Conjunctive use of Surface-Water and Ground-Water Supplies in the Principal Canal Irrigated Areas of West Pakistan

By

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FOREWORD

As a first approximation of the relationship between use of surface-water and ground-water in meeting overall irrigation water requirements in West Pakistan, results of a preliminary-trial operation study will be discussed herein. This study has no official status; no recommendations have been made and no plans of development have been derived as a result of the study. However, it may serve to demonstrate how the conjunctive use of surface-water, surface storage, ground-water and ground-water storage may be accomplished when results of basic-data gathering. regional and project-study programs now under way are available.

Since this paper merely summarizes results of a long and complicated operation, no attempt herein has been made to present details such as amounts of unit consumptive use, canal losses and other items actually derived and used in the study.

Data from another symposium paper on ground-water recharge have been used herein, as have data from many previous studies and analyses of water in the Indus Basin.

Other papers presented at the symposium will cover all aspects of the problems of water-logging and salinity, the areas affected, investigations thereon under-way, possible solutions, etc; therefore, this paper will not deal with those aspects.

INTRODUCTION

In overall treatment of the subject of control of water-logging and salinity in West Pakistan, no discussion would be complete without treatment of corollary aspects of the problem—principally disposition and use of ground-water to be pumped in the reclamation process.

Excess ground-water will probably be disposed of principally by tubewell pumping in the Northern Zone**, and partly by pumping and partly by gravity

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drains in the Southern Zone.* In the Northern Zone, part of the water recovered will be suitable for direct use, part will be suitable for use by locally controlled mixing with canal water, part may be usable downstream by mixing with river water, and part will be so saline as to require disposal to waste into the rivers at time of high flow or to inland waste areas for ponding and evaporation. Therefore, the question of handling of water recovered in the reclamation schemes has to be considered within the overall framework of ultimate irrigation water supply, and river and canal-system operation. This framework will comprise canal commands, doabs, zones, or the entire Indus Plains, with corresponding areas varying from several hundred thousand to nearly 32 million acres.

In order to give general coverage to the subject, this paper will deal with estimated irrigation-water requirements and hypothetical system operation of the area within the culturable commands of the 35 principal canal systems diverting from the Indus, Jhelum, Chenab, Ravi, Sutlej and Panjnad Rivers at a time about two decades hence, when all development tentatively scheduled for 1975 is in full operation.

Under original plans these systems were to command the following areas:

	Commanded Areas—Million Acres	
	Gross	Culturable
Northern Zone	23	19
Southern Zone	14	13
	37	32

Exhibit I presents in schematic form the relationship of the various canals, the existing link canals, and the system of link canals and two storage reservoirs of the Settlement Plan being constructed under the Indus Waters Treaty 1960.

As reported, some 23.6 million acres of irrigated land were cropped in the period April 1960 through March 1961 in the principal canal commands. Assuming three-million-plus acres of double-cropping, some 20 million acres of land were irrigated—about 13 million acres in the Northern Zone and 7 million plus in the Southern Zone. To irrigate these lands, over 70 million acre-feet of unregulated stream flow was diverted, a considerable part of which came from the Beas, Ravi and Sutlej Rivers. In addition an unknown amount of ground water was extracted for full supply or supplemental-irrigation use.

*Ex-Sind.

No storage has been provided to date; the irrigation diversions come from the natural flow of the rivers.

At the end of the construction period of the Settlement Plan Works, the waters of the "Eastern" Rivers—the Ravi, Beas and Sutlej—will go to India permanently. The waters of the "Western" Rivers—the Indus, Jhelum and Chenab (less specified uses outside of Pakistan)—will be available to Pakistan; and, in conjunction with tributaries within Pakistan, will furnish West Pakistan's primary irrigation water supply.

As West Pakistan achieves solutions to the problems of control of salinity of water-logging in the irrigated areas, a large amount of ground-water will become available annually. Most of this water will be usable, and some will have to be wasted; however, all of it will have to be handled in the process of irrigation operations. Since a large proportion of the water developed in the Northern Zone will be usable, this supply can be integrated with existing canal supplies. With wells located at or near the water courses, ground-water will become a very important factor in irrigation water supply. Likewise the underground reservoir will be utilized to provide valuable regulation.

With use of the greater part of its surface-water resources and the requirement for pumping more than the annual ground-water recharge in view, West Pakistan will be faced with the question of whether the ground-water resource of the Northern Zone (roughly estimated as 500 million acre-feet per hundred feet of aquifer depth) should be used extractively, or "mined", to progressively lower depths; or whether only the annual average recharge amount should be pumped. Determination of this surface-water/ground-water relationship will be an important phase of the master planning for development of West Pakistan's water and power resources.

WATER RESOURCES—WEST-PAKISTAN

Long-term records of runoff for the Indus, Jhelum and Chenab at the "rim stations" (above principal points of diversion) indicate combined average annual runoff of 142 million acre-feet, with a relatively unimportant component of inflow below the gaging points. Although numerous west-side tributaries enter the Indus downstream from the gaging point at Attock (below mouth of the Kabul River), eventual local use may reduce the net contribution of these streams to sporadic spills and flood flows. Likewise, contribution via occasional spill after the "Eastern" Rivers are diverted to India will be minimal.

Comparative annual (October through September) runoff data for the three "Western" Rivers at the rim stations for the period 1922 through 1961 follow:

Individual—River Data

River	Runoff in Millions of Acre-Feet			
	Maximum	Year	Minimum	Year
Indus	110	(1924)	72	(1951)
Jhelum	31	(1957)	15	(1946)
Chenab	38	(1959)	19	(1940)

Combined Data—Three "Western" Rivers

River	Average	Runoff in Millions of Acre-Feet		
		Maximum 1959	Minimum 1951	Median-Shortage* Year
Indus ..	93	106	72	94
Jhelum ..	23	31	21	24
Chenab ..	26	38	22	25
Total ..	142	175	115	143

The amount of ground-water yield on an annual basis under future hydrologic regime can only be approximated, although it is certain to be substantial. Eventually, the available annual recoverable recharge will be largely a function of irrigation diversions and applications. However, at present, of the many sources of contribution to the general ground-water body West of Pakistan, only a few can be evaluated with certainty. Therefore, this problem should be studied carefully.

PRELIMINARY SYSTEM OPERATION STUDY

Although the preliminary operation study on which this paper is based covered a 40-year period, only one year's results are used herein. This year represents that in which all factors involved resulted in a median shortage—that is, the indicated shortage was equalled or exceeded in half of the years of shortage in the study.

General Criteria

In the preliminary conjunctive surface and ground-water operation prepared, the following were assumed:

(1) Waters of the Indus, Jhelum and Chenab Rivers available.

(2) All link canals of Indus Basin Settlement Plan in use.

*Actual runoff in year of median shortage in operation study.

(3) Mangla and Tarbela reservoirs, totalling 11.4 m.a.f. active-storage capacity, in use.

(4) Irrigated acreages, cropping patterns and intensities in principal canal-system commands necessary to meet West Pakistan's estimated food and fiber needs for 1975. Assunmed irrigated and cropped areas for the Northern Zone (ex-Punjab, ex-Bahawalpur and ex-NWFP less Peshawar Vale) and the Southern Zone (the ex-Sind and the plains portion of ex-Baluchistan), respectively, for the principal canal systems of the Indus Plains as follows:

		Millions of Acres	
Zone		Irrigated	Cropped
Northern	...	19	28
Southern	...	8	8
Total	...	27	36

(5) Full irrigation-water requirements, as computed by months for assumed crops by the potential evapo-transpiration method, as modified by computed median-effective precipitation and by crop factors. Total irrigation requirements at the crop (assuming median-effective precipitation) to provide for evapotranspiration and all farm losses, including a permanent leaching requirement for the 36 million acres cropped, amounting to 98 million acre-feet.

(6) More-or-less constant reservoir-release patterns.

(7) Estimated river gains and losses under future surface-flow regimes.

(8) Arbitrary distribution-system losses and deep-percolation losses (including leaching requirements) in fields.

Starting with average total rim-station surface flow for the three "Western" Rivers and limiting possible diversion to canal capacities, taking into account computed water requirements, losses, etc., operating the IBP works—storages and links—and ending with a net outflow to the sea; the net deficiency in meeting the full computed irrigation-water requirement was obtained. This operation is summarized as follows:

OPERATION STUDY SUMMARY-YEAR OF MEDIAN SHORTAGE

(See Exhibit II for graphic representation)

Water Available and Divertible

		Millions of Acre-Feet*
(1)	Total flow—3 "Western" Rivers	143
(2)	Less link-canal losses and net river losses	—21
(3)	Net available to divert	122
(4)	Divertible within capacity of canals, including storage yield of 10 maf	—92
(5)	Spill to Arabian Sea	30
	Surface-Water Delivery to Land	
(6)	Diverted into canal systems	92
(7)	Conveyance loss	—28
(8)	Delivered to water courses	64
(9)	Conveyance loss in water courses	— 6
(10)	Net delivery	58
	Irrigation-Water Requirements and Deficiency	
(11)	Total irrigation water required at crop	98
(12)	Surface water delivered	—58
(13)	Deficiency at the crop	40

Ground-Water Requirements

The foregoing summary of a median-shortage-year overall water-balance analysis shows that, if total irrigation requirements at the crop are as computed, and if surface-water availability as regulated by 11.4 maf storage (10 maf yield) is as shown, a net annual deficiency at the crop of 40 maf would result. If the deficiency is to be made up by ground-water pumping from tubewells located at the water course heads, the pumping requirement would equal 44 maf.

In order to demonstrate graphically the relationship of available surface water and required ground-water in the year of median shortage, Exhibit II shows the following:

(1) Combined Indus, Jhelum and Chenab River flows as regulated by Mangla and Tarbela storage.

(2) Spill to Arabian Sea.

(3) River losses and gains.

*Denoted elsewhere herein as maf.

(4) Canal losses.

(5) Water stored and water released from storage.

(6) Total water required at the water course, including:

(*a*) Surface-water component available.

(*b*) Ground-water component needed because of:

(*i*) Limited canal capacity.

(*ii*) Limited seasonal surface supply.

Exhibit II demonstrates that, although the general period of highest irrigation requirement nearly coincides with the period of greatest surface flow, limitations in canal capacity result in substantial ground-water requirements to make up the deficiency. In other words, while surface flow is wasting past the canal headworks to the sea, the canals cannot divert and deliver anywhere near the full requirement. In addition, deficiencies in surface supply result during the period of low natural streamflow, even when supplemented by storage in Mangla and Tarbela reservoirs, thus imposing a heavy demand on ground water.

As demonstrated, the total annual ground-water requirement was 44 million acre-feet. Of the 44 maf total, 9 maf resulted from canal-capacity limitations and 35 maf from surface-water shortages, principally during rabi, but also during the early and late portions of the kharif season.

The question now remaining is whether the principal good-quality ground-water areas in the Northern Zone can supply the required amount from annual recharge; or whether:

(1) Over-draft of the good-quality ground-water body must take place;

(2) Additional storage needs to be provided in order to balance out the supply;

(3) Controlled mixing in the rivers of water too saline for local use can be accomplished for use downstream;

(4) Canal systems should be enlarged to eliminate shortages resulting therefrom;

(5) Artificial recharge needs to be accomplished;

(6) Sizable quantities of usable-quality ground-water will be available in the Southern Zone;

(7) Some combination of the foregoing will provide the required amount.

Obviously, a great amount of investigation and study will be required to determine the proper solution.

GROUND-WATER AVAILABILITY

In order to test preliminary evaluation of the relationship between surface- and ground-water in meeting overall requirements, it is necessary to evaluate the total ground-water resource—both as to quantity and quality—that will be available in perpetuity.

In the case of West Pakistan, the quantity of ground-water to be available on a permanent basis is related nearly directly to the amount of surface-water flowing in streams and diverted onto the land by irrigation facilities. Precipitation is believed to have only limited direct effect on recharge. Hence the distribution and extent of recharge is of utmost importance, as is the quality of the incoming surface-water and existing ground-water and the resulting potential quality deterioration as use and reuse of water takes place.

In the development of the great irrigation systems of the Indus Plans, beginning with the inundation canals centuries ago and extending up to the present time, nearly 38,000 canal (5,000 feet) miles of conveyance channels (canals, branches, distributaries and minors) and drainage channels have been constructed. Some 2,000 miles of river channels, if added to the foregoing, make about 40,000 miles of channels of varying sizes, all of which contribute by seepage to the ground-water reservoir. In addition, some 380 miles of new link canals of very large size are being constructed under the Settlement Plan, of which only a small part will be lined.

Presently, the 13 million acres of land irrigated in the Northern Zone contribute an unknown amount to the ground-water body through deep percolation. The irrigated area would increase to 19 million acres in the study under discussion, and the annual cropped area at the assumed intensity would be 28 million acres.

Various sources of contribution to ground-water are assumed to be as follows :

(1) Seepage from rivers and irrigation canals.
(2) Deep percolation from rainfall and ponded flood water.
(3) Deep percolation from irrigation.
(4) Regional under-flow into the plains areas.

Likewise there are many sources of loss or escape from the ground-water, among which are :

(1) Consumptive use of vegetation.
(2) Evaporation where ground-water level is close to ground surface.
(3) Evaporation from swamps and marshes.
(4) Escape via surface outlet.
(5) Escape via regional under-flow.

As yet, the location and quantity of the various recharge and discharge components can only be approximated. Numerous attempts to determine recharge and discharge by theoretical computations have been based on historical ground-water rise. However, such analyses are not indicative of the expected behaviour of the ground-water body under vastly changed future conditions. Since the basic quantity of available surface-water is known, the amount of ground-water required to fill out assumed irrigation requirements can be determined. The theoretical ground-water requirement can then be evaluated as to availability—from annual recharge or from "mining", or over-pumping water in storage in the ground-water reservoir.

The following quantities of irrigation-water conveyance and deep-percolation losses in maf are taken from the preliminary operation study:

Item	Zone		
	Northern	Southern	Total
Net river loss	9	6	15
Link canal loss	6	0	6
Irrigation system loss	17	11	28
Water course loss	7	3	10
Sub-totals			
Conveyance losses	39	20	59
Deep percolation and leaching	18	7	25
Total	57	27	84

The foregoing analysis shows that the total estimated potential annual amount of ground-water recharge and non-beneficial-use losses amounts to 84 maf, 57 maf in the Northern Zone and 27 maf in the Southern Zone. A large, but undetermined, part of this water will be available for recharge and possible recovery for irrigation use.

Although preliminary indications are that there are sizable areas having usable-quality ground-water in the Southern Zone, no attempt was made in the preliminary study to evaluate the amount that might be available for irrigation use.

Recent preliminary overall data on ground-water quality show that, in the Northern Zone with a regional area of some 34 million acres, about 27 million acres are underlain by good-quality ground-water—that having concentrations of 3,000 p.p.m. or less. The 34 million acres include a gross irrigation command of about 23 million acres with a culturable command of about 19 million acres under the principal canal systems. About 16 million acres of the 19-million-acre culturable command are underlain by usable ground-water.

Estimated future annual recharge (which is discussed in another Symposium Paper) to the good-quality ground-water body in the gross irrigated command is estimated at about 32 maf, after taking into account losses from the potential recharge components. In the areas of saline ground-water additional annual recharge will take place under the conditions assumed. Some part of this recharge in the saline areas might be usable locally by mixing with fresh water or by pumping to waste into the rivers for dilution and use downstream. However, no account is taken of this possibility herein.

REMAINING SURFACE-WATER AVAILABILITY

In the operation studies carried out, preliminary indications of avaliable surface water wasted to the sea were obtained. This was determined to be 30-million acre-feet. However, it should be recognized that the foregoing cannot be taken at face value as the remaining increment of available water, because of the complex inter-relationship of flow patterns, and river losses and gains. Furthermore, no requirement for allowing water to escape to the sea to flush out the accumulated basin salts, or for other purposes, was assumed in the study under discussion.

Future canal construction and canal enlargement in both the Northern and Southern Zones could result in sizable additional direct diversions of water now being spilled, with a corresponding decrease in waste to the sea.

As the river system approaches more complete regulation and control, changes in the phenomena of losses and gains will become very important. In the median-shortage year there was determined to be gross annual loss of 22 million acre-feet, but a seasonal gain of 7 maf through regeneration; hence net losses totalled 15 maf. With reduced flood flows and a shortened period of flooding, the seasonal losses would doubtless diminish, and resulting gains would likewise lessen. Whether net losses would lessen in a matter of conjecture. Therefore, storage (or additional ground-water draft—or both) might conceivably be required to off-set any reduction in present natural-regulation effect.

WATER-QUALITY CONSIDERATIONS

Quality-of-water problems will arise in some areas as soon as ground-water is pumped, whether it is used or wasted. Present surface-water quality is good, averaging about 250 parts per million (p.p.m) of dissolved solids. Ground-water quality varies from values slightly above the 250 p.p.m. to several thousand p.p.m. With proper integration of water from the two sources, root-zone salinity can be controlled, and with disposal of some ground-water to maintain a salt balance, a suitable quality of irrigation water can probably be maintained.

The foregoing quality considerations are based solely on total dissolved solids. In addition, there are other factors such as presence of boron and the relative concentration of sodium to other ions that may further restrict direct usability of ground-water. In the Southern Zone there will be quality problems in addition to those of local ground-water. For example, consideration must be given to problems arising in the future from salinity concentrations of incoming river water much greater than those at present. Disposal methods for excessively saline ground-water pumped from the bad-quality areas of the Northern Zone must, therefore, be carefully established and controlled. Disposal of water from the free-running surface drains planned for the Southern Zone may introduce quality problems, although in some areas drains will outlet directly into the sea. In other areas, however, drainage water will be pumped from tubewells directly into supply canals, and careful local quality control will be required.

DISCUSSION

Full water supplies for 27 million acres of irrigated land cropped at an intensity to provide 36 million acres of crops will be required in the near future to provide that portion of the food and fiber need of West Pakistan that must come from the principal canal-irrigated areas of the Indus Plains. With surface runoff in the median-shortage year of 143 million acre-feet, regulated by 11.4 million acre-feet of active storage in Tarbela and Mangla reservoirs, about 92 maf of surface water can be diverted to the principal existing irrigation schemes in the Indus Plains, with 58 maf deliverable at the crop. In order to meet the full irrigation requirement under conditions assumed herein about 40 maf of ground-water must be supplied at the crop in the Northern Zone, necessitating pumping of some 44 maf at the water courses.

As stated previously about 19 million acres in the gross command of the irrigation systems of the Northern Zone have usable-quality ground-water. If the full ground-water requirement of 44 maf is pumped from the 19 million-acre area, a draft of 2.3 acre-foot per acre of good-quality aquifer would occur. With estimated annual recharge components totalling 32 maf replenishing the aquifer in the good-quality areas, the net annual over-draft would be 12 maf, or about 0.6 ac.-ft. per acre. Assuming a storage co-efficient of 20 percent, an annual average lowering of the ground-water body of about three feet would result, assuming uniform pumping over the entire area.

To what extent or for how long it may be necessary or economic to "mine" the ground-water is yet to be determined. However, it is clear that it will be necessary and desirable to operate the ground-water body as a reservoir.

As apparently reasonable method of operation would allow heavier-than-average ground-water drafts in dry years and lighter-than-average drafts in wet years to keep the long-time draft in balance, if this can be accomplished without an excessive range in pumping head. The alternative would simply be to "mine" the water at whatever rate necessary or possible, with no thought of recovery of the ground-water level, and with discontinuance of over-pumping when costs become prohibitive.

If only the average annual recoverable recharge is to be pumped, additional surface flow would be needed to fill out the assumed water requirements. Enlargement of canal systems or storage beyond the 11.4 maf used herein could be utilized. With both sources of added surface water some additional resulting recoverable recharge to the ground-water would result, which in turn would help achieve a balanced use of surface- and ground-water. This is one of the principal items to be considered in detail in master-planning studies to come.

There is a possibility—on the basis of preliminary studies—that good-quality ground-water in the Southern Zone may be available in substantial quantities. If so, requirements and resources would, again, come closer to balancing. Furthermore, some saline water would have to be pumped annually from the bad-quality areas in the Northern Zone to maintain water-table control. Some part of this could be used if it could be pumped to waste into the rivers during the early or late portions of the annual flood period.

In the long run, a balanced withdrawal and recharge must be achieved, with the general water level at optimum depth, to provide the maximum annual recoverable withdrawal of acceptable quality for direct irrigation use—use after mixing, or use after disposal into rivers for dilution and downstream use. In addition, water too saline for use will have to be pumped for disposal to the sea or to waste by evaporation. The optimum depth to regulated average ground-water level will be that which will:

(1) Result in minimum pumping costs in perpetuity;

(2) Hold non-beneficial consumptive use to a minimum;

(3) Allow operation of the ground-water reservoir to:

   (*a*) Provide heavier-than-normal drafts in years of low surface flow,

   (*b*) Allow lighter-than-normal drafts in years of high surface flow, without so great a range as to impair optimum pumping-equipment efficiencies.

(4) Fit in with optimum well spacing and, therefore, well sizes, as well as economic pumping draw-down.

Optimum utilization of surface- and ground-water supplies can be achieved by complete integrated operation of modified canal distribution systems, regulated surface flows, and the tens of thousands of tubewells to be provided in the salinity- and waterlogging-control program. Ultimately, all surface flow that can be regulated economically can be utilized in the Indus Plains, with out-flow to the sea limited to that necessary to flush out basin salts, perhaps utilizing remaining unregulated spills so far as possible for this purpose.

In any event, there is promise of utilization of large quantities of ground-water annually for irrigation purposes. This water will be available at the water courses, which will help minimize transportation losses and necessary distribution-system changes. Furthermore, the vast underground storage reservoir provides potential regulation of great magnitude, as well as an enormous potential reserve of water to be "mined", or used without replacement, should that become necessary or economically desirable in the future.

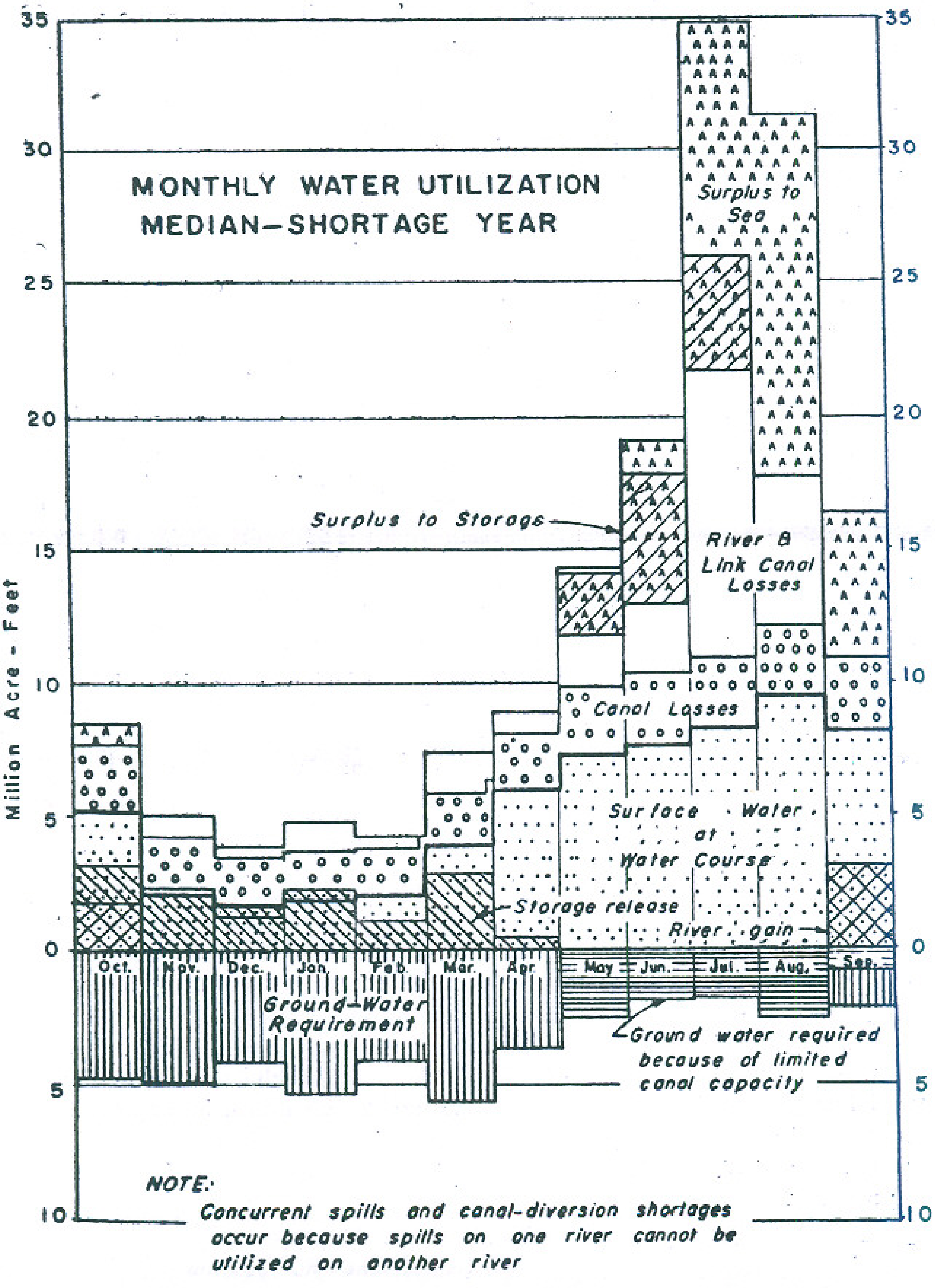
Although many problems and questions remain to be examined and resolved, the overall water resource of West Pakistan would appear to be sufficient for many years to come, if this resource is properly developed, managed and used to make possible needed advances in agriculture; which, in the final analysis, is the ultimate objective of the resource development program.

Ground-water and the ground-water reservoir will play an important part in development and control of this supply. Additional surface-water diversion capacity would enable better utilization and control of surface supplies, with consequent increase in ground-water recharge and reduction of summer pumping from ground-water—the combined effect of which would be to bring resources and requirements more nearly into balance, and to aid in quality control. Surface storage beyond the 11.4 maf assumed would aid in providing more winter supplies—again with additional ground-water recharge and reduction in pumping requirements.

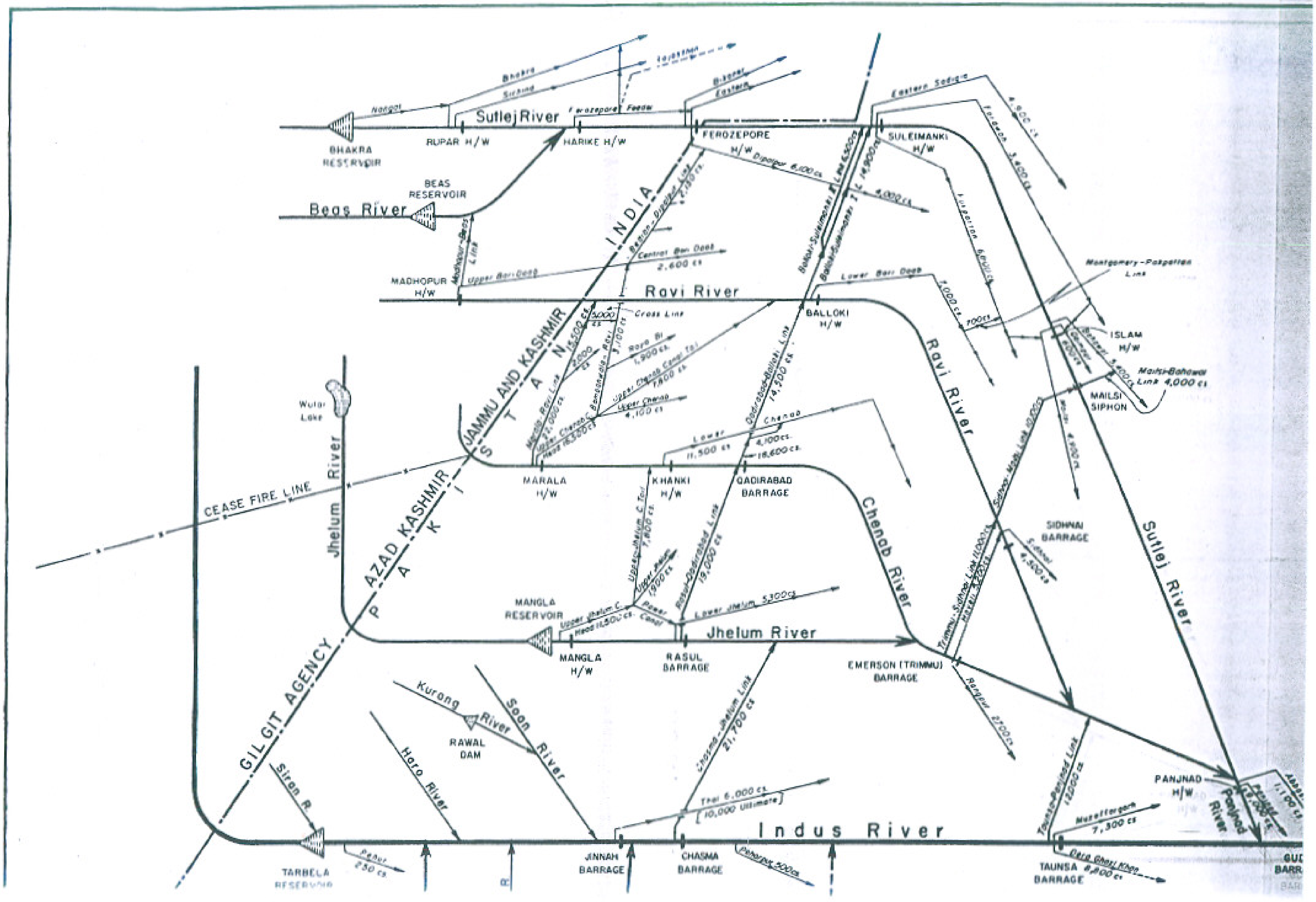
Quality-of-water problems, including local mixing for salinity dilution and prevention of soil alkalinization; disposal of excessively saline waters into rivers for waste to the sea, use downstream or delivery to evaporation areas, etc; will have to be carefully considered in water-resource management and operation. Overall regional studies of the Northern and Southern Zones, now planned or scheduled, are required to develop the needed data.

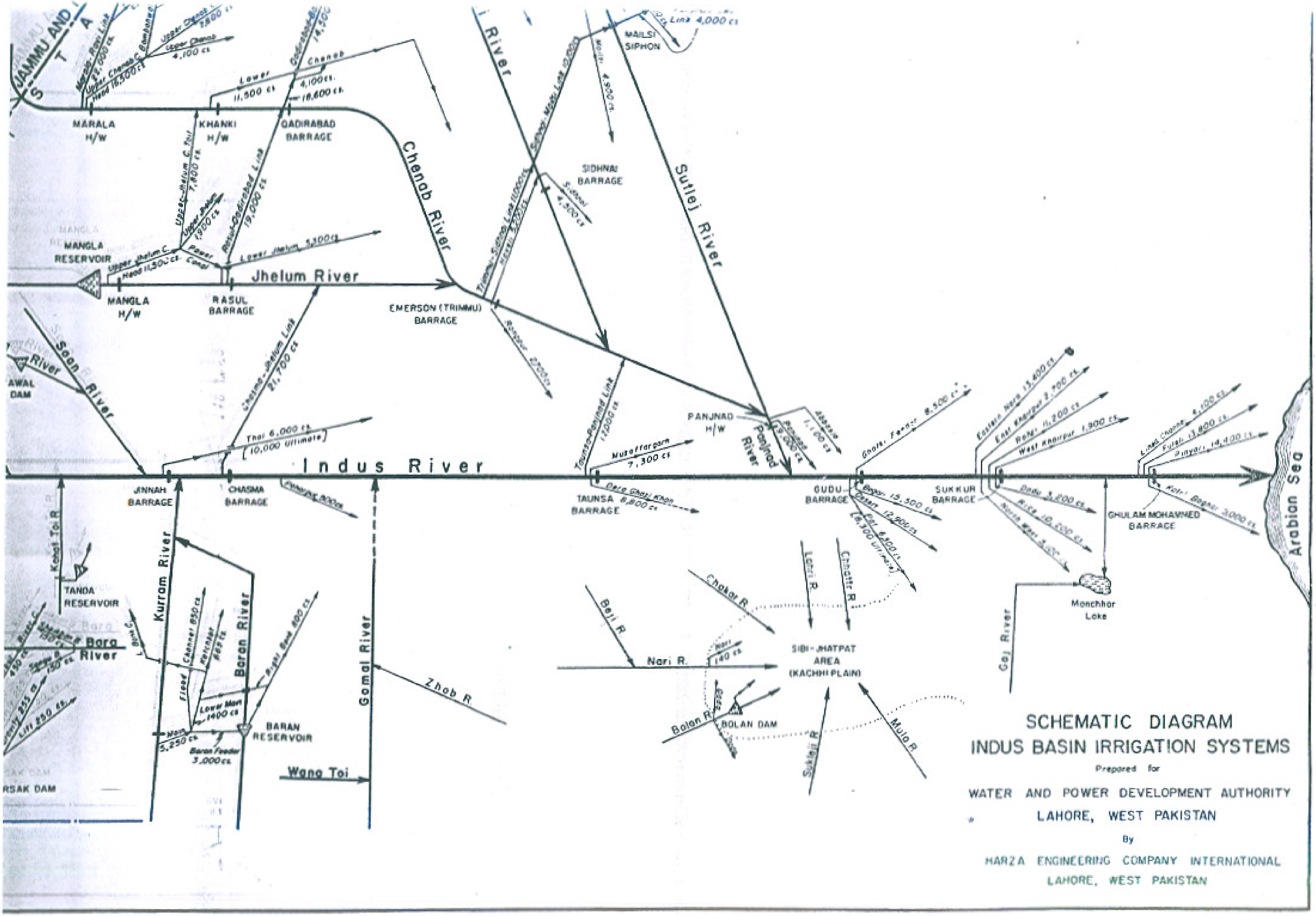
Likewise, other uses and problems must be considered, in attaining optimum, multi-functional use of water resources. Careful timing and scheduling of ground-water and surface-water developments will be required. Therefore, the concept of master planning must be followed, in order that optimum use of West Pakistan's water—which is its life blood—may be made in perpetuity.

EXHIBIT II



MONTHLY WATER UTILIZATION
MEDIAN–SHORTAGE YEAR
Million Acre - Feet
35
30
25
20
15
10
5
0
5
10
Surplus to Sea
Surplus to Storage
River & Link Canal Losses
Canal Losses
Surface Water at Water Course
Storage release
River gain
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sep.
Ground-Water Requirement
Ground water required because of limited canal capacity
NOTE:
Concurrent spills and canal-diversion shortages occur because spills on one river cannot be utilized on another river


Sutlej River
Beas River
Ravi River
Chenab River
Jhelum River
Indus River
Panjnad River
BHAKRA RESERVOIR
BEAS RESERVOIR
RUPAR H/W
HARIKE H/W
FEROZEPORE H/W
SULEIMANKI H/W
MADHOPUR H/W
BALLOKI H/W
MARALA H/W
KHANKI H/W
QADIRABAD BARRAGE
MANGLA RESERVOIR
MANGLA H/W
RASUL BARRAGE
EMERSON (TRIMMU) BARRAGE
SIDHNAI BARRAGE
ISLAM H/W
MAILSI SIPHON
PANJNAD H/W
TARBELA RESERVOIR
RAWAL DAM
JINNAH BARRAGE
CHASMA BARRAGE
TAUNSA BARRAGE
Wular Lake
CEASE FIRE LINE
GILGIT AGENCY
AZAD KASHMIR
JAMMU AND KASHMIR
PAKISTAN
INDIA
Kurong River
Soon River
Haro River
Siran R.
Montgomery-Pakpattan Link
Mailsi-Bahawal Link 4,000 cs
Chasma-Jhelum Link 21,700 cs
Thal 6,000 cs (10,000 Ultimate)
Taunsa-Panjnad Link 12,000 cs
Muzaffargarh 7,300 cs
Dera Ghazi Khan 8,800 cs
Rangpur 2700 cs
Lower Jhelum 5300 cs
Rasul-Qadirabad Link 19,000 cs
Qadirabad-Balloki Link 14,500 cs
Upper Jhelum C. Tail 7,800 cs
Lower Chenab 11,500 cs
Upper Chenab 4,100 cs
Ravi Bi 1,900 cs
Central Bari Doab 2,600 cs
Upper Bari Doab
Lower Bari Doab 7,000 cs
Dipalpur 6,000 cs
Pakpattan 6,000 cs
Eastern Sadiqia
Fordwah 3,400 cs
Bikaner
Eastern
Ferozepore Feeder
Rajasthan
Bhakra
Sirhind
Nangal
Pehur 250 cs
Paharpur 500 cs
Cross Line
Sidhnai 4,500 cs
Madhopur-Beas Link


SCHEMATIC DIAGRAM
INDUS BASIN IRRIGATION SYSTEMS
Prepared for
WATER AND POWER DEVELOPMENT AUTHORITY
LAHORE, WEST PAKISTAN
By
HARZA ENGINEERING COMPANY INTERNATIONAL
LAHORE, WEST PAKISTAN
Indus River
Arabian Sea
Jhelum River
Chenab River
Sutlej River
Panjnad River
Soan River
Kurram River
Baran River
Gomal River
Zhob R.
Wang Toi
Kohat Toi R.
Bara River
Gaj River
Nari R.
Beji R.
Chakar R.
Lahri R.
Chhattr R.
Bolan R.
Mula R.
Sukleji R.
MARALA H/W
KHANKI H/W
QADIRABAD BARRAGE
MANGLA RESERVOIR
MANGLA H/W
RASUL BARRAGE
EMERSON (TRIMMU) BARRAGE
SIDHNAI BARRAGE
MAILSI SIPHON
PANJNAD H/W
JINNAH BARRAGE
CHASMA BARRAGE
TAUNSA BARRAGE
GUDU BARRAGE
SUKKUR BARRAGE
GHULAM MOHAMMED BARRAGE
TANDA RESERVOIR
BARAN RESERVOIR
BOLAN DAM
Manchhar Lake
SIBI-JHATPAT AREA (KACHHI PLAIN)
Lower Chenab 11,500 cs
4,100 cs
18,600 cs
Upper Chenab 4,100 cs
Rasul-Qadirabad Link 19,000 cs
Upper Jhelum C. Tail 7,800 cs
Upper Jhelum C. Head 11,500 cs
Power Canal
Lower Jhelum 5,300 cs
Chasma-Jhelum Link 21,700 cs
Thal 6,000 cs [10,000 Ultimate]
Paharpur 800 cs
Rangpur 2700 cs
Sidhnai 4,500 cs
Mailsi 4,900 cs
Link 4,000 cs
Taunsa-Panjnad Link 12,000 cs
Muzaffargarh 7,300 cs
Dera Ghazi Khan 6,800 cs
Panjnad 9,000 cs
Abbasia 1,100 cs
Ghotki Feeder 8,500 cs
Begari 15,500 cs
Desert 12,900 cs
Pat 6,500 cs (8,300 Ultimate)
Eastern Nara 13,400 cs
East Khairpur 2,700 cs
Rohri 11,200 cs
West Khairpur 1,900 cs
Dadu 3,200 cs
Rice 10,200 cs
Lined Channel 4,100 cs
Fuleli 13,800 cs
Pinyari 14,400 cs
Kalri Baghar 3,000 cs
Lower Main 1400 cs
Main 5,250 cs
Baran Feeder 3,000 cs
Flood Channel 850 cs
Right Bank 800 cs
Nari 140 cs
Lift 250 cs