the demands are low during the winter months viz., December to April except in the latter half of February and first half of March when water is required for maturing of Rabi crops. During the rest of the year, the demands are high either due to the sowing of Kharif crops, or due to scanty rainfall in the command area. The supplied demands(to the model) are as per unit reservoir factor.

Nangal Hydel channel has got a capacity of 354 cumecs (12,500 cusecs) which passes through the power houses at Ganguwal and at Kotla with an aggregate power generation of 154 M.W. Subsequent to the power generation, the water is used for irrigation either through Bhakra main line or diverted to the river Sutlej through escapes which is later tapped at Ropar. The Bhakra main canal originates from the tail race of Nangal

TABLE 3 - BHAKRA INFLOW AND INDENT

10-DAILY PERIOD (CAL.YR)	AVERAGE INFLOW IN CUMEC	CU.AVAIL INFLOW IN HA.MT	CU.EXPTD INDENT IN HA.MT	UNIT R.F STOR IN HA.MT
1	1836.	568459.	828385.	459699.
2	1815.	541032.	788889.	447630.
3	2042.	516016.	749393.	433150.
4	1850.	486370.	705947.	419350.
5	1909.	460406.	653559.	392926.
6	1867.	431025.	601172.	369920.
7	2261.	406678.	559262.	352356.
8	2568.	377507.	500014.	322279.
9	3116.	347235.	440766.	293304.
10	3045.	309924.	375593.	265441.
11	3675.	275304.	334289.	258758.
12	4716.	233998.	292984.	258759.
13	5618.	183359.	251680.	268094.
14	5871.	127305.	170493.	242960.
15	7279.	70254.	89306.	218824.
16	8631.	2506223.	2379223.	72773.
17	10583.	2425709.	2296981.	71045.
18	13475.	2326606.	2214740.	87907.
19	13940.	2198701.	2132498.	133570.
20	15399.	2059437.	2059527.	199863.
21	17211.	1900435.	1986556.	285893.
22	16653.	1715066.	1906287.	390994.
23	15408.	1527826.	1833316.	505263.
24	13962.	1333164.	1760345.	626953.
25	10384.	1161716.	1680076.	718133.
26	8331.	1040520.	1597296.	756549.
27	6137.	933911.	1514517.	780379.
28	4854.	865106.	1431737.	766404.
29	3704.	812339.	1354543.	741976.
30	3356.	773178.	1277348.	703943.
31	2809.	737068.	1192435.	655140.
32	2509.	706907.	1121555.	614421.
33	2357.	679208.	1050676.	571241.
34	2155.	652940.	979797.	526629.
35	2009.	626705.	930954.	504022.
36	2088.	599617.	882112.	482268.

NOTE: JUNE IS CONSIDERED AS BEGINNING OF W.YEAR

TABLE 4 - PONG INFLOW AND INDENT

10-DAILY PERIOD (CAL.YR)	AVERAGE INFLOW IN CUMEC	CU.AVAIL INFLOW IN HA.MT	CU.EXPTD INDENT IN HA.MT	UNIT R.F STOR. IN HA.MT
1	497.	166685.	353679.	315772.
2	502.	160396.	331831.	300212.
3	797.	154099.	309982.	284660.
4	762.	141605.	285949.	273121.
5	844.	130386.	262054.	260446.
6	681.	121584.	238160.	245354.
7	917.	112900.	219045.	234923.
8	894.	100187.	182480.	211071.
9	1104.	89502.	145915.	185190.
10	772.	75340.	105693.	159131.
11	777.	64097.	90769.	155449.
12	706.	53910.	75844.	150712.
13	884.	42638.	60920.	147059.
14	1057.	29782.	41268.	140264.
15	1187.	16133.	21617.	134261.
16	2346.	1199213.	1103045.	32610.
17	2817.	1175121.	1063395.	17052.
18	4554.	1146380.	1023745.	6142.
19	7373.	1095216.	984094.	17655.
20	9759.	1018933.	950918.	60762.
21	11896.	915420.	917741.	131098.
22	14778.	783160.	881247.	226864.
23	13174.	631559.	848070.	345289.
24	9629.	497072.	814894.	446599.
25	6713.	392844.	778399.	514333.
26	4793.	323359.	740736.	546154.
27	2553.	272070.	703072.	559779.
28	1506.	244255.	665408.	549931.
29	964.	227703.	618770.	519845.
30	870.	217655.	572132.	483254.
31	644.	208037.	520831.	441571.
32	543.	200912.	488388.	416253.
33	568.	194549.	455946.	390174.
34	580.	188093.	423503.	364187.
35	513.	181014.	400979.	348743.
36	648.	174944.	378455.	332289.

NOTE: JUNE IS CONSIDERED AS BEGINNING OF W.YEAR

Hydel channel. It has a capacity of 354 cumecs(12500 cusecs) and obtains its releases from Nangal Hydel channel Sirhind canal is the left bank canal which takes off from River Sutlej at Ropar. It has a capacity of 354 cumecs (12500 cusecs) and obtains its releases from Nangal Hydel canal. Sirhind canal is the left bank canal which takes off from River Sutlej at Ropar. It has a capacity of 354 cumecs (12500 cusecs). The maximum demand of this canal system during the years 1979-1982, those were met by the Bhakra Beas Management Board are used here as the ten-daily irrigation demands. Bhakra main canal and Sirhind joins together at the downstream of Ghaggar Branch and irrigates areas in Punjab,Haryana and Rajasthan. The water releases at Bhakra dam can be available for feeding not only Bhakra and Ropar canals but also Harike canals. Whereas the releases at Beas Dam can be available for feeding only Harike canal system. Also from the reach inflow calculation. it is noticed that losses between Ropar and Harike is high & releasing water for Harike canals through Bhakra is not advantageous. Thus, the lowest priority is assigned for Harike diversions through Bhakra dam. Also, any additional releases required for Harike canals for its irrigation demand, if made available from Bhakra dam that would be at the cost of power generation. Instead, the same releases can be made through Pong dam on Beas without the loss of power provided that there is adequate storage. However, when the level at Pong dam is alarmingly low the release for Harike have to be made available from Bhakra only.

The three canals take off at Harike after the Beas joins with Sutlej are Rajasthan canal,Rajasthan feeder and Makhu canal. The water that flows beyond Harike is considered as waste, since the river enteres into Pakistan. Thus, for optimal utilisation, it is considered that the spill at Harike Head works should be the least.

Harike canals receive Ravi flow through Madhopur Beas link in addition to Sutlej flows from Bhakra and Beas flows from Pong and the reach inflows in between Bhakra-Pong-Harike. However, diversion from Ravi after meeting upper Bari Doab canal's demand is insufficient and unreliable. The maximum demands of Harike canals those were met by the Bhakra Beas Management Board in the recent years (1979-1981) have been adopted here as the Harike demand.

7.3 Maximum and Minimum Operating Levels of Reservoirs

7.3.1 Bhakra dam

The maximum permitted reservoir level of Gobind Sagar is at 515.1 m EL (1690 ft), though water level is restricted to 512 m EL (1680.00 ft) for most of the times to provide necessary flood cushion. The permissible draw down level has been fixed at 44.56 m EL (1462.00 ft) in between the above two limits, the reservoir provides a live storage capacity of 0.7154 m.ha.m(5.8 MAF) for meeting the irrigation and power irrigation and power demands.

7.3.2 Pong dam

The maximum and minimum operating levels at Pong dam are fixed at 426.7 m EL (1400 ft) and 384 m EL(1260 ft) respectively.

7.3.3 Capacities of links (canals and rivers)

The maximum capacities of Beas-Sutlej link is limited to 212.5 cumecs. Thus,maximum water that can be diverted from Pandoh diversion dam to Gobind Sagar is 212.5 cumecs. Except in case of spills, the river flows downstream of the Gobind Sagar reservoir are based on the reservoir releases in response to the demands. Hence a maximum capacity of 2000 cumecs is prescribed for the rest of the links. The maximum flows throughout the system is taken as zero (as a lower bound) to avoid any infeasible solution in case of any shortage in the system.

7.4 Priority for Storages

From a consideration of the characteristics of the system, the following general observations are made :-

1) Storage in Bhakra reservoir is much more valuable than in Pong reservoir because of its high head and its ability to supply irrigation water to demands of the entire system.

2) Storage is more valuable in a dry year than in wet or average years.

Considering the above factors, the eighteen years of data were analysed and used in the operation study to select a better operation policy that will use the available resources most judiciously, with minimum spills under the existing constraints.

8.0 RESULTS

In order to consider the effect of relative priorities between the storage and for different hydrologic states, different sets of priority ranks were used in the simulation study. To find out whether the system is in dry or wet or average state, the storages of both Bhakra and Beas are used. After considering various operation policies, it is found that using unit reservoir factor system storage (RFSS), the dry and wet states can be better demarcated from average. It is considered that dry state prevails if the value of RFSS is less than 70% average if it is between 70% and 100% and wet state if it is above 100%. The final rule curve adopted (since it has checked the loss of water from the system and produced more power) is given in Table 5. It shows priority for storage in dry year may be slightly higher than the average or wet year storages in order to avoid the large deficit in the summer months(April and May). Priority for storage at Bhakra should be lower than the demand on the Bhakra dam and can be at best equal to it. The priorities for meeting the demands at various diversions from the river corresponding to the final rule curve are given in Table 6.

The demand satisfaction of canals at Ropar and Harike are controlled by the reservoir factors of Bhakra and Pong respectively. As explained in ' Methodology' the use of reservoir factor narrows down the deviation of shortage especially when the end of water year is likely to be critical. Thus, the use

TABLE 5 - RULE CURVE
(AS A RATIO OF UNIT RESERVOIR FACTOR STORAGE)

	BHAKRA			PONG		
	**********			*******		
PERIOD	AVER	DRY	WET	AVER	DRY	WET
1	1.11	0.99	1.17	1.25	0.40	1.30
2	1.14	1.02	1.20	1.32	0.42	1.37
3	1.18	1.05	1.24	1.39	0.44	1.45
4	0.99	0.90	1.06	1.29	0.46	1.39
5	1.06	0.96	1.13	1.35	0.48	1.46
6	1.12	1.02	1.20	1.43	0.51	1.55
7	0.91	0.87	1.02	1.04	0.50	1.19
8	1.00	0.95	1.11	1.16	0.56	1.33
9	1.10	1.05	1.22	1.32	0.63	1.51
10	1.09	1.00	1.24	1.24	0.74	1.51
11	1.11	1.03	1.27	1.27	0.76	1.55
12	1.11	1.03	1.27	1.31	0.78	1.59
13	0.92	0.95	1.06	1.30	0.82	1.62
14	1.02	1.04	1.17	1.36	0.86	1.69
15	1.13	1.16	1.30	1.42	0.89	1.77
16	4.32	4.32	4.32	3.58	3.58	3.58
17	4.42	4.42	4.42	6.84	6.84	6.84
18	3.57	3.57	3.57	20.96	20.96	20.96
19	3.87	3.13	4.11	8.90	7.30	9.70
20	2.58	2.09	2.74	4.93	3.29	5.31
21	1.81	1.46	1.92	2.28	1.52	2.46
22	2.11	1.55	2.27	2.76	1.04	2.80
23	1.63	1.20	1.76	1.81	0.68	1.84
24	1.31	0.96	1.42	1.40	0.53	1.42
25	1.24	0.90	1.26	1.35	0.38	1.35
26	1.17	0.86	1.20	1.28	0.35	1.28
27	1.14	0.83	1.16	1.24	0.34	1.24
28	1.06	0.82	1.08	1.05	0.35	1.06
29	1.10	0.84	1.11	1.11	0.37	1.12
30	1.16	0.89	1.17	1.19	0.40	1.20
31	1.09	0.90	1.10	1.06	0.31	1.09
32	1.16	0.96	1.17	1.13	0.33	1.16
33	1.25	1.03	1.26	1.20	0.35	1.23
34	1.20	1.01	1.23	1.08	0.36	1.13
35	1.25	1.05	1.29	1.13	0.38	1.18
36	1.31	1.10	1.35	1.19	0.40	1.24

TABLE 6 PRIORITY RANKS FOR MEETING DEMAND AND DESIRED STORAGE

	BHAKRA			PONG			HARIKE			NANGAI			ROPAR		
	AVE	DRY	WET	AVE	DRY	WET	AVE	DRY	WET	AVE	DRY	WET	AVE	DRY	WET
PRIORITY RANKS FOR STORAGE (RESERVOIR)	5	5	5	7	7	7	-	-	-	-	-	-	-	-	-
PRIORITY RANKS FOR MEERING +DEMANDS	6	6	6	3	3	3	4	4	4	1	1	1	2	2	2

of reservoir factor has a tight control over the system in monitoring the releases.

The storage at the end of May is influenced by the inflows during the previous year. Thus, the status of the reservoirs depends very much on the carry over of the previous year. Due to the fluctuations in the demand as well as the carry over storage during the beginning of the water year, (June) it is not possible, to adopt different initially desirable storages for different status (wet,average and dry) at the end of the month. The reservoir fills up rapidly in the months of June to September and depletes from October to May. Because of the fact that irrigation activities are at their peak during filling in period,irrespective of the storage position of the respective reservoir, the reservoir factor is fixed at unity. Thus, no reduction is made in the required demand during the period between June to September. Several modifications for the desired,10-daily storage levels for the different states (viz., wet,average and dry) in the two reservoirs (Pong and Bhakra) were tried and the best possible rule curve was evaluated.

The Irrigation demand of the system has gone up from 2.7 m.ha.m during the planning stage (dependable year cycle) to 3.4 m.ha.m. in the recent years. This shows an increase of 25 percent. The evaluated operation policy is checked for the irrigation releases for the dependable year and it is found that no shortage was encountered during the entire eighteen years of operation. Using the above planning period demand the average spill (system loss) was computed as 0.92 m.ha.m. For the enhanced demand supplied by BBMB for irrigation requirement, the computed spill is only 0.39 m.ha.m. Table 7 and 8 show the yearwise simulation summary for Bhakra Beas complex during planning stage and during the present study respectively. From Table 9 it can be seen that shortages are of the order of 0.119 m.ha.m. as against a spill of 0.4 m.ha.m. Thus it indicates that if 29 percent of this surplus water can be recovered the shortage could be completely avoided. This is possible only through artificial recharge whenever surplus flow is available and conjunctive use of ground water. It is proposed to meet the shortages by tapping the ground water and adopting the conjunctive use of surface and ground water. In order to avoid lowering of ground water levels while meeting this additional demand of 0.119 m.ha.m, it is proposed that the spill over water may be used for recharging the aquifer system by adopting suitable method of artificial recharge technique. The prospectus of adopting artificial recharge in western Rajasthan area is found to be encouraging (Chatterji).

Further, the study during the planning stage for dependable year (cycle 1921-22 to 1959-60) indicates that a firm power of 920 MW at 100% load factor would be available from Bhakra, Pong,Dehar and Nangal canal power plants of which 154 MW of power from Nangal is always generated. Thus, the estimated firm power generation from Bhakra, Pong and Dehar is 766 MW of which the contribution of Pong is 72 MW. Also from the above study, it is estimated that this power would be available for 93.5% of time.

TABLE 7 - YEAR WISE SIMULATION SUMMARY FOR BHAKRA-BEAS COMPLEX
(ASPER PLANNING STAGE DEMAND)

YEAR	STARTING STORAGE	UNREGULATED INFLOW	COMPUTED R.F DEMAND	SHORTAGES ASPER ACTUAL DEMAND	EVAPORATION	SYSTEM LOSS	ENDINGING STORAGE	DEMAND USED IN THE STUDY
1	1165658.	4252491.	3415178.	0.	34935.	640587.	1327448.	3415185.
2	1327448.	3006398.	3340615.	74563.	35309.	145823.	812098.	3415185.
3	812098.	3639430.	3157086.	460394.	29144.	329729.	1137870.	3415183.
4	1137870.	3915453.	3401479.	50437.	32449.	407084.	1249049.	3415185.
5	1249049.	3459521.	3415178.	0.	37976.	285322.	970094.	3415183.
6	970094.	3799700.	3316517.	98662.	31114.	269337.	1152826.	3415185.
7	1152826.	3329508.	3366626.	99626.	29295.	127585.	1009903.	3415183.
8	1009903.	4246529.	3324403.	160335.	32469.	816018.	1153100.	3415185.
9	1153100.	3221556.	3393155.	22023.	30339.	63870.	887072.	3415185.
10	887072.	4636903.	3337459.	77720.	34755.	911893.	1239869.	3415185.
11	1239869.	2671211.	3299747.	115432.	29298.	45761.	536275.	3415185.
12	536275.	4347084.	3109315.	332893.	29544.	542332.	1229197.	3415185.
13	1229197.	3788491.	3415178.	0.	37646.	393401.	1171462.	3415185.
14	1171462.	3983478.	3401690.	70980.	33484.	479388.	1297870.	3415185.
15	1297870.	4945959.	3415178.	0.	40301.	1495752.	1292598.	3415183.
16	1292598.	3211514.	3415178.	0.	39081.	152579.	897274.	3415185.
17	897274.	3019229.	3169768.	355848.	27004.	74785.	755384.	3415183.
18	755384.	3223187.	3183187.	231992.	27332.	13795.	754258.	3415185.
PERIOD TOTALS		66697648	59876932	2150903	591695	7195040		61473324
PERIOD AVERAGES		3705425	3326496	119494	32871	399724		3415184

ALL THE UNITS ARE IN HECTARE METRE

TABLE 8 - YEAR WISE SIMULATION SUMMARY FOR BHAKRA-BEAS COMPLEX
(ASPER PRESENT DEMAND)

YEAR	STARTING STORAGE	UNREGULATED INFLOW	COMPUTED R.F DEMAND	SHORTAGES ASPER ACTUAL DEMAND	EVAPORATION	SYSTEM LOSS	ENDINDING STORAGE	DEMAND USED IN THE STUDY
1	1165658.	4252491.	2725781.	0.	44372.	1059700.	1588296.	2725786.
2	1588296.	3006398.	2725781.	0.	50463.	388742.	1429707.	2725786.
3	1429707.	3639430.	2725781.	0.	44354.	863599.	1435404.	2725786.
4	1435404.	3915453.	2725781.	0.	46584.	1057289.	1521203.	2725786.
5	1521203.	3459521.	2725781.	0.	51099.	793274.	1410569.	2725786.
6	1410569.	3799700.	2725781.	0.	47223.	1000841.	1436424.	2725786.
7	1436424.	3329508.	2725781.	0.	44267.	469018.	1526867.	2725786.
8	1526867.	4246529.	2725781.	0.	48228.	1562688.	1436699.	2725786.
9	1436699.	3221556.	2725781.	0.	46572.	368143.	1517759.	2725786.
10	1517759.	4636903.	2725781.	0.	51082.	1868524.	1509275.	2725786.
11	1509275.	2671211.	2725781.	0.	46033.	144500.	1264172.	2725786.
12	1264172.	4347084.	2725781.	0.	46981.	1339903.	1498589.	2725786.
13	1498589.	3788491.	2725781.	0.	49897.	1056343.	1455059.	2725786.
14	1455059.	3983478.	2725781.	0.	46763.	1098716.	1567277.	2725786.
15	1567277.	4945959.	2725781.	0.	51177.	2174276.	1562003.	2725786.
16	1562003.	3211514.	2725781.	0.	51374.	703813.	1292549.	2725786.
17	1292549.	3019229.	2725781.	0.	42711.	236571.	1306715.	2725786.
18	1306715.	3223187.	2725781.	0.	45849.	444001.	1314272.	2725786.
PERIOD TOTALS		66697648	49064064	0	855027	16629941		49064148
PERIODS AVERAGES		3705425	2725781	0	47501	923885		2725785

ALL THE UNITS ARE IN HECTARE METRE

In the present study, using eighteen years data and the final operating rule for the period from 1964 to 1981, it is observed that for five years the power generated is less than 766 MW from Bhakra Pong and Dehar. 154 MW power from Nangal Hydel channel power plants is always generated. The shortages are mainly due to the extended dry state prevailed during the previous calender years.

The details of the shortage periods are as given below:

Calender year	Period	Total No. of 10-Daily period
1966	11 April to 30 April	2
1974	1 May to 10th May	1
1975	1 Feb. to 28 Feb.	3
1980	11 April to 30 April	2
1981	10 Feb. to 20 March	4
		12

Thus, of the total number of 648 (36 x 18) periods,firm power is not produced for 12 ten-daily time periods i.e. 98.15 percent of the time firm power is available. The power produced on a 10 daily basis is given in Table 9.

In some years during monsoon months i.e. July to August for one or two time period, the power produced is slightly lesser than the firm power since power generation is considered as secondary and sufficient is available at downstream of the reservoirs to meet the irrigation demand.

The irrigation demands and power generated as per planning studies and present study are given in Table 10. It can be observed from Table 10 that except during the first ten-daily

TABLE 9— 10-DAILY POWER GENERATION IN BHAKRA-BEAS SYSTEM
(POWER UNITS ARE IN M.W)

10-DAILY PERIOD	CALENDER YEAR 1964	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81
1	1199.	1001.	995.	948.	967.	1035.	1008.	1015.	1178.	1030.	1087.	825.	1117.	1085.	981.	1051.	903.	797.
2	1074.	1285.	1060.	1278.	1104.	1135.	1183.	1076.	1194.	1158.	1186.	963.	1397.	1229.	1192.	1180.	1065.	922.
3	1104.	1113.	891.	1157.	1055.	1036.	1062.	1043.	1253.	1084.	1322.	817.	1296.	1140.	980.	1375.	1040.	833.
4	1019.	1066.	802.	1167.	1010.	966.8	1035.	987.	1173.	921.	1147.	553.	1176.	1080.	1102.	1189.	587.	805.
5	1068.	1043.	852.	993.	1122.	1032.	1012.	1001.	1158.	1117.	1197.	703.	1359.	1276.	1302.	1289.	907.	757.
6	936.	1144.	818.	934.	1077.	834.	946.	917.	984.	846.	1130.	651.	971.	893.	1140.	784.	823.	675.
7	969.	1136.	826.	986.	1088.	874.	981.	789.	1020.	981.	1011.	790.	1114.	1004.	950.	831.	780.	713.
8	1023.	1158.	891.	1082.	1244.	1063.	925.	968.	1018.	835.	1001.	767.	1187.	993.	1023.	1041.	843.	753.
9	1108.	1165.	798.	804.	1024.	978.	984.	983.	1199.	1230.	1083.	789.	1304.	1091.	1012.	1264.	749.	773.
10	1305.	1120.	782.	1016.	1312.	1165.	1127.	812.	1192.	870.	1184.	948.	1445.	1086.	1198.	1507.	947.	977.
11	1272.	1358.	458.	1169.	1363.	977.	1019.	868.	1338.	1110.	1169.	968.	1487.	1053.	1324.	1359.	691.	1033.
12	1279.	1445.	508.	1228.	1329.	1056.	1200.	1608.	1135.	848.	1223.	992.	1367.	1100.	1282.	1298.	722.	994.
13	1407.	1569.	821.	1180.	1487.	896.	1191.	789.	845.	769.	723.	908.	1467.	1060.	1495.	1339.	918.	967.
14	1353.	1571.	822.	1177.	1606.	1176.	1243.	813.	1072.	851.	1190.	1027.	1395.	1123.	1661.	1409.	896.	1211.
15	1307.	1457.	1013.	853.	1604.	915.	1043.	983.	1187.	1457.	1040.	945.	1459.	1178.	1498.	1258.	1003.	1723.
16	1361.	1392.	1069.	1243.	1518.	1366.	1081.	1268.	1262.	1518.	1283.	1288.	1561.	1113.	1538.	1296.	1265.	1352.
17	1384.	1406.	1448.	1249.	1479.	1336.	1098.	1110.	1371.	1263.	1304.	1286.	1378.	871.	1436.	1389.	1249.	1262.
18	1287.	1372.	859.	1392.	1432.	1351.	1276.	1139.	1246.	1032.	1226.	1241.	1374.	1223.	1183.	1260.	1242.	1236.
19	1093.	850.	1135.	862.	1080.	1295.	1024.	960.	1174.	1482.	1261.	1415.	1036.	1053.	1117.	990.	1255.	1239.
20	946.	771.	1439.	934.	1131.	806.	1093.	986.	920.	1274.	1156.	1279.	1470.	989.	966.	1281.	910.	1077.
21	954.	980.	1066.	1005.	966.	721.	1176.	1029.	705.	1035.	1046.	961.	941.	1071.	1035.	1035.	1034.	1074.
22	1038.	1020.	1007.	933.	751.	962.	908.	1007.	1003.	1079.	918.	1093.	951.	952.	1393.	1035.	953.	959.
23	955.	1152.	967.	963.	1035.	753.	964.	1368.	958.	1035.	929.	715.	1035.	1085.	1395.	1035.	961.	1132.
24	1035.	1103.	1035.	1058.	1035.	1035.	946.	1395.	999.	1035.	1229.	1395.	1035.	1395.	1395.	1021.	1277.	1362.
25	1395.	1336.	1107.	1024.	1546.	988.	1044.	1395.	1176.	1355.	1486.	1395.	1395.	1878.	1395.	1165.	1517.	1687.
26	1395.	869.	1207.	1381.	1688.	1343.	1162.	1658.	1254.	1304.	1524.	1395.	1733.	1395.	1358.	1584.	1605.	1656.
27	1260.	1366.	1548.	1508.	1653.	1557.	1405.	1474.	1496.	1683.	1459.	1763.	1571.	1861.	1630.	1530.	1591.	1613.
28	1570.	1102.	1503.	1409.	1567.	1378.	1383.	1454.	1604.	1349.	1233.	1587.	1547.	1544.	1440.	1422.	1435.	1413.
29	1382.	1380.	1452.	1513.	1411.	1451.	1448.	1351.	1370.	1317.	1237.	1527.	1465.	1400.	1326.	1370.	1312.	1276.
30	1363.	1245.	1332.	1357.	1409.	1316.	1355.	1261.	1262.	1357.	1145.	1530.	1289.	1367.	1185.	1281.	1268.	1292.
31	1326.	1037.	1368.	1397.	1307.	1343.	1333.	1341.	1407.	1393.	1149.	1463.	1503.	1440.	1372.	1332.	1271.	1244.
32	1322.	1162.	1327.	1385.	1424.	1379.	1243.	1316.	1225.	1344.	1149.	1396.	1367.	1437.	1328.	1411.	1241.	1162.
33	1257.	1160.	1245.	1279.	1381.	1304.	1217.	1240.	1176.	1258.	1114.	1312.	1293.	1352.	1306.	1216.	1172.	1066.
34	1111.	975.	1189.	1241.	1523.	1246.	1109.	1238.	1037.	1175.	1050.	1258.	1192.	1230.	1208.	1282.	1004.	1005.
35	1197.	1002.	1119.	1100.	1132.	1137.	1133.	1168.	1162.	1129.	961.	1273.	1192.	1135.	1219.	959.	931.	1053.
36	967.	778.	948.	983.	960.	940.	968.	994.	1019.	1032.	837.	1143.	1014.	994.	1033.	959.	798.	982.

TABLE 10- IRRGATION DEMANDS USED AND POWER GENERATED

PERIOD	IRRIGATION DEMANDS IN CUMECS: ROPAR ASPER PLANNING STUDY	ROPAR ASPER PRESENT STUDY	HARIKE ASPER PLANNING STUDY	HARIKE ASPER PRESENT STUDY	SYSTEM POWER GENERATED IN M.W: ASPER PLANNING STUDY	ASPER PRESENT STUDY
1	280.	539.	190.	581.	733.	1012.
2	280.	641.	190.	611.	733.	1149.
3	280.	583.	190.	611.	733.	1087.
4	385.	558.	281.	600.	733.	1003.
5	385.	566.	281.	570.	733.	1063.
6	385.	502.	281.	523.	733.	916.
7*	430.	572.	294.	428.	737.	936.
8	430.	531.	294.	429.	737.	990.
9	430.	534.	294.	429.	737.	1018.
10	277.	650.	215.	428.	805.	1111.
11	277.	652.	215.	428.	805.	1110.
12	277.	602.	215.	429.	805.	1112.
13	554.	634.	297.	425.	863.	1102.
14	554.	661.	297.	423.	863.	1199.
15	554.	661.	297.	432.	863.	1190.
16	563.	679.	407.	436.	898.	1321.
17	625.	666.	494.	400.	978.	1296.
18	677.	645.	595.	426.	1078.	1244.
19	602.	653.	607.	399.	881.	1130.
20	602.	618.	607.	377.	881.	1075.
21	602.	523.	607.	415.	881.	986.
22	602.	494.	601.	380.	1024.	999.
23	602.	492.	601.	328.	1024.	1025.
24	602.	575.	601.	345.	1024.	1156.
25	659.	655.	668.	395.	1520.	1351.
26	560.	695.	468.	432.	1269.	1419.
27	560.	710.	460.	474.	1266.	1554.
28	566.	666.	483.	482.	1279.	1453.
29	566.	644.	483.	519.	1279.	1385.
30	566.	610.	483.	535.	1279.	1313.
31	514.	647.	359.	640.	969.	1329.
32	514.	653.	359.	596.	969.	1312.
33	514.	622.	359.	601.	969.	1242.
34	340.	599.	236.	591.	772.	1160.
35	340.	626.	236.	456.	772.	1112.
36	340.	515.	236.	554.	772.	964.
YEAR TOTAL IN HECT.M=	1516686	1915688	1209095	1499493		

periods of August and September, more power is generated as per the present study than that of the planning study. It is observed that during the above two periods i.e., first ten-daily periods of August and September the power produced is less because of the sizeable reach inflow generated in the downstream reach consequence to which, the releases from storage are reduced. Since, irrigation is considered as the first priority, water is not released for the sake of power alone. However, in the subsequent periods the power generated as per the present study is more than the planning period value and this increase is about 25 percent on annual basis.

Also, it has to be noted that if firm power stipulation for individual reservoirs is fixed, total system power will be reduced to a large extent. This can be seen from the following. The firm power stipulated for Pong dam is 72 MW. To maintain this firm power at Pong, water which is being diverted to Dehar Power house through Beas-Sutlej link would have to be allowed to Pong reservoir. This could not be recommended since the utilisable head at Pong reservoir is much smaller than the utilisable head at Bhakra or Dehar. Also as stated earlier Gobind Sagar can irrigate both Beas and Sutlej commands. Thus, it is preferable to divert 212.5 cumecs of water(the maximum capacity of Beas-Sutlej link) from Pandoh if sufficient storage is available at Gobind Sagar Reservoir.

9.0 CONCLUSION

The updating of operational rules for Bhakra Beas System is meant for increasing assured water supply for irrigation and power production by way of better reservoir management techniques. As the demand for water is being increased day by day and since the sources are limited, continuous studies are required to explore new avenues with the additional refined informations collected after execution and sufficient period of operation of system. Conjunctive use of surface and ground water is one of the area to be explored in the above context.

The study of the behaviour of the system with a simulation cum quasi optimization model was taken up to accomplish the above objective. The demands used herein are the maximum indents met in the recent years and it was assumed that these releases are as per unit reservoir factor. A new operation policy was evolved and presented. The new policy defines the releases. Priority was given for irrigation demand over power demand. The releases are always slightly less than the authorised supply of the canals except in the case of Nangal Hydel Channel wherein the release was considered as full supply of the canal. The extent to which the total water released to the downstream demand points (canals) depended upon the total available water i.e. existing storage and the expected inflow at the upstream reservoir during the time period under consideration.

Normally the releases for irrigation would also meet the firm power requirements of Bhakra Beas powerplants. However, during certain dry years releases had fallen below power requirements in which case releases in the interest of power might have to be made depending upon the prevailing situation. While striving to meet the firm power demand with suitable operation rule no attempt was made here for any extra releases in the interest of power. But due to the restricted release during the critical periods additional head was maintained.

During summer months in some years power shortage was observed. If power is considered on a priority basis during summer months future studies may be focussed in this direction. The complexity of operation of this system rises the question whether a single reservoir factor for the whole system has to be practiced or a individual one has to be used for each reservoir. In this study, reservoir factor for individual reservoirs was worked out and releases were made accordingly. The new operation policy evolved from this study, had reduced the spills (loss from the system) from 0.92 m.ha.m at planning stage to 0.39 m.ha.m. (by adopting the new operational rule) while meeting the larger irrigation demand (3.3.m.ha.m an increase of nearly 25.3%) but maintaining existing power production. Also, it reflected the need for stipulating the total firm power production for the system as a whole instead of fixing the firm power production for individual units.

It is further pointed out that even the depleted spills may be effectively utilised in the parts of west Rajasthan area (at Harike diversion) for artificially recharging the aquifer system which can be tapped to meet the shortages.

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