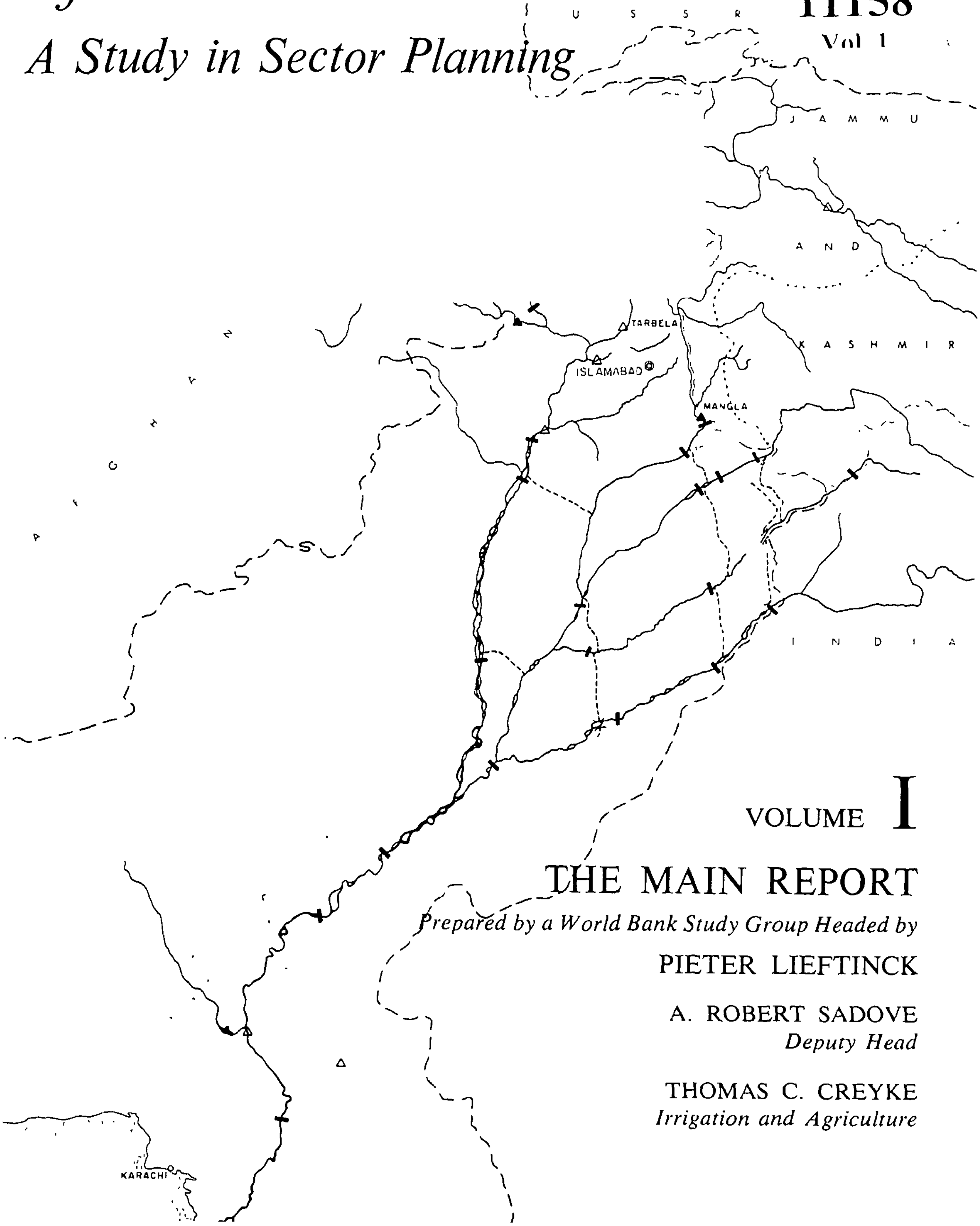
Water and Power Resources of WEST PAKISTAN

A Study in Sector Planning



VOLUME I

THE MAIN REPORT

Prepared by a World Bank Study Group Headed by

PIETER LIEFTINCK

A. ROBERT SADOVE
Deputy Head

THOMAS C. CREYKE
Irrigation and Agriculture

WATER AND POWER RESOURCES OF WEST PAKISTAN

A Study in Sector Planning

Volume I: The Main Report $10.00

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$28.50 the set

Prepared by a World Bank Study Group Headed by Pieter Lieftinck; A. Robert Sadove, Deputy Head; Thomas C. Creyke, Irrigation and Agriculture.

Without doubt, the greatest single coordinated development operation in which the World Bank has been involved is the massive program for development of the Indus Basin. This pioneering study is an integral part of that project and is unique both in its conceptualization and its comprehensiveness. It demonstrates the feasibility of a new and more rigorous approach to resource planning and development and will serve as an indispensible model for engineers, economists, and planners for years to come.

Focal points of the Study are the Indus River, which runs the length of west Pakistan, several of its tributaries, and a huge natural underground reservoir. In developing a realistic investment program for water and power, the Bank's Study Group had to consider a host of interrelated factors: the objective of maximizing economic returns, the competition for scarce resources, all aspects of agricultural production, alternate sources of water for irrigation, the country's projected electricity requirements, and the coordination of decisions regarding power generation and agriculture.

VOLUME I

Water and Power Resources of West Pakistan
A Study in Sector Planning

THE MAIN REPORT

ARTIST'S SKETCH
TARBELA DAM PROJECT

SOURCE: TIPPETTS - ABBETT - McCARTHY - STRATTON, CONSULTING ENGINEERS FOR WAPDA.

TARBELA DAM PROJECT

SOURCE: TIPPETTS - ABBETT - McCARTHY - STRATTON INTERNATIONAL COMPANY. CONSULTING ENGINEERS FOR THE WATER AND POWER DEVELOPMENT AUTHORITY OF WEST PAKISTAN.

VOLUME I

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Foreword

The assignment by the President of the World Bank to undertake a Study of the Water and Power Resources of West Pakistan, with a view to clarifying their potential for development and identifying investment priorities, was a difficult but most rewarding experience for me and my principal assistants. Our work began with a review of existing reports and studies; we concluded that these provided an inadequate basis for judgment in regard to the many issues involved. We further recognized the limitations of what might be called the "traditional" approach to investment planning —one that proceeds via the summation of various economically viable projects, individually evaluated. Even a cursory look at the problems of the Indus Basin indicated that a high degree of interdependence exists between different development and investment decisions. There is, in brief, competition for scarce resources: whether they be, for example, water, capital, general farming inputs, or entrepreneurial skills.

The Study, therefore, would have to be comprehensive in every sense of the word. It would entail not only a careful examination of all aspects of agriculture but also a real understanding of the whole irrigation system in all its intricate complexity, including the integration of programs for the simultaneous exploitation of both groundwater and surface water. It would also involve a detailed investigation of West Pakistan's energy needs and resources over the long term with a view to drafting the broad design of an integrated system of generating plants and transmission networks for meeting those needs. Moreover, it was necessary to consider the available resources against the background of the overall economic objectives of Pakistan in order to assist in formulating an efficient strategy of development.

We soon realized that the magnitude of the Study made it well suited to the use of modern programming techniques—made possible by the use of computers—by which many projects can be viewed as components of a larger sector for which only restricted resources are available. As our conceptions crystallized, we came to regard investment proposals not only in terms of their general priority, but in terms of their specific strategic place in the development of a complex system of economic interactions. And the broader the scope of the program evaluations, the greater became the requirements for data, as compared to what could be considered adequate for conventional project evaluations, and the more crucial became the selection of specific analytical methods. Equally, the general procedures adopted made for a long and rather discursive report. This published document could have merely presented the main conclusion and recommendations, with supporting arguments. However, because we felt that the methodological and analytical approach would be of wide interest, it was decided to publish large parts of the report in their entirety.

This Study has been made possible only by intensive international cooperation of men of wide international experience and experts in modern technology and analysis. Close contact was maintained throughout the course of the Study between the Group, which formed my immediate team, our consultants, the Pakistani authorities, and their consultants. We have had many rounds of discussions, both formal and informal, in Pakistan and the United States and at the European headquarters of the consultant firms involved. These frequent contacts and the fruitfulness of them were practical expression of the spirit of international cooperation which was at the heart of the Study. I would like here to express my deep appreciation for the assistance afforded us by the Pakistani authorities and by our and their consultants. Our consultants accomplished a major task in preparation of their comprehensive reports, totaling more than 30 volumes, and their knowledge and technical judgment were invaluable to the Bank Study Group.

In coordinating and directing execution of the Study and in preparing this final report—following a separate report on Tarbela—I have been assisted particularly by A. Robert Sadove and Thomas C. Creyke. Together with other selected members of the Bank's technical staff, we formed the Study Group for whose findings, opinions and recommendations, as expressed in these reports, I assume full responsibility. Each of the staff members associated with the Study has given a great deal of his thought and effort, some of them over a period of nearly four years, to this challenging experiment in comprehensive sector planning. I feel deeply indebted and most grateful to them for their individual contributions, their spirit of cooperation and their unfailing loyalty. My appreciation, too, goes to those responsible for the task of accurately reproducing large volumes of written material.

The work of the Study Group, which was carried out under my personal direction, was organized functionally. In addition to Mr. Sadove, who acted as Deputy Head of the Study, and Mr. Creyke, who supervised the work on Irrigation and Agriculture, General Herbert D. Vogel was in charge of Dam Site Engineering; and A. D. Spottswood was in charge of Electric Power. From the beginning Willi A. Wapenhans was principal assistant to Mr. Creyke in supervising the work and preparing the reports on Irrigation and Agriculture, Christopher Willoughby assisted Mr. Sadove in the preparation of this Volume One and was primarily responsible for the background work on electric power; he drew heavily on the assistance of Prof. Henry D. Jacoby of the Harvard Water Program who prepared a simulation model of the West Pakistan power system. Heinz Vergin assisted Mr. Sadove in the economic aspects of the Study and carried out the linear programming analysis of investment in irrigation and agriculture with direction from Professor Robert Dorfman of Harvard University. E. P. Delany and K. B. Norris, on assignment in Washington from Sir Alexander Gibb & Partners, assisted considerably with engineering aspects of the Study. To assist in the preparation of Volume Two an agricultural group was established, consisting of James B. Hendry, Harold Manning and Kyaw Myint, all of the Bank's staff. Added to this group for a period of several months at Bank headquarters were key members of the Irrigation and Agriculture consultant groups, including W. R. Rangeley, James Turtle and Roger White, of Sir Alexander Gibb & Partners, Thomas Jewitt of Hunting Technical Services, and Pieter Mulder of International Land Development Consultants. Professor Edward Kuiper of the University of Manitoba provided substantial assistance in the field of hydrology.

Execution of the Study has taken longer than originally envisaged. The main phase of the work started in the spring of 1964 when the consultants who had been retained first gathered in Pakistan. Technical delays were inevitably encountered. Moreover, it was found that the scope of the Study —combining general planning to identify directions of development for agriculture, irrigation, surface storage and power with preparation of feasibility reports for selected projects—was such as to require more time than originally envisaged for investigations, analyses and final integration of results into phased multisector programs for the systematic exploitation of West Pakistan's water and power resources.

I hope that, despite its shortcomings, which I fully recognize, this report will go some length in serving the purposes that both Mr. Woods and President Ayub had in mind when including it in the supplemental agreement with the members of the Indus Club. I would like to reemphasize a statement I made at the last round of meetings in Islamabad, in April 1967, that the main purpose of the Study Group's report is to assist the Pakistan authorities in achieving the maximum feasible rate of economic development in the fields covered. The Study has been concerned with collecting as much basic data as possible and analyzing these with a view to clarifying the potential for productive growth and identifying investments, particularly for the Third and Fourth Plan periods. I hope that the report will serve as a useful background document to the Pakistan Government in taking decisions about future development and to the World Bank in assessing Pakistan's progress and plans. The report is in no sense intended to be binding, either for Pakistan or for the World Bank.

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Preface

On November 14, 1963, Mr. George Woods, President of the World Bank, reached an understanding with Field Marshal Mohammed Ayub Khan, President of Pakistan, to the effect (among others) that the Bank would organize a Study of the Water and Power Resources of West Pakistan.

The chief purpose of the investigation, which became known as the Indus Special Study, was to develop a program for the optimum exploitation, for agricultural and power purposes, of the water resources that would be available to Pakistan after implementation of the Indus Waters Treaty of 1960.

Dr. Pieter Lieftinck—an Executive Director of the World Bank and former Finance Minister of The Netherlands—accepted an invitation from the President of the Bank, in January 1964, to head the Study. Several senior members of the Bank's technical staff were also assigned to assist Dr. Lieftinck in the organization and execution of the Study. This nucleus, augmented for particular purposes, is referred to collectively in this report as the Bank Study Group.

To provide the various skills required for the complex and detailed field work involved in the Study, the Study Group obtained the services of a number of consulting firms. For the irrigation and agricultural aspects of the Study, three firms of international repute agreed, at the request of the Bank, to assume joint responsibility and to form, for this purpose, an Irrigation and Agriculture Consultants Association (IACA); the member firms were Sir Alexander Gibb & Partners and Hunting Technical Services Limited, both of the U.K., and International Land Development Consultants (ILACO) of The Netherlands. To handle questions concerning dam sites, Chas. T. Main International, Inc., a U.S. firm, was retained. For power aspects of the Study, the Bank retained the services of Stone & Webster Overseas Consultants Inc., also from the United States. In addition to their role in IACA, Sir Alexander Gibb & Partners were responsible for overall coordination among the consultants.

The Agreement between the President of the World Bank and the President of Pakistan which instituted the Study divided it into two distinct phases. In the first phase, attention was concentrated on a proposal to build a large multipurpose dam and reservoir on the Indus at Tarbela. This project was widely considered to be of high priority but it was also a center of controversy. Immediately after completing their initial Tarbela studies, the consultants were to move into the Study's second phase, which was to result in comprehensive reports on the development of the water and power resources of West Pakistan.

To set the Study in motion as rapidly as possible, the Bank Study Group set out first to establish what information already existed on potential development in the Indus Basin and where the efforts of the Study should consequently be concentrated. A preliminary reconnaissance dedicated to this task was carried out by consultants in February-March 1964—Sir Alexander Gibb & Partners covering irrigation and hydrology, Hunting Technical Services reporting on agriculture, Stone & Webster dealing with electric power, and Chas. T. Main covering dam sites. Reports on this preliminary reconnaissance led to preparation by the Study Group of terms of reference for the major part of the Study. These terms of reference were agreed with the Pakistan authorities and the consultants to the Study Group mentioned earlier were appointed to start work on May 1, 1964.

The consultants' teams gathered in Lahore during May and June of 1964, building up to an eventual resident expatriate strength of about 40, supported by nearly 100 Pakistanis most of whom were assisting the agriculturalists. Gibb established a coordinating office and handled the administrative side of the Study. Continuous liaison with the Pakistan authorities was maintained through the West Pakistan Water and Power Development Authority (WAPDA), the main agency responsible for water and power development, and more specifically through Mr. Monawar Ali, Director General of Planning and Investigations. A forum was provided by monthly meetings which were devoted to an exchange of information and ideas; these meetings were attended by representatives of various government departments and agencies, such as irrigation, agriculture, planning and development, and Agricultural Development Corporation (ADC), in addition to WAPDA. Members of the Study Group maintained a fairly continuous contact with the consultant teams and visited them in Lahore on a number of occasions; it was at these times that Coordinating Committees, providing the official link for the Study Group, the Pakistan authorities and the consultants, were convened.

It was recognized from the beginning of the Study that the time element and the scope of the problems made imperative the closest possible cooperation between the Bank Study Group, the Pakistan authorities and the consultants. All phases of the work, including such matters as the consultants' terms of reference, were therefore discussed in detail with the Pakistan authorities. Three tripartite committees were established: a Coordinating Committee in the sphere of irrigation and agriculture, which met on eight occasions; a Dam Sites Committee which also met on eight occasions; and an informal Power Consultative Committee which met twice. Although these committees had only an advisory role, they served to ensure that Pakistan and the Study Group remained in agreement with the consultants on the scope of the work and the detailed methodology. The consultants' terms of reference were supplemented from time to time through the provision of additional written guidelines and other instructions from the Study Group.

The consultants' first task, to prepare the special preliminary reports on the Tarbela Project, was completed in what must be considered record time. The consultants' reports were discussed with the Study Group by a Pakistan delegation which visited Washington in early December 1964. The Study Group's "Report on a Dam on the Indus at Tarbela" was submitted by Dr. Lieftinck, as Head of the Study, to the President of the Bank and by the President of the Bank to the President of Pakistan in February 1965.

The final reports of the consultants were submitted simultaneously to the Bank and to Pakistan between May and November 1966. One report, in 23 volumes, prepared by IACA, covers the irrigation and agriculture aspects of the Study. Another report, in six volumes, prepared by Chas. T. Main, covers surface water storage. And the third report, in two volumes, prepared by Stone & Webster, covers the power aspects of the Study. In addition, Sir Alexander Gibb & Partners, as coordinators among the consultants, submitted two reports, one entitled "Summaries of Reports by Consultants on Irrigation and Agriculture, Electric Power and Surface Water Storage," and a second which updated the information presented earlier on Tarbela. At the request of the Pakistan authorities and the Study Group, Sir Alexander Gibb & Partners also undertook, with the assistance of Harza Engineering Company International, of Chicago, a sequential analysis of the power and irrigation programs recommended by the consultants. This analysis resulted in a special report entitled, "Sequential Analysis of a Programme for Irrigation and Power Development in West Pakistan."

These reports, together with their supporting annexes, provided a basis for discussion between the Study Group and the Pakistan authorities in November 1966. Discussions were held with the Government of Pakistan in Rawalpindi and with the Government of West Pakistan and affiliated agencies in Lahore. Senior members of all the consultant firms which had shared in the Study participated in these meetings.

Following the discussions in Pakistan in November 1966, the Study Group prepared drafts of a four-volume document, which represented the conclusion of the Study. The report was based on the work and findings of the consultants, on suggestions made by the Pakistan authorities and on studies carried out by the Study Group itself. Preparation of the report had to be compressed into a short space of time. Drafts of the three main parts—on irrigation and agriculture, surface water storage, and power—were sent to Pakistan in March 1967. A final round of discussions between the Group and the Pakistan authorities was held in Lahore and Islamabad in mid-April on the basis of these drafts. The Pakistan authorities made many helpful suggestions and comments.

After the discussions in Pakistan, further revisions were carried out and the report was finally presented to the Pakistan Authorities and the Contributing Governments in August 1967. The report consisted of four main volumes,with their various annexes. The first volume of the report brought together the main findings and related them to the problems of development and development planning in West Pakistan. The second volume dealt with the agricultural potential of the Province and the steps needed to realize that potential—not only surface and groundwater development projects but also policies and institutional measures to secure improvements in farming standards and wider usage of farm inputs. The third treated in detail several alternative sites for surface water storage—in particular Tarbela, Kalabagh and High Mangla—and set forth a tentative schedule for their development. The fourth volume projected the long-term growth of power loads in West Pakistan and proposed a program for meeting these loads.

The report as now presented consists of Volumes One and Two, slightly re-edited, in their entirety as well as several Supplemental Papers—Volume Three on Background and Methodology—dealing with some of the more important issues raised in the course of carrying out the Study.

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Water and Power Resources of West Pakistan
A Study in Sector Planning

THE MAIN REPORT

I

Introduction

The subject of this Study is the Indus Basin of West Pakistan. The Indus River and its six main tributaries—the Kabul, Jhelum, Chenab, Ravi, Beas and Sutlej—together form one of the greatest river systems of the world. While diversion of these waters for irrigation purposes has been going on for more than 3,000 years, the existing irrigation system has been established mainly over the last century. A vast area is irrigated to varying degrees by a network of barrages, weirs and canals, but the system is still far from adequate to meet present and future needs.

A major obstacle in the path of further development was created by the partition of the Indian subcontinent, and in particular of the Punjab, in 1948 between Pakistan and India. A decade of negotiation between the two new countries, aided by the good offices of the IBRD, led eventually to the signing of the Indus Waters Treaty of 1960, which provided for peaceful division of the river system. There was to be a ten-year transitional period at the end of which Pakistan would have the right to full use of the Indus itself and the two "western tributaries" (Jhelum and Chenab) while India would be entitled to divert all flows of the "eastern tributaries" (Ravi, Beas and Sutlej) for her own use.

The engineering concept which underlay the treaty was a system of 'link' canals of unusually large capacity for transferring water from the Indus and, to a lesser extent, from the Jhelum and the Chenab, to meet the irrigation requirements of eastern portions of West Pakistan which had hitherto been served by the three rivers, the water of which is now made available in their entirety to India. To provide funds for implementing this concept, an international agreement was signed, simultaneously with the Treaty, to establish the Indus Basin Development Fund (IBDF). The World Bank was designated Administrator to the Fund. The parties to the Agreement were Australia, Canada, Germany, New Zealand, Pakistan, the United Kingdom, the United States and the Bank. The Fund represented the equivalent of US$ 895 million, including an equivalent of US$ 174 million to be provided by India under the Treaty and a loan of US$ 80 million from the World Bank. The Fund was estimated to be sufficient to cover the total cost, foreign and domestic, of the works to be constructed in Pakistan envisaged by the Treaty.

As engineers began to take a closer look at the proposed works following the Agreement, it became increasingly clear that the cost of the works would far exceed the resources of the IBDF. Revised estimates indicated that the total cost of the Indus works would be not less than twice the amount available to the Fund for this purpose. Negotiations were undertaken with a view to increasing the resources of the Fund. However, the contributing governments were not ready to subscribe additional amounts to the full extent required. Furthermore, there were unresolved problems with regard to the precise works to be built under the Agreement.

As Administrator of the Fund, the World Bank was directly concerned with finding a solution to this unsatisfactory state of affairs. The settlement finally worked out, in the latter half of 1963, was based on a prospective addition of US$ 315 million to the Fund—assurances from the contributing governments of additional subscriptions amounting to approximately US$ 257 million plus a US$ 58 million pledge from the World Bank. The availability of the various subscriptions to the IBDF was subject to satisfactory appraisal of the remaining projects to be executed.

At the time that this financial settlement was reached, an order of priority was also agreed upon for spending the available funds. First priority was given to the construction of an earthfill storage dam and related works on the Jhelum River (Mangla), link canals, barrages and other works set forth in Annexure D of the 1960 Agreement. Second priority was extended to a Study of the Water and Power Resources of West Pakistan to be organized by the Bank as Administrator of the Fund. Thirdly, any remaining balance would go toward the foreign exchange costs of a dam on the Indus near Tarbela, if the Special Study proved it justified, or to other water projects agreed upon between Pakistan and the Bank on the basis of the Special Study.

A Memorandum of Understanding which outlined these arrangements was signed on November 14, 1963, by Field Marshal Mohammed Ayub Khan, President of Pakistan, and Mr. George D. Woods, President of the World Bank. After the Memorandum of Understanding had been approved by the contributing governments, its substance was incorporated in the Indus Basin Development Fund (Supplemental) Agreement 1964. This Agreement, which was signed on April 6, 1964, by all parties contributing to the Fund, provided that Pakistan would accept the arrangements set forth as a full and complete discharge of all obligations, whether legal or moral, expressed or implied, of the other parties under the 1960 Agreement.

The Study of Water and Power Resources mentioned in the Memorandum of Understanding and the Supplemental Agreement was to include a detailed survey of the basic water and power resources of West Pakistan and of farming conditions and prospects in the Province and it was to identify the most practical means of developing these resources in keeping with the needs of the Pakistan economy. The general character of the Study was established in Paragraphs 1 and 2 of the Memorandum of Understanding in the following terms:

1. The Study would consist of a survey of the water and power resources of West Pakistan, primarily but not exclusively related to the potential for agricultural development. Its purpose would be to provide the Government of Pakistan with a basis for development planning within

the context of successive Five Year Plans. It would be sufficiently detailed to assist the Pakistan Government in formulating a sound program for the systematic exploitation of water and power resources of West Pakistan.

2. While the Study of the Water and Power Resources of West Pakistan should be a continuing process, the Study presently proposed would be the initial stage and would serve to determine which of the several potential water and power projects are economically viable and feasible of execution during the following two Five Year Plan periods (1965–70 and 1970–75). The Study would take account of, and serve as a useful guide to the possible future development of water and power projects beyond 1975.

It was stipulated that the first objective of the Study would be the completion of an interim report covering the technical feasibility, the construction cost and the economic return of a dam on the Indus at Tarbela. The second phase of the Study was to deal in a more comprehensive manner with West Pakistan's water and power resources as a whole, giving full emphasis to the broader aspects of development planning and the identification of other projects besides Tarbela suitable for early development. The organization of the Study Group and its approach to the Study are covered in the Foreword and Preface of this Volume.

The Study Group's "Report on a Dam on the Indus at Tarbela" was submitted by Dr. Lieftinck, as Head of the Study, to the President of the Bank and by the President of the Bank to the President of Pakistan in February 1965. The main conclusions may be summarized as follows:

1. That the Tarbela Project as envisaged was technically feasible and its estimated cost would be more than compensated by the agricultural and power benefits which Pakistan should derive from it.
2. That the economic life of the Tarbela Project could beneficially be extended by the provision of side-valley storage or further development on the Indus main stem.
3. That the financial requirements for construction of the project would amount to about US$ 900 million equivalent including the first eight power units but excluding transmission, and without allowance for Pakistan duties and taxes.
4. That the Tarbela Project compared favorably with other studied alternatives for water storage on the main stem of the Indus and would yield an economic return in the form of agriculture and power benefits in the order of 12 percent.
5. That both with and without additional surface water, very considerable agricultural benefits could be obtained by the application of higher inputs for raising the productivity of farm operations.

There were obviously certain difficulties involved in reaching judgment about a project that would have such far-reaching effects as Tarbela before completion of the comprehensive studies of the basin as a whole. Dr. Lieftinck, in submitting the Study Group's Tarbela Report, noted that "the obligation to study, as agreed, a specific project which would be part of a large and complex irrigation system before studying the system as a whole was rather cumbersome." To handle this problem certain priority areas were selected—lower portions of Rechna and Bari Doabs and the Indus left bank from Khairpur to Bahawalpur for irrigation, and the Northern Grid area for electric power—and studied intensively as a basis for estimating the main power and irrigation benefits of the project; and extrapolations and adjustments were made to cover benefits from water and electricity supplies which could not be absorbed within these areas. The reports on this phase of the Study were thus largely concerned with quantifying the potential benefits of the Tarbela Project by comparing it with alternative storage projects and alternative means of meeting power and irrigation requirements.

In undertaking the second phase of the Study, the preparation of comprehensive programs for water and power development in West Pakistan, the consultants were specifically instructed to make full use of existing studies and field investigations and to avoid duplicating previous work. Most of the work of particular interest was carried out under the auspices of WAPDA, whose establishment in 1958 led to a rapid acceleration of work on planning and project preparation. Many studies have been carried out by personnel of the Irrigation Department and WAPDA. In addition, WAPDA has received substantial assistance over the years from its general consultants, Harza Engineering Company International, who have prepared a number of studies on specific projects as well as having been responsible for master planning activities. WAPDA has also drawn upon the resources of a number of other international consultant firms for studies of individual projects—such as Commonwealth Associates and Kuljian on the power side, and Tippetts-Abbett-McCarthy-Stratton (TAMS) for Tarbela.

A very important study which appeared when the consultants were commencing their field work was the report on Land and Water Development in the Indus Plain by the U.S. White House Panel, usually referred to as the Revelle Report. This report was prepared by a panel of American experts headed by Dr. Roger Revelle. The panel had been assembled by President John F. Kennedy in 1961 following a discussion with President Ayub Khan. The Revelle Report proposed a massive program of public groundwater development as a means of increasing irrigation supplies and overcoming the problems of waterlogging and salinity.

Two of WAPDA's consultants were engaged in ongoing studies throughout the period of investigation. The so-called Lower Indus Project (LIP) Group, made up of Hunting Technical Services Limited and Sir Murdoch Macdonald & Partners, had been working in the Sind, in the southern part of West Pakistan, since 1959; since 1962, they had been preparing a regional survey of the Sind—focusing on the development of irrigation and agriculture. The LIP team submitted a comprehensive regional report, including some project identification and project preparation, during 1966, and information from LIP on the South largely fulfilled the needs of the Special Study. Slower progress had been made in completion of a regional plan in the North as the consultants responsible for the Northern Zone, Tipton and Kalmbach of Denver, were more concerned with individual public groundwater projects. Over the years the Tipton and Kalmbach firm had prepared a series of reports of great interest on the Salinity Control and Reclamation Projects—the so-called SCARPs. Their regional plan for the North was not ready in draft form until early 1967, after most of the Special Study had been completed. Thus the North was the scene of a good deal of field work by the Study Group consultants.

The circumstances of the Indus Basin made for a wide coverage of matters relating to irrigation, power, and agriculture in its broadest sense. The Study Group's report considers the need for increased supplies of irrigation water in relation to other means of increasing agricultural production, and finds them essential complements to one another. It analyzes in detail the main means of providing more water for irrigation purposes—enlargement of canals to enable increased diversions from the rivers, storage of flood flows in surface reservoirs, and development of West Pakistan's extensive groundwater resources by means of tubewells. Implications for electric power—both hydroelectric potential at dam sites and requirements of energy for tubewell pumping—have been studied in the context of the long-term development of the entire electric power system of the Province. Each mode of development has been assessed in the light of its potential contributions to the economic development of West Pakistan.

Specific water development projects—comprising an Action Program—have been selected for execution in the years before 1975. Priorities for projects in the Action Program were assessed on the basis of detailed studies of the long-term potential for integrated water resource development, what part of this potential it may be physically, administratively and financially feasible to realize before 1975, and preliminary studies establishing the technical feasibility of the specific projects, their anticipated investment and operating costs, and the benefits they could yield to the economy of West Pakistan. The report also deals with prospects through the remainder of this century, but especially with steps for further development of the Province's irrigation and power systems in the decade 1975–85. These suggestions are more tentative than the recommendations for the early years, but they should provide a useful guide to future development possibilities. All the proposed programs, for early or later years, are subject to revision and updating as new information becomes available.

Finally, it is emphasized that the Study Group has attempted to relate its findings to the economic objectives of West Pakistan. Development planning has reached an advanced stage there, and most of the proposals offered here are concerned with subjects under active review by the authorities. Development policies have emphasized the combined efforts of the private and public sectors. Thus the Study Group has carefully assessed the role and capability of the individual farmers and the technical and financial assistance they need to fulfill their potentials. At the same time, the implementation rate for public sector programs presumes an increased effort by agencies which already carry heavy responsibility. In the last analysis, the proposals in this report are dedicated to goals which Pakistan has set for itself.

II

Development and Adequacy of the Irrigation System

A. HISTORICAL DEVELOPMENT

Introduction

The Province of West Pakistan is bordered on the west and north by mountain ranges; there are desert areas over much of the lower western portion of the country and also along the southern half of the common boundary with India on the east. The major agricultural areas lie within the basin formed by the Indus River and its tributaries, which run in a general northeast/southwest direction. The system is like a funnel, with numerous sources of water at the top converging into a single stream which flows into the Arabian Sea east of Karachi. The availability of water for irrigation has led to a high concentration of population, irrigation investment, infrastructure and markets in this basin.

The irrigation system which exists today has been built up over the course of more than a century. Many of the engineering works were unprecedented in the world at the time they were undertaken. The area under irrigation has been increased from a few hundred thousand acres to a cropped area in the neighborhood of 26 million acres. In the process of expansion, the irrigation system has been totally transformed. A hundred years ago, it consisted simply of a series of inundation canals which captured water for irrigation when river stages were high. Today, it consists of some 38,000 miles of canals and a series of river barrages and canal headworks which control the diversion of river flows into the canals. Many of the canals are very large indeed: 15 have capacities of 10,000 to 22,000 cusecs.[1] The largest barrage, at Sukkur on the Indus, completed in 1932, is nearly a mile long and alone diverts water into seven large canals currently irrigating some five million acres. Works underway as this is written will have greatly enhanced the main canal system by 1970, resulting in a system as shown in Map 1.

Early Development

The most productive agricultural area in West Pakistan is the Punjab—the northeast region watered by four important Indus tributaries, the Jhelum, Chenab, Ravi and Sutlej Rivers. The heartland of the Punjab is

[1] For definitions of technical terms, see Glossary at end of Volume One.

composed of areas, between these rivers, called doabs. The names of the three doabs are acronyms: Bari, once between the Beas and the Ravi but now between the Sutlej and the Ravi; Rechna, between the Ravi and the Chenab; and Chaj, between the Chenab and the Jhelum. Even a hundred years ago this heartland was the most densely populated part of northwest India and included the administrative capital of Lahore. The initial development of the modern canal system took place here under the auspices of British colonial administrators and engineers. The tributary rivers were easier to control than the Indus itself. Moreover, there were extensive areas of flat land in the doabs suitable for irrigation development: the land slopes towards the sea at about one foot per mile on average. However, these same advantages caused problems. The tributaries of the Indus are more dependent on monsoon rains than the Indus itself and consequently more variable in flow and subject to destructive flooding.

The first major modern canal, the Upper Bari Doab Canal, took off from one of the most variable of all the rivers, the Ravi (after Partition, the portion of this canal which lies in West Pakistan was renamed the Central Bari Doab Canal and is so shown on Map 1). It was originally designed to extend 247 miles through the northern part of Bari Doab but the minimum discharge of the Ravi had been considerably overestimated and the canal had to be tailed out 100 miles short of its goal. It was finally opened in 1859, and irrigation began in 1861. Difficulties soon arose, siltation at the entrance to the canal became a problem and the canal itself, designed with too steep a gradient, began to erode its banks. Engineers came to realize that canal design called for minimizing both scouring caused by steep gradients and sedimentation caused by too-slight slopes. By 1900 these and other problems had been overcome and canals had been built commanding some five million acres of agricultural land in the doabs.

Early in the twentieth century, a decision was made to continue development in the same area rather than to attempt any work on the main stem of the Indus. In 1905, the Government of India approved the Triple Canals Project, a landmark because each of the three canals (the Upper Jhelum Canal, Upper Chenab Canal and Lower Bari Doab Canal) was designed to take off from a western river, supply some water for irrigation purposes as it crossed the doab, and finally discharge into the next river to the east to make available more water for irrigation in the eastern areas. The headworks for this project were built at Mangla on the Jhelum. The project served in effect to transfer water from the Jhelum, where it was surplus, for use in the Rechna and Bari Doabs; this in turn meant that the flows in the easternmost rivers, the Beas and the Sutlej, no longer were required to water land in Bari Doab; instead, they could be preserved for use in the independent states of Bikaner and Bahawalpur downstream. The Triple Canals Project clearly contained the essentials of the Link Canal concept which later was to become a key element in the division of water between Pakistan and India.

In those earlier years of canal development, the question of whether to build irrigation works on the Indus was essentially a question of whether to develop the Sind, or Lower Indus area lying between the confluence of the

Indus with its major tributaries and the Arabian Sea. The question was debated for decades. Many factors contributed to the delay—doubts as to the technical feasibility of such a project, which would require a huge barrage spanning the shifting beds of the Lower Indus; a shortage of funds for additional irrigation investment (the early developments in the Punjab were not considered very remunerative); a feeling that the Sind was already receiving enough water from inundation canals to support its relatively sparse populations; and, finally, doubts that sufficient cultivators would settle in the area to make a heavy investment in irrigation infrastructure worthwhile. Almost a hundred years elapsed between the time that the Rohri Canal, the main canal in the Sind and one of the longest and largest in the Province, was first mooted and the time it was finally built as part of the Sukkur Barrage Project, the first major development on the Indus itself, in the early 1930's. This massive project was designed to irrigate a culturable commanded area (CCA) of 7.5 million acres.

Simultaneously with this project, work went ahead on a series of further irrigation developments in the Punjab, this time on the far eastern side, and in downstream Bahawalpur. The project, known as the Sutlej Valley Project, comprised nine separate major canals. The areas to be developed lay on either side of the Sutlej. It was the first irrigation project to include large areas—some five million acres—designated for nonperennial supply only. Canals supplying those areas would be open only during kharif (summer) season when river flows are high. Design of such a large area, some 60 percent of the total, for nonperennial canal irrigation was indicative of the water shortage in rabi (winter) season; it also marked an important change in farming policy. The pre-1900 canals had been mainly designed to encourage wheat production for use elsewhere in India; the main crop for these nonperennial areas was expected to be cotton for sale abroad. As it turned out, flows in the Beas and Sutlej were even less than the project had been designed for. There was also a shortage of finance and in general a disturbed state of affairs resulting from the world depression of the 1930's. Extensive portions of the project area were abandoned.

Apart from the Sind and the Punjab, there is one other important area of canal development—the Peshawar Vale in the northwest. The area draws water mainly from the Swat River, a tributary of the Kabul, which joins the Indus from the west. Canal development dates from the 1890's. With its more northern and higher location, the Peshawar Vale has more plentiful rainfall and greater seasonal variations in temperature than occur in the other canal-irrigated areas. In terms of relative levels of agricultural development, it equals, or may even exceed the Punjab. It is less significant (in terms of output) because of its much smaller area, but it is very important in the production of fruits, sugarcane and tobacco.

Developments Since World War II

Since World War II, Partition and Independence, the irrigation system has been greatly expanded, particularly along the main stem of the Indus. Some nine million acres have been added to the CCA, new link canals

TABLE 2–1
AVERAGE ANNUAL IRRIGATION WITHDRAWALS FROM RIVERS IN WEST PAKISTAN
1947/48 TO 1965/66
(MAF at canal head)

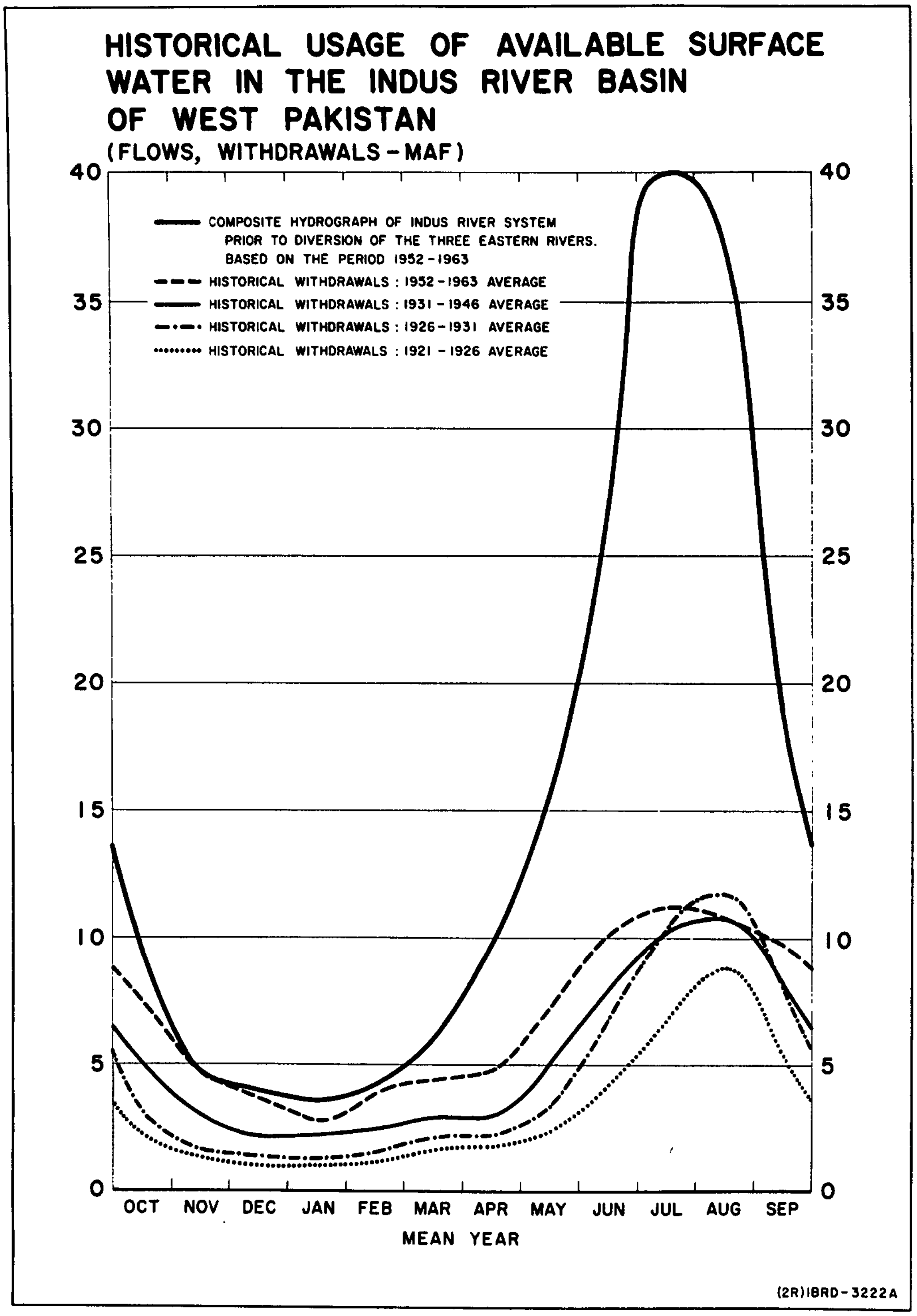
	Kharif	Rabi	Total
1947/48–1950/51	44.4	20.7	65.1
1951/52–1955/56	51.3	22.8	74.1
1956/57–1960/61	52.4	27.0	79.4
1961/62–1965/66	57.6	27.2	84.8

have been built to transfer water from the Jhelum and Chenab to the Ravi and Sutlej, and the groundwater aquifer has been brought into extensive use as a source of irrigation water. Average annual irrigation diversions have increased from about 65 MAF to about 85 MAF, with most of the increase concentrated in the kharif season. As Table 2–1 indicates, average kharif diversions have increased substantially over the last decade, while average rabi (October–March) withdrawals have remained little changed. Average rabi withdrawals between 1952 and 1963 were almost equivalent to the mean monthly flow in the rivers. Figure 1 shows the usage of available surface water since the 1920's.

Before World War II, it was envisaged to alleviate the water shortage in the Sutlej Valley Project by the addition of canals to bring water from the west, together with a dam and large storage reservoir to be built at Bhakra on the Sutlej. However, partition would leave Bhakra in India and thus aggravate the problem of shortages in the Sutlej Valley canals. The headworks of the old Upper Bari Doab Canal at Madhopur and those at Ferozepore on the Sutlej were also awarded to India. Pending final settlement of the Indus Waters Dispute, it became urgent for Pakistan to secure a supply of water for the Upper Bari Doab and the Sutlej Valley. Thus the 63-mile Marala-Ravi Link was built between 1954 and 1956, the 102-mile Bombanwala-Ravi-Bedian-Dipalpur Link between 1948 and 1959, and the Balloki-Suleimanke Link between 1951 and 1954, all to bring additional water from the Ravi and Chenab to the east.

The main additions to the irrigated area have resulted from the construction of four barrages on the Indus main stem. Jinnah Barrage, the farthest north, was completed in 1947; it feeds the Thal Canal which irrigates an extensive portion of Thal Doab, between the Indus and the Jhelum. Lower down in the same doab is the Muzaffargarh Canal, fed from the barrage at Taunsa completed in 1958. Some 70 miles upstream of Sukkur is Gudu Barrage, feeding canals both to the left and right of the Indus to irrigate the northerly Sind; it was completed in 1962. Far downstream, close to Hyderabad, is the Ghulam Mohammed Barrage, completed in 1955. Along with these works, almost all the old inundation canals have been converted into more permanent structures controlled from headworks on the river; such conversion had become more and more necessary over the years as upstream diversions resulted in a general lowering of downstream river stages. These postwar barrages and their accompanying canals were designed to command nine million acres, and large portions of these

VOLUME I
FIGURE I



areas are still under development. But more than 50 percent of the total have been designated for nonperennial supply, indicating that on the Indus, as on the tributaries, virtually all dependable rabi flows have already been committed.

In terms of power, the most important development since World War II —prior to Mangla—has been a series of relatively small hydroelectric projects on the canals and on some of the smaller rivers. In 1947, there was only about 70 mw of public power in West Pakistan—20 mw from a hydroelectric station in the Malakand Hills northeast of Peshawar and the remainder coming from small diesel and oil-fired plants at various towns in the Province. However, the demand for electric power was growing rapidly; between 1950 and 1955 total utility generation grew at an estimated rate of about 30 percent per year, and even so supply was unable to keep up with the growth of demand. To help meet the load growth, the Malakand Project was extended: a long canal along the edge of the hills carries water to 20 mw station at Dargai, from which the water discharges into the Swat River and canal system. In the 1950's and 1960's, a number of small low-head hydroelectric stations were added to the Upper Chenab and Upper Jhelum canals. These are perennial canals which receive fairly reliable supplies; when the canals are running full, the power plants can provide a steady base-load output. Hydroelectric capacity of much more significant size—some 160 mw—was introduced in the early 1960's at Warsak, a major multipurpose dam with a small storage reservoir on the Kabul River. The dam also diverts water into two canals, one on each bank, designed to bring 120,000 acres under irrigation in the Peshawar Vale. By 1965, Warsak and the other small hydroelectric plants were generating some 40 percent of the total amount of electricity produced in the Province.

As the fourth major development of the postwar period, there has been an upsurge in the exploitation of groundwater for agricultural purposes. The vast plains of the Indus Basin are covered with a deep layer of silt, sand and clay laid down by the Indus and its tributaries; this alluvium constitutes a groundwater aquifer containing very large quantities of water generally suitable for pumping. Groundwater has, in fact, been a traditional source of irrigation water, especially in the Punjab. Several methods of raising water from open wells were used, but the predominant method was the so-called Persian wheel; it is estimated that about 200,000 of these wheels still exist. A large wheel is placed vertically across the center of a shallow well and on it is suspended an endless chain of buckets. The wheel is connected with a drive shaft which is operated by draught animals walking round and round. The change which has come about in the last 10–20 years has been the introduction of the far more efficient tubewell. A Persian wheel can lift about one-tenth of a cusec from 20–40 feet. One of the smaller modern tubewells can deliver one cusec with a well depth of about 100 feet, and the larger wells can deliver four or five cusecs with a well depth of 200–300 feet. The development of tubewell pumping has been aided by the growth in power capacity: electricity used for pumping purposes rose from about 90 million kwh in 1960, or some 7 percent of utility generation, to about 540 million kwh in 1965, some 17 percent of utility generation. Installation of private diesel wells has also grown rapidly.

Government-operated or public wells were the first to be established on any significant scale. These are generally larger wells, ranging between two and five cusecs. A few were introduced before World War II and a few more in the late 1940's and early 1950's; the first large-scale development came in 1959 with commencement of the Government's Salinity Control and Reclamation Project No. 1 (SCARP I) in central Rechna Doab. SCARP I was intended to be the first of a series of projects designed to overcome salinity in the soil, which had made its appearance in many parts of West Pakistan but was particularly severe in this area; the plan was to overcome salinity by pumping large quantities of water from the aquifer and spreading it over the land, thus leaching down the surface salts. Pumping the water from the aquifer also lowers the groundwater table.

The SCARP program brought to an end a decades-long debate about the merits and demerits of high groundwater. Some had emphasized the beneficial effects it could have on water supplies, particularly for rabi when river flows were low, by greatly increasing the potential of the Persian wheels with their shallow draft, and by causing water which was stored in the river banks during kharif to percolate back into the river during rabi. Others had stressed the dangers of waterlogging and soil salinization. Soil salinity is not, in fact, confined to areas of high groundwater table, but since it arises from the upward capillary action and evaporation of moisture containing salts, it tends to be particularly prevalent in areas of high groundwater. The debate about the pros and cons of high water table grew particularly strong when the first link canals were proposed around the turn of the century, for these would cut across the natural drainage lines which sloped towards the sea. In any event, the surface irrigation system was greatly expanded, as described above, and percolation to the aquifer is estimated today to be some three or four times what it was in the original state when some kind of natural equilibrium between recharge and discharge was maintained. As a result, the water table has risen to within 10 feet of the surface over some 12 million acres of the canal-commanded areas. Soil salinity is believed to affect some 15–25 percent of the CCA, sometimes putting them out of production, but more commonly reducing yields significantly. Evidence gathered by IACA and others suggests that there is no continuing net loss of land to salinity: actual losses are more than offset by current efforts at reclamation, generally of small scale, and expansion of cropped acreage. Nevertheless, waterlogging, salinity and the related problem of alkalinity do have severe effects on production in wide areas. Naturally, they became major concerns of the Pakistan authorities, and the large program of SCARPs was begun as the main effort to deal with them.

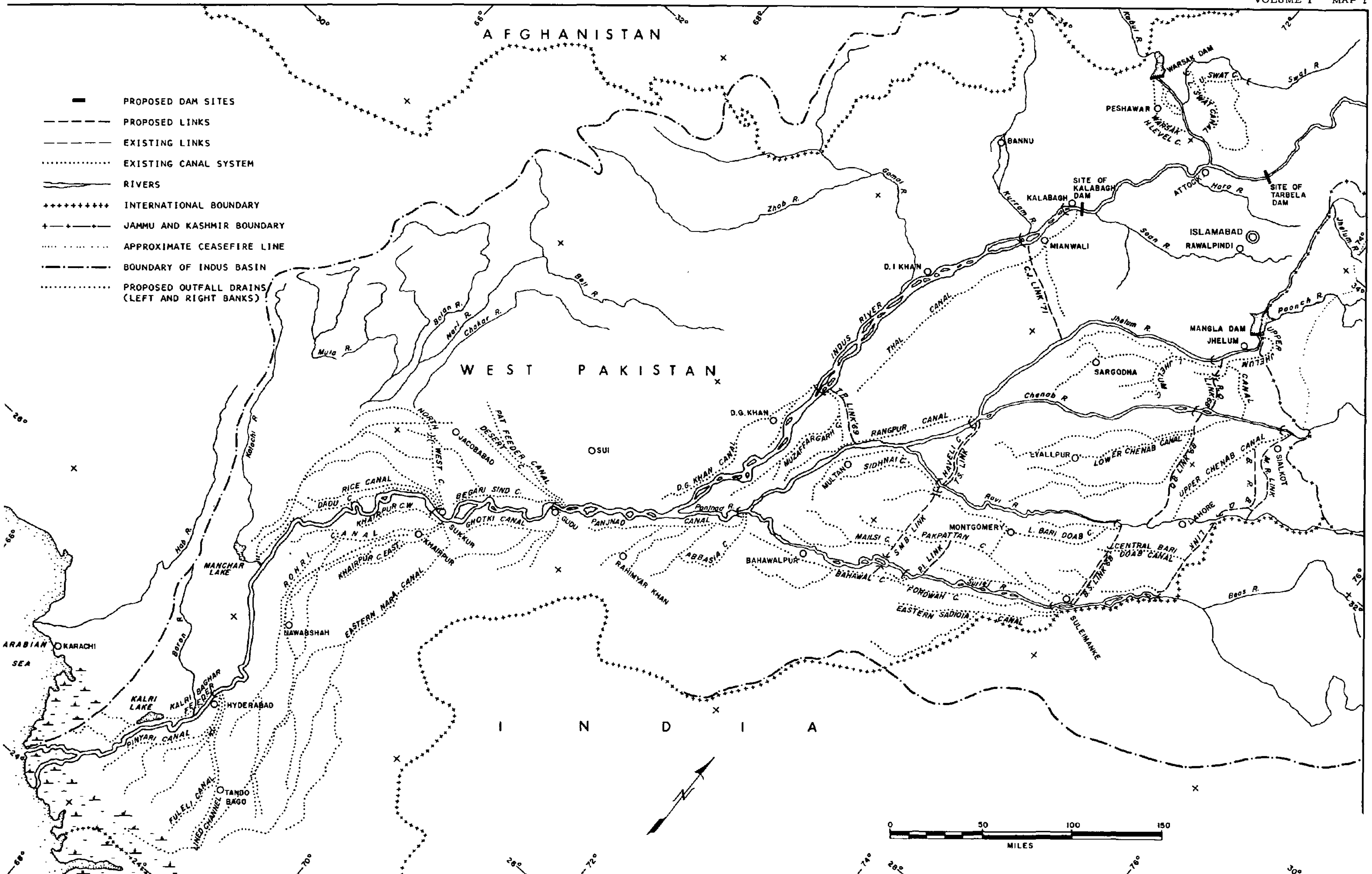
A second type of tubewell development, which has occurred primarily since SCARP I was initiated, has been almost entirely the work of private enterprise: small-scale manufacturers in the Punjab who produce pumps, engines, strainers and well casings, entrepreneurs who handle the well drilling with primitive rigs, and farmers who pay for the wells and put them to use. The growth of private tubewells has been dramatic; by 1965, private wells were producing an estimated six MAF annually, more than twice as much as the public wells. Generally about one cusec in size, private wells have been installed by large farmers, by groups of small farmers and even by landless artisans who pump water for sale to farmers. The numbers of private wells apparently increased from about 5,000 in 1959/60 to some 34,000 in 1964/65. About 6,500 private wells are believed to have been drilled in 1963/64, compared with only a little more than 1,000 in 1959/60, and as many as 8,500 may have been sunk in 1965/66. Private well development so far has been very heavily concentrated in the Bari and Rechna Doabs, the best and wealthiest farming areas, but growth of wells has not shown much correlation with specific data such as farm size or land tenure structure in a particular area. Proximity to power lines has been an important factor. In recent years large numbers of diesel-powered wells also have been installed. And though they seem to be much more expensive to operate, diesel wells now represent some two-thirds of the wells installed. Private wells are not installed according to coordinated pattern, as with the public tubewell projects; in some areas they appear to be quite dense, averaging one per 60 acres, while in others they are quite isolated. Reclamation of saline land or lowering of the water table are generally achieved only incidental to the private pump owner's main concerns—to increase the certainty of water supply, especially at certain critical moments in the farming cycle, and/or to increase the acreage which he crops each year.

Irrigated Agriculture in 1965

The development of irrigated agriculture in West Pakistan is summarized in Table 2–2 by major area. The Sutlej Valley Project command is divided between the right bank of the Sutlej, the areas within Bari Doab, and the areas on the left bank. Areas commanded from Jinnah and Taunsa Barrages are grouped together under Thal Doab and Indus Right Bank. And the whole of the Lower Indus area is treated in one group. Table 2–2 brings out the importance of the three oldest areas of modern canal development—Bari Doab, Rechna Doab and Peshawar Vale—in the total economic and agricultural activity of the canal-irrigated areas in the Province. They include only 38 percent of the total CCA and receive only 30 percent of annual canal water supplies. But they contain 50 percent of the population of all canal-irrigated areas, 85 percent of the tubewells, and are responsible for more than 50 percent of canal-irrigated production.

For purposes of analysis, the Study Group has adopted IACA's view that the total area suitable for irrigated agriculture amounts to a total of 29.4 million acres, which is some four million acres less than the officially designated CCA. The lower figure omits 0.5 million acres which will be needed for roads and canals, etc., and another 3.5 million acres in the Sind which, according to LIP, is of very inferior quality, has been abandoned, or is basically unsuitable for development in conditions of water shortage. Even with full development of the available water resources, there does not appear to be enough water to meet in full the irrigation re-

INDUS BASIN - LOCATION OF CANALS AND LINKS



on agricultural commodities. It follows that agricultural output must grow nearly as fast as the total output of the economy as a whole simply to meet increasing domestic demands. If it grows at less than this rate, then domestic consumption eats into the surpluses that were previously available for export.

The dilemma can be expressed in fairly precise terms. It is estimated that the expenditure elasticity of demand for directly consumed agricultural products is in the neighborhood of 0.85. This in turn implies, according to the Study Group's analysis, that if provincial income grows at 6 percent per year, then value added in agriculture must grow at about 5 percent per year simply to keep up with the growth of domestic demand. Agriculture in West Pakistan has not grown since World War II at this rate; between 1950 and 1960 it grew at about 1.5 percent while provincial product grew at about 3.2 percent, and between 1960 and 1965 it grew at about 3.8 percent while provincial product was growing at nearly 6 percent per year. The latter rate of growth in provincial product cannot be sustained for very long without a substantial step-up in agricultural production, unless foreign aid is made available in amounts and on terms that are, in the current world situation, becoming more and more difficult to sustain. (For further discussion see Supplemental Paper No. 1, Volume Three.)

The Shortage of Electric Power

The electric power sector of the West Pakistan economy has grown rapidly in recent years. But supply has not grown rapidly enough to keep up with the growth of demand; shortages of electricity have recurred frequently. In most parts of the Province, additions to the system have been fully absorbed almost within months of its completion. The recurring shortages have had an unfavorable effect on the growth of industrial production. Continued shortages would have increasingly serious effects on agricultural production as electrified tubewells become more widespread.

Per capita consumption of electricity remains extremely low. Still, the 70 kwh consumed in 1964 compares favorably with the six kwh or so consumed in 1950. Over this 15-year period, electricity production grew at about 20 percent per year; it slowed down somewhat between 1955 and 1960 but since then production has been boosted by the demand from tubewell pumps.

The availability of electricity is still largely confined to the towns and surrounding areas. Stone & Webster estimated that some 5 percent of the houses in rural areas (defining rural, or nonurban, as any place with less than 25,000 inhabitants) are connected to the electricity distribution system. Most of the existing rural electrification has been accomplished since the mid-1950's: in the second half of the 1950's, many villages in the Peshawar area were electrified in connection with hydroelectric projects; in the first half of the 1960's, many villages in the Chaj Doab and parts of Rechna Doab were electrified in connection with the public tubewell program. By 1965, about 2,000 of the Province's 40,000 villages had been electrified. All the public tubewells and about a third of the private wells are operated by electricity, leaving perhaps half of the total amount of

TABLE 2–6
COMPARATIVE AVERAGE CROP YIELDS
(maunds/acre)

	Wheat	Rice[a]	Cotton[b]	Maize	Sugarcane[c]
West Pakistan					
Province-wide Average (1962/63–1964/65)	9.2	10.3	2.9	11.5	376
Irrigated[d]					
Peshawar	12.0	14.0	2.3	16.5	360
Punjab Cotton Region	13.5	14.0	3.0	13.0	360
Sind Cotton Region	10.6	13.0	2.6	6.0	220
Other Countries (national averages)[e]					
Japan	21.7	51.8	—	26.0	1,760
Egypt	—	36.3	5.9	24.5	—
Mexico	19.5	—	5.9	9.2	590
USSR	10.5	23.5	6.8	11.7	—
USA	16.6	41.4	5.2	40.5	670
Punjab Progressive Farmers[f]					
Average	25–35	30–40	5–7	20–30	600–800
Maximum	66	80	13	84	1,900

[a] Unhusked.
[b] Lint.
[c] Cane.
[d] IACA estimates for 1965.
[e] Averages 1961–63 from FAO Production Yearbook 1965.
[f] Data collected by IACA.

pumped groundwater raised by diesel-powered wells. Provision of diesel fuel for these pumps probably cost about Rs. 20 million in direct foreign exchange expenditure in 1966. It is still fair to say that most villages and farms still rely on kerosene for lighting, dung and firewood for heating and cooking, and animal power or diesel oil for wells. But kerosene and diesel oil are costly in foreign exchange, firewood is becoming scarce, and the use of dung for fuel deprives the fields of needed organic material.

CROP YIELDS AND AGRICULTURAL INPUTS

A very low level of yields is attained on most crops in West Pakistan, in irrigated and nonirrigated areas. Some comparative data are presented in Table 2–6. National field averages, covering irrigated and unirrigated areas combined, are most directly comparable with the Province-wide averages for various crops; West Pakistan does not fare very well in the comparison. Some exceptionally high yields for Pakistan have been recorded by IACA for a small number of progressive farmers in the Punjab. Thus, while it is a fact that current average yields in West Pakistan are among the lowest in the world, there is evidence that high yields can be obtained which compare well with those obtained in other countries.

The low yields, to a large extent, are due to poor farming and irrigation practices and inadequate use of agricultural inputs such as fertilizer and plant protection. Insufficient attention is given to land leveling, seed-bed preparation, post-planting cultivations and weed control. While soils of the plains are generally well suited for irrigated agriculture, in some areas where fine silts are present—to illustrate the need for careful seed-bed preparation—a crust can form which interferes with water infiltration and so with seedling emergence. Also, there is a widespread deficiency of nitrogen and organic matter in the soil as is typical of countries with hot dry climates. Response rates in nitrogenous fertilizer tests have been high in both the Sind and Punjab, particularly with certain crops such as wheat. Phosphate, when used in combination with nitrogen, also gives a good response, particularly in the Punjab. But use of these nutrients has seriously lagged. Phosphatic fertilizer is scarcely employed at present. Application of nitrogenous fertilizer was estimated at about 90,000 tons nutrients in 1965/66 or, assuming that virtually all was applied to irrigated areas, an average of only nine pounds per cropped acre. This is less than 5 percent of the level applied in Japan and Taiwan and hardly 10 percent of use in such countries as Ceylon, Egypt and Korea. Plant protection, which is particularly important for crops such as cotton, rice, and sugarcane, is provided almost entirely by the Agriculture Department; IACA observations indicate that wrong timing and inadequate applications of the required chemicals are prevalent. The quality of most of the seed used at present also leaves much to be desired; even when it goes under the name of an improved variety, it frequently has low germination rates due to adulteration and improper handling.

There is no doubt that improved farming, together with greater use of farm inputs, could produce substantially greater output from the existing cultivated area and water supply. Major efforts are currently being made by the public authorities in Pakistan to promote the use of fertilizer and improved varieties of wheat, rice, and maize. An increasing number of farmers are responding to the opportunities offered. Nevertheless, it would be misleading to plan on the assumption that the new inputs, and all the improved cultural practices that must go along with them for best results, will be widely adopted in the very near future. Even the tubewells are affecting only a small proportion of the farmers; there may be 50,000 private tubewells in existence, and some of the wells are providing water to several farmers, but there are some five million farmers in the Province.

The modernization of agriculture will likely be achieved by means of a gradual increase in the use of some inputs, with particular interest in one or two at a time. Adoption of the practices that should accompany use of such inputs would gradually follow. To secure these increases on a large scale, tremendous improvement will be required in both Government and private services responsible for agricultural research and extension work, as well as procurement and distribution of farm inputs. If large numbers of farmers are to take the steps necessary to increase yields, they must be informed of the proper steps, and by people who can demonstrate convincingly the reliability of the information they convey. Such people are presently in short supply.

Strength of Demand for Irrigation Water

Irrigation water supply is another major factor connected with the comparatively low crop yields in West Pakistan. The most obvious evidence of the need for greater and more regular irrigation supplies is the demand for water which has translated itself into installation of private tubewells. The amount of water pumped by private wells probably increased from about one MAF in 1960 to about 6.5 MAF in 1965, despite the fact that private tubewell water is much more expensive than canal water; however, it is hard to make a direct cost comparison because farmers are charged for canal supplies (at rates that appear uneconomically low) on the basis of acres planted and harvested rather than the amount of water actually used. Cotton is an important cash crop, for which water charges are relatively high and to which the farmers tend to give priority in use of available water. Water charges for an acre of cotton are about Rs. 11, and a reasonable average figure for the amount of water required is about two acre-feet. For this crop, then, the average cost of an acre-foot of canal water is in the neighborhood of Rs. 6. The actual cost to the farmers of an acre-foot pumped by a diesel well, including capital costs amortized over 10 years with 8 percent interest, is about Rs. 26; the cost of an acre-foot pumped by a private electric well (at the subsidized price for electricity) is about Rs. 13. These figures can only be rough. But the relative price difference indicates the strength of demand that use of the more expensive source of water represents. The facts about actual private tubewell development, however, cannot show how many farmers want water but are unable to install private wells because the aquifer is unsuitable, the necessary equipment is unavailable, loans cannot be obtained at a reasonable interest rate, etc. Water is an input to which the farmers of West Pakistan are very accustomed; they realize its value and they are ready to pay a high price for additional supplies.

The Choice Between Water and Other Inputs

The problem of yields can now be discussed in terms of development policy. Demand for more water is undoubtedly great and there is also evidence of heavy demand for larger supplies of certain farm inputs in some areas. At the same time, Government funds and foreign exchange are in short supply, so that the public authorities face a choice between investing funds in water development and investing them in provision of additional farm inputs. This choice is very hard to make, for the costs and likely benefits of each type of investment probably vary greatly among different areas, are hard to forecast, and are not really indicated by any free or effective market mechanism.

As a practical matter, however, there are very definite limits to the range of choice that exists between expenditures to increase supplies of farm inputs and expenditures to increase irrigation water deliveries, and this is so for a number of reasons. There is no doubt that the farm inputs discussed are essential ingredients of the modernization of agriculture and that they should be given much more emphasis than in the past; just because they are new and unaccustomed to most farmers in Pakistan, a major extension and demonstration effort is needed to apprise farmers of profitable opportunities for their use. The relative novelty of the improved techniques also means that the pace of progress—by which is meant effective utilization of farm inputs—is limited by constraints which are real, though hard to define with precision: first, an organizational constraint limiting effective expansion of the extension and distribution services and, second, an absorption constraint, resulting from lack of knowledge and financial resources on the part of the farmer, limiting the rate at which he will respond to the new opportunities as they become available. Therefore, while a maximum effort is needed to increase the use of all farm inputs, there is still a need for a major effort with the traditional input, water, which the farmers already know how to handle. Nonwater inputs alone cannot increase the rate of agricultural growth to the levels required for balance with the rest of the economy, let alone increase the foreign exchange earnings of the sector to the extent required.

Absorption capacity suggests the desirability of allocating resources to water development as a residual after a maximum effort has been made with missing farm inputs. But, in fact, the choice between public efforts on water and farm inputs is further limited by technical complementarities between these factors on the farmland. On most farms of the Province, shortages are such that increased water supplies and increased applications of farm inputs yield best results when used together. The complementarities apply whether additional water is used to expand the cropped acreage, e.g., by increasing cropping intensity or whether it is used to increase the irrigation applications to the existing cropped acreage. The typical response of the farmer to increased supplies of water, either from canals or from private tubewells, has been to extend the acreage which he crops each season by reducing fallow on the land which in the past he left totally unused, rather than to increase the water "delta" applied to the acreage he was already cultivating. Agronomic studies indicate that, as long as traditional crop varieties are grown and little use is made of other agricultural inputs, production can be increased more by bringing additional land under cultivation than by concentrating the water—at least in the short term before prolonged underwatering leads to salinization of the topsoil. Reduction of fallow in areas of high water table, for example, is also attractive because fields left uncultivated and therefore unwatered are particularly prone to salt efflorescence, which tends to reduce yields or even make land uncultivable. But to sustain a higher cropping intensity over a period of years, the time given to land for rest has to be reduced, and this requires giving chemical supplements in the form of fertilizer to maintain its fertility. As more fertilizer and other improved farm inputs come to be used, the need for additional amounts of water per acre cultivated increases. For example, for a variety of reasons, acreage under new crop varieties such as Mexican wheat yields best at higher applications of water per acre than the old varieties. In addition, as more money is invested by a farmer in inputs which require additional water to interact with one another to best effect, it becomes more important to increase the water delta on each acre. Table 2–7 compares the current estimated irrigation water availabilities in different areas with IACA's estimates of the average annual water required per cropped acre for best results with full recommended supplies of other farm inputs. The table suggests wide variations in the adequacy of water supply

TABLE 2–7
APPROXIMATE INDICATION OF ANNUAL WATER SUPPLIES AVAILABLE NOW AND NEEDED WITH RECOMMENDED INPUTS

	Acre-Feet per Cropped Acre	
	1965 Condition	Ultimate
Bari Doab	2.0	3.0
Sutlej/Panjnad Left Bank	2.2	3.4
Rechna Doab	2.3	2.6
Chaj Doab	1.8	2.6
Thal and Indus Right Bank	2.7	2.8
Peshawar and Swat	1.8	2.3
Lower Indus (Sind)	2.9	3.5

in different areas. The Thal and Indus Right Bank region is reasonably well provided for existing cropped acreage because of the relatively recent start of development there, although the available water is ill-distributed by months and by areas within the region. The figures for Rechna Doab show the effects of heavy public and private tubewell development. In these global terms, Bari Doab and the Sutlej and Panjnad Left Bank show up as the areas of most serious water shortage. The table also brings out the relatively higher requirements of canal irrigation water per cropped acre in the more southerly portions of the Basin than in the North, due to lower rainfall and higher evaporation in the South.

While these figures show the general inadequacy of current water supplies for supporting an improved agriculture, they fail to bring out what may be the most critical aspects of irrigation in West Pakistan at the present stage—the unreliability of water availability at particular times during each cropping season. To make it worthwhile to invest in other inputs, the farmer must be assured that he will receive the amounts of water needed to realize the benefits of the inputs and hence a good return on his investment; and the water must be available in sufficient quantity at certain critical times of high crop-water requirements. Watercourse studies have verified how strong an obstacle that insecurity of water supply is to acceptance of other inputs. Many farmers were found to be sowing at much below recommended densities, for instance, because of uncertainty as to whether or not sufficient water would be available at critical times. And as mentioned before, one of the most important purposes of the private tubewells appears to be increased reliability of total irrigation supplies. Available evidence indicates a strong correlation between acceptance of new inputs such as fertilizer and installation of a private tubewell. Thus the effect of water shortages is actually considerably more severe than global estimates suggest.

The importance of critical periods for water also deserves comment. The general period of water shortage, it is true, is the rabi season when most of the available river flow is already being used. But the shortage tends to be more acute in some months than in others, depending on varying crop-water requirements and year-to-year fluctuations in the time pattern of river flows. The shortage of water also affects kharif crops in a number of areas because irrigation needs overlap in time with rabi irrigations. For instance, before the Sukkur Barrage was built, large areas on each bank of the Indus had previously depended entirely on inundation canals and therefore received little but kharif water; after the Barrage was built there was a conversion into perennial areas and a large expansion of the acreage cropped in rabi. But the more critical contribution of the Sukker Barrage was actually in lengthening the kharif season for cotton grown in these areas. To secure the best flowering and boll formation, cotton needs to ripen when temperatures are still moderately high, when days are long but nights are still cool; cotton does best in the Sind, therefore, when planted relatively early, between late April and late May. Sukkur made possible earlier planting of cotton and better harvests. The critical periods for water supply remain a few months in the year—particularly those around the beginning of each season, when water is required for preplanting and sowing, and at the end of each season when water is required for final maturing. October is a critical month because most kharif crops, particularly cotton, are maturing and many rabi crops, particularly wheat, are beginning to be sown. March is also a critical month because final waterings are being given to the wheat crop. Peaking requirements are intimately linked with crops and varieties grown; new varieties, with shorter growing seasons or requiring different planting and harvesting conditions, can have an important effect on the pattern of water requirements over the year.

The Effect of the Indus Basin Works

Substantial changes in the irrigation system will result from the implementation of the Indus Waters Treaty of 1960. Out of the total measured discharge entering the Indus Plains (in Pakistan and India together) averaging about 175 MAF per year, at present, about 167 MAF enters West Pakistan. From March 31, 1970—or as late as March 31, 1973, if Pakistan decides to make use of the contingency extension provided for in the Treaty—India will have the right to divert virtually all the flows in the Ravi, Beas and Sutlej, which have an average annual discharge of 25 MAF. Thus, the average annual flows remaining available to West Pakistan will be 142 MAF in the Indus, Kabul, Jhelum and Chenab. Some supplementary supplies will inevitably be provided from occasional flows in the Ravi and Sutlej Rivers and there will also be minor contributions of a few MAF each year from lesser tributaries within West Pakistan; flows from these two sources, being very dependent upon monsoon rains, will fluctuate greatly from year to year and are unlikely to occur to any significant extent in the winter. As a base figure, the lowest combined flow of the Indus, Kabul, Jhelum and Chenab experienced within the last 40 years was 116 MAF in 1961/62.

The largest water development works presently under way in West Pakistan are those intended to compensate for the irrigation supplies which have depended in the past on the flows in Ravi, Beas, and Sutlej. There are two main components of the Indus Basin Works: on the one hand, a number of barrages and link canals designed to transfer water from the Jhelum below Mangla and from the Indus to the eastern tributaries and, on the other hand, the Mangla Dam Project. The following description of the works, which is inevitably rather complicated, is illustrated by the pull-out map at the end of this chapter. Three of the link canals are remodeled and enlarged versions of those built by Pakistan in the 1950's close to the Indian border, between the Chenab, Ravi and Sutlej—Marala-Ravi (22,000 cusecs), Bambanwala-Ravi-Bedian-Dipalpur (5,000 cusecs) and Balloki-Suleimanke (18,500 cusecs) (see Map 2). A new barrage was built at Marala because, although not originally included in the Treaty, it was found that this would be cheaper than remodeling the old one. Two more of the link canals give the Balloki-Suleimanke link a direct supply from the Jhelum; they are Rasul-Qadiribad (19,000 cusecs) and Qadiribad-Balloki (18,600 cusecs); a new barrage at Qadiribad was provided for in the Treaty and it was subsequently found that a new barrage was also necessary at Rasul, a short distance downstream of Mangla. Two other links are designed to convey water from the Indus to the Jhelum: Taunsa-Panjnad (12,000 cusecs) in the south a short distance upstream of the confluence of the Indus with its tributaries and, the largest link, Chasma-Jhelum (22,000 cusecs) just below Jinnah Barrage. It was originally envisaged that the Jinnah Barrage at Kalabagh would form the terminus of this link on the Indus, but careful investigation showed that even if remodeled it could not perform this function efficiently in addition to serving the Thal canals. So it was decided to build another barrage under the Treaty, at Chasma, and to take the link off from there. The last of the eight links referred to in the Treaty was one between the Chenab, Ravi and Sutlej which would be able to transfer Indus water delivered by the Kalabagh-Jhelum link across the lower parts of Rechna and Bari Doabs to the heart of the Sutlej Valley Project area. It was described in the Treaty as the Trimmu-Islam link (11,000 cusecs) with two new barrages, one on the Ravi and one on the Sutlej. Further studies led to various changes in concept, and the project finally built was the Trimmu-Sidhnai-Mailsi-Bahawal link, with a new barrage at Sidhnai on the Ravi and a syphon for transferring water overhead, known as the Mailsi Syphon, on the Sutlej. Most of these works have been built, and the links from the Indus are expected to be completed in 1969—Taunsa-Panjnad, and in 1971—Chasma-Jhelum.

The other main component of the Indus Basin Works, Mangla Dam, the largest dam of its type in the world, was brought in largely to replace the historic deliveries from the Ravi and the Sutlej to the canal commands in Bari Doab and on the left bank of the Sutlej in the rabi season. October-April flows on the Ravi and the Sutlej average about 4.2 MAF. With an initial live storage of about 5.3 MAF (with drawdown level of 1,040 feet), or more than 20 percent of the average annual discharge of the Jhelum of 23 MAF, Mangla Reservoir will greatly alter the pattern of flows on the river. Transferring this amount of water from kharif to rabi will more than double mean-year discharges and increase discharges under critical year conditions by some 130 percent in the rabi season. Mangla will also play

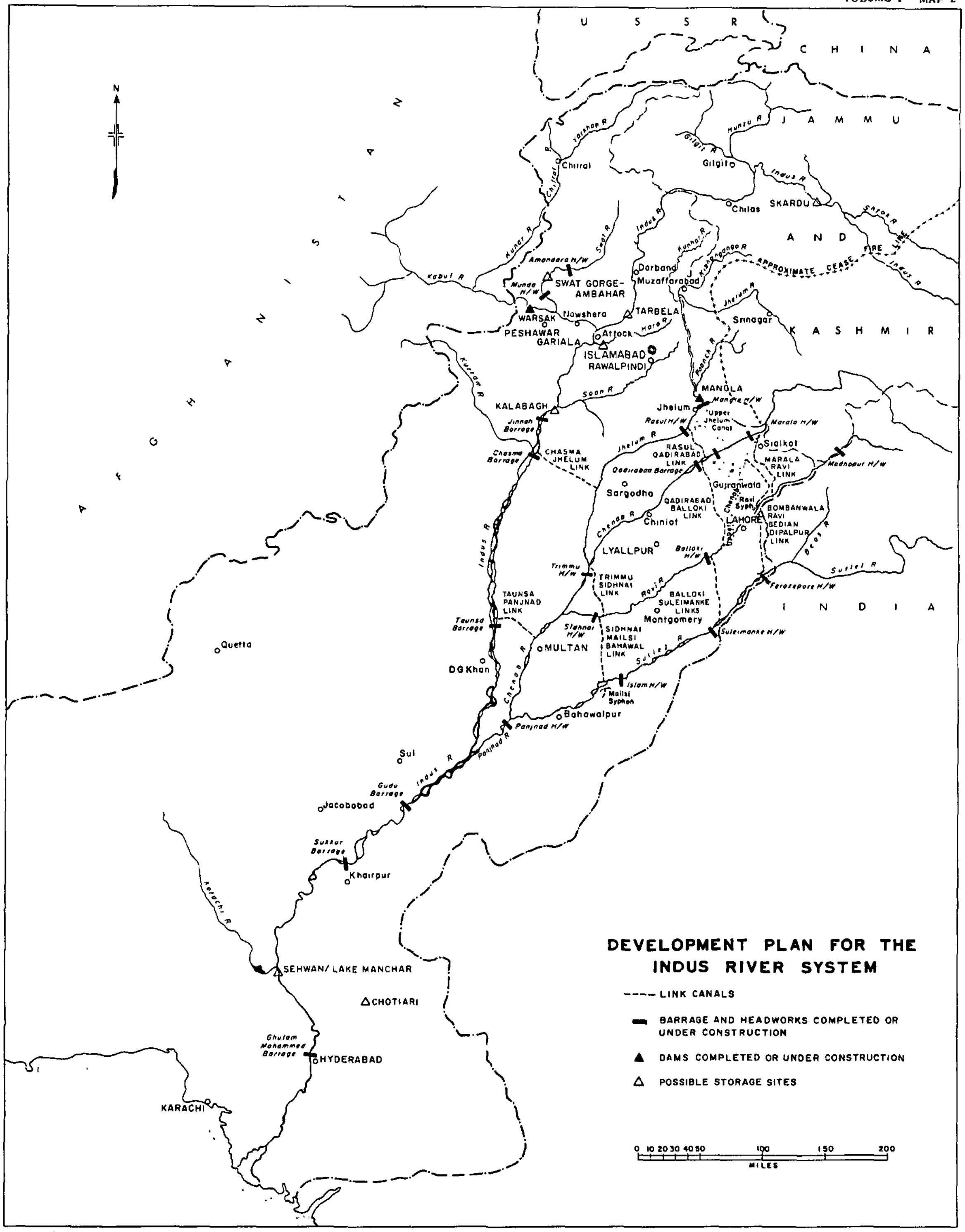
TABLE 2–8
RECORDED RABI DISCHARGES OF JHELUM AT MANGLA, 1922–63
(MAF)

	Mean	Maximum	Minimum
October	0.85	1.78	0.49
November	0.54	1.57	0.34
December	0.48	1.64	0.32
January	0.53	1.06	0.34
February	0.73	1.94	0.33
March	1.56	2.99	0.68

a very important role in regulating the discharges of the river over the course of each season and particularly the rabi season. The Jhelum, being quite heavily dependent on monsoon rains, is an exceedingly variable river. Annual recorded flows on the Jhelum at Mangla range between 65 percent and 135 percent of the mean flow of 23 MAF, and this variability operates in the rabi season as much as in kharif. Recorded discharges between the beginning of October and the end of March range between 65 percent and 165 percent of the mean of 4.7 MAF (see Table 2–8). Variability of discharges in a single month is of course even greater. Maximum recorded flows in a month are in some cases as much as five times minimum flows in that month. From the point of view of agriculture it is the availability of water at a particular time which counts. The barrages have been able to even out water deliveries to some minor extent, but Mangla will make it possible for the first time to control a sizable proportion of the total flow.

Mangla will also make a major contribution to economic growth in West Pakistan in the form of electric power. The first three power generation units will be installed under a provision of the Indus Basin Development Fund Agreement. Two units, each rated 100 mw, came into operation before the end of 1967; the large fluctuation in reservoir content, and consequently in the head on the turbines over the course of the year, will cause the capability of each unit to vary between a minimum of about 45 mw in the spring when the reservoir is fully drawn down and a maximum of about 135 mw in the summer after the monsoon floods have refilled the reservoir. But flows will be sufficient to generate a large amount of base load energy throughout the year; the first two units will produce about 1,800 million kwh under mean-year flow conditions or nearly 50 percent of the total amount of electric energy generated in West Pakistan in 1965. The rapid growth of electricity consumption in the Province means that most of this output will soon be absorbed, and additional units will have to be added. The powerhouse was initially built for eight units, but there are five tunnels each designed to take two units; thus the ultimate installation could be 10 units with a combined minimum capability of about 450 mw and a combined maximum of 1,350 mw; together these units would be able to use virtually all the water passing through the dam for power generation, except at times when the reservoir is very low or when floods are exceptionally high, and they would produce an average of about 6,000 million kwh per year.

VOLUME I MAP 2



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Completion of Mangla Dam makes it possible to store a large proportion of the surplus summer flow on the Jhelum. Indeed, in years of low kharif flow, it will store virtually all of the surplus. As irrigation develops further and kharif requirements increase, the margin of surplus will fall; then a choice will arise between filling the reservoir to ensure greater availability in the following rabi season and allowing more of the kharif flow to go straight through the dam for immediate irrigation use. If all conceivable kharif irrigation obligations, even those which have not generally been met in the past, were taken into account, this choice would be real in some hydrological years even now. Mangla Dam has been designed and constructed in such a way that it could be raised 50 feet and the live storage capacity of the reservoir consequently increased 3.5 MAF; clearly, the larger reservoir would be filled less frequently than the existing reservoir, given the same kharif irrigation requirements, but at some stage it might become attractive to accept this situation and to develop the full potential storage capacity of Mangla so that water could be held over from years of high flood for use in low-flow years.

From the point of view of irrigation system development, the main importance of the Indus Basin Works is in making traditional water supplies fully secure, initiating a new direction of development in the form of interseasonal surface storage and offering scope for further development. The works have been designed to meet their primary purpose of replacing historic deliveries from the Sutlej and the Ravi—Mangla providing the rabi water and the links serving to transfer water from there in rabi and from the natural flows of the Indus and the Jhelum in kharif. They add considerably to the flexibility of the system. The link canals built under the Treaty will provide a total capacity of 2.0 MAF/month for transfers from the Indus to the Jhelum and Chenab, while they, together with the canals built earlier under the Triple Canals Project, will provide 4.2 MAF/month capacity for transfers from the Jhelum and Chenab to Bari Doab and the Sutlej Left Bank. They will make it possible to compensate to some extent for hydrological fluctuations in flows on the Jhelum and Chenab by transfers from the Indus. With Mangla operated in an integrated fashion with the link canals, deliveries from the rivers of the Punjab can be matched more closely to the time pattern of crop-water requirements than has been possible in the past.

The flexibility added by these works will become increasingly valuable as the integration of the system is tightened by further development. The hydroelectric plant at Mangla should provide a cheaper and more reliable source of electricity than has yet been available in the Province, and this will be especially important in connection with further tubewell development. Nevertheless, most of the water storage and transfer capacities of the Indus Basin Works will be required for their main purpose of replacing flows released for use by India. Therefore, the works in themselves leave unresolved the fundamental problem of the inadequacy of irrigation water supplies for supporting the kind of modernized agriculture that West Pakistan so urgently requires.

III

Guidelines to Further Development

A. ALTERNATIVE TECHNIQUES OF WATER DEVELOPMENT

With the Indus Treaty Works nearing completion, thus ensuring that West Pakistan will continue to receive the irrigation supplies that have been available in the past, this report addresses itself to the next steps that should be taken in development of the Province's water resources. As noted earlier, the main water resources available, apart from rain falling directly on the irrigated lands, are surface water and groundwater. Some 142 MAF of surface water will be available in a mean-flow year following full implementation of the Indus Waters Treaty. The chief source of groundwater is a very extensive aquifer, underlying the Indus Plains, with a gross area of the order of 40 million acres. The groundwater aquifer is believed to exceed 1,000 feet in depth over much of the area. An estimated 14 million acres of the canal-irrigated area lies over groundwater of sufficient quality to be used directly for irrigation, and another five million acres have groundwater that is low enough in noxious chemical elements to be used for irrigation after mixing with surface water. The uppermost 100 feet of the usable groundwater aquifer in the irrigated areas contain about 300 MAF of usable water. The physical characteristics of the aquifer are generally favorable to groundwater development, except in parts of the Lower Indus Region (Sind) where it has low permeability and the groundwater is generally saline.

Of the various ways in which these water resources can be developed, there are four which are particularly important to West Pakistan at its current stage of development. While some reference is made to other techniques which may play some part, especially in later years, this report focusses primarily on four: canal enlargement enabling increased natural flow diversion, interseasonal surface storage, private tubewell pumping and public tubewell pumping to balanced recharge. All four modes of development are to some degree interdependent: none can be adopted alone without eventually creating the need to embark on one or more of the others. In addition, each is subject to administrative and technical constraints which limit the speed with which it can be pursued. Nonetheless, an impression of the relative cost of the four different techniques and the ultimate scope for each can be gained by examining the tentative projections made by IACA. The unit cost of an acre-foot of water made available by each technique is roughly estimated by discounting to 1965 at 8 percent—

TABLE 3–1
FOUR TECHNIQUES OF WATER DEVELOPMENT

	Economic Costs	"Ultimate" Potential	
	(Rs./acre-foot)	Water	Land Supplies
Surface Storage (total reservoir volume)	63	26 MAF/yr.	—
Canal Remodeling (carrying capacity)	19	5 MAF/mo.	16 mln. acres
Private Tubewells / Public Tubewells (mean annual output)	16	44 MAF/yr.	19 mln. acres

both the costs and the water yield at watercourse head—the programs recommended for each of the four modes of development and discussed later in this report. The corresponding "ultimate" potential is taken from IACA's projections for the reference year 2000. The economic costs and ultimate potential of the four techniques are shown in Table 3–1. The surface storage cost is estimated on the basis of the full development program set out in Table 5–6 of Chapter V, using the total costs of the reservoir works and the amount of stored water which is estimated to be delivered directly to watercourses from storage over the years. Each of the figures in the table is discussed in greater detail later in the report, but they are presented here together for rough comparative purposes. There is one other aspect of water development which is very important in West Pakistan but cannot be presented in a cost context; this is drainage, which is related to all the modes of increasing water supply listed above and which will receive considerable attention later in this chapter.

CANAL REMODELING AND ENLARGEMENT

Gradual expansion of the modern canal system into new areas, the traditional form of development over the last century, is continuing into the present day in certain areas, such as from Thal, Gudu and Ghulam Mohammed Barrages on the Indus. However, more and more development in recent years has had to be designated nonperennial, since most of the rabi river supplies were already committed. Table 2–1 (Chapter II) showed that while total canal diversions have increased substantially over the last 20 years, rabi diversions have increased little—and scarcely at all over the last decade. Several consultants have recommended in favor of reducing rather than further increasing the area designated for canal irrigation supplies. More generally, there is much interest today in a more efficient utilization of the irrigation system.

Canal diversions have had to be rationed for a long time. The perennial/nonperennial distinction came about as a rationing device, and the distinction is still maintained even though flows are seldom adequate to maintain delivery of the quantities of water that were originally allocated. The main lines of this rationing procedure are laid out in a document known as the Sind-Punjab Draft Agreement which was prepared by the Chief Engineers of the Sind and the Punjab in 1945; it was never ratified, because agreement could not be reached on financial implications and then

Partition ensued. But it is still closely observed. Under this Draft Agreement, it is generally the areas of longest established irrigation that have first claim on available flows. First right to the flows on the Jhelum and the Chenab, for instance, goes to the three canals built under the Triple Canals Project of 1905 (Upper Chenab Canal, Lower Bari Doab Canal and Upper Jhelum Canal) and to the two major canals in the vicinity which were built before them (Lower Chenab and Lower Jhelum Canals). These, together known as the five linked canals, supply all the CCA in Chaj Doab, almost all the CCA of Rechna Doab and about a quarter of the CCA in Bari Doab. Monthly withdrawals by these five canals are generally within about 10 percent of mean levels. The remainder of the Bari Doab and all the area on the left bank of the Sutlej, forming essentially the Sutlej Valley Project area, depend primarily on the Sutlej but also receive supplementary supplies via the link canals. Nevertheless, the flows available for transfer down these links are often inadequate to make up the deficiency, and monthly withdrawals by the canals in the Sutlej Valley Project area often diverge by more than 30 percent from the mean levels. On the main stem of the Indus the picture is similar: first priority is shared by Thal Canal at Jinnah Barrage, farthest upstream, plus the canals at Sukkur Barrage and certain channels which used to receive supplies from old inundation systems; deliveries to the areas served by these canals are maintained at fairly consistent levels. The newer canals at Taunsa, Gudu and Ghulam Mohammed Barrages have lower priority and tend to bear the brunt of shortages on the Indus.

With such differences in priority claims on canal flows, one would expect the areas allocated perennial canal supply to show a substantially higher cropping intensity in rabi season than those with nonperennial supply; or, even if no differences were to be found in intensities, yields should be higher in areas benefiting from regular canal supplies in rabi. In general, however, IACA found rather little difference between the rabi intensities in the nonperennial and perennial areas in the Punjab or between equivalent areas in the Sind. Actually, of nine agricultural regions into which they divided the irrigated area for purposes of analysis, the area with the highest rabi intensity and the highest overall intensity is the nonperennial area on the right bank of the Indus commanded from Gudu and Sukkur; rabi crops are grown there largely on the basis of residual moisture remaining in the soil at the end of kharif (residual moisture is quite high because the main kharif crop is rice, which has high water requirements) or on the basis of one watering just before the canals are closed at the end of kharif. Rabi yields in this area are, it is true, quite low. But in the North there was not even a noticeable difference in yields. What IACA did find were some indications of higher intensities in the areas with priority in water allocations—such as the Chaj, Rechna and Upper Bari Doab areas and some of the areas commanded from Sukkur. For the Basin as a whole, however, the conclusion appears inescapable that the perennial/nonperennial distinction seems to bear extremely little relationship to the existing pattern of crop production.

A more meaningful generalization is that the rights to withdrawals from the rivers which have been built up over the years are in fact almost everywhere below actual water requirements. Even those areas with the highest priority for use of the available flow in the rivers suffer from an inadequate supply of canal water, at least in terms of the amount of water needed to support a modern agriculture (Table 2–7); in fact, the shortage appears to be particularly acute, for instance, in Chaj and Bari Doabs. The reason for this is that the rights of each area were established on the basis of the original design of the various canals, and most of the canals were designed to support a much lower cropped acreage than has in fact come to be cultivated. There appear to be various reasons why the canal systems were designed for cropping intensities so much lower than the land was capable of supporting. The British colonial administrators were concerned with settling large numbers of people and also with showing a good financial rate of return on their canal investments. Financial returns came mainly in the form of land revenue, and per-acre tax on land was higher for irrigated areas, plus proceeds of sales of Crown Land. Thus, to settle more people and raise more revenues, there was advantage in designing for low cropping intensity or, in other words, for spreading the water thinly over the Basin. But there was another factor that also played some part in their considerations: realization that design for a higher intensity and subsequent heavier deliveries of canal water to a limited area would lead more quickly to waterlogging. Typical design cropping intensities were in the neighborhood of 80 percent, whereas actual cropping intensities in many of the older-established areas of canal irrigation are around 100 percent. With adequate waterings and applications of fertilizer, it is believed that most of the canal-irrigated area could support an intensity of 150 percent and in some areas more.

It would be possible to expand the canals in the best agricultural areas to give them sufficient delivery capacity to provide water for the much higher cropping intensities that these lands are capable of supporting. But this would be no solution, primarily for two reasons already discussed in other contexts. The present withdrawal capacity of the canal system is about 13.3 MAF/month and this equals or exceeds the combined natural mean flow of the Indus, Kabul, Jhelum and Chenab in all months except June, July and August. In those months flows are substantially larger—often more than double—and there are a few weeks in May and in September when river flows are also sometimes in excess of canal diversion capacity. But three to four months in the summer are barely sufficient to mature most summer crops. Thus, the first deterrent to canal remodeling is that most of the river flows except in a very few months of the year are already committed. In the second place, the water table has risen to high levels in extensive areas, especially in some of the older irrigated areas; it is doubtful whether these areas could cope with additional large supplies of surface water unless extensive drainage works were also provided.

The nature of these two problems suggests that the real scope for improving water supplies by canal remodeling occurs in close coordination with tubewell development. Tubewells can provide drainage and, in the extensive areas where the groundwater is usable for irrigation, tubewells

TABLE 3-2
COMPUTED EVAPORATION AND EFFECTIVE RAINFALL
(in inches—rainfall in parentheses)

	North	South
Winter (October to March)	18 (3.6)	27 (0.8)
Summer (April to September)	41 (15.6)	49 (2.6)
Annual Total	59 (19.2)	76 (3.4)

can provide irrigation water in the months when river flows are already fully committed, thus making additional canal deliveries in other months far more useful than they could otherwise be. Fortunately, as a result of circumstances, there are extensive areas of fresh groundwater in West Pakistan which already have sufficient canal capacity to realize very large increases in irrigation supply from the installation of tubewells.

The original design of the existing canals becomes very important in this context. The canals which exist today have greater delivery capacity per farm acre in nonperennial than in perennial areas. To understand why this is so, it is necessary to digress to some extent on agricultural requirements in the Basin. When the canals were originally designed, detailed crop-water requirements were not estimated in quite the precise way that is used today, but the requirements of the main crops like rice and cotton in kharif and wheat in rabi were carefully established. Temperature is the main determinant of evaporation and thus of the difference in water requirements of a plant between regions. Average temperatures in the Indus Plains range from about 40 degrees Fahrenheit during December and January to over 100 degrees in June and July. They are generally higher in the Sind, particularly in the Upper Sind which does not benefit from the sea breezes which extend north of Hyderabad (Jacobabad, for instance, northwest of Sukkur, has one of the highest average temperatures in the world, reaching a mean maximum of 114° Fahrenheit in June). Rainfall is of importance in some areas, but it is largely confined to the summer. The southeast monsoon drops in the Punjab what remains after its long journey across the Indo-Gangetic Plain in India and the southwest monsoon delivers to the Sind a small rainfall from the Arabian Sea. And when the rain does come, it is often so light that it evaporates before reaching the crop roots or so torrential that it runs off the fields. A broad indication of variations in evaporation and rainfall is given in Table 3-2. Evaporation net of effective rainfall is, in each season, almost twice as high in the Sind as in the Punjab and Peshawar and in all parts of the Province it is nearly twice as high in summer as in winter. While these are broad averages, they indicate why the amount of canal water needed to grow an acre of crops is significantly larger in the Sind than in the Punjab and why it is also much larger in kharif than in rabi.

In the design of the canals, the variations in requirements for canal water had to be taken into account. Another significant factor was that the canals of West Pakistan, running on a principle of hydraulic equilibrium, were best operated either close to full or not at all. Taking account of both these considerations, the perennial irrigation projects were generally designed for a rabi cropped acreage between 1.5 and two times as great as the kharif cropped acreage; thus with an annual 80 percent cropping intensity, the design kharif intensity would be between about 27 and 32 percent. The nonperennial areas, by way of compensation for their right to canal supplies being limited to one season of the year, were generally given canal capacities sufficient to support a somewhat higher kharif intensity, typically in the order of 30–40 percent. Thus the canals are generally larger in the nonperennial areas than in the perennial areas.

Moreover, in recent development—and almost all the nonperennial development has taken place since 1920—nonperennial canal supplies have generally been allocated to areas where the groundwater was sweet, while perennial supplies have been allocated to areas with poor quality groundwater. It was considered that in areas of fairly shallow, fresh groundwater, Persian wheels and other wells could be used for both drinking water and for rabi irrigation, as previously practiced in the inundation canal commands. The designation of perennial or nonperennial areas on the basis of groundwater was especially important in the design of development in the Sutlej Valley, which constitutes a large proportion of the total nonperennial area in the Basin.

Thus, over large areas of nonperennial supply, circumstances have combined larger canals with highly favorable aquifer conditions. Tubewells are uniquely suited to take advantage of this situation. Because most of the recharge to the aquifer currently comes from canal seepage, areas of nonperennial supply also tend to have higher recharge in kharif per acre of crop land. By concentrating pumping in the months when existing canal capacities are the constraint (e.g. the overlap months between kharif and rabi) and in the rabi season when surface supplies are scarce, it is possible to produce enough water from surface and groundwater resources together in each month of the year to permit a significant increase of cropping intensity. IACA estimated, for instance, that sufficient water could be provided to meet full irrigation requirements at average cropping intensities of about 135 percent in Rechna and in Bari Doabs; very large proportions of these areas are underlain by fresh groundwater. Altogether, the areas where the aquifer could be developed sufficiently to permit a high intensity—close to 150 percent—without any canal remodeling are estimated to cover about 13 million acres, almost entirely in the Punjab. These high intensities would be obtained partly with the aid of additional surface supplies in the winter to provide sufficient recharge within existing canal capacities.

Canal remodeling is essential to gain the same benefits in areas not underlain by fresh groundwater. In these zones, the groundwater is either too saline to be used for irrigation purposes, or it must be mixed continuously with fresh water before being applied to the crops. As pointed out, these areas also tend to have rather less existing canal capacity per acre of canal-commanded area. This combination of characteristics obviously makes them less attractive for development than the fresh groundwater areas discussed, but they are extensive (some 15 million acres) and could support much higher agricultural production if additional water were made available. They will be discussed more in connection with public tubewells later in this chapter.

The large program of canal remodeling foreseen in Table 3–1—16 million acres before the end of the century—covers virtually all the zones without fresh groundwater in the 29-million acre CCA adopted for planning purposes; it covers very few of the fresh groundwater areas. The unit cost of Rs. 19/a.f. derived for water made available at watercourse head by means of canal remodeling refers to the estimated cost of this program. The cost figure may not be very reliable because, despite the enormous experience that Pakistan has had in the extension of complete canal commands, there has been very little experience in enlargement or large-scale remodeling of existing canals. Canal remodeling will in fact be a most complex and difficult process, particularly in regard to acquisition of additional land in areas which, being near to canals, are often densely cultivated (though sometimes also waterlogged and useless), and in regard to maintenance of essential water supplies to farmers during the time that the work is in progress. IACA thought that it would generally be easiest and most economical to build an entirely new canal alongside of, and eventually linked with, the existing canal whenever any extensive degree of canal enlargement was required. Preparation and design of any work in large-scale canal remodeling could not be done quickly.

Canal remodeling could also be carried out in areas underlain by fresh groundwater, but with a special purpose in mind. Rather than increase irrigation supplies within these areas themselves, the primary purpose would be to release surface water supplies they had been receiving in rabi for use elsewhere. Enlarged canals would enable more surface water to be brought in during kharif or when river flows happened to be high; the recharge to the groundwater reservoir would thereby be increased and all water requirements in the remainder of the year could be supplied from pumping. These areas would thus be rendered completely independent of rabi river flows. Canal remodeling of this sort, enabling underground interseasonal storage, could be an alternative to some extent to surface storage. It would be a moderately expensive alternative, involving not only canal enlargement but also pumping for each additional acre-foot produced to replace surface water deliveries from storage.

Surface Storage

Total river flows in West Pakistan, including those in the Ravi and Sutlej, have averaged somewhat more than 130 MAF in the five months May–September, of which some 50 MAF have been diverted into canals in recent years. Deduction of the Ravi and Sutlej (the Beas runs into the Sutlej) will leave a mean-year flow in these months of about 110 MAF. Mangla Dam will absorb about 5 MAF of kharif flows. Thus about 55 MAF, or half the available flow rivers in a mean year, still remains unused.

Most of this unused water will be in the Indus River itself, which in a mean year has a flow of 93 MAF (at Attock). In terms of the three

VOLUME I
FIGURE 2

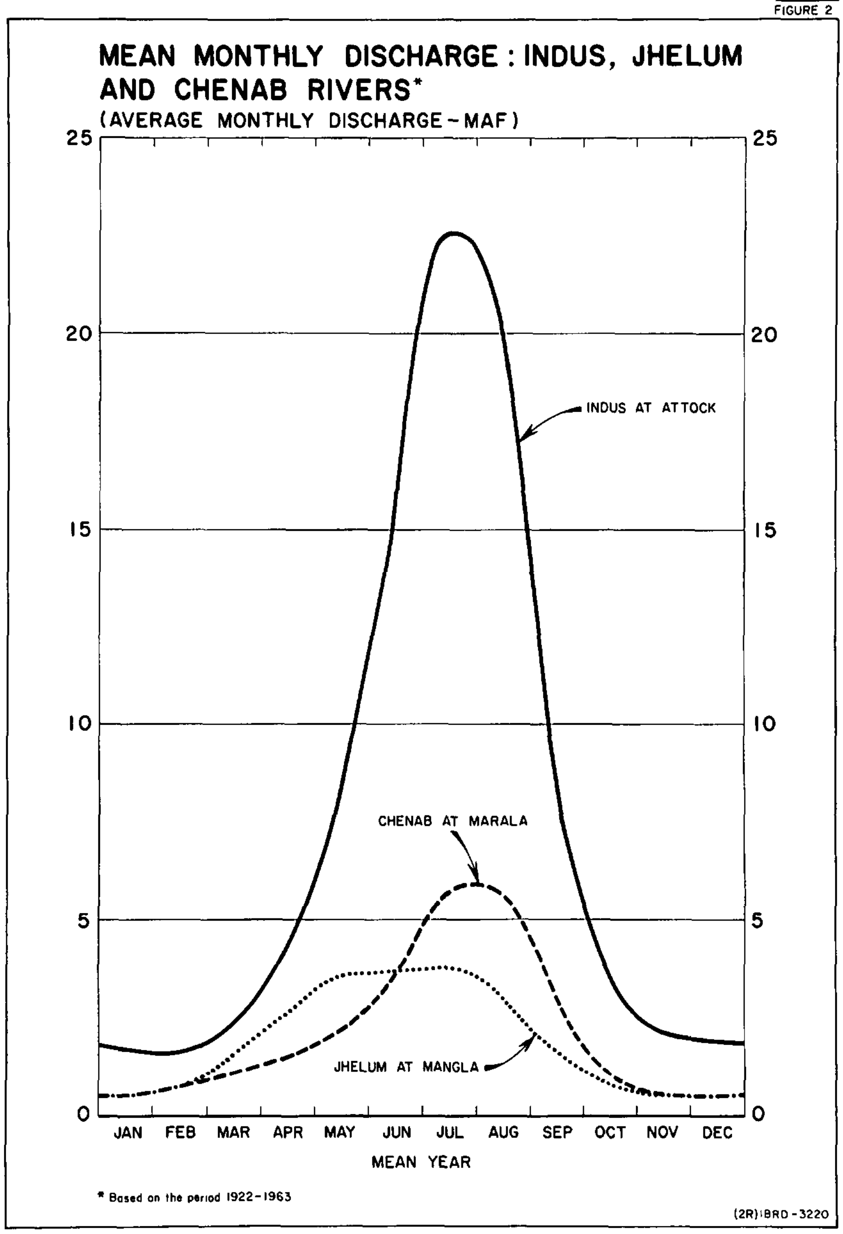

TABLE 3–3
AVERAGE ANNUAL DISCHARGE OF THE INDUS, JHELUM, AND CHENAB RIVERS (1922–63)
(MAF)

River	Location	Discharge		
		Mean	Minimum	Maximum
Indus	Attock	93	72	110
Jhelum	Mangla	23	15	33
Chenab	Marala	26		
		142		

western rivers allocated to Pakistan under the Indus Waters Treaty, the Indus (at Attock) itself represents about 65 percent of the total mean annual flow and 70 percent of the June-to-September mean flow. The Indus is more highly peaked than the other two rivers: about 67 MAF, or 72 percent of the mean flow on the Indus, occurs in the four months June to September. Flows in the Indus also vary proportionately much less from year to year than do those in the Jhelum and Chenab. The historical range is from 75 to 120 percent below and above the mean. Hydrographs of the three rivers are illustrated in Figure 2; average annual discharges are given in Table 3–3. The greater regularity of Indus flows from year to year shows up especially in the rabi season: on the Jhelum, for instance, maximum flows are as much as five times the minimum recorded in the same month (Table 2–8), whereas the range on the Indus is generally on the order of 3:1 or 2:1 in rabi months. The greater reliability of the Indus is attributed mainly to its higher dependence on snowmelt from the Himalayas. The importance of snowmelt from the mountain peaks also accounts for the fact that the Indus typically begins to rise toward the end of February, about a month later than the Jhelum. Peak flows on the Jhelum tend to occur in July, peak flows on the Indus in August.

The massive extent of the kharif surplus on the Indus and the relative reliability of this surplus argued that the next site for storage development, following Mangla, should be on the Indus. However, the case in favor was not prima facie. The river presents no sites that, with present techniques of dam construction, would be both cheap to develop and capable of providing large storage capacity. A brief tour of the Indus will show why this is so. The Indus is 2,000 miles long, rising in Tibet and traversing some 500 miles of Tibet and disputed territories in Kashmir before entering West Pakistan. Some 100 miles after crossing into Pakistan territory it enters the steep and narrow 300-mile-long Indus Gorge. After being joined by the Kabul River it enters the Lower Indus Gorge which cuts through the soft sedimentary rocks of the Attock hills and the Salt Range between Attock and Kalabagh. At Kalabagh the river breaks out on to the vast, flat plains of the Punjab and the Sind; for the remaining 700 miles to the sea, the river is very broad and runs in many shallow channels dug and redug in the silt. The available sites are discussed in Chapter V, and each has its own disadvantages. The most promising sites were considered over a

TABLE 3–4
PRINCIPAL FEATURES—MANGLA AND TARBELA PROJECTS

		Mangla	Tarbela
Maximum Initial Live Storage	(MAF)	5.3	9.3
Length of Reservoir	(miles)	40	48
Site Excavation	(mln. cu. yds.)	55	95
Earth and Rockfill	(mln. cu. yds.)	122	178
Main Dam			
Earth and Rockfill	(mln. cu. yds.)	78	159
Maximum Height	(feet)	380	485
Crest Length	(feet)	11,000	9,000

number of years; finally, a 20-mile stretch of river around Tarbela was selected for thorough investigation. (See discussion in Chapter 5, p. 53.)

The specific Tarbela site was selected for detailed studies and design work in 1961 (see Annex I for engineering details). The dam which has been designed would provide a reservoir with some 11 MAF gross storage capacity and up to 9.3 MAF live storage capacity. The cost of water from Tarbela Reservoir delivered at the watercourse would be about Rs. 93 per acre-foot, which means that it is expensive compared to the other ways of making water available.

The high cost of surface storage is not unique to the Indus, however; Mangla water is also relatively expensive. For West Pakistan as a whole, a number of factors account for the costly nature of surface water storage. The sites with potential for large storage happen to be in broad valleys—on the Indus or a tributary—meaning that dams have to be unusually large relative to the storage capacity created, and foundation conditions also pose considerable difficulties. The nature of the structure costs is illustrated in a general way by the principal features of the Mangla and Tarbela projects. Both dams will be earth and rockfill structures, each consisting of a main dam, two auxiliary dams and two spillways. Table 3–4 presents some of the main statistics regarding the two projects. Another major component of Tarbela is an impervious earth blanket—continuous with the impervious core of the dam—extending upstream for about a mile along the river bottom.

Apart from the general scale of works required in each case, a large amount of spillway capacity is another major factor accounting for the high costs of surface water storage. For somewhat different reasons on each project, the spillways represent a very significant item of total cost: for Mangla, about 20 percent of the main civil engineering contract (or $90 million) and for Tarbela only a slightly lower proportion (about $95 million). Spillway capacity is related to flood protection. Table 3–5 gives some details for the two projects.

The design flood and recorded peak are higher on the Jhelum at Mangla than at Tarbela. As pointed out, the Jhelum River is considerably more variable, unpredictable and dependent on monsoon rain than the Indus. The high design flood at Mangla results from the possibility of simultaneous occurrence of heavy monsoon storms in the various upstream catchment

TABLE 3-5
FLOODS AND SPILLWAY CAPACITY, MANGLA AND TARBELA

	Mangla, Jhelum	Tarbela, Indus
Maximum Flood of Record (cfs)	1,100,000	875,000[a]
Date	August, 1929	August, 1929
Design Flood (cfs)	2,600,000	2,127,000
Spillway Capacity,[b] total (cfs)	1,130,000	1,410,000
Main Spillway (cfs)	900,000	615,000
Auxiliary Spillway (cfs)	230,000	795,000
Reservoir Full Supply Level (feet SPD)	1202	1550
Height of Main Dam (feet SPD)	1234	1565

[a] Indus at Attock, after confluence with Kabul; it will have been somewhat less at Tarbela.
[b] Discharge capacity at normal full supply level.

areas. Despite this, however, Mangla has a lower spillway capacity than Tarbela. This is because high floods, which should be relatively rare, will be handled partly by the spillways but to an important extent by superstorage in the reservoir; between full supply level of 1202 feet and elevation 1228, there is about two MAF superstorage capacity at Mangla.

The design flood at Tarbela is considerably lower than Mangla despite additional components. While the main component of the design flood is again the maximum probable monsoon storm, substantial allowances also had to be made for late snowmelt runoff from the Himalayas and for the possibility of a natural dam break upstream. Natural dams have formed fairly frequently in the past on the Upper Indus and its tributaries, due to glacial movement or avalanches; the flood of August 1929 on the Indus occurred in connection with the breaking of a natural dam on the Shyok River. However, because of the high concentration of Indus flows in a few summer months and the relative regularity of the river, the floods of an average year will approach much more closely the design flood. The spillways will be the main means of dealing with floods, rather than superstorage—capacity for which is much more limited at Tarbela—and it is estimated that even in the initial years of the project's life the spillways will carry some 40 percent of the river's annual discharge in the two or three flood months of the summer.

The other noteworthy factor accounting for the high cost of stored water, particularly on the Indus, is siltation. The build-up of silt deposits in a reservoir means rather rapid depletion of live storage capacity. The average annual sediment load of the Indus at Tarbela is estimated at 440 million short tons and almost all of it is borne by the summer flood flows. The sediment load can reach 10 million tons a day. Little is known for sure about its origin, but two causes appear to be (a) current glacial action and avalanches in the upper reaches of the river and its tributaries, and (b) landslides and river scouring in the vast piles of debris built up in the lower parts of the Upper Indus by past glacial movement and silt deposition. The Jhelum also has a sizable sediment load, although much smaller (about 70 million short tons per year) than the Indus. Another difference is that human activities appear to be a more significant cause of the sediment load on the Jhelum: it has been estimated that about 30 percent of it could be eliminated by conservation measures and erosion control. Sediment on the Indus, apparently being much more the result of geological forces, may be harder to reduce.

One method of siltation control has long been practiced in West Pakistan. Sedimentation proved itself a serious difficulty on the early barrages and canals. The canal intake of the first major modern canal, the Upper Bari Doab, became seriously silted up soon after a permanent weir was built at its head—this was in 1870. A solution was found in a design idea that is still valid, based on sluicing the river bed during high flood flows. A divide groyne was built out in an upstream direction from the weir, thereby creating a pond of relatively calm water in front of the canal intake. High flood flows, allowed to pass the weir, would carry away silt deposited in the pond. To this day, sluicing in this manner has kept the barrages of the irrigation system reasonably free of silt. A barrage, of course, has virtually no storage capacity and flood waters have to be passed through. A storage work, however, has to capture flood flows and hold them for later release. The deleterious effect of siltation on a reservoir has already been proved, in the case of the Warsak Dam on the Kabul River, completed in 1960. While built mainly for run-of-river power generation, the dam has a storage capacity which helps to make the power plant more flexible; unfortunately, the initial live storage of 23,000 acre-feet has already been greatly reduced and is expected soon to reach a residual minimum of about 10,000 acre-feet. A sluicing solution was not practical at Warsak, but would it not work on the Indus—building a dam with sluice gates, similar to a barrage, and sluicing with the early flood flows and storing on the receding flood? There are severe disadvantages to such a procedure, in particular the fact that power capability is eliminated at the time of sluicing. And it is also extremely difficult to find sites on the Indus which meet all requirements: accessibility, the necessary topography for forming a reservoir, and a rock foundation hard enough to carry the stresses which would go with such a sluicing structure.

In view of these difficulties, planning has been carried out on the assumption that about 440 million tons will be deposited in Tarbela Reservoir each year. This figure is equivalent to about a quarter of a million acre-feet compacted volume, and, allowing for a portion of this to be deposited in the live storage area, it is projected that Tarbela Reservoir will be fully silted up, except for a residual one MAF of live storage volume, in about 50 years. Mangla Reservoir, at a siltation rate of 70 million tons per year, should only lose about 30 percent of its initial capacity over the same period. In addition, the heavy silt loads will cause abrasion problems of uncertain severity on the spillways, tunnels and turbine blades, making for added maintenance. These factors add to the cost of stored water. But for the Indus, they also mean that the cost of stored water will, other things being equal, be somewhat less when a second dam is added either downstream of Tarbela and protected by Tarbela, at least for a number of years, or upstream of Tarbela and therefore protecting Tarbela. This is one reason why the cost per acre-foot of stored water delivered at the water-

TABLE 3-6
DEPTH TO GROUNDWATER IN CANAL-COMMANDED AREAS
(million acres)

	Usable Groundwater (0-3,000 ppm)		Saline Groundwater (above 3,000 ppm)	
	Less than 10 feet	More than 10 feet	Less than 10 feet	More than 10 feet
Punjab	6.1	8.6	1.2	2.6
Sind	1.1	1.2	3.9	2.9
Total (excl. Peshawar)	7.2	9.8	5.1	5.5

course is substantially less when a long-term program is considered as a whole than when Tarbela is considered on its own.

Compensating somewhat for its high cost, stored water should prove relatively easy to use effectively. First of all, there is a clearly indicated demand for additional stored water in rabi. To its advantage, stored water represents an addition to a customary source of water—from canals—of assured quality at a time of year when shortages are currently felt acutely. It has great flexibility in use, in that it can be diverted via the distribution system wherever it is required. Mangla water, as pointed out, can be carried to practically any part of the Punjab, and Tarbela water can be supplied to the western and southern Punjab and all the Sind; by substitution, the effects of Tarbela may be felt in the northern Punjab, since it could replace downstream deliveries from Mangla and leave more of Mangla's water available for use upstream. The flexible use of stored water is seen to good advantage in connection with the tubewell program. Under changing hydrological conditions, it can be taken to those areas where the need is greatest. For instance, in areas where groundwater requires continuous mixing or is too saline to be used for agricultural purposes, a steady supply of fresh surface water will be required; the contribution from Tarbela will be especially important in this regard. Adding to the flexibility, areas of fresh groundwater that absorb additional surface water in rabi (to postpone the need for canal remodeling) may be able to pump more water in poor hydrological years to ensure a continued supply to the areas with groundwater of lesser quality. The possibility of readily transferring surface water among different areas is particularly important under such conditions.

However, there is one important limitation, under present circumstances, to the flexibility of stored water. The simple addition of stored water to rabi surface supplies, unaccompanied by other measures, could exacerbate the problem of waterlogging and high groundwater table—and the related problem of salinization of the top soil. It would be extremely difficult to quantify the extent of this hazard, or to specify which areas have both adequate canal capacity and a sufficiently low groundwater table to receive additional surface supplies. The waterlogging problem is highly localized, affecting small parts of one canal command and large parts of another. Table 3-6 gives a broad impression of canal-irrigated areas having a groundwater table more than 10 feet below the surface. Nowhere near the total of about 15 million acres, however, could safely receive additional surface supplies on a sustained basis without measures to improve drainage: some of these areas are already receiving rabi canal supplies up to canal capacity; a 10-foot water table is already on the high side, considering the effects of summer floods; and in general the water table, though apparently stabilizing in the areas with highest existing level, is still rising in areas where the present levels are deeper.

In almost all areas, before substantial additional quantities of surface water can safely be applied, improved subsurface or surface drainage is needed. The necessary drainage can be performed by tubewells, surface drainage channels or underground tile drains. There is very little experience in Pakistan with building either of the latter two types of drains. For all areas with usable groundwater, tubewells have the great advantage that they can provide additional irrigation water and at the same time fulfill their drainage function (and they can be run in a fashion which integrates their irrigation supplies with surface water supplies). For areas underlain by saline groundwater, where conditions vary considerably, each of the drainage techniques may have a place. Tubewell drainage of saline water has the advantage that it can be easily controlled; as increased irrigation diversions displace river flows over several months of the year, this control feature could make tubewell drainage especially important in areas where the river constitutes the only outlet into which drainage water can be discharged. For extensive areas in the Sind where the aquifer is unsuitable for tubewell pumping, horizontal drains may be the best solution. These drains are estimated to cost about the same as tubewells per acre drained. For saline areas where a crop that benefits from a fairly high groundwater table is grown, such as rice, open surface drains may be most appropriate; these drains would be compatible with a high groundwater table and would leave the more saline, deeper groundwater underground. Whatever the technique used, extensive drainage work is an essential accompaniment of surface storage (as it is of canal enlargement). Better drainage will enable additional areas to benefit from increased rabi supplies; and where the drainage is performed by tubewells in certain usable groundwater areas, it will also increase the proportions of stored water that can be beneficially used.

The discussion so far has concentrated on stored water as a high cost input. There are compensating advantages, such as flexibility. The usefulness of stored water would be enhanced by the better regulation of water supplies over time. Storage capacity has been discussed as a means of converting excess floods in the kharif season into useful irrigation supplies in rabi. But it was pointed out earlier that irrigated agriculture depends not only on adequate water supplies over the course of a season but adequate supplies in each month—and particularly in some months. Even within a season, and especially in the rabi season, the presence of storage capacity on the system can help to bring natural river flows more into line with the time pattern of crop-water requirements. This potential benefit depends on the coordination of reservoir releases with natural inflows and downstream crop-water requirements. For the rabi season, it is known as the intrarabi regulation benefit.

But there are also factors of varying importance which were not included in the cost figure cited earlier for Tarbela water, Rs. 93 per acre-foot delivered to the watercourse head. One adjustment is related to the treatment of seepage losses. A very large proportion of the stored water released from Tarbela—some 40–45 percent—will be lost to seepage from the river and the canals, and to evaporation. These losses are included in the Rs. 93 figure; in fact, that figure corresponds to Rs. 53 per acre-foot as released from Tarbela Reservoir. However, seepage loss constitutes additional recharge to the aquifer and thus a considerable part can be recovered at relatively low cost and applied to the crops. The use of this recovered water would directly lower the true cost of stored water.

A still more crucial element of exaggeration in the Rs. 93 cost figure for stored water is the omission of power usage of the water. Electric power supply has been met partly from various small new hydroelectric stations, but since the early 1950's, until Mangla was built, natural gas has been the major motive force (following its discovery in West Pakistan in sizable quantity). Of 3.7 billion kwh generated in 1965, some 50 percent was produced from natural gas, 40 percent from Warsak and the other small hydroelectric stations, and the remainder from petroleum fuels, mostly imported, and some indigenous coal.

A large increase in generation requirements is projected for the future. If these are to be met from indigenous energy reserves, the choice boils down to two possible sources of energy—natural gas and the hydroelectric potential. The known coal reserves are generally of rather low quality—more lignite than coal—and rather inaccessible; there is one coal field, in the south of the Province, which might become useful for large-scale production of electricity, but it could never meet more than a small portion of the total requirement. The natural gas reserves in the Province are considerably larger than the coal reserves and much easier to develop. However, natural gas is also a raw material for nitrogenous fertilizer, production of which is of high priority. In 1965, about 50 percent of the natural gas consumed in the Province was used for power generation and about 5 percent for nitrogenous fertilizer production. In recent years, fertilizer supplies have been imported in increasing quantities. However, a large new nitrogenous fertilizer plant was due to come into production in 1968; several other plants were at more or less advanced stages of planning. Production of fertilizer from gas could grow to very significant proportions in coming years. Use of gas for power generation thus competes directly with conservation of the gas for production of fertilizer and other purposes for which gas is more suitable than alternative fuels available. As the major alternative source of power, the hydroelectric potential is larger than any other known energy resource in West Pakistan but it is also expensive to develop with present technology. It is primarily concentrated in the 300-mile-long main Indus Gorge. Including other minor sites on the Indus tributaries, full hydroelectric development might ultimately be some 35 million kw, capable of producing annually the energy equivalent of about a fifth of the total known gas reserves in the Province. Perhaps some 15 percent of this ultimate hydroelectric potential will be developed before the end of the century; Tarbela, with 12 generating units installed, would represent about 6 percent of that ultimate potential. (See Supplemental Paper No. 5, Volume Three.)

The hydroelectric facet of surface storage can thus make a major contribution to meeting the power load imposed by the tubewells, at the same time conserving much of the natural gas reserves for manufacturing fertilizer to make up the nitrogen deficiency of the soil and to permit the reduction of fallow with its unfortunate tendency to promote salt-efflorescence. Tarbela's power benefits may be about one-quarter of total benefits; these power benefits may be even higher if adequate allowance is made for the saving in natural gas that the hydroelectric plant would make possible. Attribution of three-quarters of the cost of Tarbela Dam to its irrigation function would mean that the average cost of stored water delivered to the watercourse would be about Rs. 70 per acre-foot rather than Rs. 93. Some adjustment can also be made for the addition to useful recharge made by conveyance losses on water released from storage at Tarbela. Adjustments to the above figure, allowing for the time pattern of such recharge (small initially because only a few of the areas affected may have tubewell fields and tailing off in the last years of the century as Tarbela's live storage declines) and for the costs of pumping such recharge, suggest that this would reduce the average cost of stored water from Tarbela delivered at watercourse head either directly by canals or indirectly by pumping from the aquifer to about Rs. 61 per acre-foot.

Private Tubewells

So far, private tubewell development has been largely confined to the Punjab, in areas underlain by fresh groundwater. Of the private tubewells in existence in 1965, about 30,000 were estimated to be in the canal-irrigated areas. Since these tubewells are providing water supplementary to canal supplies, they are estimated to serve relatively large acreages—on average about 100 acres each. This would mean supplementary irrigation supplies to about three million acres.

In recent years, private tubewells have been the most rapidly expanding source of increased irrigation supplies, increasing from about one MAF in 1960 to more than five MAF in 1965. The wells are inexpensive in terms of capital cost—about Rs. 7,000–9,000 ($1,500–$1,900) each. But operating costs are quite high. The wells are not very efficient, often being poorly designed for the aquifer conditions in which they are set. As a result, the effective economic cost per acre-foot of water comes out about the same as an acre-foot pumped by a more expensive and more efficient public well. Private wells, however, have the great advantage that they lay only a small burden on public finances—except for electrification for electric wells and the foreign exchange burden of diesel fuel for diesel wells. However, diesel wells make a substantial contribution to Government tax revenues.

As was pointed out in Chapter II, the reasons are not clearly known why private tubewells have grown very rapidly in some areas, such as Bari and Rechna Doabs, and relatively little in other areas that appear to have equally suitable aquifer conditions. As a result, it is very difficult to predict the likely future growth of private tubewells. But clearly there still remain large fresh groundwater areas open to private development. There are about 14 million acres within the canal-irrigated area underlain by fresh groundwater, 12 million of them in the Punjab. All these areas are believed to have aquifers with good permeability characteristics. So far some three million acres have been covered by private tubewells and another three million acres of fresh groundwater area have been, or will soon be, covered by the public SCARP tubewells. In projecting future development, one might suppose that private tubewells would continue to grow most rapidly in those areas where they are already widespread and well-known; equally it could be argued that these are the very areas where the farmers who have the interest and the money have already installed wells, so that development will tend to slow down there and pick up elsewhere. While the evidence is inconclusive, in some areas it appears that, while most of the larger and wealthier farmers have already installed wells, the growth of wells is being sustained in those areas by smaller farmers, sometimes clubbing together and building a well for joint use.

From the viewpoint of the total irrigation system, private tubewells appear to offer a rapid, but rather uneven and unpredictable, means of overcoming the constraints set by limited canal capacities and limited river flows. They are used intensively in certain months when crop-water needs are high relative to canal supply. It is probable that they are also used more intensively in years when river flows and canal deliveries are low. And in general it is noticeable how carefully the farmers use the water from private tubewells. In terms of water use, the tubewells are automatically integrated with the rest of the irrigation system. But this "integration" has limited application to the efficient use of water resources in a more general sense and for the purposes of planning. In some areas, wells are located sufficiently close together that they may have started to lower the water table and thus carry out some of the drainage needed before additional surface supplies can be brought in. However, the capability of the private tubewells to control the water table over large areas is clearly limited by their being located haphazardly and operated according to the needs of the individual farmers. Another difficulty is that some farmers will continue without private tubewells in areas which could be self-sufficient, at least for short periods. Since canal water is provided at a price so much below the cost of water pumped by private tubewells, it will be hard if not impossible to cut off surface water supplies to an area where the aquifer has been privately developed even though other areas may have much greater need for the surface water temporarily. It is also doubtful whether private wells will be established in areas that require extensive reclamation. Finally, private tubewells are not very suitable for areas where close control is needed to ensure that groundwater is mixed with fresh surface water in the right proportions before application to the crops.

These technical problems, which are important in quite large areas, circumscribe the ultimate development contribution of private tubewells. Nevertheless, there are very large areas where they are more or less absent and where private groundwater development could probably continue to make a large and early contribution to increased irrigation water supply.

Public Tubewells

Although it has been discussed for more than a decade, public tubewell development is still largely confined to a relatively small area—about 1.5 million acres—in the northern Punjab. A number of other SCARP projects, in Rechna, Chaj and Thal Doabs in the Punjab and at Khairpur in northern Sind, are under way. Though some of the wells were sunk in the late 1940's and early 1950's, the SCARP I project in Rechna Doab has been in operation as a unit only since 1961. The water table in the area has been lowered and a certain amount of land reclamation has been carried out.

The potential strengths of public tubewell development are its capability to provide large increases in irrigation supplies, its flexibility for handling technically difficult groundwater and aquifer conditions, and its ability to be more fully integrated than private wells into the overall operation of the irrigation system. Irrigation supplies could be substantially increased by public tubewell development in virtually all areas that have groundwater of usable quality. Areas with usable and unusable groundwater are defined in this report according to a system developed by IACA on the basis of information gathered on the quality of groundwater at 300 feet. Fresh groundwater was defined as water with less than 1,000 parts per million (ppm) Total Dissolved Solids (TDS) and IACA took the view that this could be applied directly to the crops provided it was made available in adequate quantity. Zones with groundwater of between 1,000 and 3,000 ppm TDS were defined as Mixing Zones, in which the groundwater would have to be mixed with fresh surface water before application to the land. Groundwater over 3,000 ppm TDS was considered unusable. These categories applied to the Punjab; somewhat stricter limits were selected for the Sind, partly because groundwater there may have a higher admixture of noxious chemicals such as sodium at any given level of TDS and partly because surface water tends to be somewhat more saline in the Sind than in the North (where it is generally in the order of 250 ppm), because it tends to gather salt on its passage through the Punjab. Mixing zones in the Sind were defined as those with groundwater between 1,000 ppm and 2,000 ppm TDS, and groundwater of more than 2,000 ppm TDS was categorized as unusable. Table 3–7 shows the extent of these areas by regions. The table shows that some 19 million acres are underlain by groundwater of usable quality. Nearly 17 million of these acres are in the Punjab and Peshawar.

For the groundwater areas as a whole, there are alternative approaches to the exploitation of the groundwater reservoir. Since the groundwater aquifer is very deep in most areas—estimated at over 1,000 feet—it would be possible to sink deep wells and to mine the groundwater reservoir so that the water table would gradually fall. The Revelle Panel recommended groundwater mining for a 30-year period, over which the groundwater table would be lowered to about 100 feet below the surface. The alterna-

TABLE 3-7
REGIONAL GROUNDWATER QUALITY ZONE AREAS
(million acres of development CCA)

Region	Fresh	Mixing	Saline	Total
Vale of Peshawar	0.58	0.10	—	0.68
Thal Doab and Indus Right Bank	2.03	0.99	0.60	3.62
Chaj Doab	1.19	0.36	0.49	2.04
Rechna Doab	3.37	0.84	0.49	4.70
Bari Doab	3.95	1.34	0.54	5.83
Sutlej and Panjnad Left Bank	1.29	0.47	1.75	3.51
Lower Indus	1.81	0.45	6.72	8.98
Total	14.22	4.55	10.59	29.36

tive would be to pump out only "balanced recharge"—the amount of groundwater that annually seeps into the aquifer from rivers, canals, watercourses and fields. IACA studied these alternatives and found that pumping to balanced recharge at a groundwater table of about 15 feet would cost about Rs. 16 per acre-foot—the same as private tubewell pumping; the higher initial capital cost of the large public well would be offset by higher utilization, better hydraulic efficiency, longer life and lower costs for electricity distribution lines. Groundwater mining would require the installation of deeper wells and also considerably more electric power for raising the water from a greater depth. On a comparable basis the cost of an acre-foot mined, with the groundwater table finally stabilized at 100 feet, would average Rs. 64. Mining to lesser depths would cost less, because of the smaller quantities of electricity involved. However, besides being relatively expensive, mining of groundwater in West Pakistan would raise some technical problems—in particular the danger of migration of saline water into the freshwater aquifer, once its level was substantially lower than that of neighboring saline aquifers.

Without prolonged mining, however, the groundwater reservoir could be used, under public development, as a flexible "buffer" in integration with surface water supplies, particularly in areas underlain by fresh groundwater. The public tubewell project would have a grid design which would give complete coverage of an area and bring the groundwater reservoir under full control. Initially, because most areas need drainage and a lowering of the groundwater table, the aquifer would be "mined" but only down to a depth of about 15 feet. Thereafter, pumping would be concentrated in periods when canal capacity or river flows were inadequate to meet irrigation requirements. This would make it possible to maximize the water supply assured to the farmers without necessitating canal remodeling; in most fresh groundwater areas, enough water could be produced to meet full crop-water requirements at cropping intensities of 150 percent. Many of the areas where integration would be feasible would be nonperennial. But in some perennial areas, such as part of the perennial portion of Upper Chenab Canal Command, SCARP IV, integration would be feasible and might make it possible to release existing rabi canal supplies; the rabi supplies would be replaced with water pumped from the groundwater aquifer, which in turn would be fully replenished from seepage from the rivers and from kharif surface water supplies. In the case of SCARP IV it would be possible to release about 0.75 MAF of current rabi canal supplies. Also, by stretching the balanced recharge concept the groundwater reservoir could be used as the buffer against hydrological uncertainty, eliminating the need for provision of expensive reserve capacity at the surface storage reservoirs. This would be done by pumping more than recharge in a low-flow year to ensure continued availability of full irrigation water supplies, making up the overdraft on the aquifer by pumping less than recharge in high-flow years.

Mixing zones would not be so flexible in regard to aquifer operation and their development to a high cropping intensity would be somewhat more complicated. But, since they generally represent portions of canal commands that are predominantly underlain by fresh groundwater, they would be gradually brought under development along with the fresh groundwater areas. This has been the case with SCARP I. IACA established technical criteria for mixing groundwater with surface water before application to the crops: groundwater of 1,000–2,000 ppm TDS would be mixed in a 1:1 ratio with fresh surface water, while groundwater of 2,000–3,000 ppm TDS would be mixed in a 1:2.5 ratio with surface water. Mixed water should be applied in quantities great enough to keep salts from collecting on the surface. Also, IACA estimated that about 5 percent of the mixed water might have a hazardous alkali content, which if allowed to remain in the topsoil would cause soil conditions to deteriorate, reduce soil permeability and adversely affect plant growth. Although further research is required on the alkalinity problem, the application of sufficient water should contribute to reducing its severity. The mixing of surface and groundwater would need to be continuous, i.e. a groundwater cannot be used unless surface supplies are available. This surface water would generally mean surface supplies in larger amounts than current canals in the areas would be able to carry. For as it may be recalled, these zones of saline water were originally generally designated perennial and given smaller canal capacity per unit of area than nonperennial areas. In addition to larger canal capacities, they would also require larger supplies of canal water than they have had in the past. Hence their development would be particularly dependent on the availability of additional rabi supplies from surface storage.

Zones underlain by groundwater above 3,000 ppm TDS (2,000 ppm in the Sind), because this water is not usable for irrigation, would be entirely dependent for additional irrigation supplies on surface water. Table 3–7 showed that these areas are not very large in the Punjab, except on the left bank of the Sutlej and Panjnad, but they are extremely important in the Sind. They would require drainage—tubewells or surface drainage channels—before they could absorb significant additional quantities of surface water. Drainage from the Sutlej/Panjnad Left Bank might be into the neighboring Thar Desert; in the Sind, drainage would require very large channels running through the canal commands on each side of the Indus and discharging into the lower reaches of the Indus or the sea. To provide additional quantities of surface water, canal remodeling would be required in virtually all these saline groundwater areas. Canal lining might also prove justified. At present almost none of the canals in West Pakistan is lined because one of the normal advantages of canal lining, namely that it gives a higher capacity for a canal by allowing increased velocity, is generally slight because of the extreme flatness of the land. The main benefit of canal lining in Pakistan would be reduced seepage; in most of the Province the cost of water saved in this way, according to calculations by IACA (on a comparable basis with Table 3–1) would be Rs. 110 per acre-foot. But in the saline zones the cost would be less—about Rs. 65 per acre-foot, because there canal lining would reduce not only seepage losses but also the related drainage pumping. Lining could in fact only be carried out after the groundwater table had been lowered, because otherwise it would not stick; and in general lining would be difficult to carry out except on new canals because otherwise it would involve complications due to interruption of canal supplies. Thus lining of canals would be complicated and relatively expensive but it might make a small contribution to additional supplies to the saline groundwater areas in later years. The main additional supplies of water to the saline zones will be from the river flows in kharif and from Tarbela, plus any rabi water released by public tubewell development in fresh groundwater areas.

From a purely technical standpoint, to sum up the discussion, substantial increases can be made in irrigation water supply in the fresh groundwater zones by means of public tubewells without running into bottlenecks due to lack of development in other facets of water development. Increase of water supply in the mixing zones and saline zones is a much more complex matter, depending on interdependent enlargement of canal capacity and increased supply of surface water in the rabi season, as well as provision of drainage. In contrast, the irrigation supplies in the fresh groundwater areas can be greatly expanded simply with the installation of public tubewells and the provision of electric power in sufficiently large quantities.

The implementation of a large public tubewell program will not be as simple as that, however. Executive and administrative capacities are limited for the still complex task of designing tubewell projects, carrying them through from initial land acquisition to final electrification, and operating them efficiently; funds for these purposes are also limited. These problems of implementation capacity (discussed in greater detail in Chapter VII) make it necessary to ration out the public effort very carefully, allocating it to areas where public development shows the greatest advantage over what could occur simply with continued private tubewell development—rather than allocating public effort to those areas which might show the greatest benefit to public development per se. A coordinated effort will make it possible to bring additional water supplies to much wider areas than would be possible if all development depended on the public effort alone. It also means that the public development effort may become active in areas involving greater difficulties and complexities, rather than being confined to areas where development can be had simply by putting in tubewells to pump fresh groundwater. Moreover, selections of areas with priority for public and for private groundwater development have to bear in mind projects in other fields of water development such as surface storage and drainage, with a view to the ultimate need for integrated operation of West Pakistan's water resources.

B. PROJECT IDENTIFICATION AND SELECTION

INTRODUCTION

The report so far has described past development in the use of water resources for irrigation and power generation in West Pakistan, the present inadequacies, and the chief alternative means of future development to meet the needs of the Pakistan economy. This section discusses the analyses that were undertaken in the course of drawing up the proposed programs for irrigation, agriculture and power. A coherent approach to water development, which requires selecting among alternatives, is reflected in the methodology of the Study.

As formulated by the Bank Study Group and agreed with the Government of Pakistan, the methodology was to stress the comprehensive nature of the development task. Analyses were to start on a Basinwide scale, within the framework of development planning in West Pakistan. The review of resources for power development would cover all aspects, from water power to gas, oil and coal energy, as well as the potentials of nuclear power. A comprehensive review would be made of the main factors governing agriculture, particularly irrigated crop production, including land, population, ground and surface waters and crop yields. Specific attention would be paid to identifying the development potential of the various regions of the Basin and the steps needed to realize that potential. Specific project proposals for water and power development, fully integrated into a comprehensive program, were to be the end product of the Study.

The exact course of the investigative effort, however, could not be predetermined. Originally, it was envisaged that selection of projects for irrigation development would be mainly a matter of reviewing the priority status and technical aspects of projects already formulated by the Pakistan authorities. In the course of the Study, it became apparent that—apart from Tarbela and the Sukh Beas Drainage Scheme—there were virtually no projects prepared and formulated for which financial commitments had not already been obtained or were being negotiated. This finding led to the conclusion that the scope of IACA's assignment had to be broadened to include, in addition to a review of so-called "ongoing projects," the identification and tentative formulation of new projects, deserving of incorporation in a regional development program. Thus, early in the Study, it was decided that IACA would have to assign about three-quarters of their strength to work on projects.

To maximize the use of the available manpower, the consultants were instructed to concentrate their initial efforts on subjects and areas which were important for planning purposes but which were not being investigated intensively by others. Therefore, the direction of their effort was influenced by work already underway. For example, work of considerable scope and magnitude was being done by the LIP consultants on the development of irrigation and agriculture in the Sind. The available data indicated that it would not be necessary for the Study Group consultants to undertake intensive field activities in this area. Consequently the proposals in this report for irrigation development in the Sind are largely based on a critical review by IACA and by the Bank Study Group of the program prepared by LIP.

Crucial importance was attached to a correct assessment of distinctions among areas and regions regarding the present state of agriculture and the potential for future growth of productivity. Therefore, several major efforts were undertaken to gather data about different regions in addition to information already available from Government sources or from other consultants. The main gap in existing knowledge concerned the current state of agriculture. LIP had begun to remedy this in the Sind with an intensive study of selected watercourses. For detailed study in the Punjab, IACA chose 20 watercourses, each of about 300 acres, on the basis of ground reconnaissance and aerial photographs of sample areas which had been made by the Government of Pakistan's mapping organization at the request of the Study Group. Field observers were established on each selected watercourse to record, on a daily basis, all agricultural activities over one full kharif season and two partial rabi seasons. The aerial photographs were also useful for comparison of land use patterns with those made a decade before, in 1953/54, under a Colombo Plan Survey; the comparison was made with special reference to land which had gone out of cultivation, land which had been reclaimed, new land which had been developed, and changes in cropping intensity.

The consultants organized questionnaire surveys of farm practices in three selected zones. A special study, using a similar survey technique, was made with a view to identifying changes which had resulted from the first of WAPDA's Salinity Control and Reclamation Projects (SCARP I). IACA undertook detailed soil surveys as part of the watercourse studies, primarily to give information on the relationships between yields and soil; permeability and infiltration rates were also covered. In addition, two somewhat less detailed soil surveys were carried out for a 240,000-acre area in the northern parts of Rechna and Chaj Doabs. Some direct experimentation was undertaken on the reclamation of saline and alkaline soils in these areas.

For the studies of dam sites and power projects, major field work was precluded by the timetable of the Study. However, aerial photography was undertaken of some areas on the Indus, including sites at Chasma and Kalabagh (for backwater studies), the confluences of the Soan and the Haro with the Indus (for studies of side-valley storage) and the Skardu area. Considerable attention was given to backwater studies for a dam at Kalabagh and to the approximate location, length and size of conveyance channels that would be required for side-valley storage on the Haro (Gariala) or on the Soan (Dhok Pathan). Rough preliminary designs were made for a number of sites, particularly Kalabagh. Independent studies of the engineering design of Tarbela were not made, but the progress of designs and the program for constructing the project were reviewed on a number of occasions with the designer, TAMS.

Identification of Irrigation Projects

With the basic data in hand, the first step towards formulation of a Basinwide program for irrigation development was analysis of alternative possible modes of development in different areas. For purposes of analysis, the 42 principal canal commands in the Basin were subdivided and rearranged somewhat for technical reasons, such as the partitioning of commands arising from the Indus Basin Works, proposals for the Sind made by the LIP consultants, and canal capacity considerations. The 61 units of analysis which were adopted became basic to the Basinwide planning as well as to project formulation. At various stages of the Study, each unit of analysis was further subdivided and treated separately for four groundwater salinity zones: fresh groundwater, two mixing zones of intermediate salinity, and a saline (unusable groundwater) zone.

Irrigation water requirements, determined by three factors—cropping pattern, crop water requirements and cropping intensity—were projected for each of the 61 areas. Cropping patterns (proportions of each area devoted to each crop in kharif season and rabi season) were projected on the basis of a number of factors, such as: present cropping patterns; the quality of climate and soils in each area; anticipated increases in crop yields; estimated future national requirements of food and fiber; the farmer's preference for growing certain crops when more water becomes available; and the possibilities of concentrating production of certain crops in areas with an absolute advantage in their production. Evidence suggested that increases in water supplies would tend first to be used mainly on cash crops. A general increase in fodder acreage was expected, to feed the livestock required to meet growing demand for milk and meat. With regard to wheat, a substantial increase in acreage was projected by 1975; after this date, the widespread acceptance of Mexican wheat varieties and fertilizer would probably increase yields sufficiently to permit a gradual reduction in wheat acreage, with a corresponding increase in land planted to cotton. The result of these various trends would be, in Basinwide terms, a slight reduction in the kharif-rabi ratio between 1965 and 1975 followed by a gradual increase through the year 2000 (cf Table 5–1). Monthly crop water requirements were estimated for each crop in the cropping pattern in each canal command.

IACA assessed water requirements in terms of the full amount that they believed to be needed, under conditions obtaining in the different areas, to support modern agricultural techniques, including the use of technical inputs like fertilizer. This is the concept of 'full delta' which represents rather more water for each acre of crop than the farmers are currently receiving. Full delta is defined as the summation of (a) the net consumptive use of water by crops after making allowance for effective rainfall, (b) an allowance for preplanting, (c) an allowance for soil moisture retention, and (d) an allowance for seepage loss which also provides for leaching of salts. In computing the full delta water requirements at watercourse head, the consultants totaled items *a*, *b* and *c*, and adjusted this sum upward by assuming that *d* involves a loss of 37 percent, including conveyance losses in the watercourses.

For most areas, the maximum cropping intensity that would be attainable, if all the water that was needed could be delivered, was assumed to be 150 percent. Theoretically, it would be possible to reach a cropping intensity of 200 percent, or full use of all the CCA in an area in both seasons. For a variety of reasons, this theoretical ceiling does not appear to be a feasible target for development. The physical difficulty of growing certain crops—such as cotton and wheat—in succession is one reason. But overlap in growing seasons is not the only obstacle. Shortages of animal power or labor may make it impossible for some farmers to complete the harvesting and marketing of one crop in time to prepare the land for a succeeding one. Some portion of the CCA, moreover, should be considered reserved for livestock and not available for cropping. On some farms or some watercourses, an intensity over 150 percent might be reached, but IACA concluded that the average intensity over areas as large as canal commands would not rise above this level, with one exception. The exception was in the Peshawar Vale, where the special combination of crops grown, in particular the importance of perennial crops, might permit an ultimate cropping intensity of about 175 percent. For a portion of the Ghulam Mohammed Barrage Command in the Sind considered not suitable for perennial cropping, it was assumed that the maximum attainable intensity would be 130 percent.

The time required to reach these target intensities will vary among different canal commands. The time element will depend partly on the availability of water. Among other factors, IACA attributed importance to the starting intensity in each area and the extent of soil salinity. The starting intensity indicates the change in agricultural practices which would have to take place, whereas the prevalence of soil salinity indicates the extent to which soil reclamation was needed. Estimated average lengths of time required to reach the prime target level from different starting levels and under various salinity conditions, once water supplies are increased, are given in Table 3–8. The figures are based on IACA studies.

The next step was to calculate the extent to which the irrigation supplies required at the maximum attainable intensity would be provided by the various techniques of water development (tubewells, surface storage, etc.). A computer simulation of canal command operation was employed for this purpose, using the calculated water requirements. The most important role of the simulation model was in the analysis of the potential for integrated use of groundwater and surface water; this required that certain feedback effects, such as that arising from the need to pump annual recharge, be taken into account. The information provided

TABLE 3-8
GROWTH OF CROPPING INTENSITIES, IN TERMS OF TIME REQUIRED TO REACH 150 PERCENT
(IACA's average projection)

Starting Intensity	Salinity Category[a] I	II	III
(percent)	---(years)---		
135	5	—[b]	—[b]
120	6	10	—[b]
110	7	10	—[b]
100	8	11	15
90	9	11	15
80	10	12	16
70	11	13	16
60	12	14	17

[a] Salinity categories are defined as follows:
I: 15 percent of CCA requires reclamation.
II: 30 percent of CCA requires reclamation.
III: 45 percent of CCA requires reclamation.
[b] No cropping intensity this high in the salinity category.

by this analysis was essential to the formulation and design of the public tubewell projects proposed. Formally, the simulation model maximized the intensity level in each of the 61 canal commands in the reference years 1975, 1985 and 2000, subject to the following constraints.

1. Cropping intensities cannot exceed the maximum figures adopted for this Study.
2. Required surface water deliveries cannot exceed the delivery capacity of the existing canal system.
3. Groundwater use cannot exceed the annual recharge to the area's aquifer.
4. Groundwater will be used to the extent of the usable part of annual recharge before additional surface water is used.
5. In mixing zones the mixing ratios of groundwater with surface water have to be observed.
6. In the fresh groundwater zones, the greater part of the pumping would be in rabi, to economize in the use of scarce surface water at the time and to overcome canal delivery constraints during seasonal overlaps in irrigation requirements.

It should be noticed that the fourth constraint—relating to use of annual recharge—is based on the premise, discussed earlier, that in each canal command the least costly source of increased irrigation supplies, namely groundwater, will be fully developed before the next source of increased supplies—canal remodeling and/or supplies from storage—is brought into play.

Beyond this basic analysis of potential public groundwater development, a number of additional variants were tested with the simulation model.

What would be the maximum full-delta cropping intensity attainable if the only irrigation supplies available were historic surface water deliveries (i.e. generally the average of those over the period 1952–63), or if such deliveries were supplemented by supplies from private tubewells? Suppose that surface water deliveries and their monthly pattern would be limited not to their historic levels but simply by existing canal capacities? Or suppose canal capacities were increased to the extent needed to enable the 150 percent cropping intensity to be reached without mining the groundwater aquifer, but with integrated use of surface water and groundwater?

The case involving private tubewell development, as an alternative to integrated operation with public wells, was crucial to the choice of areas for inclusion in the proposed public program. This was because of the need, discussed earlier, to allocate public tubewells to areas where they would show the greatest advantage over likely private development rather than the greatest absolute rate of return. The quantification of likely private development was therefore very important. At the same time, because large-scale development of private tubewells was of such recent origin, it was difficult for IACA to find a reliable basis for projection of future growth. The basis finally selected was derived from data on private tubewells estimated to exist in different areas in 1963, 1964 and 1965; these years were considered most relevant because, apparently, it was only after 1962 that diesel wells became widely accepted. The general trend of future private tubewell development was projected by relating the achieved levels of private tubewell development with changes in their density observed for these years. In deriving a projection for each area, from the general trend, two factors, the prevalence of large farms and of owner-occupied farms, were selected to serve as proxy indicators of more general determinants such as farmers' enterprise and financial resources. IACA expected private tubewell development to be most rapid in Bari and Rechna Doabs and slowest in the relatively backward areas of the Lower Indus and in Thal and Indus Right Bank. In all areas, however, the general pattern would be a slow initial development stimulated by the most enterprising farmers and supported by the Department of Agriculture, and then a more rapid development as farmers come to appreciate the profitability of private tubewells, leading to a declining rate of installation as the constraints of farm size, land tenure and finance become more operative. Table 3–9 shows some samples of their projections of private tubewell growth in the absence of public development. Ideally, due to the uncertainty of knowledge about possible private tubewell growth, a range

TABLE 3–9
SELECTED PROJECTIONS OF PRIVATE TUBEWELL GROWTH
(number of wells)

	1965	1970	1975	1985
Dipalpur above BS Link (Bari)	860	1840	2470	3115
Rohri North (Sind)	100	300	800	1600
Panjnad-Abbasia (Sutlej Left Bank)	615	1990	3230	4570

of private tubewell projections should have been used rather than one single projection per area; the complexity of the Study precluded this approach within the context of a Basinwide determination of project priorities. However, in individual project reports made by IACA, and in the Study Group's reviews, attention was given to the sensitivity of the project's priority to alternative projections of private tubewell growth.

The most important output of the canal command simulation is a series of hypothetical water development "projects". These "projects" are in the form of water budgets which reflect a particular mode of irrigation development and indicate the maximum cropping intensity attainable with this type of development. For instance, the water budget would show, depending on the type of development to which it related, the amount of public tubewell capacity required per acre of CCA, the quantity of scarce rabi surface water required, the extent to which canal capacity had to be increased to permit attainment of 150 percent cropping intensity, and the amount of horizontal drainage capacity needed in the more saline zones to preserve a stable water table with increased surface water deliveries. Each of these items has a corresponding cost estimate, so that the total cost of the hypothetical project can be estimated. The full-delta cropping intensity for each budget constitutes one dimension of project benefits.

To derive a full picture of the agricultural benefits attached to development proposals, it was necessary to examine the likely growth of crop yields. IACA considered that the key factors accounting for current low yields are unreliable and inadequate water supplies, waterlogging and salinity, limited use of fertilizers and pesticides, the inferior quality of seeds, and poor farming practices. Further, the consultants believed that increased irrigation supplies would not only have a direct effect on yields but would also act as a catalyst in the adoption of more productive nonwater inputs. Projections of average crop yields showed a threefold increase between 1965 and 2000. In projecting the transition from the present to the ultimately attainable yields, the consultants assumed that the farmers will first concentrate inputs and attention on cash crops and wheat. After reasonable levels have been reached for these crops, then the improvements would be extended to other crops, particularly fodder and maize. The basic yield projections for each canal command were derived from a regional average, allowing for local differences in climate, soils, standard of farming, etc.; the standard reference was to areas with full water supplies and adequate drainage; adjustments had to be made where water shortage was expected to continue or where there were serious problems of soil salinity and waterlogging. In waterlogged, saline areas, in the absence of water development and reclamation, yields were assumed to be some 45–55 percent below normal by 1975. For the case of water shortages, IACA assumed that over the short-term there would be advantage in extending the area cropped through under-irrigation as long as traditional crop varieties are cultivated and no fertilizer is applied. To allow for the additional production that would be associated with such area extension, IACA made separate assumptions for production of minor and major crops. For minor crops grown in extended areas with under-irrigation, IACA added 10 percent to the estimated output of minor crops produced with available water utilized at full-delta supply, i.e. if the water had been concentrated on a smaller area. In the case of major crops, IACA assumed that, in areas where underwatering prevailed, provision of additional water would be equally productive whether used to increase water deliveries to full delta or to expand the acreage cultivated at less than full delta; furthermore, in the event that the degree of delta was increased, it was assumed that yields would be increased almost instantaneously by the degree to which underwatering was corrected—for example, if the increase in irrigation supply raised the irrigation level from 80 percent of full delta to full delta, then yields would increase automatically some 25 percent. Finally, yield projections were based on IACA's proposed program for development of irrigation and agriculture. Sample projections are given in Figure 3, which shows the yield growth for four major crops in the Punjab, Sind, and areas outside the Indus Basin for the reference years. The very sharp rises between 1965 and 1985 reflect in part IACA's assumption that yields would increase markedly as soon as additional water is provided.

To get the gross benefit streams of the different hypothetical water projects, yield projections were combined as appropriate with the cropping intensities derived from the canal command analyses. An allowance was added for increased production of livestock products expected from additional fodder output and increased crop residues, and with a gradual improvement in the productivity of the animals. Gross benefits were converted to net benefits by deduction of on-farm costs, including allowance for wages of hired labor. Although very little is known about detailed farm costs, estimates were made by the consultants, for various levels of intensity and yields, on the basis of detailed farm budgets built up for different regions of the Basin.

At this point IACA had generated a number of alternative water budgets with their related benefits. These "projects" in effect summarized the potential consequences of public and private investment in different areas. Next, IACA went on to aggregate the projects and to test them within the context of the irrigation system as a whole. As pointed out in connection with the canal command analyses, a key premise was that the least costly water source—groundwater—would be used to the maximum possible extent before the next source would be tapped. In this way, the requirement for stored water, the more expensive source, was determined as a residual rather than a foregiven quantum. Storage requirements were calculated with the aid of a second computer model which IACA designed to simulate the operation of the irrigation system as a whole. Canal command requirements were accumulated up to the rim stations and to Mangla and Tarbela Reservoirs, with allowances for seepage and evaporation losses from the link canals and river reaches, as well as a storage allowance representing the travel time of water between reservoir and major distribution points. Another important purpose of this simulation model was to indicate link-canal capacity requirements. As with the canal command studies, the analysis was carried out for a number of reference years up to the year 2000. It was generally conducted in terms of mean-year river

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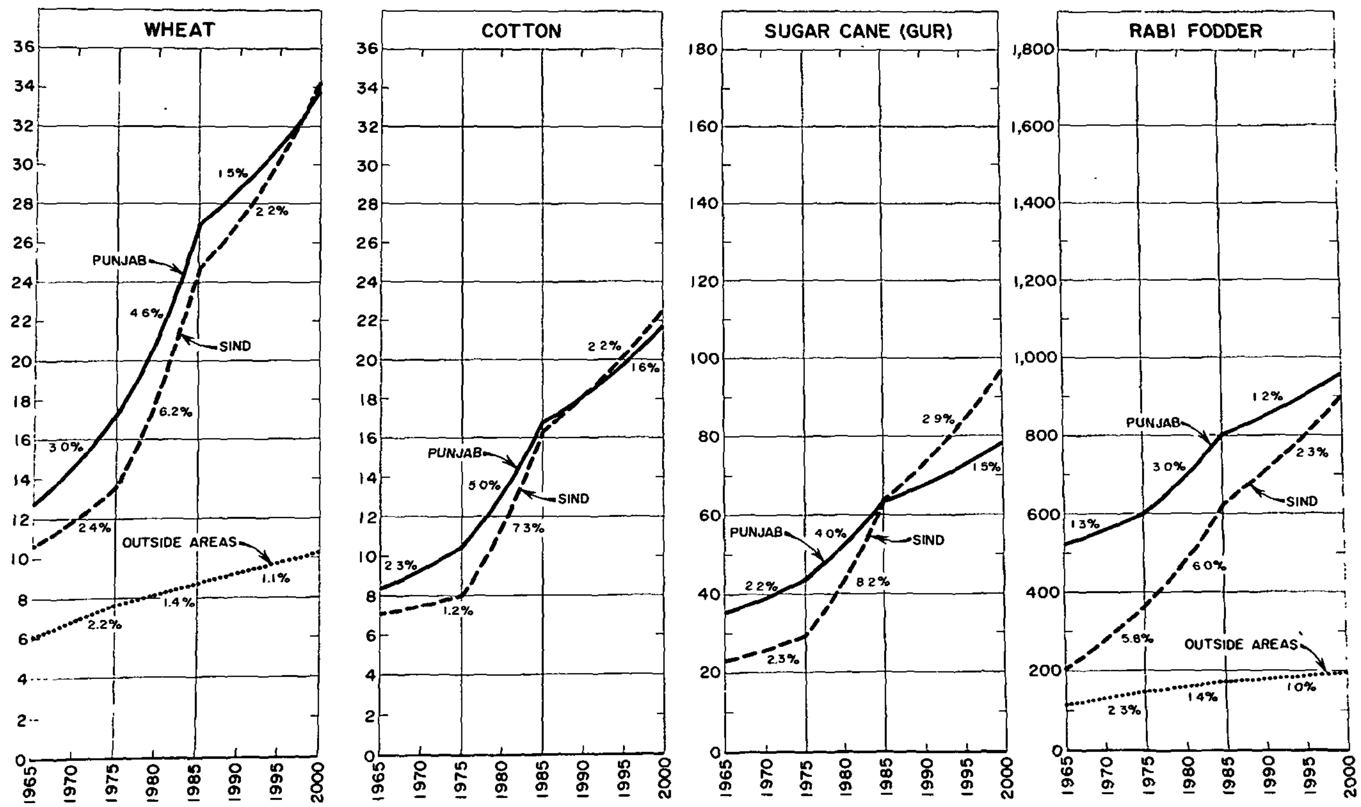
FIGURE 3

DERIVED AVERAGE YIELDS FOR REFERENCE YEARS
(MAUNDS PER ACRE)



(R)IBRD-3287

flows; however, various combinations of main-stem and tributary low-flow figures were used in the study of, for example, the monthly pattern of water releases from Mangla and Tarbela Reservoirs.

SELECTION OF IRRIGATION PROJECTS

Out of these simulation studies, IACA developed an increasing sensitivity to the implications of alternative patterns of water use. Thus, it became possible to establish criteria for making more refined choices among alternative types of water development for each canal command. At the same time, IACA concluded that implementation capacity set certain limits to what could be expected to be achieved by 1975. IACA defined these limits specifically as a maximum of 20,000 public tubewells completed in 1965–75 and a maximum of one million acres for which canal remodeling could be carried out over the same period. A second limitation which came to mind was the absorptive capacity for expansion of nonwater inputs. Preliminary estimates of the increased output—the output possible within the limitations—suggested to IACA that growth in agriculture would fall short of the rates projected in Government planning documents. It appeared to IACA, moreover, that these specific scarcities—limited absorptive and implementation capacity—would prove more restrictive on development than any global resource constraint such as availability of foreign exchange or of development finance. It followed that development should proceed at the maximum pace possible within the specific constraints; therefore, in the preparation of the development program, a general criterion became the allocation of the scarce factors among areas in such a way as to maximize the return to these factors.

It then became necessary to establish more specific technical and economic criteria for the selection of public tubewell and canal remodeling projects. From the technical point of view, areas which were underlain by usable groundwater but which also had water table within 10 feet of the surface were considered to be of high priority for public tubewell development. Among these areas, the first place in the program should go to those underlain by fresh groundwater which could be applied directly to the crops; second place should go to areas where the groundwater required mixing with surface water and where canal remodeling was required to permit attainment of a high cropping intensity at full-delta irrigation. The coupling of public tubewells with high water table reflects IACA's judgment that private tubewells would have much more limited capacity to accomplish subsurface drainage in such areas. Contrarily, the areas which seemed most suitable for deferment of public projects in favor of continued private tubewell development were those underlain by usable, especially fresh, groundwater, and a water table more than 10 feet from the surface.

On the basis of these technical criteria, the more promising areas for public tubewell development and canal remodeling were identified. However, there was technical scope for a larger public tubewell program during the Third and Fourth Plan periods than the specified limit of 20,000 wells would allow. Therefore, a further analysis was made giving explicit recognition to the limitation of implementation capacity during the period to 1975, focusing on the timing of public tubewell development in the various groundwater quality zones of the 61 canal commands. To simplify the calculations, the alternatives were specified as public tubewell installation in the period up to 1974, in the period 1975–79, or in the period 1980–84, plus the possibility of canal remodeling. Canal remodeling would take place either parallel to public tubewell development or at a deferred date. Finally, rabi surface water was incorporated as an additional limiting input in the years 1972, 1973 and 1974. For other years, the surface water used with the various 'projects' was assigned an imputed cost corresponding to the estimated scarcity value of rabi water in the system. This analysis, which in effect compared the various tentative water budgets or 'projects' for each area, was designed to allocate the limited numbers of public tubewells and amounts of canal remodeling among areas, taking account of the prospects for private tubewell development, so as to maximize the net present worth of output in irrigated agriculture in the Indus Basin. The outcome of this analysis was a list of priority areas for public tubewell development and canal remodeling in the three specified periods.

Despite the complexity of the various analyses, they oversimplified reality. For instance, alternative 'projects' had to be put on a standardized basis for use in formal analysis of priorities over the whole Basin. This meant that many individual peculiarities of a project area had to be ignored—the quality of the soil, specific drainage problems, variation in farm size and tenure, location of canals, etc. Thus, more detailed investigation of priority areas identified had to be carried out. Even the scope of some projects had to be changed because, for practical purposes, they could not be smaller than the smallest controllable surface water distribution unit: this was usually a distributary. In some cases, zones of low quality or even unusable groundwater had to be included in the project; in turn, the need for canal remodeling in some of these added areas affected the canal remodeling program. Detailed phasing and integration of all development activities connected with the recommended program also had to be performed outside the formal analyses; technical and operational interdependencies were of particular importance in cases where one activity was a prerequisite for the execution of another, e.g. drainage before canal remodeling in areas with saline groundwater and high water table.

Thus, through a series of approximations, the proposals for irrigation development were reduced to a single program consistent with implementation capacities, internally consistent in terms of availability and usage of surface water and groundwater, and phased in terms of project priorities. The proposed program for irrigation and drainage development up to 1975 contains 13 public tubewell projects additional to those presently underway. These new projects are different in several ways as a direct result of the approach to project selection adopted in this Study. First, because of the concern to maximize the contribution to agricultural growth from both public and private tubewells, there is a built-in tendency for the proposed public tubewell projects to cover smaller areas than in the past, leaving maximum scope for private enterprise development wherever it could occur. Second, because a net-present-worth evaluation of benefits gives priority to areas where returns from investment can be expected sooner rather than later, the proposed projects imply greater emphasis in the early future on increased crop production, by development of usable groundwater in areas where it can be applied immediately to crops, and less emphasis on reclamation of saline lands and water-table control in non-usable groundwater zones. Third, the proposed public tubewell projects are more closely integrated into the overall irrigation/power system. Previously, pumped water had been regarded largely as a supplement and not a substitute for canal supplies, with the result that total water supplies in some tubewell areas are more than adequate while elsewhere crops suffer shortages. The proposed projects are based on the integrated use of surface and groundwater. For each project area, there is sufficient pumping capacity for full irrigation requirements to be met from groundwater and surface water combined in any month in four years out of five, under assumed river flow conditions. Also, there is sufficient margin in the project design to allow that the wells could be shut off at the time of evening peak on power system without reducing the amount of water that could be pumped below daily requirements.

Behavior of the System

Prior to a final review of the projects and programs by the Study Group, the then Chairman of WAPDA (Mr. Ghulam Ishaq) suggested that the development program proposed by the Bank's consultants be subjected to a behavior trial utilizing a sequential model of irrigation and power systems operations developed by WAPDA's general consultants, Harza Engineering. It will be recalled that the basic analyses had all been made in terms of reference years and generally on the assumption of mean-year river flows. Some adjustments had been made, however, to allow for other hydrological conditions. The most important of these relates to operation of the system in years of water shortage. In these years, according to IACA's plan of action, groundwater pumping would be temporarily increased beyond the balanced recharge level, and the consequent overdraft on the aquifer would be replaced by reducing pumping and increasing surface supplies during periods of above-average surface water availability. This form of integration was one of the most important proposals implicit in the recommended program; it resulted in additions to the tubewell capacity in project areas. WAPDA and the Study Group agreed that it would be highly desirable to assess in detail the operational implications of using groundwater to compensate for surface flow variations through temporary pumping in excess of recharge.

The Study Group's coordinating consultant, Sir Alexander Gibb & Partners, with the cooperation of Harza, executed this additional study. The operation of the water and power system, during 1965 to 1985, was simulated under the assumption that IACA's program would be carried out as recommended. This behavior test demonstrated in detail how the irrigation system as a whole would meet the water requirements of each area unit under various sequences of river flow conditions over the course of 20 years. The test led to the conclusion that the proposed program and each component thereof is operationally feasible provided the existing pattern of water distribution is gradually changed so as to establish, step by step, a fully integrated system of groundwater and surface water use.

REVIEW OF THE PROGRAM FOR IRRIGATION AND AGRICULTURE

As the Study progressed, the Bank Study Group subjected the emerging program for irrigation development and its project content to systematic and detailed review. To test the economic efficiency of the project priorities proposed by IACA in a Basinwide context, the Study Group employed a linear programming model. This model focuses upon those overall resource constraints which, in the judgment of the Study Group, would strategically control the complex phenomenon of irrigated agriculture development. The programming analysis made use of IACA's projections of output responses to water and other agricultural inputs; their judgment about the importance of constraints, such as implementation capacity in the field of public tubewell development and canal remodeling, provided points of departure. However, use of the linear program provided an opportunity to further explore the various constraints on development and variations in the specific values attributed to these constraints. About 500 water "projects," based on the water budgets produced in the consultants' canal-command simulation, were considered. The alternatives for each area were public tubewells, private tubewells, canal remodeling, increased supply of regulated surface water in the rabi season by construction of further storage reservoirs, and improvement in drainage by installation of drainage wells or tile drains. Alternative "projects" were considered for execution in each of the two time periods, 1965–75 and 1975–85, either singly or, where appropriate, in combination with one another. The special value of the linear program lay in its ability to take into account simultaneously a variety of constraints on development, their interaction, and the possibility that they may change over time. Specifically, five resource limitations were selected: foreign exchange, availability of surface water supply during rabi, construction and project-management capability in regard to implementation of public tubewell projects, the same limitation for canal remodeling projects, and the availability of budgetary resources to support groundwater development. Because of the explicit consideration given to the availability of rabi surface water supplies, the linear programming analysis was also useful for study of the size and composition of the proposed surface water storage program. (For details of linear programming, see Supplemental Paper No. 4, Volume Three.)

While this elaborate testing of basinwide implications was underway, each of the priority projects proposed by IACA was subjected to detailed scrutiny. The Study Group devoted a major effort to appraising projects selected for early execution. It was felt that these projects, on which the consultants had spent a great deal of effort, represented one of the most important outcomes of the Study. Some differences in approach to project appraisal were adopted by the Study Group. In its economic review, the

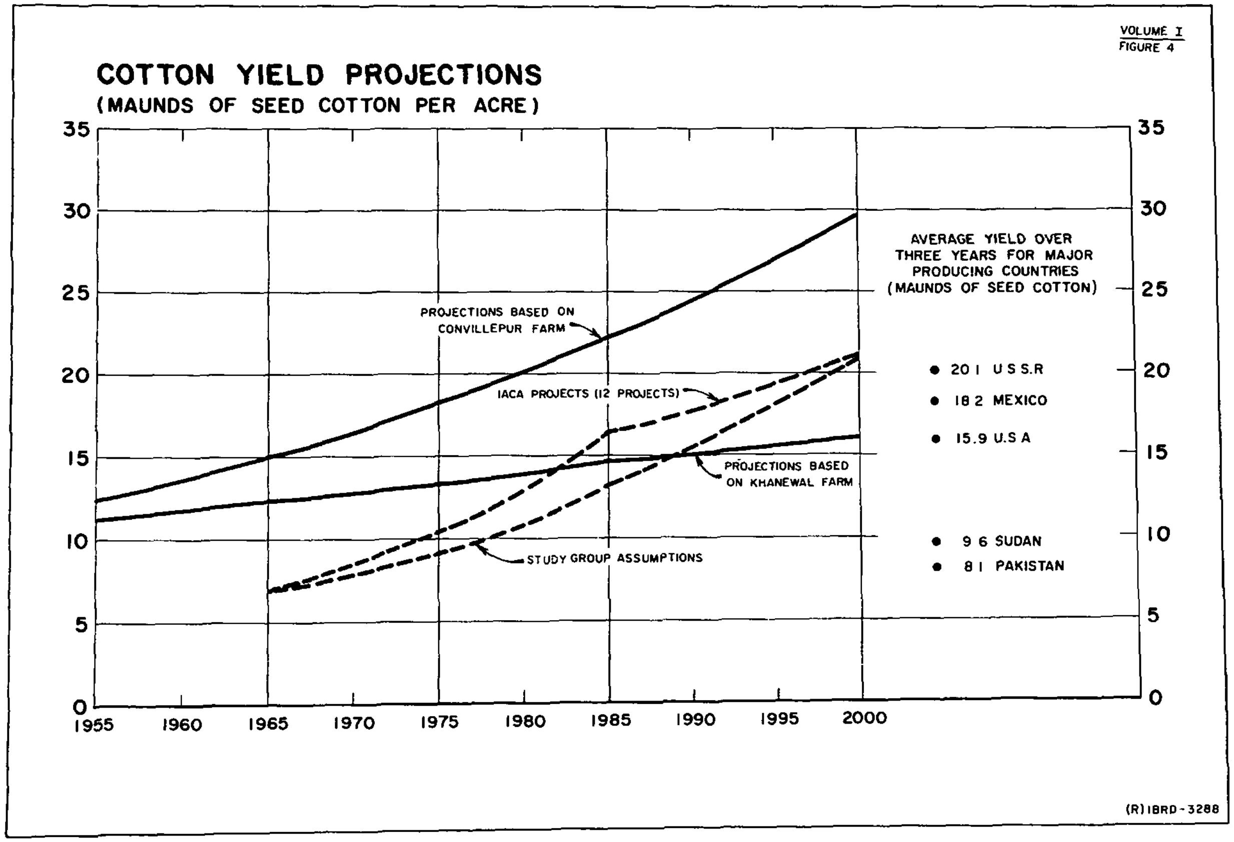
Group made an attempt to quantify those aspects of the projected cost and benefit streams on which its views diverged from the views of the consultants. On the whole, these adjustments tended to strengthen the case for private groundwater development. In contradistinction to the IACA approach, the Bank Study Group attempted to isolate the effects of groundwater by attaching an economic value to the use of surface water by a tubewell project and subtracting that value from the gross benefits of the project. In its calculations of the rate of return on public tubewell investment, the Study Group has assumed that the rates of increase in the use of nonwater inputs would be similar wherever adequate supplies existed whether or not the public projects were undertaken. The Study Group also checked the proposed projects against the alternative of stimulated and accelerated private tubewell development wherever this was deemed technically feasible.

One important divergence of views between the Study Group and IACA concerned future crop yields. In its review of the consultants' studies, the Study Group recognized the need for adequate water application to meet both crop consumptive use and to maintain the long-term productive capacity of the soil, but it considered that the full-delta concept had been too rigidly applied. IACA assumed that a sudden increase in water supplies up to full delta would be accompanied by a sudden increase in yields of the same magnitude; the Study Group concluded that in all likelihood it would take considerable time to organize the higher level of nonwater inputs required to match the increase in water. In practice, the probable course of development would be a simultaneous increase in acreage as well as an improvement in delta and inputs. This implies for some time a larger cropped acreage at a lower level of production per cropped acre than assumed by IACA; overall production would be higher. The effect of the Bank Group's adjustments on an important crop yield can be seen in Figure 4. It shows the average yield increase for cotton projected by IACA for the 12 selected tubewell project areas and the Study Group's modified projection; it also shows projections based on the continuation of past performance on two large, well-managed commercial farms in the Punjab.

IACA did not specifically formulate any nonwater development activities in the form of projects, but they did prepare a general program for agricultural improvement, closely interlinked with the proposed irrigation development program. IACA studied the technical feasibility of using different levels of farm inputs in areas with water supplies of varying adequacy, their cost, and the contribution that they would make to the growth of agricultural production. The chief inputs covered were improved seed varieties, fertilizer, insecticides, chemicals for land reclamation, various measures for improvement of animal husbandry and improvement in farming and irrigation techniques and equipment. The Study Group made use of these data in its programming analysis and project review.

Formulation of the Power Development Program

Parallel to formulation of an irrigation development program, and closely interlinked with it, the Study was to produce a comprehensive plan for the development of the power sector. The assumption adopted for the


VOLUME I
FIGURE 4
COTTON YIELD PROJECTIONS
(MAUNDS OF SEED COTTON PER ACRE)
35
30
25
20
15
10
5
0
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
PROJECTIONS BASED ON CONVILLEPUR FARM
IACA PROJECTS (12 PROJECTS)
PROJECTIONS BASED ON KHANEWAL FARM
STUDY GROUP ASSUMPTIONS
AVERAGE YIELD OVER THREE YEARS FOR MAJOR PRODUCING COUNTRIES (MAUNDS OF SEED COTTON)
20 1 U S S.R
18 2 MEXICO
15.9 U.S A
9 6 SUDAN
8 1 PAKISTAN
(R) IBRD-3288

second phase of the Study—that Tarbela Reservoir would be completed by 1975—was as important for the formulation of the power program as it was for the irrigation program. The hydroelectric potential of Tarbela is so large relative to prospective power loads that even an action program for interim power development would need to anticipate the existence of Tarbela in 1975. Because the data on the irrigation program were subject to so much study and review, the power consultant had to make certain interim assumptions about tubewell pumping loads and reservoir operation and proceed on that basis to formulate a power program. The power characteristics of the Tarbela and Mangla plants had to be determined for different assumptions as to flows, reservoir release patterns, number of generating units installed, etc.; reservoir simulation studies were undertaken to indicate the implication for power of different modes of operation. Rather than using a fully integrated system analysis, however, the power consultant relied on judicious partial analyses related to his judgment of the overall character of the power system and the relative attractiveness of individual investments. Various alternatives were compared by hand. The long-term program for power was based on a set of detailed regional load forecasts. The load data and the related bulk supply program were prepared on a month-by-month basis for the full period, 1965–85.

In its review of the proposed power program, the Study Group's objectives were similar to those adopted in its review of agricultural and water proposals: to build up procedures which would enable it to broaden the range of alternatives and to test the economic efficiency of the consultants' proposals. In addition, the Group made an effort to contribute to the process of developing techniques appropriate for updating the power program finally recommended. Using a computer, the Study Group developed a simulation model of the electric power system of West Pakistan down to, but not including, the distribution stage. By providing a means for comparing the costs and operational characteristics of alternative proposals, this simulation technique played a central role in the formulation of the Bank Group's conclusions and recommendations; the power consultant's bulk supply proposals were checked with the aid of the simulation model, and some alterations were made on the basis of the Group's analyses. (For details of the simulation model see Supplemental Paper No. 9, Volume Three.)

Joint Planning for Power and Irrigation

There are many points of overlap and interdependence between the power and irrigation sectors in West Pakistan. Considerable effort was devoted throughout the Study to problems of consistency, both in the analytical effort and in the programs which resulted from it. One difficult problem concerned costs and prices. The basic cost concepts were easy to specify: all economic comparisons between alternative investments were made in terms of the economic costs of the alternatives—i.e. costs excluding transfer payments such as import duties, sales taxes and interest during construction—while financial calculations, designed to indicate the total costs of the selected projects and programs, were carried out in terms of financial prices including these transfer payments. The Study Group also tried to approximate opportunity costs, representing the value of factors in alternative uses: in the case of farm budgets, for instance, by pricing hired labor at current rural wage rates but assuming family labor to be available free. However, there were many uncertainties which had to be solved by judgment. For instance, were 1965 prices valid for purposes of comparison? In one sense, reasonable comparability among economic costs of engineering works could be ensured by using 1965 prices, on the assumption that increases in unit prices would affect all works compared in a similar way, but this was less reasonable for crop prices, among which the differential may well change over the years. 1965 farm prices were in fact taken for most crops, but where change seemed particularly likely—in a downward direction, for instance, in the case of rice and upward in the case of meat—special adjustments were made. Another problem related more particularly to the costs of engineering works which varied greatly in the amount of knowledge and experience available on them. Very large amounts of money have been spent, for instance, to firm up the costs of the Tarbela Project, but only a tiny fraction of that amount has been spent on most other surface storage projects. Or again, in the case of irrigation works, considerable experience has been accumulated regarding the costs of tubewells—though there is still room for disagreement about their costs—whereas there is practically no experience of large-scale canal remodeling. Adjusting cost data for purposes of comparability, a problem throughout the Study, was handled by techniques such as taking price ranges, making contingency allowances of varying size, and always coming back after making a comparison to reassessing the validity of the data used.

There were a number of technical interrelations between the agriculture and power sectors. Electricity for tubewell pumping will increasingly become an important part of the total power load; thus the projection of tubewell load growth was an important aspect of the irrigation and the power program; its monthly pattern was derived partly with a view to the seasonal variations that will occur in the capability of the power system as well as coordination with daily system peaks so it will fit better with the overall pattern of power demand and system capacity. Another technical overlap concerned repercussions from the recommended tubewell program on the pace of rural residential electrification; it was possible to make some broad projections of this interaction.

It was recognized that the agriculture and power sectors would, to some extent, be competing with one another and with other sectors for the same scarce resources. It was hard to be very specific about this in macroeconomic terms, because no official provincial breakdown of the Perspective Plan for Pakistan (1965–85) was available. However, some allowance was made for macroeconomic constraints in regard to foreign exchange and capital costs. For foreign exchange costs, certain comparisons were made at both current official exchange rates and various alternatives, most often a scarcity rate twice the current rate (i.e. Rs. 9.52 instead of Rs. 4.76 to the US dollar). Regarding capital, an interest rate of 8 percent was used in all economic comparisons; this rate was chosen as an approximation to the real opportunity cost of capital, i.e. the marginal productivity of capital in uses outside the sectors under study. In the selection of an appropriate interest rate, the Study Group was conscious also of the need to give due recognition to, first of all, the relative scarcity of capital in the Pakistan economy and, secondly, to the importance of not biasing the project selection process unduly against longer lived alternatives such as storage reservoirs and hydroelectric plant which are relatively expensive in capital cost and relatively cheap in operating cost. The 8 percent rate ultimately chosen is somewhat above the prevailing rate of interest on Government bonds in Pakistan and somewhat below typical rates of return on private investment. Use of the 8 percent interest rate meant exclusion on economic grounds from the program of projects yielding less than 8 percent rate of return.

The agriculture and power sectors will also compete for the use of water stored behind the Mangla and Tarbela Dams and, related to fertilizer production, for use of the Province's natural gas reserves. Once Mangla is completed, and even more when Tarbela is completed, there will be room for choice between (a) drawing down the reservoirs fully and thus releasing all the water stored from the kharif season for irrigation use in rabi and, (b) retaining some water in the reservoirs throughout the year and thus increasing the power capability of the hydroelectric plants in the season when power supplies will be most short. To the extent that the reservoirs are drawn down more fully, there will be a greater requirement for thermal generating capability—and this will be largely based on natural gas, especially up to 1980. But use of more natural gas for power generation means that less will be available for manufacture of fertilizer for the agricultural sector. This conflict was dealt with through pricing adjustments.

The most critical meeting point between agriculture and power in the Study was the analysis of the justification for Tarbela itself. As the final, comprehensive phase of the Study was coming to an end, the coordinating consultant readdressed himself to this question and broadly confirmed the conclusion reached in the first phase of the Study regarding the rate of return to be anticipated from the project. The Bank Study Group also reappraised the Tarbela Dam in a number of studies; one was a consideration of the project within the framework set by the agricultural projects recommended; another was an assessment, with the aid of the linear programming analysis of irrigation investment and the power system simulation model, of the loss that would be sustained if execution of the project were delayed 10 years. All these studies concurred in indicating that Tarbela should be executed as scheduled.

IV

Agricultural Improvements and Irrigation Projects

This chapter discusses in broad terms the program for the development of irrigation and agriculture presented in Volume Two of this report. The program is based on the work of the Irrigation and Agricultural Consultants Association (IACA); it also reflects views expressed by the Pakistan authorities during the course of the Study and the Study Group's own experience in Pakistan.

A. AGRICULTURE

In looking at the future of agriculture in West Pakistan—throughout the next decades of this century, but particularly for the period 1965–75—the Study Group has been concerned with what is practically achievable within the constraints that are likely to be operative, rather than with the technical potential. It has been assumed that the development of irrigation and agriculture would receive high priority in the allocation of resources, which its importance deserves, and that these would be efficiently and effectively deployed. Water development and agricultural development are essentially interdependent, and both receive due emphasis in the recommended program which the Study Group considers appropriate and desirable under prevailing conditions. The level of agricultural production which has been projected as being possible of achievement by 1975 will require a major effort of an emergency character and spectacular improvement in performance in all sectors. Its attainment, however, would go far towards meeting West Pakistan's most pressing needs in food and exports of agriculturally based commodities.

The Pattern of Agricultural Development

The Province of West Pakistan covers a land area of some 200 million acres, of which about 70 million acres are considered potentially suitable for agricultural production. However, less than 40 million acres are presently cultivated. The Indus Plains include nearly 70 percent of the cultivated acreage, supply about 80 percent of the foodstuffs produced, and contain a large majority of the population of the Province. The

TABLE 4–1
CROPPED ACREAGE AND GPV FOR CANAL-IRRIGATED AND OTHER AREAS (1965)
(millions)

	Canal-Irrigated		Remainder		West Pakistan	
	Area in acres	GPV Rs	Area in acres	GPV Rs	Area in acres	GPV Rs
Annual Food Crops						
Wheat	7.72	1,222.5	4.99	412.5	12.71	1,635.0
Millets	1.02	68.2	1.99	136.8	3.01	205.0
Maize	1.09	128.6	1.07	122.4	2.16	251.0
Others	3.08	412.9	3.12	288.1	6.20	701.0
Rice	3.52	589.0	—	—	3.52	589.0
Perennial Crops	1.62	1,112.0	—	—	1.62	1,112.0
Total Food Crops	18.05	3,533.2	11.17	959.8	29.22	4,493.0
Cotton	3.71	880.0	—	—	3.71	880.0
Fodder	4.99	—	1.20	—	6.19	—
Total Crops	26.75	4,413.2	12.37	959.8	39.12	5,373.0

irrigated plains also offer the greatest scope for further agricultural development. For these reasons, this area has received primary emphasis in the Study.

Crops. The predominant importance of the canal-irrigated areas is illustrated in Table 4–1 in terms of the acreage under various major crops and the contribution of these crops to the Gross Production Value (GPV) of agricultural output. Production of three of the important crops grown—rice, cotton and sugarcane—is virtually confined to the canal-irrigated areas, and these account for nearly half the GPV of crops. Three-fourths of the GPV from wheat comes from these areas. Cotton is the most important cash crop and accounts for some 14 percent of the total cropped acreage in the irrigated areas; it is grown mainly in the southern Punjab, Bahawalpur and Northern Sind. Production of rice and sugarcane as cash crops is heavily concentrated in the irrigated areas of the northern Punjab and Peshawar. Table 4–1 also indicates that food crops account for about 75 percent of the total acreage currently cultivated, though somewhat less in the canal-irrigated areas. What, the staple food in most areas, alone accounted for nearly one-third of total acreage cropped.

Livestock. Indicating the importance of animals in West Pakistan's rural economy, no less than 15 percent of the 39 million cropped acres are used for the production of fodders of various kinds; four-fifths of this area falls within the canal-irrigated plains. The 15 percent under fodder crops understates the actual area devoted to livestock because crop residues provide about half the animal nutrient supply and large rainfed areas are also used primarily for grazing. Table 4–2 shows the estimated livestock population of West Pakistan in 1965. A few of the larger farms in West Pakistan have begun to use tractors and other mechanized equipment, but the vast

TABLE 4-2
LIVESTOCK POPULATION OF WEST PAKISTAN, 1965
(in million heads)

Bullocks	7.4
Other Work Animals	2.4
Bovine Cows	4.4
Bovine Followers	3.5
Buffalo Cows	5.4
Buffalo Bulls and Followers	3.1
Sheep	9.8
Goats	7.2
Total Larger Livestock	43.2
Poultry	10.0

majority rely entirely on draught animals for cultivation, threshing and farm transport. Draught animals account for about one-quarter of the total animal population of 43.2 million head. While draught animals also produce some meat, most of the milk and meat in Pakistan come from the other 75 percent of the herd. Livestock products account for a very significant proportion—estimated at some 35 percent—of total agricultural output. Production of milk, meat, hides and skins, etc., is somewhat less heavily concentrated in the irrigated areas than production of field crops, since the nonirrigated areas provide extensive grazing land: farmers in the canal-commanded areas may be responsible for 70 percent of total output of livestock products, though some of this occurs on the higher regions of the doabs not commanded by canals. Animal power will continue for a long time to be important in West Pakistan. One reason for this is that there is a very large number of small farms.

Farms and Farmers. The 1960 Pakistan Census of Agriculture shows that 49 percent of the farms are under five acres. However, there is wide variation over the Province. The average farm holding is 10.1 acres (with a cultivated area of 7.7 acres), but the range extends from an average of 5.5 acres in Peshawar Division to 35.9 acres in the largely nonirrigated Kalat Division, west of the Indus. In general terms, farms are smaller in the more productive, irrigated areas of the Punjab and Peshawar Vale than elsewhere.

Despite the very large number of small farms, much of the farm area is in relatively large farms. The 49 percent of farms under five acres account for only 10 percent of the culturable area, while 40 percent is in farms over 25 acres in size.

The pattern of land tenure also shows considerable variation over the Province. Owner-operated farms account for nearly half the acreage in the Punjab, but only about one-third in the Khairpur Division of the Sind. This reflects the fact that tenancy is more prevalent in the less developed parts of the Province, where large acreages are owned by absentee landowners. Land reform legislation has sought to deal with the problems posed by farms that are either excessively large or unusually small. The right to subdivide land below a minimum size designated as an "economic holding" has been limited, and the largest landowners (those with more than 500 acres of irrigated or 1,000 acres of nonirrigated land) have been required to divest themselves of land in excess of the legal limits. Both kinds of measures have had some success in achieving their objectives, and the strategic position of the larger landlords may have been partially weakened in the process. Efforts to consolidate land holdings which are fragmented have proceeded slowly. It is difficult to relate the recent increase in production directly to the effects of land reform programs—as one reason, land reform has had little measurable impact on the size distribution of land holdings. On the other hand, land reform may be a factor in changing the attitudes of large landowners, and awakening a more active interest in improving the productivity of their lands through increased investments, including tubewells and mechanization of farm operations.

The Role of Fertilizer

One indication of the responsiveness of farmers to new inputs has been the very rapid increase in use of fertilizer in recent years. During the First Plan period (1954/55–1959/60), fertilizer use grew by only some 5,000 nutrient tons. Thereafter, the rise was more spectacular, as shown in Table 4–3. The increase in fertilizer use was supported by a Government subsidy. The drop in growth of offtake in 1961–63 coincided with a decrease in the rate of subsidy. After reinstatement of full subsidy, consumption again grew rapidly. Shortages in supply probably limited use in the final year of the Second Plan to the quantities shown, for there have been pervasive reports of sales of fertilizers at black market prices since 1964/65. Though still small in absolute terms and largely confined to areas of higher standard farming, fertilizer use has probably made an important contribution to the growth in production of cash crops, on which applications have tended to be concentrated.

Even within the context of present water shortages, there would appear to be great scope for raising yields by increasing the use of fertilizer. Increased use of fertilizer will be the most important single factor in bringing about rapid agricultural growth in the near future. Various short-term projections of future fertilizer use tend to coincide at an absorption target of about 370,000 nutrient tons by 1969/70, indicating a rate of growth of

TABLE 4–3
FERTILIZER USE DURING THE SECOND PLAN PERIOD
(tons of nutrient)

Year	Nitrogen (N)	Phosphate (P_2O_5)	Total	Annual Increase (%)
1959/60	19,300	100	19,400	0.8
1960/61	31,100	400	31,500	62.7
1961/62	37,200	500	37,700	19.7
1962/63	42,900	1,400	44,300	17.5
1963/64	62,400	1,100	63,500	43.3
1964/65	84,000	2,000	86,000	35.4

TABLE 4-4

PROJECTIONS OF FERTILIZER CONSUMPTION BY IACA AND STUDY GROUP

('000 tons of nutrient)

	1964/65		1970		1975		1985
IACA:							
(a) Nitrogen	90		120		217		573
(b) Phosphate	-		55		103		335
Total	90		175		320		908
Rate of Increase (% p.a.)		14%		13%		11%	
Study Group:							
(a) Nitrogen	90		250		470		620
(b) Phosphate	-		100		230		330
Total	90		350		700		950
Rate of Increase (% p.a.)		30%		15%		5%	

well above 30 percent per year over the next several years. This would imply a further acceleration over the already impressive experience during the Second Plan period. While the actual performance during the first year of the Third Plan (1965/66) does not show a major increase over 1964/65, steps taken by the Government of West Pakistan for fiscal year 1966/67—aimed at having some 250,000 nutrient tons available during the 1966/67 year—would tend to support such an optimistic assessment. However, problems of production and procurement as well as transportation and actual distribution should not be discounted, nor should the influence of price supports be underestimated in an environment where the mass of farmers are still preoccupied with subsistence farming. Considering these difficulties, the major efforts being made to overcome them and the rate of growth of fertilizer usage achieved in the Second Plan, it would appear that the target for 1969/70, of about 350,000 nutrient tons (about 1.6 million tons of ammonium sulphate equivalent), although much above that implied by IACA, is, nonetheless, reasonable for planning purposes.

The rate of growth of fertilizer offtake may slow down somewhat during the Fourth Plan period, but it should be feasible to maintain an average growth of 15 percent per year, implying consumption of 700,000 tons of nutrients by 1975. This would again be double the IACA estimate. While a high degree of uncertainty is necessarily inherent in all these projections, it would be possible for the West Pakistan authorities to reach these targets provided appropriate arrangements are made for supplies and distribution. After 1975, the growth in consumption would probably slow down.

Achievement of the Study Group targets (Table 4–4) would mean that the coverage and rates of application envisaged by IACA for 1975 (Table 4–5) would be more than met by 1970. The rates of application for each crop shown in Table 4–5 are based on rates presently recommended by the Department of Agriculture. The projections imply that about half of the

TABLE 4–5
IACA's Projection of Fertilizer Coverage by 1975
(in percent of crop acreage covered; applications in lbs of nutrients)

	Punjab		Sind		Outside Areas	
	% of crop acreage covered	Application in lbs per cov'd acre	% of crop acreage covered	Application in lbs per cov'd acre	% of crop acreage covered	Application in lbs per cov'd acre
Wheat—nitrogen	50	50	25	50	15	25
phosphates[a]	50	30	25	25	–	–
Cotton—nitrogen	60	40	40	40	–	–
phosphates	30	30	20	20	–	–
Fine rice—nitrogen	50	30	–	–	–	–
phosphates	30	30	–	–	–	–
Sugarcane—nitrogen	70	60	50	60	–	–
phosphates	30	30	15	20	–	–
Kharif fodder—nitrogen	20	60	20	60	5	10
Rabi fodder—phosphates	20	50	–	–	–	–

[a] P_2O_5.

fertilizer usage would be for the wheat crop and another quarter for cotton. The Group target for 1970 is ambitious and its attainment will require determined efforts.

The Contribution of Improved Seeds

The use of improved seed material has considerable potential for increasing farm output. Apparently, cotton is the only crop for which a widespread supply of improved varieties has been made available to farmers, and the significance of this improvement is open to doubt since controls on seed selection and protection against adulteration have not been very effective in all areas. Though occurring too late to affect production during the Second Plan, important progress has been made in developing superior strains of other crops, particularly wheat. Since 1959, West Pakistan, in collaboration with Mexican wheat-breeding experts and supported by the Ford Foundation, has embarked on an active wheat-improvement program. Several higher yielding varieties have been developed and are in various stages of progress from the research stations to commercial multiplication. Presently, imported Mexican varieties (Penjamo and Lerma Rojo) are being multiplied, while the locally produced Mexipak varieties are expected soon to reach the stage of distribution for commercial production.

Experts say the yield potential of the newly introduced wheat varieties is about 45 maunds per acre, compared with a current wheat yield in the better farming areas of 13 maunds. Harvesting data for 5,000 acres in the first year of commercial multiplication (1965/66 rabi season) show yields ranging between 26 and 34 maunds under actual farming conditions. While maximum yields exceeded 80 maunds, the yields on some Agricultural Development Corporation (ADC) seed farms did not even approach those presently achieved with indigenous varieties in the better farming areas of West Pakistan. A number of causes have been indicated: suboptimum

TABLE 4–6
SEED REQUIREMENTS FOR MAJOR CROPS
(million maunds)

	1965	1975	1985	2000
Wheat	8.90	16.00	18.80	17.80
Cotton	0.90	1.60	2.60	4.00
Rice	0.70	0.80	0.80	0.90
	10.50	17.40	22.20	22.70

moisture conditions of the seedbeds; excessive depth of sowing, carried over from practices used with indigenous varieties; seed rates below recommended rates; shortage of irrigation water and insufficient waterings; and deficient application of fertilizer. It is important to recognize that, where there was failure, not any one single factor was the cause; to some extent, practically all major elements of efficient cultivation practices were lacking. Thus, the future success of the accelerated wheat-improvement program is dependent not only on the availability of improved seeds but also on an overall improvement of crop husbandry practices.

Seed requirements for the major crops, at present and as projected by IACA, are shown in Table 4–6. Actual distribution of improved seed in 1964/65 (by the Agricultural Department and the ADC) was 0.4 million maunds for wheat, 0.3 million maunds for cotton, and 0.7 million maunds for rice. Thus, improved seed covers only a small proportion of total requirements, except for rice. Large quantities of improved seed will also be required for coarse grains and fodder.

For wheat, the percentage of crop-acreages covered by improved varieties, as projected by IACA and adopted by the Bank Study Group, will be targeted at 50 percent by 1975 and 100 percent by 1985. Improved wheat seed material of 18.8 million maunds (700,000 tons) will be required by 1985 and about half this amount by 1975. Assuming that the seed is produced by the best farmers, with an average yield of about 30 maunds per acre of seed material, this would require about 320,000 acres being devoted to improved seed production by 1975; in 1965/66, there were some 12,000 acres under improved wheat varieties. Thus the task is substantial. The wheat-breeding experts advising the Government of West Pakistan have predicted that even more rapid progress is possible—coverage of six million acres of irrigated land by 1969/70, implying a need for more than seven million maunds of improved seed material. At least 250,000 acres would be required to produce this quantity of seed. The aim is desirable but it is doubtful whether such an increase is achievable by 1970. The production, handling and distribution of such quantities of improved wheat seed would require establishing a crash program for improved extension services, a commercialized seed growing program with strict quality control over extensive areas, storage facilities to ensure retention of high germination rates, and an extensive and efficient distribution network.

Regarding cotton, IACA estimates that about 40 percent of the present acreage is planted with improved seed and that this could be raised to 100 percent by 1975. From evidence in IACA's watercourse studies, typical cotton plant populations are less than half the recommended 16,000 plants per acre. The low plant population appears to be due partly to poor-quality seed and partly to low seed rates, emergence difficulties, and post-emergence mortality. Thus, in conjunction with improving cotton seed quality, IACA projects increasing seed rates and full plant populations; the seed requirements shown in Table 4–6 are calculated on the basis of recommended seed rates and plant densities.

For coarse rice, important progress has been made with the development of high-yielding dwarf varieties at the International Rice Research Institute in the Philippines. These varieties are being tested at Dokri Rice Research Station in West Pakistan, with apparently good results. The possibilities of large-scale introduction are under consideration by the Agricultural Department, which plans for improved varieties to cover about one million acres by 1970, roughly equivalent to the target adopted here for 1975. By 1985, IACA would expect improved rice varieties to be in common use.

In the case of sugarcane, the choice of sets material needs improvement as does the planting rate. At present, only about half the recommended number of sets is being planted, and most of these are two-node sets while IACA considers three-node sets desirable. As for maize, hybrid and synthetic varieties have potential for West Pakistan, but they require considerable organizational and scientific support for maintenance breeding as well as large-scale planting in contiguous areas.

In general, IACA believes that progress in the use of improved seed will occur mainly with wheat and three main cash crops, cotton, rice and sugarcane, because these are the ones on which farmers will concentrate attention. Use of improved seed will probably increase much more rapidly in the irrigated areas than outside them.

In reviewing IACA's projections of the use of improved seed, the Study Group was aware that measuring progress in terms of quantity—the amount of improved seed employed—could be quite misleading. In the past, much of the so-called improved seed has been little if any better than farmers' own stocks. If improved seed is interpreted to mean seed of high genetic quality, produced and distributed under controlled conditions, free from adulterants, and of high germination, then the Study Group would feel that IACA's estimates are not unreasonable. The main point is that progress must be measured qualitatively as well as quantitatively and much depends upon the institutions responsible for production, multiplication and supervision of the distribution of improved seed material.

The Outlook for Improved Plant Protection

In the past, plant protection has been provided to farmers virtually free through the agricultural extension services. Even so, the results have not been very satisfactory. At best, some 12 percent of the cropped area has been receiving some form of plant protection, to varying degrees of effectiveness. As much as 15 percent of the potential yield of crops has been lost each year to pests. The reasons are not hard to find. There is a shortage of properly trained personnel to carry out this service, treatments often are

TABLE 4–7
IACA PROJECTION OF PLANT PROTECTION COVERAGE
(percent of acreage under crop)

	1965	1975	1985
Rice Nurseries	20	45	65
Fine Rice	3	20	40
Coarse Rice	3	5	17.5
Cotton	5	20	40
Sugarcane	5	27.5	47.5
Fruit	25	25	45
Vegetables	10	15	35
Maize	3	7.5	27.5
Kharif Fodder	–	5	17.5
Oilseeds	–	5	20
Wheat	–	–	10
Rabi Fodder	–	–	–
Gram	–	–	–
Kharif Pulses	–	–	10

neither timely nor of proper dosage, insecticides have not been available in adequate quantities at the critical time, and the selection of areas for treatment appears to have been not always based on an objective assessment of the most pressing needs. Some of the problems have been on the farmers' side too. Necessary farm practices, such as the elimination of pest-host weeds and destruction of crop residues immediately after harvesting, are not practiced on a wide scale. Little attention is given to adjusting planting dates in accord with pest-control needs.

IACA believes, and the Bank Study Group agrees, that plant protection measures are unlikely to improve much before yields are increased through the use of fertilizer and better husbandry practices. Plant protection will then become recognized as increasingly important. But there will be serious constraints on the rate of progress: lack of knowledge on the part of the farmer and the extension service, the critical importance of applying the pesticide at the right time, the need that will arise for pesticides to be properly stored and transported in quantity, the problem of cost sharing between tenant and landlord. Therefore, IACA has assumed a relatively small increase in the acreage sprayed by 1975, but more general use of chemical control in later years. A rough assessment of the proportion of the acreage of different crops presently sprayed, and IACA's projection of the increase in this proportion, are given in Table 4–7.

MECHANIZATION AND IMPROVED IMPLEMENTS

Existing farm implements are adapted to local conditions and mostly manufactured from local materials, but there is room for substantial improvement in them. Efforts are being made to develop improved hand tools and animal-drawn equipment at research centers and to promote their use with the aid of subsidies. However, in contrast to the rapid spread of private tubewells, the improvement in tools and simple equipment appears to be progressing rather slowly. Thus, the Study Group calls attention to the considerable potential for improving agriculture through better tools

TABLE 4-8
IACA's Projected Rate of Mechanization
(percent of farm area covered)

Farm Size Group	% of Total Farm Area in Group	1975 Percent Mechanization	1985 Percent Mechanization	2000 Percent Mechanization
Farms above 25 Acres	40	20	50	85
Farms 5-25 Acres	50	4	10	30
Farms below 5 Acres	10	-	5	10
Total Farm Area	100	10	25	50

and equipment. Use of tractors and tractor-drawn equipment is expanding more rapidly but is still confined at present to a few larger farms; in the whole of West Pakistan, there are perhaps only about 6,000 tractors working on farms.

Mechanization will become more advantageous to farmers as cropping intensities increase. High cropping intensities mean tighter farming schedules and higher labor peaks, particularly in the overlap periods between seasons when harvesting and land preparation coincide. Mechanized cultivation is apparently not generally more expensive than bullock farming and has the additional advantages of setting free the land devoted to fodder. It also enables timely land preparation, which contributes to better crop performance. However, there are a number of factors restraining the expansion of mechanization. The farm-size problem and its financial implications have already been mentioned. In addition, land fragmentation and the tenure and share-cropping system are likely to be a substantial barrier to rapid mechanization. And the small size of individual fields (enclosed by irrigation bunds) presents a physical barrier to the efficient use of machinery. Furthermore, even on larger farms, the rapid adoption of mechanized farming would depend greatly on the existence of satisfactory service facilities, including adequate supply of spare parts and mechanics. Research is still needed to select the right types of equipment and to develop equipment better suited to local conditions.

For purposes of projection, IACA has developed a "rate of mechanization" based on a hypothetical percentage of farm area fully mechanized. This would not be the case in practice because mechanization is a progressive process. Initially, mechanization would be partial, concentrating on specific activities such as cultivation and land preparation. In its approach, IACA has taken this into account and has equated this with full mechanization on a reduced area. The coverage and rate of mechanization by farm size groups, as projected by IACA for reference years, are given in Table 4–8. The rate of mechanization is related to a hypothetical mechanization unit—a tractor with tilling and mowing equipment, seed drill and thresher, and a trailer and miscellaneous equipment. A mechanization unit costs about Rs. 25,000 and is capable of serving a cropped area of about 100 acres. For the reference years in Table 4–8, the area assumed to be mechanized would require about 33,000 such units in 1975, 83,000 in 1985, and 165,000 in 2000.

Livestock Development

Despite the great importance of livestock in total agricultural production in West Pakistan, the keeping of animals is haphazard: livestock plays a subsidiary role in the mixed farming system of the Province. The livestock population consists mostly of scrub animals with poor genetic qualities. Many of the animals are underfed and depleted. Indiscriminate breeding is widely practiced. The rural population appears to be fairly well supplied with milk and milk products, but effective distribution systems for making milk and milk products widely available in the towns are almost non-existent.

The projections in Table 4–8 imply that animals will continue for a long time to be the main source of power on the farm. Even after a farmer has introduced some mechanical equipment—usually for cultivation and threshing, at the early stages—he still requires bullocks for operations such as cane crushing and transport, and so it is only with a fuller degree of mechanization that he can dispense with work animals. Apart from the continuing need for animals for work, more livestock will be required for meeting the demand for milk and meat, a demand that is likely to grow rapidly as population and incomes grow. Moreover, as cropping intensities increase and work animals are called upon to do more work, and as improved animal husbandry results in production of more milk and meat per animal, the intake of fodder per animal will be greater.

The size of the existing livestock herd in West Pakistan is uncertain. Bench mark estimates were given in Table 4–2. IACA's projections are given in Table 4–9. An animal unit, as used in the table, is a common denominator equivalent in terms of total annual fodder consumption to one bullock. Draught animals are assumed to decline, in rough correspondence with the growth of mechanization, from about 12 million now to about 6 million in 2000. Bullocks are the main component of the animal work force and will remain so. In terms of total herd, the projected increase in cattle and buffaloes raised for milk production more than offsets the decline in the number of working bullocks. Sheep and goats are important sources of meat in West Pakistan; they also increase, though somewhat less rapidly than cows and buffaloes.

The main producers of milk in the Province at the present time are the 5.4 million buffalo cows. IACA projects continued growth in their number until about 1985, then a decline in accordance with IACA's recommendation to build up an improved herd of Zebu cows, which would eventually become the main source of milk in the Province. The buffalo is at present a greatly superior producer of milk; but as a heavy, late-maturing animal, the buffalo requires more food intake for growth and maintenance than the less heavy and earlier maturing Zebu cow. Moreover, the buffalo tends to be a seasonal breeder, resulting in long intercalving periods. There are promising dairy Zebu breeds in West Pakistan, such as Sahiwal in Punjab and Red Sindi in Sind; these would be used as the base of the new milk

TABLE 4-9
COMPOSITION OF PROJECTED LIVESTOCK POPULATION

	1965		1975		1985		2000	
	No. of Stock	Animal Units	No. of Stock	Animal Units	No. of Stock	Animal Units	No. of Stock	Animal Units
	(in millions)							
Work Animals:								
Bullocks, adults	7.4	7.40	6.6	6.60	5.6	5.60	3.7	3.70
followers	1.8	1.40	2.3	1.77	2.0	1.54	1.4	1.08
Horses, camels, etc.	2.4	1.20	2.1	1.05	1.8	0.90	1.0	0.50
	11.6	10.0	11.0	9.42	9.4	8.04	6.1	5.28
Milk/Meat Animals								
Bovines:								
Milk cow adults	4.4	3.32	3.8	3.11	3.0	2.52	2.0	1.78
Female followers	1.7	1.25	2.4	1.73	1.9	1.35	1.4	0.98
Milk zebu & followers	–	–	–	–	0.7	0.58	7.6	6.76
Buffaloes:								
Bulls & followers	3.1	3.19	6.4	6.08	10.9	9.92	8.4	7.22
Cows	5.4	6.53	6.9	9.35	9.6	12.97	7.0	10.74
Browsing Animals:								
Sheep & goats	17.0	2.77	20.1	3.16	24.7	3.82	27.2	4.15
Poultry:								
Existing desi	10.0	0.13	10.0	0.13	10.0	0.11	10.0	0.10
Improved stock	–	–	2.4	0.06	7.1	0.24	20.3	0.68
Total		17.9		23.62		31.51		32.41
Grand Total		27.19		33.04		39.55		37.69

herd, built up by a massive program of artificial insemination of existing cows. IACA's draft outline of such a program calls for a rapid expansion of the existing artificial insemination organization under the Directorate of Livestock Farms. IACA believes that the program should be started in the near future, since it may take 10 years to achieve significant progress.

The projections of total livestock population in Table 4-9 imply an increase of nearly 40 percent in animal units between 1965 and 2000. IACA measures animal feed in terms of Total Digestible Nutrients (TDN), which includes fodder, crop residues, and grazing. To feed this larger animal population, and to supply it with a gradually increasing feed intake over time, IACA has provided for expansion in the acreage of fodder crops: part of the increase in feed requirements would be met by crop residues; and anticipated improvements in pasture management and control would also help to supply some of the additional TDN consumed by the larger herds. The acreage under fodder in the canal-commanded areas, now some five million acres, would have to increase to 6.2 million acres in 1975 and 8.5 million acres by 2000. Total production of fodder (including that from areas outside the canal commands) would then double between 1965 and 2000. The consumption of TDN per animal unit would increase from an average of about 1,035 kilos at present to about 1,400 kilos by 2000; included in this would be enough digestible protein to ensure a reasonably balanced diet for the livestock.

Improved Farming, Physical Inputs and Water

So far, we have emphasized physical targets. But mere increases in quantities of agricultural inputs and herd numbers will not necessarily mean a commensurate increase in production of crops, milk and meat. Much depends on the quality of the inputs used and of the livestock herd developed. The Study Group's projections of development imply a steady improvement of quality—seed that is more disease-resistant and of higher germination rate, insecticides that are easier to apply and more effective, animals that produce more milk and meat per kilo of TDN consumed. Production and distribution facilities capable of inputs of improved quality to millions of farmers will have to be developed. And the Study Group believes that much more attention should be given to research, especially to research with a practical orientation.

If larger quantities of better-quality inputs are to be used to maximum effect, improvement of farming practices is essential; indeed, the Study Group believes that there is scope for large increases in production simply by improving farming practices. These improvements will probably come about largely as accompaniments to increased absorption of agricultural inputs and increased use of water. But, however they come, there is a basic need for a much improved and expanded extension effort, capable of providing better advice and assistance to large numbers of farmers. Extension work will be a very critical input, and certain measures—discussed later—are most urgently needed to improve the effectiveness of the extension service.

The reader may have noted that, in this chapter, discussion of agriculture precedes discussion of water supply. This focuses attention on the importance of the farmer. The Study Group believes that adoption of more advanced and efficient farming techniques, including use of modern physical aids to productivity, could lead to considerable increases in crop yields even with current water supplies. For this reason, pride of place in this chapter has been given to the main measures required in this direction. In the past, and still to some extent today, there has been a tendency in West Pakistan to overstate the importance of further public water development as a means of securing increased agricultural production and to understate the importance of improving farm practices and farm inputs. The evidence is that typical water applications may now be in the neighborhood of 80 percent of the full delta irrigation level (defined in Chapter III). The Study Group believes that this level of irrigation delta, even given the unreliability of supplies at certain critical times, is sufficient to support much greater use of other yield-improving inputs than presently obtains. Efforts to help farmers get better value from the water they now have are less spectacular than major construction works. In the Study Group's opinion, however, such efforts can contribute more in the immediate future to a broad improvement in farmers' productivity; and the importance of the people responsible for such efforts should be recognized.

Notwithstanding this opinion, the Study Group recommends that a major effort be made to increase and improve water supplies to farmers.

Uncertain irrigation supplies are a serious deterrent to investment and enterprise by farmers at present. Unless this situation is corrected, it will inhibit growth in the use of farm inputs. Water, moreover, is an accustomed input. Once it is available in adequate and reliable quantity, interest seems to quicken in other new means of increasing production. There are thus both technical and psychological complementarities between water and other inputs. Since few improvement measures can be taken in isolation, and maximum benefits can be obtained only from a balanced combination of water and other inputs, it is important to avoid thinking of developmental inputs in mutually exclusive terms. An integrated approach to development means calling upon all inputs to play their proper roles in reasonable balance at the appropriate time.

In conclusion, the projections of increasing absorption of nonwater inputs, though presented independently, are intimately interdependent with the water program presented below. The program as a whole applies to the period up to 2000, but the Study Group has been particularly concerned with the initial period 1965–75. This is a critical time in Pakistan's development effort; it is also a time for which plans can be more specific—in fact, the 1965–75 decade is already underway. (A full discussion of these problems is incorporated in Volume Two.)

B. IRRIGATION DEVELOPMENT

Third Plan Period (1965/66–1969/70)

With the importance of agriculture established, the basis of the near-term program for water development can be stated boldly: there is an urgent need in West Pakistan for more reliable and greater supplies of irrigation water. This would enable farmers to extend their cropped acreage and increase their water applications per acre cultivated, and improvements in water supply would also encourage them to absorb farm inputs in larger quantities.

Because surface water cannot be increased quickly above existing levels, there are only two important, immediately feasible ways by which irrigation needs can be even partially met within the Third Plan period—public tubewells and private tubewells.

In regard to public tubewells, WAPDA had under way, at the beginning of the period, a number of projects which added up to a construction program several times larger than what it has accomplished in the past. It is doubtful that this program can be fulfilled as scheduled. There is certainly very little scope for commencement of additional projects within the Third Plan period. There are four important ongoing public tubewell projects—SCARP II in Chaj Doab, SCARP III in Thal Doab, SCARP IV in Upper Rechna Doab and the Khairpur groundwater development project. Some 955 wells had been completed in SCARP II by the end of 1966; none had been completed in any of the other areas. Completion of all four projects will require installation of a further 7,183 wells. WAPDA's approximate schedule for completing these wells is shown in Table 4–10.

TABLE 4–10
SCHEDULE OF IMPLEMENTATION FOR THE ONGOING PUBLIC TUBEWELL PROJECTS
(numbers of wells completed)

Project	1966/67	1967/68	1968/69	1969/70	1970/71	1971/72	Total
SCARP II	420	630	418	307	100	-	1,875
SCARP III	240	570	495	165	-	-	1,470
SCARP IV	110	500	780	790	745	345	3,270
Khairpur	80	200	288	-	-	-	568
Total	850	1,900	1,981	1,262	845	345	7,183

IACA suggested deferment of 1,010 wells scheduled for the SCARP IV area, where there is already extensive private tubewell development. This deferment would considerably reduce the peak levels of installation for 1967/68 and 1968/69. Nevertheless, even with this adjustment, the remaining program would still amount to about 5,850 wells in three and a half years, an average of about 1,670 wells per year. This target rate compares to an average of about 450 wells per year completed between 1959 and 1966. About 1,000 wells were drilled in 1965/66 but only about 140 were electrified and brought into operation. As of early 1967, financial and contractual arrangements had not been made for about half the wells included in the table. Bringing 5,850 new public wells into effective operation before the end of the Third Plan would require increased financial allocations to WAPDA, removal of the constraints on electrification, establishment of proper inventory system and procurement schedules for electrical distribution equipment and supplies, and early creation of management cadres capable of putting tubewell fields into operation immediately upon completion. For these various reasons, the Study Group considers it doubtful that the ongoing program can be completed as scheduled —unless it is given exceptional priority and the status of an emergency operation.

If made a matter of urgency, the Study Group believes that completion of about 2,000 wells per annum should become feasible towards the end of the Third Plan. The program presented here foresees completion of

TABLE 4–11
ACTION PROGRAM FOR PUBLIC GROUNDWATER DEVELOPMENT DURING THIRD PLAN
(number of wells installed)

	1966/67	1967/68	1968/69	1969/70
SCARP II	420	590	615	580
SCARP III	270	520	465	215
SCARP IV	50	370	565	635
Khairpur	80	200	288	
Wagah			95	
Shorkot-Kamalia			100	326
Rohri North				140
Panjnad Abbasia				183
Total wells	820	1,680	2,128	2,079

TABLE 4–12
NEW THIRD PLAN PROJECT AREAS—TECHNICAL CHARACTERISTICS

	CCA Perennial / Non-perennial ('000 acres)	Water per Cropped Acre (a.f. per acre)		Water Quality and Depth (% CCA)		
				Less than 1000 ppm		Above 1000 ppm[a]
		Present	Required	less than 10 feet	more than 10 feet	
Shorkot-Kamalia	214/80	2.2	2.8	71%	5%	24%
Panjnad-Abbasia	59/819	2.5	3.5	73%	9%	18%
Rohri North	598/–	2.6	3.4	37%	38%	25%

[a] All groundwater of mixing quality, except for 13 percent of Shorkot-Kamalia area.

TABLE 4–13
NEW THIRD PLAN PROJECTS—PROPOSED DEVELOPMENT

	No. of Public Wells	Cropping Present	Intensity Proposed	Rate of Return to Project	Present Worth of Increase in Production (Rs mln.)	
					With Project	With Private Tubewells
Shorkot-Kamalia	426	92%	149%	21%	159	95
Panjnad-Abbasia	1,623	95%	148%	22%	596	288
Rohri North	1,580	95%	145%	16%	329	162

some 894 wells in projects additional to those included in WAPDA's ongoing program. Table 4–11 shows the Study Group/IACA Action Program for the final years of the Third Plan, including the additional projects, a revised WAPDA schedule for installation of the SCARP IV wells, and various other minor changes from WAPDA's schedule (Table 4–10). All projects, with the exception of SCARP III, Wagah and Shorkot-Kamalia, would continue into the Fourth Plan period. Wagah, the first of the additional projects, a small area (about 50,000 canal-commanded acres) will lose canal supplies when the Indus Treaty is fully implemented. It lies in the area of the Bambanwala-Ravi-Bedian-Dipalpur Link, as remodeled under the Indus Basin Works. It has in the past been served by the Upper Bari Doab Canal from the Ravi. Canal supplies in the BRBD Link are required for other areas and transfer of water from the Link into this area would anyway involve lift pumping and remodeling of the distributaries. The area is underlain by fresh groundwater and IACA estimates that the recharge to the aquifer from surface runoff and seepage from the adjacent link canal would be sufficient for tubewells alone to provide full-delta supplies for a cropping intensity of 150 percent.

The remaining three projects have been subjected to preliminary feasibility studies by IACA, and these reports have in turn been reviewed by the Study Group. The main technical characteristics of the areas in question and some details of the development proposed are shown in Tables 4–12 and 4–13. The location of the projects is shown on Map 3 at the end of the chapter. These projects were selected for early scheduling largely because they are in a more advanced stage of preparation than most other projects. Nevertheless, their priority was borne out to a strong degree of unanimity in the various analyses carried out by the Study Group and its consultants.

The Shorkot-Kamalia area, lying at the southern tip of Rechna Doab, includes areas of former river flood plain along the banks of both the Ravi and the Chenab. Part of the area has been irrigated since the 1890's by the Lower Chenab Canal, but much of it has only received perennial supplies in the last 30 years, chiefly under the small Haveli Project completed in 1939. It is part of a larger area where WAPDA has prepared a public tubewell project, SCARP V, covering the whole of Lower Rechna Doab. SCARP V would involve some 1.5 million acres with 2,300 wells; scheduled to start in fiscal 1967/68, it would complete the public tubewell coverage of Rechna Doab started with SCARP I and continued with SCARP IV. However, in the meantime, private tubewells have spread very rapidly in the Rechna Doab—there were an estimated 10,500 private wells in the area by 1965—and chances seem to be good for further rapid growth. To take advantage of this opportunity to ease the burden on the public sector, IACA suggested confining public tubewell development initially to the Shorkot-Kamalia portion of SCARP V. Rapid growth of private tubewells is less likely to occur in this sector, farming being less advanced there; moreover, there are very serious problems of soil salinity and waterlogging—some 25 percent of the CCA is saline and more than 25 percent of the CCA has a water-table depth of less than five feet—and private wells are unlikely to be able to cope adequately with these problems for a long time to come. Climatically, this area is well suited to cotton, but yields are low compared to other areas due to waterlogging and salinity; rice, the other important cash crop in the area, is more tolerant to waterlogging, but yields are again low because climatic conditions are unsuitable. Public tubewell development will help to deal with these pressing problems, will enable substantial immediate increases in irrigation supplies—three-quarters of the area is underlain by fresh groundwater—and will provide sufficient water-table control so that rabi deliveries from Tarbela, when they become available, can be absorbed without threat of further waterlogging. The tubewells required would all be installed within the Third Plan period.

To bring additional rabi surface supplies to the quarter of the project area not underlain by fresh groundwater, a small amount of canal remodeling will be required. Though not proposed for execution until the Fourth Plan, the canal remodeling was included in the cost base for calculating the rate of return on the whole project (Table 4–13).[1] For this reason, it is discussed here. The area for which enlarged canal capacity is required is mainly in the Haveli Canal Command. For the distributaries supplying the 11,000 acres underlain by groundwater of between 1,000 and 2,000 ppm TDS, IACA estimate that a capacity increase of about 30 percent will be adequate; the existing channels could be widened and deepened.

[1] Rates of return and priorities are discussed for each project in Volume Two and in Supplemental Paper No. 4, Volume Three.

But very much larger increases in canal capacity will be required in the 50,000 acres underlain by saline water or water that is to be mixed with large quantities of surface water; for these areas, IACA recommends construction of entirely new channels paralleling the existing ones. The area underlain by water that is totally unusable for irrigation purposes is relatively small—about 37,000 acres. IACA suggests that this would be an appropriate place for a pilot project in tile drainage; however, the costs of this work have not been included in the cost base of the project because it would be an experiment to test the feasibility of this type of drainage in the Punjab.

The Panjnad-Abbasia Project covers a much larger area than Shorkot-Kamalia. It would be started within the Third Plan but most of the tubewells would become operational in the early years of the Fourth Plan. The project area, which is adjacent to the confluence of the Indus with its Punjab tributaries, is one of the chief nonperennial areas originally developed as part of the Sutlej Valley Project. It typifies many of the advantages and disadvantages of that region. It has, in the past, suffered from severe water shortage because of unreliable river flows and low priority for surface water allocations. Crop-water requirements are high for the Punjab, because of the southern location, and current average irrigation supplies fall very seriously short of requirements (Table 4–12). The shortage and unreliability of water supplies is reflected in the cropping pattern, which has an unusually large component of drought-resistant coarse grains such as jowar and bajra. What water is available appears to be concentrated on the main crops—cotton, for which the area is very well suited, and wheat—and yields on these crops are comparable with yields obtained in the perennial areas of the Punjab. More than 80 percent of the project area is underlain by fresh groundwater, but private tubewells have so far grown slowly; an estimated 600 were installed by 1965, an average of only one well for nearly 1,500 acres of CCA. A small part of the project area is designated perennial; rabi surface supplies to this area may become somewhat more regular after completion of Mangla Dam, but otherwise the shortage and variability of irrigation deliveries will not be substantially altered by the Indus Basin Works. Apparently because of its location at a confluence of rivers, Panjnad-Abbasia suffers from a high water table—groundwater is within 10 feet of the surface in more than 80 percent of the area—and severe waterlogging. The proportion of the land affected by soil salinity varies between about 20 percent and 60 percent in different parts of the project area. According to the Study Group's calculations, public tubewells, supplemented by some additional rabi surface deliveries from Tarbela after the groundwater table has been brought under control by public wells, would enable full irrigation supplies to be provided for an intensity of 148 percent by 1985; private wells, on the other hand, as far as can be foreseen, would only be able to support an intensity of about 114 percent at that date. Hence, as indicated in Table 4–13, the increase in the net value of agricultural production with public wells, in present-worth terms, is anticipated to be more than twice the increase attainable with private wells.

To enable attainment of 150 percent cropping intensity over the whole of the project area, canal remodeling would be required in about 100,000 acres underlain by groundwater of mixing quality. There are also extensive areas with saline groundwater and high water table adjacent to the project area where, IACA estimates, canal remodeling could increase water supplies sufficiently to support a cropping intensity at full-delta irrigation of 150 percent, compared to a present level of 82 percent. The economic analyses carried out by the Study Group and its consultants suggested quite high priority for this work. However, before additional surface water could be absorbed, it would be necessary to provide drainage for these high-water-table areas. The most economical form of drainage for the area, IACA believes, would be tubewells discharging into channels that would dispose of the water in the neighboring Thar Desert. This scheme would need considerable investigation before it could be undertaken; but, in conjunction with remodeled canals for the saline area and surface storage to provide the necessary rabi supplies, it would enable large increases in irrigation supplies and agricultural output. Within a few years of public tubewells commencing irrigation in the fresh groundwater zones in the area, drainage probably would have to be provided in the saline zones to prevent migration of saline water and consequent contamination of the fresh groundwater aquifer. Thus drainage and related canal remodeling for the saline zones in the Panjnad-Abbasia area are foreseen in the development program for the Fifth Plan (1975–80), and, as a start, canal remodeling for the mixing zone of Panjnad-Abbasia is proposed for the end of the Fourth Plan. Neither the costs nor the benefits of this work, however, are included in the Panjnad-Abbasia Tubewell Project presented.

Rohri North is one of the most promising areas of the Sind, located on the left bank of the Indus immediately south of the ongoing Khairpur tubewell project. The area is designated perennial. Irrigation supplies, which are drawn from Sukkur Barrage, vary relatively little from year to year. Rohri Canal is in fact often run somewhat above its design capacity. However, irrigation supplies are inadequate for the acreage now cropped: while the canal was designed for a kharif cropping intensity of 27 percent, the existing kharif intensity is about 36 percent. The area includes some of the most extensive areas of fresh groundwater in the Sind. Nevertheless, private tubewells are very few and farming is generally backward. It is estimated that about 60 percent of the farm area or nearly three-quarters of the farms are operated by sharecropping tenants. The landowners generally live away from their lands, and apparently in many cases take little interest in their farms. The main cash crops are cotton in summer and oilseeds in winter, but relatively small acreages are devoted to them. However, crop yields are rather above the very low averages representative of the Sind. IACA believes that the average cropping intensity could be increased from its current level of about 95 percent with underwatering to about 145 percent with full watering by installation of a public tubewell scheme and some slight additional surface supplies at times when canal capacity is not a constraint. Tubewells alone could provide sufficient water, in combination with current canal deliveries, to reach 150 percent intensity in almost all the fresh groundwater areas. The average intensity will be held down by the mixing zones where intensities will be severely limited until canal remodeling is accomplished. Because it will be exceptionally complicated as a result of the scale of the Rohri Canal, canal remodeling is not recommended by IACA until the Fifth Plan period. Since surface salinity is not a widespread problem in this area, additional water supplies could be used immediately to grow more crops rather than for land reclamation. And while waterlogging is not a serious problem in most parts, 40 percent of the area has groundwater within 10 feet of the surface; the water-table control provided by the public tubewells will be valuable. Despite the generally favorable technical conditions for private tubewell development, the prevailing situation is such that private wells are unlikely to spread rapidly. Nevertheless, the Study Group tested the proposed public project against an accelerated introduction of private tubewells (which were assumed to grow from about 100 in 1965 to about 2,200 in 1975). The public project appeared more attractive than the private project, producing twice as much in terms of present value of the increase in agricultural production. In practice, however, private tubewells might develop rapidly in certain confined areas—for instance, in blocks where groundwater is fresh and well below the surface. These desirable areas cover nearly 40 percent of the project area and the Study Group thinks that serious attention should be given to the possibility of encouraging private development there. The public effort could be concentrated initially in the hydrologically more complicated parts of the project area.

The Study Group believes that the proposed public tubewell program, including initiation of the three projects mentioned above, is at the outside limits of what can be accomplished during the Third Plan period. This emphasizes the crucial need for continued rapid growth of private tubewells. The contribution from the public program alone will be inadequate to support the needed growth of agricultural production—the growth that West Pakistan must have to achieve a high overall growth rate in provincial output. While the public tubewell program was falling very far short of expectations, despite the high priority it was accorded, private tubewell development with little Government support was achieving an impressive record of progress: for example, private tubewells added more irrigation supplies during the Second Plan period than the public efforts as a whole. In view of relative performance, the need to ration public resources, the urgency of improving agricultural growth, and the desirability of fostering private initiative amongst farmers, a lack of emphasis on continued private development, at least for the time being, would appear inconsistent with the needs of the situation.

IACA's projection of private tubewell installation appears modest in the light of past experience. Their figures, adjusted in the light of information for 1965, would suggest that private tubewells would increase from about 34,000 in 1965 to about 55,500 in 1970. In their projection, IACA made allowance for the fact that public wells will gradually be replacing private wells—the announcement of a forthcoming public tubewell project will tend to slow down the installation of new private wells in the area.

In absolute terms, the IACA figures imply a drop in the average annual increase from more than 5,000 wells during the Second Plan to slightly more than 4,000 wells in the Third. Preliminary estimates indicated that between 1965 and 1966, in the northern zone alone, private well installations exceeded 8,400, of which about 7,900 were apparently new wells and the remainder replacements. While there may be a gradual slowing down of private tubewell development, and while some areas may be approaching a "saturation point," it is reasonable to expect that further extension can be brought about by public stimulation and encouragement, as envisaged in the Third Five Year Plan documents. Assuming that active support for private development is forthcoming and that any undue competition by public groundwater development is carefully avoided, the Bank Study Group sees no reason why the installation rate achieved towards the end of the Second Plan period, about 6,500 wells per year, should not be maintained during the Third Plan period. This would bring the total number of private wells in operation to 66,500 by 1970.

The need for such development is emphasized by Table 4–14. This shows the maximum contributions to irrigation supplies in 1969/70 that can be expected from both the public and private tubewell programs—the public program as rescheduled—and the number of private wells projected by IACA. The pump output is then compared with the amounts of groundwater required to meet irrigation requirements under mean-year conditions. About 9,000 of the private wells projected by IACA for 1969/70 would be located outside the canal commands. The private wells within the CCA should deliver about 9 MAF. Even with the maximum number of public wells—assuming the recommended program were fully adhered to—there would still be a shortfall in groundwater in 1969/70, as compared to the requirements calculated by sequential analysis. It would appear, therefore, that continued private groundwater development on about the scale presently experienced is imperative in the short run if the essential growth in agricultural production is to be

TABLE 4–14
GROUNDWATER PUMPED DURING THIRD PLAN IF ACTION PROGRAM IS CARRIED OUT

	1965/66		1969/70	
No. of Tubewells in Operation	Canal Commanded Area	Outside Area	Canal Commanded Area	Outside Area
Public	2,900	-	9,600	-
Private	29,000	5,000	46,500	9,000
Estimated annual pumpage in MAF				
Public	2.7	-	10.2	-
Private	7.0	1.0	9.0	1.8
Total	9.7	1.0	19.2	1.8
Private as percent of total	72%	100%	47%	100%
Requirement as calculated in the sequential analysis	9.6	-	21.7	-

achieved. The Study Group would strongly suggest that the Pakistan authorities implement policies conducive to rapid private tubewell development as a matter of urgency. The improvement of existing institutional support, in particular credit facilities, technical advice, and counsel for cooperative ownership and utilization, should be given high priority. Financial resources required for such support would be small compared to the extra cost of an over-extended public tubewell program and savings to the public sector accruing from the ability to forego imports by producing more food at home.

The Study Group's proposed program contains two other major public projects in the water sector which are recommended for commencement before the end of the Third Plan period. One is the Sukh Beas Drainage Scheme, for which IACA has prepared a project report on the basis of a proposal by the Government of Pakistan. The other is the Left Bank Outfall Drain, proposed by LIP for the Sind but for which no project report is yet available. Both are large projects which will take many years to execute, especially the Left Bank Outfall, and it is important to start them early.

The purpose of the Sukh Beas Scheme is to permit reclamation of waterlogged lands and to prevent further waterlogging and flood damage caused by surface runoff in the upper and central parts of the Bari Doab. The main element of the project would be the canalization of the old bed of the Beas River. But a substantial part of the cost would be in the extension and remodeling of branch drains discharging into Sukh Beas. The course of the proposed 327-mile-long drain runs from Kasur in Lahore District diagonally across Bari Doab to the Chenab River near Jalalpur Pirwala in Multan District. The catchment area is about 3.3 million acres bordering on the Dipalpur, Pakpattan and Mailsi canals on the east, and the Lower Bari Doab main canal on the west. The drain would have a discharge capacity of 462 cusecs at the head and 2,263 cusecs at the tail. Construction, including completion of field drains, is estimated to take nine years. IACA estimated the agricultural benefits of the project by comparing flood damage with and without surface runoff drainage. In this way IACA has established, on the basis of agricultural benefits alone, a rate of return of about 15 percent and a benefit/cost ratio of 1.8. The Bank Study Group considers the project to be of high priority. It would help protect crops in one of the most productive areas of the Province and would support private as well as (later) public tubewell development. To the extent that the reduced flooding would reduce the recharge to the groundwater aquifer, the project would also contribute to the control of the water table in large parts of Bari Doab.

The Left Bank Outfall Drain, the first stage of a large drainage complex proposed by LIP for the Sind, would carry some surface runoff, particularly from areas south of Nawabshah (see Map 1 in Chapter I), but its main purpose would be to remove to the sea saline subsoil drainage water from the greater part of the Indus Left Bank south of Sukkur. It would have an overall length of 257 miles stretching from near Khairpur to the Rann of Kutch, and would provide a maximum discharge of 15,000 cusecs. The cost has been estimated by the LIP consultants at Rs. 610 million, exclusive of the branch and lateral drainage system. The massive scale of the works in this project, involving construction over some 16 years, necessitates an early start; also effluent disposal works would need to be available by the time drainage wells in saline groundwater areas come into operation. For these reasons, the Bank Study Group concurred with LIP's proposal for construction to start in 1968. This meant a rapid program of studies and site investigations.

The Fourth Plan Period (1970/71–1974/75)

The principal objectives of irrigation development in the Fourth Plan period, as during the Third Plan, must be to supply more water to the farmers in areas where it can be used to greatest immediate advantage and to deliver it to the land in a manner suited to the crop calendar. Subsidiary to these objectives, but not without importance, are two considerations directly related to Tarbela, which is due to be completed at the end of the Fourth Plan. First, the drainage capacity of the land, and especially areas with a high water table, needs improvement before additional supplies of irrigation water can safely be accepted on a long-term basis. Second, irrigation developments should be consistent with gradual movement towards the integrated use of all water resources, which will become increasingly important in later years when water resources are more fully used.

In public tubewell development during the Fourth Plan, the first job will be to complete the projects started before 1970. According to the recommended program for the Third Plan, four projects will be ongoing in 1970: SCARP II, SCARP IV, Rohri North and Panjnad-Abbasia. In these four projects alone, more than 4,800 wells will need to be completed during the Fourth Plan. If these projects are assured of completion on schedule, then consideration would be given to further projects. If, in addition, private-well performance goes well and WAPDA seems able to commit itself firmly to completion of an average 2,200 wells a year, then the Study Group recommends the schedule presented in Table 4–15 as worthy of serious consideration. However, the Study Group believes that further experience with private development may well justify some rephasing of this program. Detailed project preparation, which normally takes about two years before the start of construction work and therefore three years before the first wells come on stream, will have to proceed apace. The Study Group's analysis indicates that highest priority in the preparation of Fourth Plan projects should be accorded to Rohri South, Fordwah Sadiqia and Bahawal Qaim. Decision on the Bari Doab projects—Dipalpur, Shujaabad and Ravi Syphon-Dipalpur—should be made in the light of further experience with private development. The Sukkur Right Bank and Begari Sind projects, both in the Lower Indus, would appear appropriate for execution late in the Fourth Plan. These projects are shown on Map 3 at the end of the chapter.

The Fordwah Sadiqia and Bahawal Qaim projects, which are contiguous with one another as well as with Panjnad-Abbasia, constitute a narrow strip of land, not more than about 20 miles wide, extending some 200 miles

TABLE 4–15
ACTION PROGRAM FOR PUBLIC GROUNDWATER DEVELOPMENT DURING FOURTH PLAN
(number of wells installed)

	1970/71	1971/72	1972/73	1973/74	1974/75
SCARP II	305				
SCARP IV	600	600	450		
Rohri North	360	360	360	360	
Panjnad-Abbasia	540	500	400		
Dipalpur above BS Link	130	360	140		
Shujaabad	165	360	200		
Ravi Syphon-Dipalpur Link		170	360	250	
Fordwah Sadiqia			150	360	155
Rohri South			230	360	360
Bahawal Qaim				210	360
Begari Sind				180	360
Dipalpur below BS Link				90	360
Sukkur Right Bank					180
Initiation of New Projects				180	540
	2,100	2,350	2,290	1,990	2,315

along the left bank of the Sutlej River. IACA defined the project to include parts of four canal commands, originally developed under the Sutlej Valley Project, which, largely because of their proximity to the river, are underlain by usable groundwater. Like other parts of the Sutlej Valley Project, these areas suffer from inadequate and unreliable canal deliveries. Although conditions are quite suitable for private groundwater development, the installation of private wells has not compared with the pace in the neighboring Bari Doab. Supplemental supplies from private tubewells were reaching about 10 percent of the canal-irrigated area in 1965, by IACA's estimates. The standard of farming and average crop yields are also somewhat below those in Bari Doab. Though the area is very suitable for cotton, only about 7–8 percent of the canal-commanded acreage is devoted to this crop; and average cotton yields are some 15–30 percent below the average of the main cotton-growing areas of the Punjab. Drought-tolerant jowar and bajra are important kharif crops, especially in Bahawal Qaim. Coarse rice has become important in Fordwah Sadiqia because of the high water table—within 10 feet of the surface over more than half the project area—despite climatic conditions which are not very favorable. As a result of under-irrigation and high water tables, there are areas of severe salinity; the problem is worse in Fordwah Sadiqia, where nearly 17 percent of the land is believed to be waterlogged waste and where additional areas are affected by soil salinity. Table 4–16 gives some details of the existing technical conditions and the proposed public tubewell development in the two areas.

The analysis of development potentials is in terms of private versus public development. With nearly two-thirds of each area underlain by fresh groundwater, the Study Group believes that the number of private tubewells installed in each area might, in the absence of public development, increase some 300 percent by 1975 and 400 percent by 1985. In neither case would private tubewells be able to pump more than about half of

TABLE 4–16
PROPOSED NEW FOURTH PLAN PROJECT AREAS—SUTLEJ LEFT BANK

Technical Characteristics	CCA Perennial / Non-perennial ('000 acres)	Water per Cropped Acre (a.f./acre)		Groundwater Quality and Depth (% CCA)		
				Less than 1000 ppm		Above 1000 ppm
		Present	Required	less than 10 feet	more than 10 feet	
Fordwah Sadiqia	61/298	2.0	3.0	32%	34%	34%
Bahawal Qaim	167/355	2.2	3.1	7%	57%	36%

Proposed Development	No. of Public Wells	Cropping Intensity		Rate of Return to Project	Present Worth of Increase in Production (Rs mln.)	
		Present	Proposed		With Project	With Private Tubewells
Fordwah Sadiqia	665	81	145	30%	302	87
Bahawal Qaim	924	85	146	34%	431	117

annual recharge. This characteristic has different implications for the two areas. For Fordwah Sadiqia, with its already high water table, it would be imprudent to deliver any more surface water, when it becomes available from Tarbela. There is less of a deterrent in the case of Bahawal Qaim, where the water table is below 10 feet over more than 90 percent of the area. And according to IACA's judgment, substantial quantities of Tarbela water could safely be delivered to Bahawal Qaim. In that case, with private tubewell development, Bahawal Qaim might be raised to a full-delta cropping intensity averaging 125 percent by 1985; Fordwah Sadiqia could only be raised to about 96 percent by that time. Public tubewell development, on the other hand, would raise both areas to cropping intensities in the neighborhood of 145 percent average; for Bahawal Qaim this would also leave available for use elsewhere most of the Tarbela water required for private development. Economic analysis reflects these technical differences. All tests concurred in showing high priority for the Fordwah Sadiqia project. But the benefits of the Bahawal Qaim project were found to be sensitive to assumptions regarding the feasibility of altering surface water allocations and regarding the value of surface water released from the project area. In the proposed program, the project is scheduled for completion at a time when the overall availability of surface water would be a less severe constraint; so that the rate of return given in Table 4–16, which includes the benefits from the saving in surface water, is to some extent an overstatement. The Study Group therefore concluded that Fordwah Sadiqia was a priority project for early execution and that Bahawal Qaim, while fully worthy of inclusion in the program, should be scheduled one year later.

In the Lower Indus area, the recommended program includes three tubewell projects for initiation during the Fourth Plan period. One, Rohri South, is of relatively high priority and proposed for commencement early in the Plan, and two, Begari Sind and Sukkur Right Bank, are of

TABLE 4-17
PROPOSED NEW FOURTH PLAN PROJECT AREAS—LOWER INDUS

Technical Characteristics	CCA Perennial/ Non-perennial ('000 acres)	Water per Cropped Acre (a.f./acre)		Groundwater Quality and Depth (% CCA)		
				Less than 1000 ppm[a]		Above 1000 ppm
		Present	Required	less than 10 feet	more than 10 feet	
Rohri South	528/–	2.6	3.5	4%	72%	24%
Begari Sind	–/349	2.4	3.2	90%	10%	–
Sukkur Right Bank	232/41	3.1	3.2	58%	1%	41%

Proposed Development	No. of Public Wells	Cropping Intensity		Rate of Return to Project	Present Worth of Increase in Production (Rs mln.)	
		Present	Proposed		With Project	With Private Tubewells
Rohri South	1,500	83	132	23%	342	118
Begari Sind	880	80	150	14%	180	41
Sukkur Right Bank	820	111	150	16%	178	52

[a] Less than 1,200 ppm in case of Begari Sind.

somewhat lower priority and presently scheduled later in the period. Table 4–17 gives some details regarding these project areas and the development proposed. The Rohri South project area, over 500,000 acres of CCA, covers the lower half of the existing Rohri Canal Command on the left bank of the Indus; it extends from the site of the proposed Sehwan Barrage to Hyderabad. The area shares many of the same problems as Rohri North (discussed in connection with the Third Plan): very heavy dependence on share-cropping; prevalence of absentee landlords; canal supplies that are fairly reliable, since they come from Sukkur, but very inadequate in total quantity; and almost complete lack of private tubewell development. Rohri South actually fares somewhat worse than Rohri North for canal supplies, partly as a natural consequence of being at the tail of the Rohri Canal and partly due to problems of siltation and canal regime. The water shortage restrains the rabi intensity, which is lower here than in the North, and it causes water applications in kharif to be below the optimum. Crop water requirements in the area are relatively high because of its southerly location. Nevertheless the area has some advantages. Problems of waterlogging and salinity are minimal, being confined to barely 2 percent of the area. Three-quarters of the irrigated land is underlain by fresh groundwater; the remainder by water between 1,000 and 2,000 ppm, which by definition can be mixed with surface supplies. Rohri South has the reputation of being the best cotton area in the Sind and nearly a quarter of the land is sown to cotton each year; yields, at about 2.8 maunds of lint per acre, are not high but they compare favorably with other parts of the Sind. Oilseeds, mainly for export to East Pakistan, and wheat are the main rabi crops; yields on these crops too are relatively high. It is clear that the main irrigation need in this area is simply for increased supplies of water.

Water supplies can be greatly increased merely by installing tubewells, but this is one of the areas where even in the fresh groundwater zones tubewells alone will not provide sufficient water for 150 percent intensity at full delta. Canal remodeling is planned in connection with the Sehwan-Manchar Project in the 1980's. In the meantime, the proposed public tubewell project could raise the project area to 132 percent intensity. Maximum effort should be made in the years before it starts—construction could start in 1970—to get private enterprise to install wells in the extensive areas that are technically suited for private well development. Should private development succeed, then the Study Group would suggest the public project be redesigned and limited to the areas less well suited for private development.

Begari Sind and Sukkur Right Bank areas, on the right bank of the Indus and adjoining each other at the city of Sukkur, contrast in many respects with Rohri South. From a technical point of view, they belong to a slightly later stage of development: the main need in these areas is for drainage, though more reliable water supplies could also help; and in both areas there are very extensive areas which, heavily ravaged by salt, will need a major reclamation effort. The projects include the usable groundwater portions of the canal commands in this area: most of Sukkur Right Bank is commanded from Sukkur; the Begari Sind area gave up a reliance on inundation canals with the completion of Gudu Barrage in 1962. Coarse rice is the most important single crop in both areas, especially in Sukkur Right Bank where it occupies about 95 percent of the acreage cultivated in kharif. The standard of rice husbandry is relatively good. Although average rice yields are among the highest in the Province, they vary greatly among farms, mainly due to the uncertainty of water supply and shortage of labor at the critically important transplanting stage. In Begari Sind, in the past, inundation canal supplies were not adequate to meet highly peaked requirements of rice but water supplies were put to maximum use by planting cotton, which requires about the same total quantity of water but spread over a much longer period. Cotton yields were very low, however, and have remained so partly because of the predominantly high water table conditions. As the water table is lowered, and better seed, improved plant protection and more fertilizer come to be used, IACA believes that cotton will probably become a relatively more attractive crop; a large increase is projected for acreage devoted to cotton, with a reduction in the acreage devoted to coarse rice. However, substantial increases in cropping intensity will only come about with reclamation. Some 35 percent of Sukkur Right Bank and 45 percent of Begari Sind are totally unused at present, mainly because of severe soil salinity, and much of the land that is cultivated is affected by yield-reducing salinity. Eventually it will be possible, without any canal remodeling, to make the nonperennial portions of the project areas perennial and to raise the annual cropping intensity to 150 percent. But the process will inevitably be slow. And the returns to these public tubewell projects are rather low compared to some others recommended. Private tubewells, on the other hand, appear incapable of providing adequate water-table control—and their productivity

TABLE 4-18

POSSIBLE NEW FOURTH PLAN PROJECT AREAS—BARI DOAB

Technical Characteristics

	CCA Perennial/ Non-perennial ('000 acres)	Water per Cropped Acre (a.f./acre)		Groundwater Quality and Depth (% CCA)		
				Less than 1000 ppm		
		Present	Required	less than 10 feet	more than 10 feet	Above 1000 ppm
Dipalpur above BS	–/372	2.1	2.6	54%	38%	8%
Shujaabad	33/346	2.4	3.2	65%	15%	20%
RSD Link	595/–	1.5	2.3	10%	33%	57%
Dipalpur below BS	–/611	2.2	2.6	8%	51%	41%

Public Development

	No. of Public Wells	Cropping Intensity		Rate of Return to Project	Present Worth of Increase in Production (Rs mln.)	
		Present	Proposed		With Project	With Private Tubewells
Dipalpur above BS	630	74	150	25%	150	150
Shujaabad	725	95	149	31%	259	178
RSD Link	780	113	150	25%	301	301
Dipalpur below BS	850	83	150	36%	192	192

would likely be only a fraction of productivity with public development. Water-table control is needed here more urgently than almost anywhere else; whether this can begin to be provided during the Fourth Plan will depend greatly on the rate at which WAPDA can speed up its execution of tubewell projects and the extent to which private enterprise can take over development in areas sutiable for private wells.

There are four areas in the Bari Doab that have been identified as possible projects for inclusion in the Fourth Plan. They include some two million acres of CCA, about one-third of the total in the Doab, but almost two-thirds of the area having groundwater within 10 feet of the surface. The most northern of the project areas, Ravi Syphon-Diapalpur Link Command, includes within its boundaries the city of Lahore; it is one of the oldest areas of canal irrigation in the Province, having been supplied in the past mainly from the Upper Bari Doab Canal (called the Central Bari Doab Canal in Pakistan since Partition) with headworks at Madhopur on the Ravi. It is a perennial area. As the name of the area implies, the canal which commands it represents the last stretch of the Bambanwala-Ravi-Bedian-Dipalpur Link; and after 1970, it will draw all surface water supplies from the Chenab through this Link. Of the three remaining project areas, most is nonperennial and, apart from some 250,000 acres supplied from Sidhnai Barrage, it is almost entirely within the area on the right bank of the Sutlej which, after 1970, will also depend entirely on the links for surface water supplies. Table 4–18 gives some details of the four areas and of the public development projects studied. Except in the Ravi Syphon-Dipalpur Link Command, with its perennial canal supplies, existing cropping intensities are low compared with the

Bari Doab average of 102 percent. Nevertheless, in all these areas, very substantial private tubewell development has taken place: in 1965, there was an average of one private well to about 400 or 500 acres; and private wells together with Persian wells supplied an estimated quarter to a third of total water supplies—and, of course, a much higher proportion in the rabi season. Some 20–25 percent of the land in each area is receiving supplemental supplies from private tubewells. Half to two-thirds of the rabi-cropped acreage is devoted to wheat. Fodder is important in both seasons in all the project areas, but especially in Ravi Syphon-Dipalpur Link and Shujaabad because of their proximity to the major cities of Lahore and Multan, respectively, where fodder is required for Tonga horses, etc. Rice, mainly of low quality, and cotton are the two other important kharif crops. As waterlogging and salinity are removed, the different canal commands will probably distinguish themselves more clearly, those in the North increasing their cotton acreage and devoting more land to fine rice, which is much more profitable than coarse rice but susceptible to soil salinity, and those in the South concentrating to an even greater extent than they do now on cotton in kharif.

There is every prospect that private tubewells will continue to develop rapidly in the Bari Doab. The Study Group believes that, even in these somewhat more difficult areas which have been delineated as possible projects, private tubewells might spread, given proper stimulus, rapidly enough to reach an average density of one well for about every 120 acres by 1975. This would represent a considerably faster rate of private well development than envisaged by IACA. The Study Group also believes that private tubewells at this density would be able to pump annual recharge in all the project areas except Shujaabad. And even in Shujaabad, the private wells might be able to provide sufficient water-table control to permit absorption, as in the other areas, of the same amount of additional surface water, mainly in rabi, as could be absorbed with public groundwater development. The result would be that average cropping intensities could be raised, entirely by private groundwater exploitation, to about the same level as could be reached with public groundwater development, except in Shujaabad where the full-delta cropping intensity would be limited to about 126 percent. Yield growth would not be expected to differ much with public or private groundwater development, provided that sufficient effort were made to support the growth of private tubewells with an expanded agricultural extension service, credit, and improved supply of fertilizer, better seed, etc. Thus, the increase in production with private tubewell growth at this rapid rate should be of the same order of magnitude as with a public tubewell project, as implied by Table 4–18.

The real prospects of this kind of private development—most likely differing somewhat among canal commands—will become clearer towards the end of the Third Plan. Even if the prospects turn out most favorable, there will still remain a large amount of irrigation work to be undertaken by the public sector in the Bari Doab during the Fourth Plan. The main construction work on the Sukh Beas Drainage Scheme (see discussion of the Third Plan) will take place during the Fourth Plan. Attainment of a

150 percent cropping intensity in Ravi Syphon-Dipalpur Link Command, with public or private tubewells, will depend on canal remodeling in some 330,000 acres underlain by groundwater which is either unusable or requires mixing; because this canal command is in one of the old perennial areas, canal capacity is severely limited. An anomaly is that all analyses agree in giving especially high priority to canal remodeling in the mixing zones, although the restraining effects of canal capacity on growth of cropping intensity would be much less severe there than in the unusable groundwater zones.

Whether or not the full public projects outlined are undertaken, the four project areas will need varying degrees of public assistance in the improvement of irrigation, based on technical considerations. According to most of the technical and economic analyses, the area least in need of a public tubewell scheme was Dipalpur below the Balloki-Suleimanke Link. Some 60 percent of the area is underlain by fresh groundwater and the remainder by usable groundwater. Canal capacity is already sufficient to provide enough water, in conjunction with tubewell supplies, to reach an effective average cropping intensity of 150 percent. Soil salinity is confined to very small areas. The water table is less than 10 feet from the surface in only about 28 percent of the area, which is considerably less than in the other proposed projects. While recognizing that it might be preferable to postpone public development of this project, IACA proposed that the portion of the project area with a high water table might be brought under public development earlier; alternatively, early public development might be required to secure proper mixing in the 40 percent of the area underlain by groundwater between 1,000 and 3,000 ppm, which also contains most of the land with high water table. Dipalpur above the Balloki-Suleimanke Link is more seriously affected by high water table—within 10 feet of the surface over some 55 percent of the area and perhaps as much as 70,000 acres effectively waterlogged—but almost the entire area is underlain by fresh groundwater which can be directly used. There, the greater problem—solution to which will certainly require public assistance—is reclamation of salt-affected land; a large portion of the project area is affected by salinity and, while simple addition to water supplies will help to deal with this, about 125,000 acres will require major reclamation efforts if the projected cropping intensities are to be reached. In the Ravi Syphon-Dipalpur Link, to the west, soil salinity is much less widespread but 45 percent of the area is underlain by groundwater of mixing quality and 12 percent by groundwater in excess of 3,000 ppm; the consequent need for canal remodeling, already referred to, is essential at a later stage, probably soon after 1975, and drainage by shallow tubewells or by tile drains will be required. Shujaabad, situated at the confluence of the Ravi and Chenab, suffers severely from high water table—within 10 feet of the surface over about three-quarters of the area and about 100,000 acres effectively waterlogged. In about 20 percent of the area, groundwater would require mixing. Nevertheless, private development has been rapid and there would appear to be considerable opportunities for its extension. Therefore, the Study Group concluded that, while the prevalence of high water table and the extensive areas affected by salinity might be dealt with most effectively by a public project, with its more efficient drainage capability, this area, like the other areas selected in the Bari Doab, might be prudently omitted from the public tubewell program if that program had to be cut back.

Finally, the Study Group notes that all recommendations for the Fourth Plan period were derived from various basinwide and project-specific analyses—and all of the indicated priorities could not be accepted. The basinwide economic analyses, using standardized data for each potential project area, suggested that high priority for public groundwater development should be attached to certain areas not included in the final recommended program. However, a number of reasons argued for exclusion of these areas—such as lack of data or doubt about the validity of the data used, uncertainty as to the feasibility of the development recommended by the economic analysis, and the use of areal units which were impractical to develop alone or which included areas of relatively low priority along with areas of very high priority. The economic analyses gave high priority, for instance, to the small Peshawar Canal Commands—largely due to the high-value crops which are widely grown there. In the recommended program, development in these areas was deferred until after 1975 because sufficient knowledge is lacking about aquifer conditions in the area and because available evidence suggests that well drilling is difficult there. The economic analyses also tended to show quite high priority for public tubewell development in the canal commands in the Thal and Indus Right Bank area—Thal, D.G. Khan and D.I. Khan (Paharpur). For these areas, too, data are severely deficient; moreover, the canal systems in these areas are still under development and natural conditions are not very favorable to irrigated agriculture. Extensive land leveling is required in Thal before efficient use of surface water supplies will become possible, and the sandy soils have poor water-retention qualities. Infrastructure, such as communications and markets, are only now under development, and the areas are thinly populated. Some of the analyses suggested priority for much wider areas in Lower Rechna Doab and Lower Bari Doab than have been included in the final program; large portions of these areas were excluded not because they have poor potential but precisely because they have such good potential that extensive groundwater exploitation will likely be undertaken by private enterprise. The small southerly portions of these areas where rapid private development seems less likely—Shorkot-Kamalia in Rechna and Shujaabad in Bari Doab—were tentatively included in the recommended program, but with reservations in the case of Shujaabad as discussed above.

While the tubewell projects constitute the most critical part of the recommended public investment in irrigation development during the Fourth Plan period, accounting for some 50 percent of the cost, canal remodeling and drainage projects should be categorized and included as part of the Plan. The canal remodeling is primarily for the purpose of supplying the additional quantities of surface water required in several areas where mixing is required, but partly it is to increase supplies in contiguous saline areas where tile drainage would be introduced simultaneously. Some

TABLE 4–19

SPECIFIC PROJECT PROPOSALS—CANAL REMODELING & TILE DRAINAGE

Canal Remodeling	('000 acres)	Tile Drainage	('000 acres)
Khairpur East & West	454	Shorkot Kamalia	40
Panjnad-Abbasia	100	Lower Bari Doab	70
Ravi Syphon-Dipalpur Link	330	Tando Bago	90
Lower Bari Doab	70	Khairpur East	120
Shorkot-Kamalia (Haveli)	60	Kalri Baghar	30
	1,014		350

of these projects were discussed in connection with the tubewell projects: canal remodeling in Panjnad-Abbasia, Ravi Syphon-Dipalpur Link and Shorkot-Kamalia and tile drainage in Shorkot-Kamalia. The surface drainage schemes, Sukh Beas and Lower Indus Left Bank, on which considerable expenditures would be incurred in the Fourth Plan period, were also discussed earlier in connection with the Third Plan. Both of these projects are proposed for starting as soon as possible, say, 1968. There would also be a number of other minor canal and drainage works which are ongoing. None of the specific proposals in canal remodeling and tile drainage listed in Table 4–19 could be underway until about 1969 and therefore have been included for execution during the Fourth Plan period.

Both canal remodeling and tile drainage are recommended for Khairpur as an extension of the ongoing public tubewell project there. The economic analyses showed higher priority for canal remodeling elsewhere, but practical considerations recommend execution of this work. After the Khairpur Project was started, much of the groundwater was found to be less saline than had been anticipated, so it can be used for irrigation provided it is mixed with surface water. IACA agreed with the LIP consultants that Khairpur, with a project team and facilities already there, would be a good place for a first attempt at the difficult task of large-scale canal remodeling in the Sind. The program also includes tile drainage accompanying canal remodeling in a small area—some 70,000 acres—at the head reach of the Lower Bari Doab Canal; this project is intended primarily as a pilot project in tile drainage in the Punjab. The other two areas listed for tile drainage are in two Ghulam Mohammed Barrage commands in the Sind; the projects proposed are essentially pilot projects in this type of drainage, which may later become very important in the extensive saline groundwater zones of the Sind.

The recommended program for the Fourth Plan period also includes a small allocation of Rs. 75 million for flood protection works. IACA's analysis suggested that there was no justification for major works designed solely to provide protection from floods. Nevertheless, they recognized the need for some works—especially because, as development proceeds, the damage that can be done by floods will become more severe. The specific projects undertaken will be guided by the work of the West Pakistan Flood Commission which is preparing a flood control plan for the Province.

The possibility of continued rapid growth of private tubewells in

TABLE 4-20
GROUNDWATER PUMPING DURING FOURTH PLAN IF ACTION PROGRAM IS CARRIED OUT

	1969/70		1974/75	
	Canal Commanded Area	Outside Area	Canal Commanded Area	Outside Area
No. of tubewells in operation				
Public	9,600	-	20,700	-
Private	46,500	9,000	38,500	14,000
Estimated annual pumpage in MAF				
Public	10.2	-	21.7	-
Private	9.0	1.8	8.5	2.8
Total	19.2	1.8	30.2	2.8
Private as percent of total	47%	100%	28%	100%
Requirement as calculated in the sequential analysis	21.7	-	31.0	-

several areas also deserves comment. The main new private tubewell investments during the Fourth Plan are expected to occur in the portions of Bari and Rechna Doabs not included in the public program and in the Indus Right Bank and Lower Indus regions. Considerable replacement investment might also be required in areas already covered by private tubewells and not brought within the public program. In areas where public tubewell programs are carried out, private tubewells probably would not be replaced as they wear out. Therefore, according to Study Group estimates, the total number of private tubewells in existence in 1975 might, on balance, be no larger than the number existing in 1970.

The final test of the proposed program for 1970–75 is whether the combined contribution of public and private wells, assuming implementation of all proposed public tubewell projects on schedule, meets projected requirements for irrigation water. Table 4–20 indicates that the proposed program can provide sufficient water. Public and private wells together would be pumping an amount of groundwater close to what IACA projected as annual recharge in usable groundwater zones by 1975—34 MAF. The more than 20,000 public tubewells in operation would cover nearly 12 million acres of canal commanded area, or more than 40 percent of the total, and nearly 70 percent of the usable groundwater zones. The 38,500 private wells within the canal commands might cover at least another 3.5 million acres, so that more than 90 percent of the usable groundwater area would be receiving additional irrigation supplies from tubewells.

THE FIFTH PLAN PERIOD (1975/76–1979/80)

The completion of Tarbela in the first year of the Fifth Plan, following the extensive public and private tubewell developments proposed for the Third and Fourth Plan periods, would create a situation in which irrigation supplies could be matched to the water requirements of crops to a

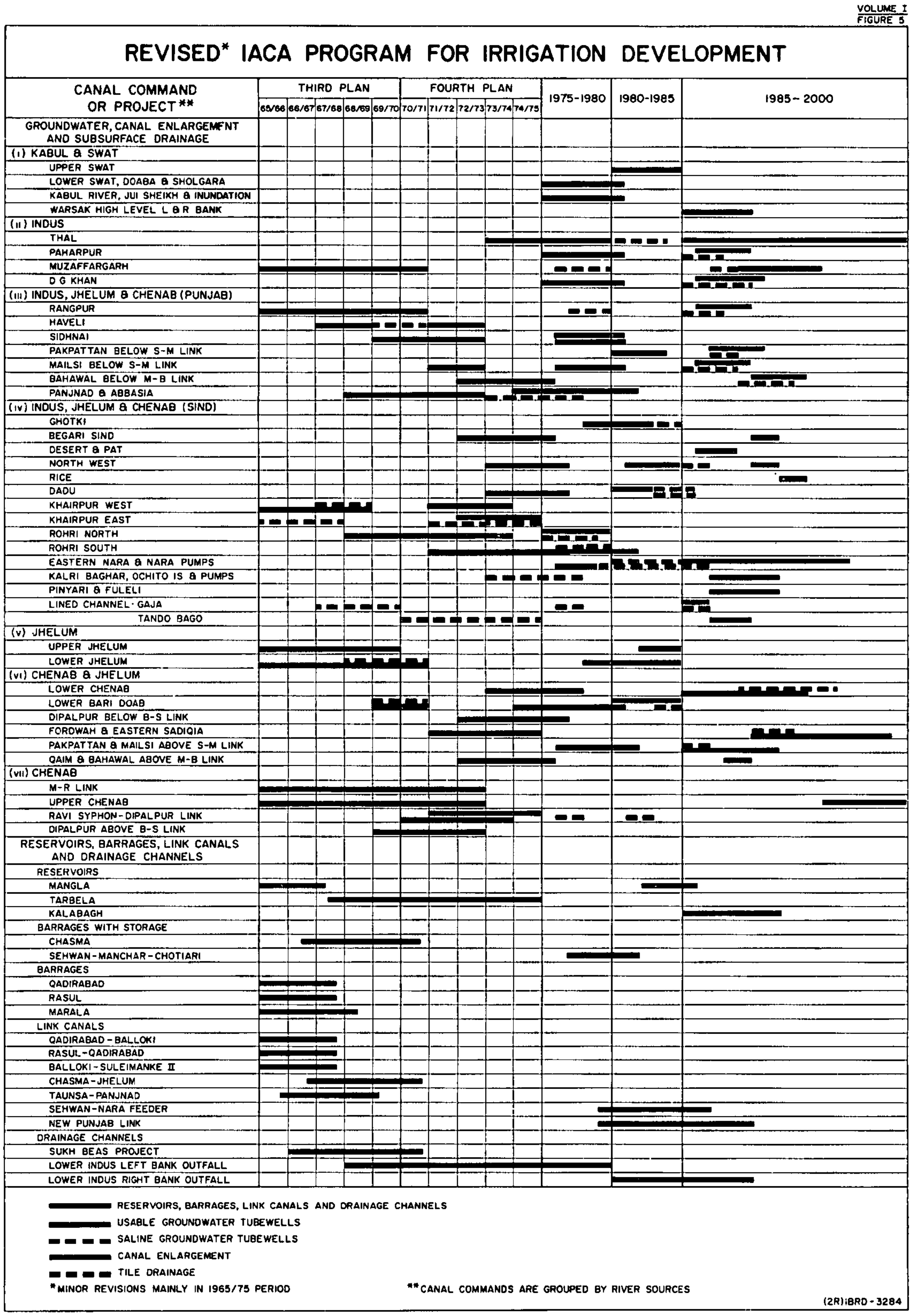

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FIGURE 5
REVISED* IACA PROGRAM FOR IRRIGATION DEVELOPMENT
CANAL COMMAND OR PROJECT**
THIRD PLAN
FOURTH PLAN
65/66 66/67 67/68 68/69 69/70 70/71 71/72 72/73 73/74 74/75
1975-1980
1980-1985
1985-2000
GROUNDWATER, CANAL ENLARGEMENT AND SUBSURFACE DRAINAGE
(i) KABUL & SWAT
UPPER SWAT
LOWER SWAT, DOABA & SHOLGARA
KABUL RIVER, JUI SHEIKH & INUNDATION
WARSAK HIGH LEVEL L & R BANK
(ii) INDUS
THAL
PAHARPUR
MUZAFFARGARH
D G KHAN
(iii) INDUS, JHELUM & CHENAB (PUNJAB)
RANGPUR
HAVELI
SIDHNAI
PAKPATTAN BELOW S-M LINK
MAILSI BELOW S-M LINK
BAHAWAL BELOW M-B LINK
PANJNAD & ABBASIA
(iv) INDUS, JHELUM & CHENAB (SIND)
GHOTKI
BEGARI SIND
DESERT & PAT
NORTH WEST
RICE
DADU
KHAIRPUR WEST
KHAIRPUR EAST
ROHRI NORTH
ROHRI SOUTH
EASTERN NARA & NARA PUMPS
KALRI BAGHAR, OCHITO IS & PUMPS
PINYARI & FULELI
LINED CHANNEL · GAJA
TANDO BAGO
(v) JHELUM
UPPER JHELUM
LOWER JHELUM
(vi) CHENAB & JHELUM
LOWER CHENAB
LOWER BARI DOAB
DIPALPUR BELOW B-S LINK
FORDWAH & EASTERN SADIQIA
PAKPATTAN & MAILSI ABOVE S-M LINK
QAIM & BAHAWAL ABOVE M-B LINK
(vii) CHENAB
M-R LINK
UPPER CHENAB
RAVI SYPHON-DIPALPUR LINK
DIPALPUR ABOVE B-S LINK
RESERVOIRS, BARRAGES, LINK CANALS AND DRAINAGE CHANNELS
RESERVOIRS
MANGLA
TARBELA
KALABAGH
BARRAGES WITH STORAGE
CHASMA
SEHWAN-MANCHAR-CHOTIARI
BARRAGES
QADIRABAD
RASUL
MARALA
LINK CANALS
QADIRABAD-BALLOKI
RASUL-QADIRABAD
BALLOKI-SULEIMANKE II
CHASMA-JHELUM
TAUNSA-PANJNAD
SEHWAN-NARA FEEDER
NEW PUNJAB LINK
DRAINAGE CHANNELS
SUKH BEAS PROJECT
LOWER INDUS LEFT BANK OUTFALL
LOWER INDUS RIGHT BANK OUTFALL
RESERVOIRS, BARRAGES, LINK CANALS AND DRAINAGE CHANNELS
USABLE GROUNDWATER TUBEWELLS
SALINE GROUNDWATER TUBEWELLS
CANAL ENLARGEMENT
TILE DRAINAGE
*MINOR REVISIONS MAINLY IN 1965/75 PERIOD
**CANAL COMMANDS ARE GROUPED BY RIVER SOURCES
(2R)IBRD-3284

much greater extent that has heretofore been possible. Irrigation supplies should then become adequate to increase the cropped acreage at full delta, including the conversion to full perennial cropping of nonperennial areas where canal capacities, recharge to the aquifer, or groundwater quality are inadequate to permit this to be done by groundwater development alone. By 1975 public and private tubewells would have begun to reduce the water table in extensive areas where sustained application of increased surface supplies would otherwise cause a danger of waterlogging. Tarbela water would also play an important part in raising cropping intensities in the 12 designated tubewell project areas to the full 130–150 percent attainable without canal remodeling (e.g. see Appendix 6–1, Volume Two). It would be particularly important in the zones with groundwater of mixing quality. According to IACA projections, all the tubewell project areas, barring Sukkur Right Bank, would absorb Tarbela water—though the amount absorbed initially in 1975/76, when additional drainage pumping will still be required and intensities will still be below the ultimate attainable, will be less than what will be required later.

New projects for the Fifth Plan have not been studied but some probable lines of priority can be foreseen. First priority would attach to completion of the public tubewell projects initiated in the Fourth Plan period. Also, public tubewell development probably should be carried further, especially in some of the usable groundwater zones that were not included in the previous programs. In addition, installation of tubewells for drainage purposes in saline zones might start on a large scale. Canal remodeling will become much more important with the increase in supplies during the critical overlap months, made possible by Tarbela as well as the substitution of groundwater for surface water in some of the tubewell project areas with fresh groundwater. Figure 5 illustrates the main lines of activity in different areas suggested for this later period.

According to the schedule for the proposed public tubewell projects, there would remain some 2,300 wells to be completed in the first two years of the Fifth Plan period. Table 4–21 shows the number of wells involved in each area. With the final completion of these tubewells, some 5.8 million acres of canal-commanded area would have been brought under public tubewell development by the projects specifically identified in the course of the Study. Of the total 5.8 million acres, some 4.1 million acres would be in fresh groundwater zones, 1.5 million acres in zones underlain by groundwater of mixing quality and 0.1 million acres in saline zones. In some 50 percent of the area covered by the projects, groundwater would be pumped initially from a depth of less than 10 feet, indicating the concentration of the projects in areas with usable groundwater and high water table. The total pumping capacity installed in the projects would amount to about 37,000 cusecs, designed to extract about 12.6 MAF at full development; full agricultural development would generally be reached within about 10 years of completion of well electrification but somewhat later in areas with very low initial cropping intensities or heavy reclamation needs.

Besides the wells required to complete Fourth Plan projects, IACA believes an additional 13,000 public wells might be installed during the

TABLE 4–21
COMPLETION OF PROPOSED TUBEWELL PROJECTS IN FIFTH PLAN PERIOD
(number of wells completed)

	1975/76	1976/77
Rohri South	360	190
Bahawal Qaim	354	
Begari Sind	340	
Dipalpur below BS Link	360	40
Sukkur Right Bank	360	280
	1,774	510

Fifth Plan period. Some 4,000 of these would be in saline groundwater areas, particularly in the Rohri Canal Command and in the Thal and Indus Right Bank area. Drainage wells would be provided for the saline zones in areas where the usable groundwater zones were developed in the Third and Fourth Plan periods—the Panjnad-Abbasia and Ravi Syphon-Dipalpur Link areas. New projects in usable groundwater zones, to the extent of perhaps 9,000 wells, have been proposed by IACA for the Fifth Plan period. These wells fall into two rather different categories. Some would be in areas such as Thal, D.G. Khan and D.I. Khan canal commands, where three-quarters of the area is underlain by usable groundwater, but where agricultural prospects are somewhat less bright than in the longer established farming areas; in the meantime, there is much infrastructure to be built. Some of the Peshawar commands are also proposed for development in this period. But emphasis would be on the areas such as Lower Bari and Lower Rechna Doabs that had before been left for private development. On IACA's proposed schedule, by the end of the Fifth Plan in 1980 there would be only a few small areas with usable groundwater not developed by public wells—notably Upper Swat, Warsak and parts of Pakpattan and Ghotki. This schedule reflects IACA's belief that public wells are generally more efficient than private wells, and that the complexities of integrating water supplies, water-table control, and drainage require public operation in the long term. The Study Group believes these arguments are weighty but it also thinks private wells might become sufficiently dense and well-organized in some areas to provide reasonable water-table control and some degree of integration with the overall irrigation system, so that preservation of private exploitation could be worthwhile. The Study Group recommends that this question should be left open for resolution after more experience has been gained about the full capabilities of private groundwater development, and so it concludes that some of the proposed 9,000 public wells in new projects may not be required in the Fifth Plan period.

Enlargement of canals serving about two million acres is foreseen for the Fifth Plan. Some of this would be in areas of saline groundwater, but most would be in areas where the increased canal supplies could be used in conjunction with groundwater. Apart from the small amounts of canal remodeling proposed in connection with tubewell projects discussed above, IACA, in accord with the economic analyses, attributes highest priority for major canal remodeling in the Punjab to Panjnad-Abbasia. Without canal enlargement, large parts of the mixing zones in this area would be constrained to about 120 percent cropping intensity. Therefore, continuation of canal remodeling in this area and extension of the work into the adjacent saline zones would be an important part of the Fifth Plan development. Another important area for canal remodeling in this period covers some 500,000 acres in Sidhnai which were not included in the Shujaabad Project proposed for the Fourth Plan; here, canal remodeling would be undertaken simultaneously with the installation of irrigation tubewells. Another priority area, where the canals were also originally designed to provide perennial surface supplies, is Rohri South, where a tubewell project was proposed for initiation in the Fourth Plan; as pointed out earlier, groundwater development alone would enable attainment of a full-delta cropping intensity of only about 130 percent.

THE SIXTH PLAN PERIOD (1980/81–1984/85)

By 1980, virtually all areas of usable groundwater should be covered by tubewells and high cropping intensities would have already been attained in many of these areas. Attention would then swing increasingly towards areas underlain by groundwater too saline for irrigation use. Installation of drainage tubewells would continue at a rapid pace—5,000 wells over the following five years, canals serving some three million acres would be enlarged, the Left Bank Outfall Drain (proposed for initiation in 1968) would be completed, and work would commence on the other large-scale drainage project proposed by the LIP consultants—the Right Bank Outfall Drain. In addition, the Sehwan-Manchar Project (cf Chapter V) would be completed in the Sind; and a new link canal would be built across the Punjab to provide sufficient water for remodeled canals in zones of saline and mixing quality groundwater in the eastern Punjab.

With the completion of the first stage of the Sehwan Barrage in 1980, the canal remodeling and drainage works in Rohri South accomplished during the Fifth Plan would come to fruition. The LIP consultants had proposed an earlier date for completing first-stage Sehwan, but IACA found that substantial development could be achieved in the Rohri Command, given the availability of Tarbela water, simply by the installation of tubewells in the usable groundwater zones, as proposed for the Fourth Plan period. Moreover, the benefit from canal remodeling in the saline zones of Rohri depends on the installation of drainage tubewells and, as set forth in the programs for the Third and Fourth Plans, the capacity to install wells could first be used to greater advantage in more productive zones. By 1980, however, the necessary expansion of canal capacity would have been executed and, in conjunction with Sehwan Barrage, a new feeder from Sehwan to the Rohri Canal would have been built to bring water to the enlarged canal. By 1982, the storage potential of the Sehwan Barrage and the neighboring Lake Manchar would have been developed. During the Sixth Plan period, drainage wells and tile drains would be installed in Nara further to the east and after 1985 the feeder would be extended from Rohri to Nara.

The major "outfall" drains mentioned above are also in the Sind. The Lower Indus Left Bank Outfall Drain was discussed in connection with the Third Plan; the Right Bank Drain, which would be built between 1980 and 1990, would serve the Gudu and Sukkur Right Bank areas and drain their effluents into the Indus, downstream of Sehwan Barrage. The Sind would also benefit from canal remodeling and either tubewell or tile drainage in the saline zones of the Sukkur Right Bank canal commands, and public tubewell development in Ghotki. The Ghotki area, something of an exception in the Sind, was omitted from the program for public development in earlier years because it is underlain by usable groundwater over 10 feet below the surface and it was felt that there were good prospects of private tubewell growth in the area. However, the water table appears to have been rising quickly, mainly as the result of too much surface water, and thus the case for planned public development becomes stronger.

Development in the Punjab would be closely related to construction of the new trans-Punjab Link which IACA recommends for initiation around 1980. Without such a new Link, the possibility of increased canal deliveries in the Punjab, and hence the feasibility of development in the extensive saline and mixing zones in the eastern Punjab, would be severely restricted. IACA proposed construction of a new canal with a capacity of about 1.5 MAF/month; the general alignment would be across the Punjab, running from the tail reach of the Chasma-Jhelum Link, crossing the Chenab in the vicinity of Chiniot, and leading ultimately into the Sutlej. Besides providing increased surface supplies for the eastern Punjab, such a link would add to the flexibility of the irrigation system—much land that had previously been commanded solely from the Jhelum-Chenab would then be also under the command of the Indus. As the construction of this link proceeds, it will be possible to provide increased canal supplies further eastward. Because of the importance of this link, the Study Group would stress the need for careful preparatory work, especially of alignments. Also for the Sixth Plan period, IACA recommends remodeling in saline and mixing zones in Chaj and Lower Bari Doabs. Remodeling in the Sutlej commands would come later as the Link was extended there.

IRRIGATION DEVELOPMENT AFTER 1985

Development foreseen after 1985 would consist almost entirely of canal remodeling projects, drainage tubewells and tile drains, plus the introduction of public irrigation tubewells in Warsak High Level commands. Looking to the year 2000, the main objective of the program would be to remodel canals serving some 10 million acres, bringing the total area provided with enlarged canal capacity to some 16 million acres. The emphasis would be on zones with water of poorer quality. Apart from some important areas, such as Sidhnai and Rohri which have already been discussed, where enlarged canal capacity is required to provide sufficient water for a 150 percent cropping intensity, most of the areas proposed for canal remodeling have groundwater in excess of 1,000 ppm.

The canal remodeling program proposed—which would increase the aggregate canal withdrawal capacity by some 40 percent to about 19 MAF/month—is the minimum believed necessary to achieve cropping intensities of about 150 percent in perennial areas and 95 percent in those few areas likely to remain nonperennial (or an average of 145 percent for the development CCA of 29.4 million acres). Remodeling on this scale, coupled with surface storage sufficient to meet the higher of the two sets of requirements projected by IACA (see Chapter V) would by the year 2000 result in the complete diversion of mean-year river flows into the irrigation system. Any water that enters the sea in a year of mean inflow would be essentially derived from saline drainage effluent discharged either through the river channels or through the Left Bank Outfall Drain.

Thus the proposed canal remodeling program does not include any enlargement of canals for the purpose of developing the underground storage potential of fresh groundwater zones. This type of development, mentioned in Chapter II as an alternative to surface storage, was investigated by IACA. They concluded that it might be adopted in the long term but they did not include it in the program. Since the fresh groundwater areas are mainly confined to the Punjab, development of underground storage of any scale would necessitate major link canal construction in addition to that proposed for the Fifth Plan. There would also be difficult hydraulic problems in operating such an enlarged canal system, because of wide variations in canal flow.

The Growth of Irrigation Supplies

IACA projected the irrigation water requirements implied by its program for agricultural development for 1975, 1985 and 2000, on the basis of mean-year water supplies at watercourse head. The estimated need for water would increase from 68 MAF in 1965 to 94 MAF in 1975, 117 MAF in 1985, and 135 MAF in 2000. As outlined in this chapter, it is possible to foresee a program of water development which would meet these requirements. Table 4–22 shows the quantity and relative contributions of surface and groundwater. The percentage contribution from groundwater is expected to more than double over the first 10 years. Thereafter, the ratio between the water sources would remain fairly con-

TABLE 4–22
Relative Use of Surface and Groundwater Measured at Watercourse Head

Reference Year	Surface Water		Groundwater		Total MAF
	MAF	Percent	MAF	Percent	
1965	58	85	10	15	68
1970[a]	56	75	19	25	75
1975	63	68	31	32	94
1985	77	66	40	34	117
2000	91	67	44	33	135

[a] The estimate for 1970 was derived from sequential analysis data, with some adjustment for surpluses occurring during rabi period and the effect of the adopted pumping pattern (including pumping needed for lowering of water table in project areas) on surface water use.

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FIGURE 6

PROJECTED USAGE OF AVAILABLE SURFACE WATER IN THE INDUS RIVER BASIN OF WEST PAKISTAN

(FLOWS, WITHDRAWALS – MAF)

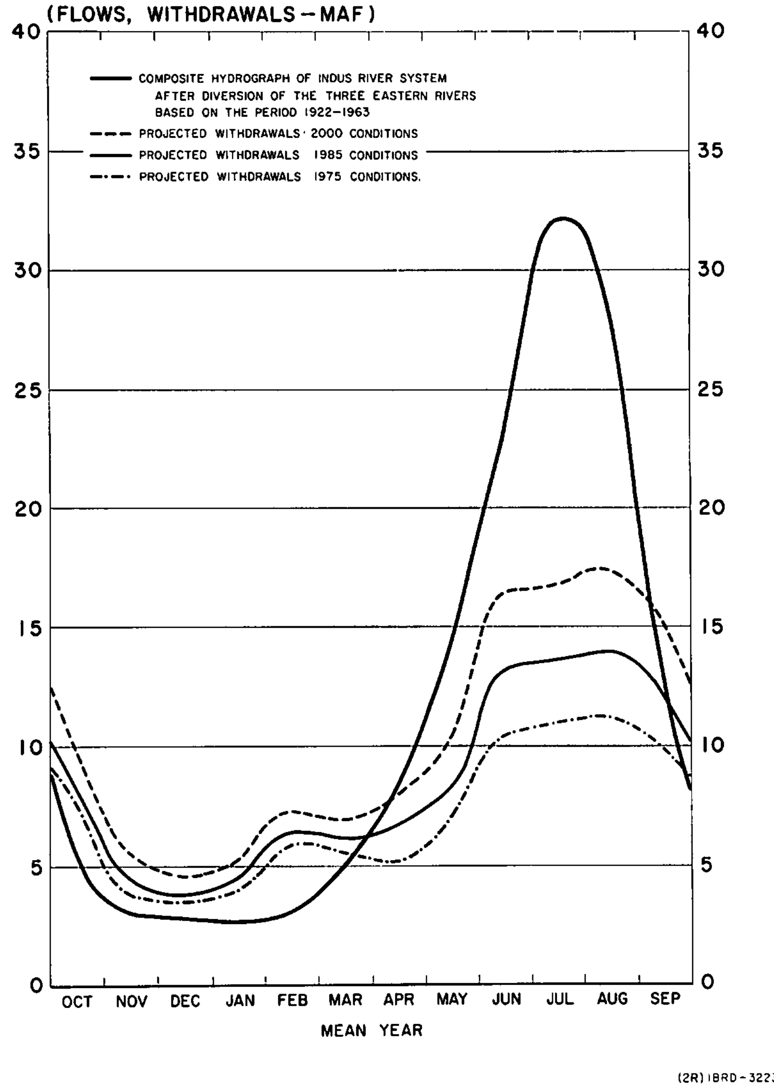


TABLE 4–23
WATERCOURSE DELIVERIES TO MAIN SECTORS OF INDUS BASIN
(MAF/Year)

Reference Year	Vale of Peshawar		Punjab		Sind		Total (rounded) MAF
	MAF	Percent	MAF	Percent	MAF	Percent	
1965	1.7	2.5	40	59.5	26	38	68
1975	1.9	2	61	65	31	33	94
1985	2.8	2.5	75	64	39	33.5	117
2000	2.8	2	85	63	47	35	135

stant because, with balanced recharge pumping, permissible pumping becomes proportional to surface supplies. From 1975 to full development, the increment in canal supplies follows canal enlargement and includes the amounts that would be available from surface storage reservoirs (cf Chapter V). The contribution of private tubewells to the total groundwater abstraction in the CCA, although rising in absolute terms from five to eight MAF in the decade 1965–75, would fall percentagewise from about 50 percent to about 25 percent, and would fall still lower in later years as public wells supersede private ones. Figure 6 compares projected growth of surface water usage with mean flows.

The distribution of total watercourse deliveries between Peshawar, the Punjab and the Sind, illustrated in Table 4–23, would remain fairly constant over time, although the Punjab areas would take a slightly increasing share in the early period. Tables 4–22 and 4–23 can be reconciled, so to speak, by noting the forecast change in the geographical distribution of groundwater. In 1965, groundwater accounted for nearly 25 percent of irrigation supplies in the Punjab and a negligible quantity elsewhere. From about 1975 onward, groundwater would account for over 40 percent of total irrigation supplies in the Punjab and about 12 percent in the Sind.

C. Expected Results of Development

On the basis of the general strategy and programs discussed heretofore, it is possible to construct estimates of agricultural production for the reference years. Projections of this kind—for a rural sector where subsistence farming is still an important element and depending on benchmark data of varying degrees of accuracy—are indicative at best. They are particularly difficult for West Pakistan, with its large territory and its great variation in farm sizes, tenure arrangements, climatic conditions, and degrees of irrigation development. The Study Group's projections are summarized in Table 4-24.

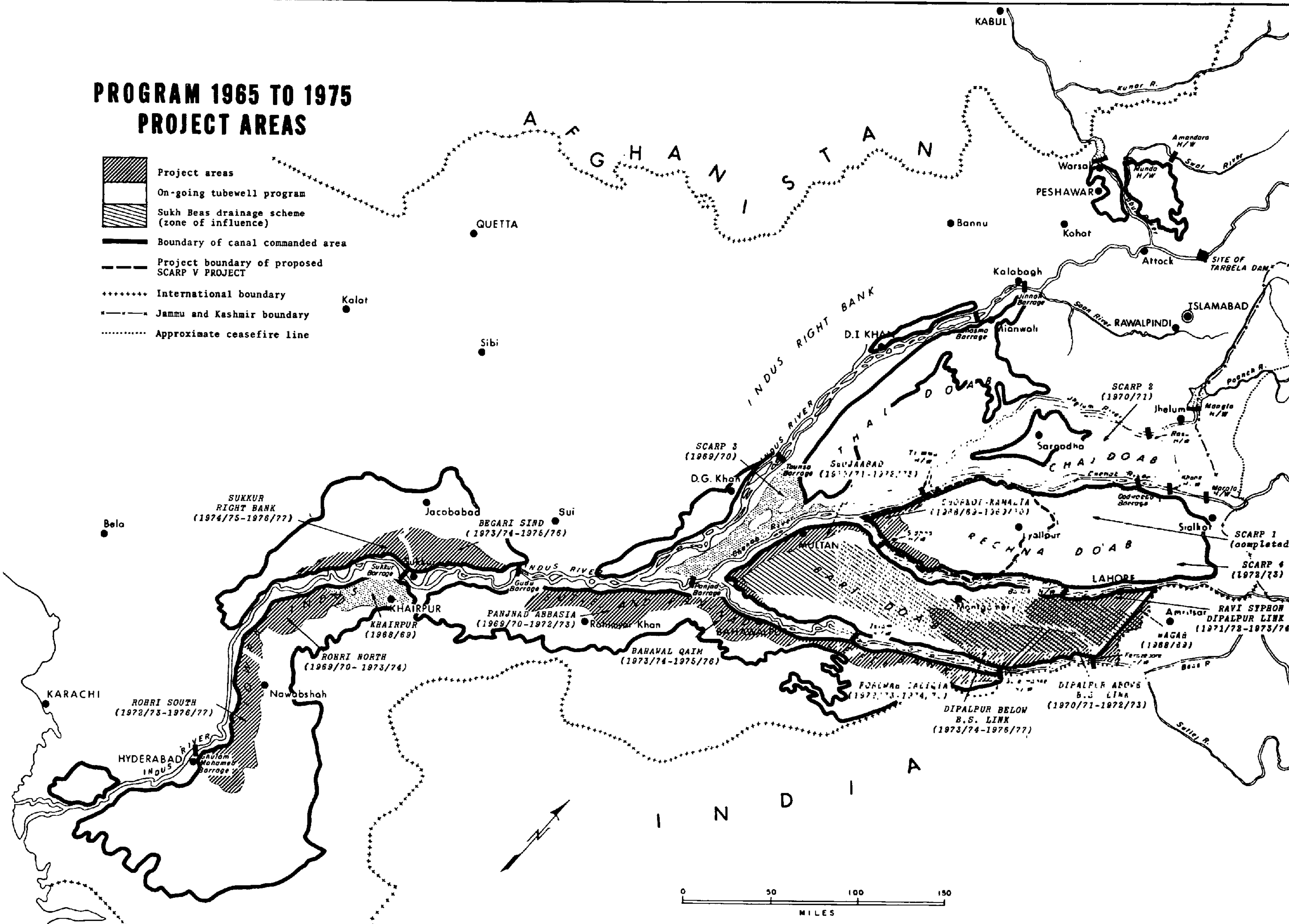
For purposes of projecting output, the production data for different regions were aggregated into four major types of area as follows:

1. Ongoing project areas—the CCA within the Indus Basin where groundwater development projects have received sanction under Government planning procedures and are already scheduled for implementation (5.5 million acres CCA).

TABLE 4–24
PROJECTION OF GROWTH OF AGRICULTURAL PRODUCTION[a]

	CCA	1965		1975		1985		2000	Average Growth Rate (1965–2000)
		Cropped Acreage							
Acreage (in million acres)									
Ongoing Project Areas	5.53	5.03	(4.1)	7.51	(1.0)	8.29	(0)	8.29	1.4%
IACA Project Areas	5.76	5.27	(2.7)	6.89	(2.0)	8.40	(0)	8.42	1.4%
Deferred Project Areas	18.35	18.05	(1.3)	20.39	(1.6)	23.85	(0.9)	27.53	1.2%
Subtotal—Canal Area	29.64	28.35	(2.1)	34.79	(1.5)	40.54	(0.6)	44.24	1.3%
Outside Areas	–	12.37	(0.6)	13.05	(0.6)	13.76	(0.3)	14.45	0.4%
Total	–	40.72	(1.6)	47.84	(1.3)	54.30	(0.5)	58.68	1.0%
Yield (in terms of Rupees of GPV per acre cropped)									
Ongoing Project Areas		261	(3.7)	375	(4.0)	551	(2.2)	760	3.1%
IACA Project Areas		227	(2.8)	299	(4.6)	469	(3.3)	760	3.5%
Deferred Project Areas		236	(3.4)	330	(3.5)	469	(3.3)	760	3.4%
All Canal Area		239	(3.4)	334	(3.9)	486	(3.0)	760	3.4%
Outside Areas		156	(3.3)	216	(3.5)	305	(3.2)	493	3.4%
All Areas		214	(3.5)	302	(3.9)	440	(3.0)	695	3.4%
Total Gross Production Value (Rs. billions)									
Ongoing Project Areas		1.30	(8.0)	2.82	(5.0)	4.57	(2.2)	6.30	4.6%
IACA Project Areas		1.19	(5.6)	2.06	(6.7)	3.94	(3.3)	6.40	4.9%
Deferred Project Areas		4.27	(4.7)	6.74	(5.2)	11.19	(4.2)	20.92	4.7%
Subtotal—Canal Area		6.77	(5.5)	11.62	(5.4)	19.70	(3.6)	33.62	4.7%
Outside Areas		1.93	(3.9)	2.81	(4.1)	4.19	(3.6)	7.15	3.8%
GRAND TOTAL		8.70	(5.2)	14.43	(5.2)	23.90	(3.6)	40.77	4.5%

[a] Figures in parentheses represent average growth rates in the respective periods in percent per annum.


PROGRAM 1965 TO 1975
PROJECT AREAS
Project areas
On-going tubewell program
Sukh Beas drainage scheme (zone of influence)
Boundary of canal commanded area
Project boundary of proposed SCARP V PROJECT
International boundary
Jammu and Kashmir boundary
Approximate ceasefire line
AFGHANISTAN
INDIA
KABUL
PESHAWAR
Warsak
Kohat
Attock
SITE OF TARBELA DAM
Bannu
QUETTA
Kalat
Sibi
Kalabagh
ISLAMABAD
RAWALPINDI
Mianwali
D.I KHAN
INDUS RIGHT BANK
INDUS RIVER
THAL DOAB
SCARP 2 (1970/71)
Jhelum
Sargodha
CHAJ DOAB
SCARP 3 (1969/70)
D.G. Khan
Taunsa Barrage
Sialkot
SCARP 1 (completed)
SCARP 4 (1972/73)
LAHORE
RECHNA DOAB
MULTAN
BARI DOAB
Amritsar
RAVI SYPHON DIPALPUR LINK (1971/72-1975/76)
DIPALPUR ABOVE B.S. LINK (1970/71-1972/73)
DIPALPUR BELOW B.S. LINK (1973/74-1976/77)
BAHAWAL QAIM (1973/74-1975/76)
PANJNAD ABBASIA (1969/70-1972/73)
Rahimyar Khan
Panjnad Barrage
Guddu Barrage
Sukkur Barrage
SUKKUR RIGHT BANK (1974/75-1976/77)
BEGARI SIND (1973/74-1975/76)
Jacobabad
Sui
Bela
KHAIRPUR
KHAIRPUR (1968/69)
ROHRI NORTH (1969/70- 1973/74)
ROHRI SOUTH (1972/73-1976/77)
Nawabshah
KARACHI
HYDERABAD
Ghulam Mohamed Barrage
INDUS RIVER
Sutlej R.
Beas R.
Kunar R.
Swat River
Soan River
Jhelum River
Chenab River
Mangla H/W
0 50 100 150
MILES

2. IACA project areas—the CCA within the Indus Basin covered by the groundwater projects recommended in the Action Program (5.8 million acres CCA).
3. Deferred project areas—the CCA within the Indus Basin not scheduled for public groundwater development projects before 1975 (18.4 million acres CCA).
4. Outside areas—noncommanded areas, including noncommanded land interspersed with the CCA within the canal system (12.4 million acres).

For each area and for all areas combined, the impact of the program is assessed in terms of cropped acreage, yields, and Gross Production Value (GPV) of agricultural production. Yields are given in terms of GPV (rupees) per acre cropped. GPV is projected to grow at an annual rate of 5.2 percent for all of West Pakistan during both 1965–75 and 1975–85. Slower growth rates for the 15 years, 1985–2000, would reduce the annual rate for the entire period, 1965 to 2000, to 4.5 percent per year. Over the 1965–75 period, the average growth rate results from a combination of growth rates: 1.6 percent in cropped acreage (primarily concentrated in the canal-commanded areas) and 3.5 percent in yields. For the 1975–85 period, cropped acreage would grow 1.3 percent and yields 3.9 percent per year. Total GPV for all West Pakistan is projected to grow nearly fivefold over 1965–2000, on a basis of a cropped acreage that increases by slightly less than 50 percent. The relatively substantial increase in acreage during the earlier years reflects the immediate effect of an increase in water supply, whereas the large increase in productivity, measured by the increase in GPV per acre, particularly reflects the expanding use of agricultural inputs combined with more adequate watering of crops.

The timing of output increases can be related to water deliveries at watercourse head (Table 4–22), which are expected to increase 38 percent over 1965–75, 25 percent during 1975–85, and 15 percent during 1985–2000. These figures reflect the assumption that opportunities for a rapid growth in water supplies will largely be exploited by 1985—a rapid growth of private and public wells plus the completion of Tarbela. During this period, 1965–85, therefore, the highest rates of growth in output would take place.

For the four area groups, the earliest effects of water resource development should occur in the "ongoing project areas." Cropping intensities would rise as new supplies of irrigation water are spread over a larger cropped acreage than before. During the first decade of development, 1965–75, these ongoing project areas should witness a growth in agricultural production, reflecting both acreage and yield increases, of about 8 percent per year.

For the "IACA project areas," the construction of the tubewell projects should be largely completed during 1965–75. However, more rapid growth for these areas is expected during 1975–85, when increased surface water supplies would also be available from Tarbela. Increases in both cropping intensity and yields would begin about midway between 1965 and 1975. Output would increase about 5.6 percent per year during 1965–75 and 6.7 percent during 1975–85.

The "deferred project areas" is not only the largest of the four categories but also contains the areas most dependent in the years before Tarbela on private tubewell installations. An estimated 15,600 private wells were in these areas in 1965, with each well commanding an estimated 100 acres at a cropping intensity of 125 percent. This would be a CCA of 1.56 million acres and a cropped acreage of 1.95 million acres. Since the full CCA of the deferred project areas is 18.35 million acres, there would still be 16.79 million acres of CCA not served by private tubewells; this remainder includes some of the best irrigated land in the Province and at present has an average cropping intensity of approximately 96 percent. By Study Group estimate, private wells in the deferred project areas would increase from 15,600 in 1965 to 37,500 in 1975; by then, they would command a CCA of approximately 3.0 million acres and a cropped area of 4.2 million acres (140 percent intensity). The remaining CCA of 15.35 million acres (18.35 million acres less 3.0 million acres) could only increase in cropping intensity slightly to 105 percent by 1975, or a cropped acreage of 16.19 million acres. After 1975 there would be further public groundwater and surface water development. The deferred project areas could then achieve an average cropping intensity of 130 percent by 1985 and rising to 150 percent by 2000. On the basis of this development, output in the deferred project areas would grow by 4.7 percent per year up to 1975 and by 5.2 percent between 1975 and 1985.

A relatively small amount of water development is projected outside the CCA, although considerable private tubewell activity is expected to take place in the outside areas, with the number of wells increasing from 5,000 in 1965 to 25,000 by 1985. This category is quite large (12.4 million acres) and the impact of this number of private tubewells would not be very great in terms of increased cropped acreage. Moreover, these areas are, by definition, outside the canal-commanded portions of the Basin and would not benefit from the increased water supplies coming from Tarbela or the construction of other storage facilities and canal remodeling. Growth in agricultural production, increasing at around 4 percent per year between 1965 and 1985, would be somewhat slower than in the other areas.

While projections for all areas show lower rates of growth after 1985 than before, as noted earlier, this does not imply that a continuation of high rates of growth is impossible. It does mean that foreseeable growth after 1985, with techniques and inputs now known, would depend largely on improvements in yields alone, and these may be increasingly difficult to obtain once the levels projected for 1985 have been reached. On the other hand, advances in agricultural technology during the intervening years could open unseen but vast opportunities for increased production.

The Study Group had to choose among many assumptions regarding cropping patterns, livestock production, future demand for agricultural projects, etc. Varying degrees of assurance attach to each element involved, of course, but the broad assumptions and conclusions should be useful for planning purposes. At the same time, the nature of the exercise emphasizes the need for flexibility in planning, and for a continuous surveillance of the project content of Five Year Plans. A brief review of the main elements of the agricultural projections is given below.

For determination of future cropping patterns, the main focus was on what farmers might actually be expected to achieve. In general terms, over the next 20 to 30 years in the Basin as a whole, fine rice was expected to become more important than coarse rice, and the acreage in jowar/bajra, gram and rabi pulses was expected to decline. The acreage in oilseeds was projected to grow only slightly larger than that sown in 1965, while wheat acreage would rise during the first decade but would be constant and then declining in later years when considerably higher yields would be obtained. There would be substantial acreage increases (in addition to that in fine rice, mentioned above) in cotton, fodder and green manure; the increase for these three crops alone would be 11.1 million cropped acres. In broad terms, the contemplated changes can be summed up as constituting a relative shift from grain production for domestic consumption toward export crops and livestock support.

The relative emphasis given to the growth of different kinds of agricultural output is also shown by percentage changes in the acreage and production of important crops and livestock products. Among crops, cotton would have the largest percentage increase in acreage and production. Wheat, which would have a high growth in acreage in the first decade and a decreasing acreage in the period 1985 to 2000, was expected to have the smallest percentage increase of physical production among the major crops. The rate of growth in wheat production is, in fact, only slightly greater than the projected rate of population growth.

The expected contributions from livestock production are substantial. The size of the production herds has been placed at levels biologically consistent with estimates of available total digestible nutrients (TDN), a concept which includes fodder production, crop residues, and an allowance for grazing. The quantities of TDN consumed per animal were assumed to increase over time because animal husbandry practice would be gradually improving. Changes in the meat and dairy herd will also take place. The buffalo herd will increase up to 1985 but then begin to decline as Zebu dairy breeds, such as the Sahiwal and Red Sindi, increase in number. The herd increase depends on a widespread and effective artificial insemination program. Milk and meat production is projected to grow at an annual rate of 5 percent between 1965 and 2000. However, the Study Group retains reservations about the rate of growth for reasons related to the conversion rate used in the projections. Basic data on West Pakistan livestock, required as bench marks, are admittedly of uncertain quality, but they have been used in the absence of any alternative that appeared more reliable. The livestock projections make allowance for the biological constraints governing production and reproduction, but they also depend implicitly on improvements in herd management and selective breeding practices. These latter may ultimately impose more critical constraints on livestock growth than the availability of TDN. The livestock estimates thus may be subject to adjustment in light of managerial lags.

Projections of demand for agricultural products are necessarily very uncertain. There are, for instance, wide differences of opinion as to the elasticity of domestic demand for agricultural products. Also, projected production by crops and estimates of demand for each crop do not show a balance for each commodity. And growth of production depends on the method used: projections indicate a 5.2 percent per year growth in GPV of agriculture and 4.5 percent per year growth in value added in agriculture. These uncertainties make it important that there be sufficient flexibility in the programs for irrigation and agriculture to permit the changes in cropping patterns needed to meet changes in demand or in output targets.

Regarding specific crops, there would in general be a fair degree of flexibility within the proposed water program for shifts in acreage toward wheat—such as might take place in response to the recent increase in price of wheat and in view of the availability of the new high-yielding varieties. For instance, rather large fodder acreages have been projected on the production side—even larger than required to support the ambitious livestock program—and some of this acreage could be shifted to wheat. Oilseeds, gram and pulses are also, like fodder, grown in both seasons; in practice, the amount of acreage devoted to them rather than to wheat in rabi will depend largely on relative yields and prices obtaining in the future. Cotton acreage, on the other hand, could not normally be transferred to wheat, within the limits of projected water availabilities —although present varieties of the two crops overlap in time and compete for the same acreage, the water requirements of wheat could not be met in other rabi months. Cotton acreage could be transferred to other kharif food crops such as coarse grains or oilseeds, though this would not be very likely in view of the important position that cotton holds among Pakistan's exports; shifts in the opposite direction—out of foodgrains into cotton—would clearly be easier because water is more readily available in the kharif season. On balance, it would appear that there is considerable scope within the outlined irrigation program for shifts at the margin to meet changing requirements.

V

Surface Water Storage

This chapter discusses the findings of the Study with regard to surface water storage needs and the manner in which they can best be met. The program is dependent on the overall framework of the irrigation program. The Study Group's analyses and recommendations are based on the work of both IACA and Chas. T. Main International.

The background data for this chapter were given in Chapter II. Briefly, from the early 1970's, when the Indus Waters Treaty of 1960 will be fully implemented, the flows of four main rivers will remain available to Pakistan —the Indus, Kabul, Jhelum and Chenab. They have a combined average annual discharge of some 142 MAF. Nearly half of the average annual discharge is in the Indus itself. The remainder is divided roughly equally among the other three rivers, plus small additional contributions from several minor tributaries; and in some years, part of the surplus flood flows in the Ravi and Sutlej will be likely to pass downstream. These flows, being heavily dependent on the size of the monsoon, fluctuate greatly from year to year (e.g. for the Jhelum see Table 2–8).

A. DETERMINANTS OF A STORAGE PROGRAM

The Role of Storage in Water Development

The barrages and weirs built on the main rivers over the last century have been able to store only insignificant amounts of water. The first dam to be built with storage capacity was Warsak, completed in 1960. The project was designed primarily for power purposes with a storage capacity of only 23,500 acre-feet, which is rapidly being reduced by deposition of sediment; it is estimated that the reservoir will shortly reach a minimum residual capacity of about 10,000 acre-feet, useful for peaking purposes on the power units but insignificant from the agricultural point of view. Mangla Dam, with its initial live storage capacity of about five MAF, provides the first sizable amount of surface water storage capacity to be built in West Pakistan.

With the completion of Mangla, in 1967, it became possible to store a portion of the flood flows on the Jhelum. The reservoir at Mangla is formed by an 11,000-foot-long main dam, a smaller dam at Jari, and long dikes, all of zoned earth-embankment type. The reservoir will have an initial gross storage capacity of 5.9 MAF and a live storage capacity of about 5.3 MAF at a drawdown level of 1040 feet, or 4.9 MAF at drawdown level 1075 feet. About 0.4 MAF of the live storage is in the Jari Arm beyond the Mirpur Saddle, but a trench has been excavated through the Saddle to enable about 0.3 MAF of this water to be diverted into the main reservoir and released through the power plant.

Live storage of about 0.5 MAF on the Indus main stem will be added in 1971 at Chasma Barrage, some 35 miles downstream of Kalabagh; construction began in the middle of 1967. The main purpose of the barrage is to divert water from the Indus to the Jhelum River, as part of the Indus Basin Works, through the Chasma-Jhelum Link Canal. The barrage was originally designed with a headpond elevation of 640 feet, but it was found that by raising the barrage structure some six feet and extending bunds on either side, live storage of about 0.5 MAF could be provided (between elevations 642 and 649 feet) at relatively low cost of about $32 million. This storage capacity is expected to be permanent since sediment collecting above elevation 642 would be flushed out during subsequent flood seasons.

Looking to the future, there are many potential storage sites on the rivers of West Pakistan. Chas. T. Main has identified upwards of a hundred (see Annex II, Figure 1). But the Province does not present opportunities for cheap storage development, as far as is now known. Technological progress could change this situation drastically, of course. Also, economic development, with concomitant improvement of the transportation infrastructure, will help significantly to reduce the costs of dam construction at some potentially good sites, such as in the Upper Indus region, where accessibility is a problem. Other factors which account for the high cost of providing storage in West Pakistan: the rarity of sites which combine the right topographic features, i.e. sites suitable for formation of a large reservoir, with bedrock formations capable of carrying heavy structures; the flow characteristics of the rivers—a concentration of annual flows within a few summer months and extreme year-to-year variability—which make for heavy investment in spillway capacity; and the heavy silt loads of the major rivers, particularly the Indus and the Kabul, which make for rapid reduction of storage capacity through siltation. The result of these factors is that surface storage is a rather expensive means of making water available to the farmers in the months that they need it. This potential of surface storage must then be placed in the context of an integrated irrigation system with two cropping seasons.

Absorption of irrigation water in the kharif season of high natural flows is currently limited mainly by canal capacity, lack of drainage, and the shortage of water during the early planting period. But as canal enlargement and tubewell pumping proceed, more surface water will be able to be absorbed in that season, and less will be available for storage. Demand for surface water in the rabi season of low river flows is presently greatly in excess of supply, but tubewells will be able to meet a large part of this demand. In IACA's integrated analysis of irrigation development, future rabi watercourse requirements were met as far as possible from the groundwater available from the proposed tubewell fields plus natural river flows.

IACA's studies indicated that groundwater pumping, when feasible in sweet water areas up to balanced recharge, was generally a much cheaper way of meeting irrigation requirements during the rabi season and in early and late kharif than provision of surface storage. But there was a limit to the speed with which tubewell development would proceed and, in some areas with somewhat more saline groundwater, surface water supplied from reservoirs would be essential to meet growing irrigation requirements. The demand for surface storage at any particular stage of development was thus estimated as the residual of total irrigation requirements that could not be met from groundwater and natural flows.

Flows Available for Storage

The amount of surface water available for storage depends on two factors: river flows during kharif and the amount of water required for immediate delivery to the watercourses in that season. Kharif requirements in turn depend mainly on the cropping patterns and intensities attained in different areas (with their different crop-water requirements), and the extent to which water can be supplied from tubewells in that season. However, in the current context, kharif requirements cannot be dealt with in isolation. From the viewpoint of IACA's integrated approach, the future pattern of agriculture is illustrated by Table 5–1, which gives IACA projections of average intensities and kharif-rabi ratios for the development CCA (as defined by IACA, covering 29.4 million acres). The expected increase in kharif intensities, of course, can be seen as a function of these ratios. In matching water requirements to these higher intensities, IACA's analysis of canal commands integrated groundwater and surface water supply over the months on the assumption of a balanced recharge policy—that no more groundwater could be pumped from the aquifer than would be resupplied in the course of a mean-flow year. Kharif pumping in usable groundwater zones was minimized, with a view to concentrating usage of recharge to the aquifer in the rabi months when river flows are low; but in some cases and in some months kharif pumping was needed to balance recharge over the course of the year or because watercourse requirements exceeded canal capacity.

Tables 5–2 and 5–3 show IACA's projections of the amounts of surface water that would be available in 1985 and at the stage of "full development" (the reference year 2000) for surface storage on the Jhelum and on the Indus. The sharp decrease in the storable surplus after 1985 reflects the increase in the kharif-rabi ratio and the increase in kharif in-

TABLE 5–1
Projected Cropping Intensities and Kharif-Rabi Ratios

Year	Average Annual Cropping Intensity (%)	General Kharif-Rabi Ratio
1965	97	1 : 1.09
1975	112	1 : 1.20
1985	125	1 : 1.16
2000	145	1 : 0.94

TABLE 5–2
MEAN-YEAR STORABLE SURPLUS BASED ON IACA'S PROJECTED PROGRAM: JHELUM RIVER AT MANGLA
(MAF)

Month	Mean Flow at Mangla[a]	1985 Irrigation Requirements[b]	1985 Storable Surplus	Full Development Irrigation Requirements[b]	Full Development Storable Surplus
May	3.6	0.8	2.8	2.1	1.5
June	3.7	0.7	3.0	1.8	1.9
July	3.8	0.6	3.2	1.1	2.7
Aug.	3.0	0.8	2.2	1.6	1.4
Sept.	1.6	1.0	0.6	2.0	Storage Release
Total	15.7	3.9	11.8	8.6	7.5

[a] 41-year period, 1922–63.
[b] After full allowance is made for use of flows from the Chenab River.

TABLE 5–3
MEAN-YEAR STORABLE SURPLUS BASED ON IACA'S PROJECTED PROGRAM: INDUS RIVER AT TARBELA
(MAF)

Month	Mean Flow at Darband[a]	1985 Irrigation Requirements[b]	1985 Storable Surplus	Full Development Irrigation Requirements[b]	Full Development Storable Surplus
May	4.4	3.1	1.3	6.0	Storage Release
June	10.2	5.0	5.2	9.4	0.8
July	16.8	1.5	15.3	5.7	11.1
Aug.	16.0	2.4	13.6	6.1	9.9
Sept.	6.8	4.5	2.3	6.6	0.2
Total	54.2	16.5	37.7	33.8	22.0

[a] 41-year period, 1922–63.
[b] After full allowance is made for use of flows from the Kabul River.

tensities from about 58 percent to 75 percent between 1985 and 2000, as a result of the large canal remodeling program envisaged for that period.

The situation under year-2000 conditions, when the plans made by IACA would reach full realization, is shown in Table 5–4 and Figure 7. These show IACA's estimates of the amounts of water that could be stored, under mean-year flow conditions, with reservoirs of different sizes on the Indus and the Jhelum. The figures are derived from an analysis of the monthly discharge records of the two rivers over the impounding season for the 41-year period, 1922–63, and take account of the required mean irrigation releases implied in IACA's program during these months at the ultimate stage of development. The figures show that, after completion of IACA's full program of canal remodeling, and on the assumption that kharif requirements will receive priority each year, it will be possible to fill a reservoir on the Jhelum only to the extent of two MAF in every year; whereas it will still be possible to fill reservoirs with total live storage capacities in excess of 15 MAF every year on the Indus. The efficiency of

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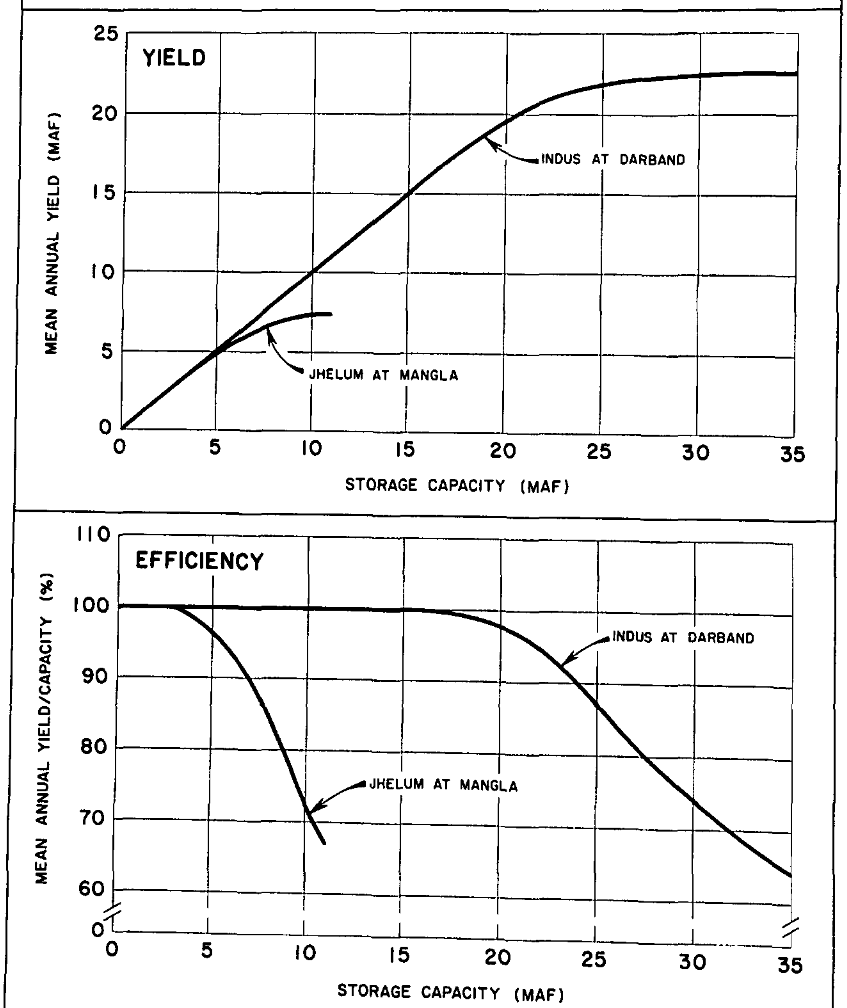
FIGURE 7

AVERAGE ANNUAL YIELD AND EFFICIENCY OF STORAGE CAPACITY ON THE INDUS AND JHELUM RIVERS*



* Based on the period 1922–1963, assuming year 2000 conditions, impounding period June through August for the Indus and May through August for the Jhelum.

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TABLE 5-4
AVERAGE ANNUAL YIELD AND EFFICIENCY OF STORAGE CAPACITY ON THE INDUS AND JHELUM RIVERS AT THE ULTIMATE STAGE OF DEVELOPMENT[a]

Storage Capacity	Average Annual Yield (MAF)		Efficiency of Storage Capacity (percent)	
(MAF)	Indus at Darband	Jhelum at Mangla	Indus at Darband	Jhelum at Mangla
1	1.0	1.0	100	100
2	2.0	2.0	100	100
3	3.0	2.9	100	97
4	4.0	3.8	100	95
5	5.0	4.6	100	92
6	6.0	5.4	100	90
7	7.0	5.9	100	84
8	8.0	6.4	100	80
9	9.0	6.6	100	73
10	10.0	6.7	100	67
15	15.0	[b]	100	[b]
20	19.5	[b]	98	[b]
25	21.8	[b]	87	[b]
30	22.5	[b]	75	[b]
35	22.6	[b]	64	[b]

[a] Assuming the year 2000 mean-year irrigation requirements as estimated by IACA continue to be met during the impounding season.
[b] Not physically feasible to provide capacity of this size on the Jhelum.

storage capacity, measured as a ratio of mean annual storage yield to storage capacity available, falls off rapidly on the Jhelum River at figures above six MAF, whereas it remains around 100 percent up to nearly 20 MAF on the Indus at Darband.

The estimate of demand which is most relevant for planning surface storage development is based on mean-year flows. This is because the plans for groundwater development include sufficient tubewell capacity to make up for deficiencies in natural water supplies (from rainfall and canal deliveries) during the rabi season in all except years of very low flow. Indeed, during the next 20–30 years, when the tubewell projects will still be in a development phase and ultimately achievable cropping intensities will not have been reached, there should generally be sufficient tubewell capacity installed to meet irrigation requirements even in years of worst hydrological conditions. This assumption that the groundwater aquifer could be used to meet shortfalls in low-flow years meant that it was unnecessary to provide reserve capacity in the storage reservoirs and so it served to minimize the requirement for surface storage capacity. It is estimated that, had the surface storage system been designed to meet all residual requirements three years in four—instead of those in a mean year—surface storage needs would have increased by 30–50 percent. Thus, the IACA approach leads to the most sparing use of the more expensive source of additional water. The IACA projections are shown in Table 5–5.

IACA estimated that mean-year demand would grow from roughly four MAF in 1970 to about 9.3 MAF in 1975 and approximately 21.5–26.5 MAF in 2000, depending on certain developments. Because of the tightly

TABLE 5-5
IACA'S ESTIMATE OF THE DEMAND FOR STORAGE ON THE INDUS AND JHELUM RIVERS: 1975, 1985, 2000
(MAF)

	1975			1985			2000		
	Indus	Jhelum	Total	Indus	Jhelum	Total	Indus	Jhelum	Total
Mean	5.0	4.3	9.3	8.8	4.5	13.3	15.5[a] 19.0[b]	6.0[a] 7.5[b]	21.5[a] 26.5[b]
Median	5.7	5.4	11.1	9.7	5.6	15.3	—	—	—
3 years in 4	6.9	6.0	12.9	12.1	6.2	18.3	—	—	—

[a] Assuming canal enlargement in all fresh groundwater areas.
[b] Assuming IACA's program of canal enlargement (see Chapter VI).

integrated nature of the irrigation system and of the plan which IACA prepared for it, these projections are sensitive to the size and location of whatever tubewell program is carried out and to any significant changes in the pattern of irrigation requirements (e.g. due to the development of new strains of crops, with different growing seasons). The 21.5 MAF figure is based on the specific assumption that canal enlargement proves to be feasible in fresh groundwater areas. If the remodeling of canals in fresh groundwater areas and the use of subsurface storage proves infeasible, storage demand in the year 2000 would be 26.5 MAF.

At present, 85 percent of water used on crops comes from surface water. Under the IACA program for 1965–75, the use of groundwater is projected to increase by 200 percent, from 10 MAF in 1965 to 30 MAF in 1975; the use of surface water at the watercourse by some 10 percent, from 58 MAF to 63 MAF. There would be further increases in the second decade and still more by the year 2000. At the stage of ultimate development, the river system will, according to IACA, supply some 67 percent of the total crop requirements.

B. RECOMMENDED PROGRAM OF SURFACE STORAGE DEVELOPMENT

The recommended program of surface storage development was drawn up to meet the low ultimate requirements of 21.5 MAF on the Jhelum and Indus combined—corresponding to the assumption that canal remodeling will be feasible in all fresh groundwater areas, permitting these areas to absorb additional surface supplies in the kharif season. This assumption relates only to the post-1985 period because, as Table 5–5 showed, the two sets of requirements are identical before that date. The component projects of the program are listed in Table 5–6. Figure 8 compares the projects recommended for construction in the 1967–85 period with the projected demand for stored water.

The projected mean-year, surface-storage requirements up to 1985 could not be met by any project other than one on the Indus. Mean-year storage requirements in 1985 were projected in Table 5–5 at a total of 13.3 MAF. Storable surpluses in 1985 were projected in Tables 5–2 and 5–3 at 11.8

TABLE 5-6

RECOMMENDED STORAGE PROGRAM

Project	In-Service Water Year	Initial Live Storage Volume (MAF)
Mangla	1968	5.22[c]
Chasma[a]	1972	0.51
Tarbela	1975	8.60
Sehwan-Manchar[b]	1982	1.80
Raised Mangla	1986	3.55[d]
Chotiari[b]	1990	0.90
Kalabagh (with power)	1992	6.40
Swat	2002	2.00
Low Gariala	2011	4.60
Skardu	After 2020	8.00

[a] Ongoing project.
[b] Timing geared to irrigation planning for the Sind.
[c] Volume recoverable through main outlet works and power plant, assuming cut through Mirpur Saddle to release 0.28 MAF from Jari Arm.
[d] Raised to maximum height now contemplated.

MAF on the Jhelum and 37.7 MAF on the Indus. However, quite apart from the size of the storable surplus on the Jhelum, it is technically questionable whether more than 8.5 MAF could be provided on that river —and even more questionable whether it would be economical to concentrate so much storage there in view of the rapidly falling efficiency of storage beyond six MAF on the Jhelum. In practice, it might be possible to reduce the demand for surface storage in 1975–85 by additional overpumping of the groundwater aquifer, and this possibility is discussed below, but there would also be considerable operational difficulties in trying to meet rabi requirements of the whole Basin with regulation on the Jhelum only. Therefore, the selection of a project to meet the projected irrigation requirements of 1985 was essentially a matter of choosing the most suitable site for first-stage development on the Indus. As stated at the outset of this report, the chosen site is at Tarbela.

Beyond 1985, the program is more tentative. Second-stage storage on the Indus—the next major decision—is listed in the Proposed Program as the Kalabagh Project, coming into service as of the early 1990's. However, it will require a major program of investigation to verify the timing and site for second-stage storage. Requirements during the "in-between" period, between Tarbela and the next big dam, will depend on progress made in irrigation planning, particularly in the Sind. Sehwan-Manchar and Chotiari Projects are listed subject to such progress; there are still unanswered questions in regard to raising Mangla Dam, but it is assumed that the project could be brought in during the mid-1980's. The chief purpose of drawing up a sequence of projects, on the basis of available data, is to give direction to the investigative effort. Further storage development on the Indus will be intimately affected by the prior existence of Tarbela, for instance, and this is but the most striking reminder that future development of storage capacity is to be aimed at the creation of a Basin-wide, integrated system of water supply.

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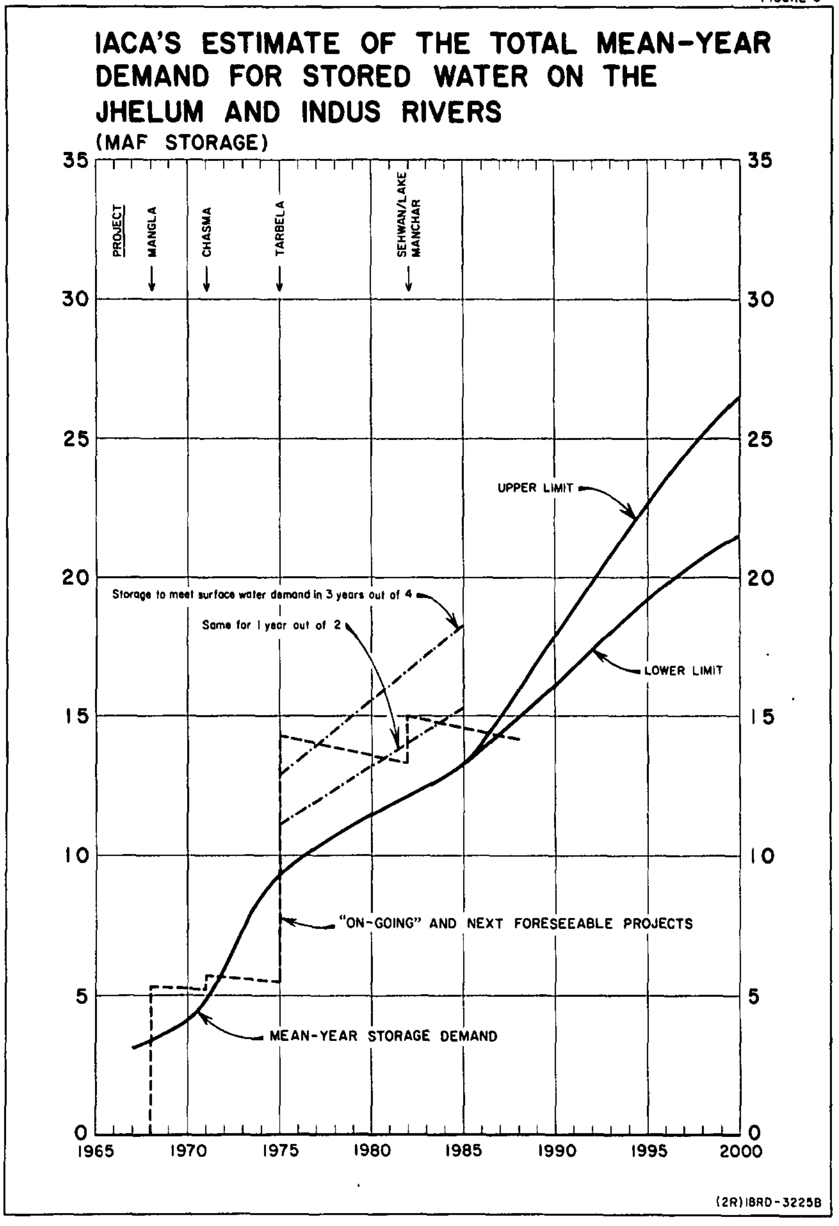
FIGURE 8



First-Stage Storage on the Indus

There are two projects which were considered contenders for first-stage storage on the Indus, given the relatively large storage capacity that would be needed to meet the projected requirements—Kalabagh and Tarbela (see Map 4 at the end of the chapter). Various sizes of reservoir might be constructed at either site, but the first phase of the Indus Study, revolving around the Tarbela Project itself, had suggested that not only was a large-scale reservoir justified but advantage lay with Tarbela; and it was around that assumption of the availability of such large storage that the irrigation program drawn up in the second phase of the Study had been built. Tarbela, towards the lower end of the 300-mile-long main Indus Gorge, would have at its maximum feasible size an initial gross storage of the order of 11.1 MAF and, with a drawdown level of 1332 feet, live storage of about 8.6 MAF. The largest dam believed feasible at Kalabagh, a site some 150 miles downstream of Tarbela at the end of a 100-mile series of gorges below Attock, would have gross storage of the order of 8 MAF. It might be feasible to construct there a structure capable of sluicing through silt—though that would be at the sacrifice of any firm power capability—and then the 8 MAF of live storage would be reduced by siltation only quite slowly. Without sluicing and with a hydroelectric installation, Kalabagh would have initial live storage capacity of the order of 6.4 MAF.

When very large-scale engineering works are required to meet early development needs, the degree of investigation to which the projects have been subjected is a very important facet of decision making. Kalabagh and Tarbela contrast strongly in this respect. The Kalabagh site was proposed in 1956 by consultants to the Government as being suitable for an earth and rockfill dam with an abutment overflow spillway. At that stage of the analysis, limited subsurface investigations were carried out, including 15 drill holes, 150 to 300 feet in depth, and 55 test pits. Foundation rocks at the proposed dam site were found to be sandstones and shales, overlain by up to 60 feet or more of alluvium in the river channel. Since 1956, further reports have been prepared by WAPDA and its consultants, but no additional exploratory work has been undertaken. The general location of the Tarbela site was established in 1954. In 1959 WAPDA made a contract with Tippetts-Abbett-McCarthy-Stratton of New York (TAMS) for final site selection and engineering. Three locations for a dam were considered in initial studies covering a 20-mile stretch of river. In May 1961, TAMS recommended adoption of the Bara site and this was accepted. By January 1962, investigations and designs were sufficiently advanced for the preparation of a project planning report covering the preliminary phases. At this stage, many of the features of the scheme were of a tentative nature and subject to further exploratory work on site. Towards the end of the year, in November 1962, a supplement to the Tarbela planning report was issued. This supplement, while still based on the adoption of the Bara site, showed considerable changes in concept of the dam, both in alignment and in design. The report further brought out that a number of additional points required investigation on site before the designs could be finalized. Planning work over the three years 1960–62 had cost nearly $10 million; over the following three years, about the same amount again was spent on further engineering investigations and design drafting. The estimated cost of exploratory work, detailed design, model tests and preparation of tender documents over the period from November 1965 to the end of 1967 is estimated at about $9 million. Thus nearly $30 million and eight years will soon have been spent in preparatory work on the project.

The Tarbela Project, as now planned, will be the largest water storage and hydroelectric project in Pakistan; and if it is executed according to the proposed schedule, it will probably also be the largest single contract ever to have been let in the world. The centerpiece of the project is a major earth and rockfill dam, rising 485 feet above river bed level, with a crest length of about 9,000 feet, and an impervious clay blanket extending some 5,000 feet upstream. This dam will be flanked by two auxiliary embankments on the left abutment. All told, the three embankments will contain 179 million cubic yards of fill materials. With a crest elevation of 1565 feet, the embankments are designed to impound 11.1 MAF of water to a normal operating level of 1550 feet. The project is designed so that the reservoir could be drawn down to 1300 feet, which would provide an initial live storage of 9.3 MAF.

Two spillways with a combined discharge capacity of 1,670,000 cusecs are to be provided at the left abutment to handle a flood inflow of 2,127,000 cusecs, with a rise of 6.8 feet in the water level of the reservoir above the normal operating elevation. The service and auxiliary spillways are designed for seven and nine radial gates, respectively, each 50 feet by 58 feet in size. Four concrete-lined tunnels, each 45 feet in diameter at the upstream end, in the right abutment, would be used to divert the flow of the river during construction and subsequently would be used as power intakes and/or for irrigation releases. The designs envisage that a power plant will be installed, ultimately to have 12 generating units each rated at 175,000 kw. (For further details on Tarbela, see Annex I.)

The cost of all these basic structures, excluding power facilities, is estimated at $625 million—at 1965 prices and excluding Pakistan duties, taxes and interest during construction. The exclusions were made because they are not germane to economic comparison among projects on the basis of the present worth of their total costs. Table 5–7 shows a breakdown of these 1965 economic costs of Tarbela. This is the cost estimate arrived at in the first phase of the Study and given in the Study Group's 1965 report on Tarbela. It is believed to be still a reasonable estimate although some individual items may be subject to minor change.

Plans for a dam at Kalabagh are obviously in a much less advanced stage and a number of very different concepts are still under consideration. Chas. T. Main considered several different possibilities and used the meager data available to prepare rough preliminary designs for each. They concluded that the best construction, from a number of viewpoints, would be a central earth and rockfill dam, flanked by a concrete buttressed sluice/spillway structure on the right bank. The project as envisaged could

TABLE 5-7
ESTIMATED ECONOMIC COST OF TARBELA
(million US$ equivalent)

Reservoir Works	Total	Foreign Exchange
Precontract Costs	16.5	4.7
Net Contract Costs	414.4	284.0
Contingencies (20%)	86.2	57.7
Engineering and Administration	36.2	30.0
Insurance and Miscellaneous	9.0	9.0
Performance Bond	4.0	4.0
Land Requisition and Resettlement	59.0	—
	625.3	389.4

have a live storage capacity of 6.4 MAF with 1,125 mw of power or 8 MAF if the reservoir were completely drawn down each year. The concrete structure would consist of some 25 low-level sluiceways built between buttresses. A massive concrete weir in the right diversion channel would form the base of the structure and provide support for the buttresses. The cost of the structure would be about $540 million and the construction time is estimated at seven years.

The time required to carry out further site investigations, model tests and design work on Kalabagh should not be enormously different than for Tarbela. Consequently, Chas. T. Main estimated that if Tarbela could be completed by 1975, Kalabagh, which would take about the same amount of time to build, could not be completed before 1979. The early stage of preparation at which the Kalabagh Project now stands, relative to Tarbela, also means that the cost estimates are subject to a much wider margin of error. Some allowance was made for this, by using higher contingencies—30 percent as against the 20 percent for Tarbela—on comparable cost items for Kalabagh. Still, it is difficult to attribute an equal degree of validity to the cost estimates. A brief look at the history of Tarbela cost estimates will make this clear. The dam on the Indus envisaged in the Indus Waters Treaty of 1960 was estimated to cost about $194 million; the total amount of fill required would be about 94 million cubic yards; and the dam would create a reservoir with initial gross storage of about 5.1 MAF. The dam now proposed for Tarbela is much larger; it would involve nearly twice as much fill; and it would create a little more than twice as much gross storage capacity. This would suggest that the cost estimate should not be more than about twice what it was in 1960. In fact, the cost estimate has doubled and then gone up by an additional $250 million: in other words it has more than trebled. It should also be noted that the cost of a dam at Kalabagh depends heavily on the type of structure finally chosen, and in turn the type of structure which is feasible depends on foundation conditions at the site, which remain a matter of considerable uncertainty. Chas. T. Main estimated that the Kalabagh Project might cost as much as $734 million if a conventional Mangla-type spillway proved the only structure feasible. Thus, while the Study Group feels that the estimate of $540 million for a sluicing structure at Kalabagh is the best that can now be prepared, it agrees with Chas. T. Main that the feasibility of the sluicing concept could not be established without much more investigation and study. The cost estimates must be considered subject to a wide margin of uncertainty.

The siltation problem is another major factor in the comparison between the Kalabagh and Tarbela Projects. It was an important consideration in the minds of those who had originally rejected the Kalabagh Project as an alternative to Tarbela. Kalabagh is downstream of the confluence of the heavily silt-laden Kabul River with the Indus. As a result, the sediment load of the river there is on the order of 540 million tons a year, or some 20 percent more than at Tarbela. Thus the reservoir created by a large earthfill dam there, comparable to the dam proposed for Tarbela, would fall in live storage capacity to about one MAF within some 25–30 years after construction.

The reservoir at Tarbela, being somewhat larger and having a lower estimated silt inflow, would be reduced to a residual permanent live storage of about one MAF over a somewhat longer period—about 50 years. Average annual sediment transport of the Indus at Tarbela is estimated at about 440 million tons, equivalent to about 0.25 MAF compacted volume; the rate of depletion of storage capacity has been calculated on the assumption that, initially, about half of the annual sediment load will be deposited in the live storage area, the remainder being passed through the dams or over the spillway or else accumulating below minimum reservoir drawdown level. It is estimated that about 90 percent of the total annual sediment load is carried by the river during the period of peak flood flows between the middle of June and the middle of August.

As a possible solution to the siltation problem, Chas. T. Main suggested for Kalabagh the sluicing structure mentioned above—a type of design which would not be feasible at Tarbela primarily because of the combination of unconsolidated foundation material and very great width of the river there. Chas. T. Main's proposal for Kalabagh included an earth and rockfill dam across the river and a concrete sluicing structure on the right bank. Under this scheme, Kalabagh Reservoir would be drawn down completely in May of each year and, in years of mean flow, all the Indus water would be allowed to pass through the low-level sluices essentially unrestricted until near the end of July. Impounding would be achieved in late July and August. With this schedule, more than 60 percent of the annual total of sediment would be passed through the dam during June and July. During seasons of particularly high flow, with the reservoir empty, some of the sediment previously retained in the river channel might be scoured out. Assuming that operational problems can be solved, Chas. T. Main estimated that the live storage capacity of the reservoir would be depleted by only about 25,000 acre-feet a year for 100 years and that it would then reach a permanent minimum of 5.2 MAF. The chief operational dilemma which needs solution is that, with varying conditions of river flow, it is difficult to decide when to close the sluice gates to make sure the reservoir is filled each year.

However, the chief disadvantage that attaches to "sluicing Kalabagh," aside from the requirement of a concrete structure, is that passage of maximum sediment would involve elimination of power generation during three or four months in the year. Around the sluicing period the reservoir level would be below that required for turbine operation. It is questionable whether it would be worthwhile even installing power facilities at all when they would be out of operation for more than one-quarter of the year.

These characteristics of Kalabagh then had to be put in the context of a proposed program of development—the projected requirements for power and for storage capacity on the Indus. Tarbela was the alternative. Kalabagh as a conventional structure without sluicing was clearly not very attractive because of its lower live storage and smaller power potential than Tarbela and the extremely short life of the main body of storage volume. Kalabagh with sluicing would have nearly the same initial live storage as Tarbela and the storage volume would last very much longer; it might also be somewhat cheaper than Tarbela. However, the longer life would be gained at the sacrifice of all firm power capability, whereas Tarbela's shorter storage life would be compensated to some extent by the project's output of electricity, which would provide more than one-quarter of the total electric energy required by West Pakistan between 1975 and 1985 and very substantial amounts thereafter. And there was the earlier completion date for Tarbela to consider. However, if the project were to have substantial technical advantages over Tarbela, or to be significantly cheaper, it might be worth accepting lack of storage on the Indus for an additional four years. Or, the Study Group could have recommended a delay to provide opportunity for further investigations and studies to firm up the Kalabagh Project. This would have been to gamble that further investigation would show that the net advantages of a project at Kalabagh, in terms of lower cost and longer lived storage, would sufficiently outweigh the disadvantages, in terms of lack of firm power, to make it worthwhile accepting the certain loss of four years' live storage.

The possible benefits of delaying Tarbela in favor of Kalabagh can be quantified to a reasonable degree. The present worth in 1965 of the saving in construction costs that would result from completing Kalabagh in 1979 rather than Tarbela in 1975, on the most optimistic assumption regarding the costs of Kalabagh, would be $125 million. The loss of four years' live storage (1975–78) can be estimated at about $85 million in present worth terms, on the basis of an average value at watercourse head of Rs. 80 per acre-foot of stored water provided to meet the IACA irrigation requirements. The power benefits of Tarbela between 1975 and 1985 alone are estimated at about $100 million in present-worth terms and most, if not all, of this would be lost if Kalabagh with sluicing were built in 1979. Experience with the cost estimates on Tarbela, plus the real lack of evidence for deciding whether or not a sluicing structure is feasible, means that a sizable risk factor must be attached to the potential saving on cost of $125 million and also to the larger amount of storage that Kalabagh would provide in later years; moreover, this potentially larger amount of storage is not in fact very important because it would occur after the time when a second storage project was built on the Indus, which would almost necessarily be upstream of Kalabagh and would therefore protect it to a considerable extent from siltation. Opting for these uncertain benefits would mean suffering certain losses of power and irrigation benefits in the order of at least $150 million. Therefore, the Study Group concluded that Tarbela appeared still to be the better project for first stage storage on the Indus.

The Benefits of Tarbela. Because of the expense and importance of large-scale surface storage development on the Indus, it was highly desirable to define as precisely as possible the benefits which attach specifically to such a project; because of the closely integrated nature of the proposed program of irrigation and power development, it was also difficult to do this. The Study Group and its consultants carried out several separate evaluations of benefits attaching to Tarbela. The economic test revolved around the Tarbela project's functional contribution within the context of a system which is about to undergo radical change: from a natural flow diversion system into a system based on river regulation and the integration of surface and groundwater. In the course of this transformation, the value of surface water storage will be enhanced by the presence of tubewell fields and, conversely, main-stem storage will greatly improve the efficiency of tubewell development. This report proposes the adoption of an integrated water supply schedule that would satisfy crop-water requirements on time, provide for mixing, avoid acceleration of waterlogging, and be compatible with the recommended power program in terms of amount and timing of groundwater pumping and of releases of water through the hydroelectric plants.

Under the planned water supply schedule, Tarbela releases would take place between November and April, but a small reserve would be held over into May because Indus flows are particularly variable in that month. The operating pattern upon which IACA finally resolved for planning purposes is shown in Table 5–8. This pattern was drawn up on the basis of lower than average river flows in the rabi season—to minimize the risk of water shortages—and exceptionally heavy groundwater pumping loads in the later part of the season. In practice, the release pattern will probably be varied from year to year, but this basic pattern is adequate for planning

TABLE 5–8
TARBELA RELEASE PATTERN

Reservoir Filling		Reservoir Release			
Month	Percent of Total	Month	Percent of Total	Month	Percent of Total
June	45	October	nil	February	26
July	55	November	8	March	19
August	nil	December	11	April	10
September	nil	January	21	May	5
	100				100

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FIGURE 9

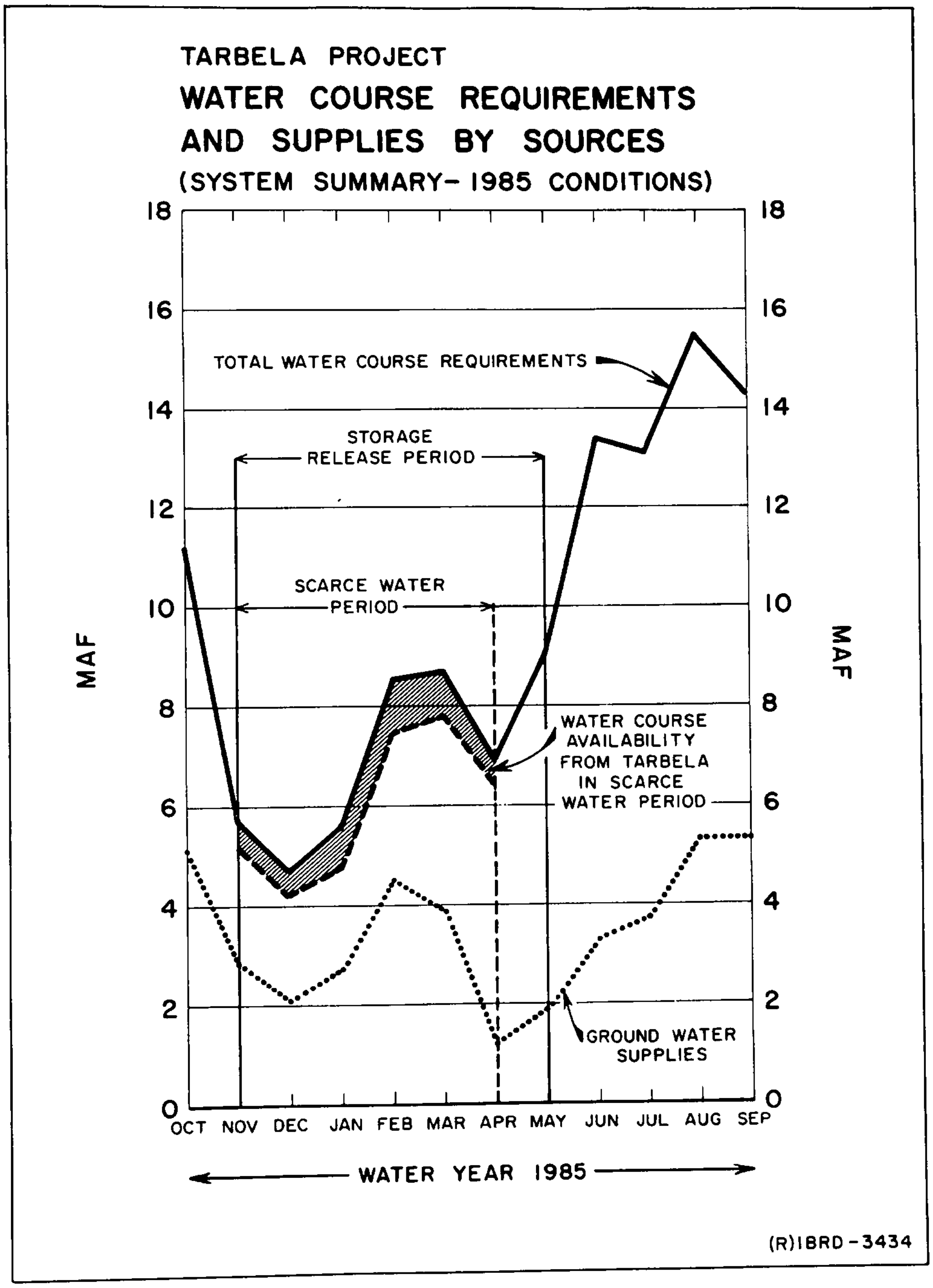


TABLE 5–9
MONTHLY DISTRIBUTION OF WATERCOURSE SUPPLIES BY SOURCES
(Mean-year flows—1985 conditions)

	Surface Water		Tarbela		Groundwater		Total	
Month	MAF	Percent per Month	MAF	Percent per Month	MAF	Percent per Month	MAF	Percent per Month
October	6.1	54.5	—	0.0	5.1	45.5	11.2	9.6
November	2.3	41.1	0.4	7.1	2.9	51.8	5.6	4.8
December	2.1	44.7	0.5	10.6	2.1	44.7	4.7	4.0
January	2.0	35.7	0.9	16.1	2.7	48.2	5.6	4.8
February	3.0	34.9	1.1	12.8	4.5	52.3	8.6	7.4
March	3.9	44.8	0.9	10.4	3.9	44.8	8.7	7.5
April	5.1	73.9	0.5	7.3	1.3	18.8	6.9	5.9
May	7.1	78.9	—	0.0	1.9	21.1	9.0	7.7
June	10.0	74.6	—	0.0	3.4	25.4	13.4	11.5
July	9.3	71.5	—	0.0	3.7	28.5	13.0	11.2
August	10.2	65.8	—	0.0	5.3	34.2	15.5	13.3
September	9.0	62.9	—	0.0	5.3	37.1	14.3	12.3
	70.1		4.3		42.1		116.5	100.0

purposes. Nearly 70 percent of storage at Tarbela would, on this pattern, be released during January, February and March. With power benefits being calculated separately, agricultural benefits can be approached in terms of IACA's projected pattern of irrigation requirements. Tarbela's specific contribution would be in terms of its relative supply of water requirements. As an illustration, what would Tarbela releases accomplish in the reference year 1985, under mean hydrological conditions? Figure 9 and Table 5–9 illustrate the 1985 "water year" and Tarbela's role under assumed 1985 conditions. The live storage capacity of Tarbela in 1985, after 10 years of siltation, would be about 7.5 MAF, but actual watercourse deliveries from Tarbela storage would be only about 4.3 MAF because of conveyance losses. However, the higher than natural river flows in the rabi season and the resultant additional conveyance losses would add to the recharge to the aquifer and, to the extent that it occurred in areas of fresh groundwater—and most of the areas close to the river are fresh groundwater areas—a part of it could be recovered by tubewells. IACA estimated this recoverable recharge in 1985 at 1.4 MAF; the availability of this water represents an additional benefit.

Taking account of Tarbela's contributions to irrigation supplies over the years, under various assumptions, the Study Group and IACA evaluated the agricultural benefits of Tarbela and added them to the power benefits in order to derive an overall rate of return. IACA valued Tarbela's direct irrigation contribution during the scarce water period, November through April, at an average value per acre-foot derived by dividing total water availability in that period (including natural flow and groundwater deliveries) into total estimated value of rabi crops; this was done for each year to 2015, allowing for a gradually increasing absorption of Tarbela water in the early period and a gradually decreasing contribution in later years as live storage is depleted. (The assumed siltation rate is discussed below under the Silt Problem.) Estimates were also made of the value of recoverable recharge, on the basis of an average unit value for irrigation water over the whole year (since recharge might be recovered in kharif as well as in rabi) and a deduction for the cost of pumping such recharge. Power benefits were taken by IACA to be as estimated by Stone & Webster in the first phase of the Study; the basis was a comparison of the present-worth costs of generating programs including and excluding Tarbela up to 2015. These benefits are compared to the present worth in 1965 of the total costs of the Tarbela Project, including operation and maintenance costs, estimated at Rs. 1,959 million.

The Study Group introduced a number of modifications to IACA's evaluation. In particular, it derived a time series of average values for the additions to present rabi water supplies; this was done on the basis of its analysis of the 5.8 million acres designated in IACA's program of new projects for commencement of public groundwater development within the next 10 years; all but one of the 12 project areas identified would absorb some Tarbela water. The time series indicates rising average values as the water is used to greater advantage by farmers in combination with more agricultural inputs. The Study Group applied these incremental water values to the total water available from Tarbela in each year, rather than to that portion of Tarbela water which happened to fall within IACA's estimated storage requirements. The Study Group took the view that once Tarbela was completed, all the water which it stores would be used, though initially to rather low advantage. Recoverable recharge, in the amounts estimated by IACA, was valued at the same unit value of incremental water supplies less an allowance for costs of pumping. For purposes of this evaluation, the Study Group added net power benefits, first the value used by IACA (about Rs. 365 million in present-worth terms) and second a value calculated by the Study Group (about Rs. 600 million in present-worth terms) on the basis of studies (described elsewhere in this report) which, to note one detail, costed fuel at current financial prices.

Table 5–10 summarizes the results of these calculations. The Study Group is satisfied that, to the extent that the functional contribution of

TABLE 5–10
RESULTS OF TARBELA EVALUATION UNDER VARYING ASSUMPTIONS

	Consultant's Evaluation	Consultant's Evaluation Modified	Study Group Evaluation[a]	
			I	II
Net Present Worth of Benefits at 8% (Rs million)	3,770	3,353	1,994	2,241
Power Benefits as % of Total	10.0	10.7	18.3	27.3
Benefit/Cost Ratio (at 8%)	1.9	1.8	1.1	1.2
Rate of Return (%)	13.3	12.5	8.4	9.2

[a] Analysis I is based on the use of IACA's estimate of power benefits, while Analysis II includes the power benefits assessed by the Study Group.

Tarbela in the overall program is measurable, the benefits of the project may fairly be considered to lie within the range of 9.2–13.3 percent.

Besides estimating the absolute rate of return on the Tarbela Project based on directly measurable benefits, the Study Group also attempted to check the proposed timing of the project by considering what would be the effects of a 10-year delay in construction. With the linear programming technique, set up to analyze various types of irrigation investment in different areas, it was possible to compare the net costs of the IACA program, which included Tarbela in 1975, with those of a hypothetical program including Tarbela as of 1985. The delayed Tarbela alternative was built around an early completion of Raised Mangla (1975) and Sehwan-Manchar (1980), plus a public tubewell program emphasizing overpumping as a substitute for some of the rabi surface water supplies that were to be provided from Tarbela. The hypothetical alternative met the main power load forecast through the construction of additional thermal plant using natural gas as fuel.

The costs of the two programs, both designed to produce the same net amounts of power and agricultural output, were calculated both in terms of the current exchange rate for foreign currency and in terms of a shadow rate. Comparison of the cost streams indicates that the sacrifice involved in delaying construction of Tarbela 10 years would be in the neighborhood of Rs. 230 million ($50 million equivalent), in present-worth terms, when a shadow rate of twice the current exchange rate is used for valuing foreign exchange expenditures. At the current exchange rate, the costs of delay would be about Rs. 490 million ($100 million equivalent) in present-worth terms. The validity of this comparison rests on the assumption that, if Tarbela were delayed, the hypothetical program, equally if not more complex than the one built around Tarbela, could in fact be implemented. The Study Group believes that the alternative program is valid for purposes of economic evaluation of Tarbela but it also believes that the program formulated around the early completion of Tarbela has a degree of security that cannot be matched by such a hypothetical alternative. Because the Tarbela Project has been so thoroughly investigated, there is a fair degree of certainty that once construction is started its contribution to power and irrigation supplies will indeed become available eight to nine years later. In contrast, the use of public tubewell projects for extensive overpumping, on which the alternative partially depends, would represent a new and yet untested form of operation of the irrigation system. The very scale of the Tarbela Project also provides a margin of safety—for meeting unanticipated growth in power demand, for instance, or for providing additional irrigation supplies in the first few years after its construction, when computed requirements of stored water are below the capacity of the reservoir.

In physical terms, the Study Group emphasizes that the Tarbela Project, by regulating the natural river flows and by supplying additional water, will make a major contribution to the projected increase of rabi crop production in the Indus plains. Of the total future increase in rabi water delivered to the farmer, both from ground and surface sources, Tarbela will, by 1985, contribute almost a quarter. As for electric power, Tarbela's 12,000 million kwh of energy would be absorbed relatively quickly into the system; and in a situation where the present known gas reserves are not so ample in comparison with the calls that will be made upon them, Tarbela will provide a badly needed supplement to potential hydro and thermal power development.

The Silt Problem. The silt load of the Indus was discussed in general terms above in the context of the choice between Kalabagh and Tarbela. Extremely little is known about the silt load of the Indus—its origin, time of occurrence, nature, etc.—and very little work has been devoted to trying to find a solution; obviously the problem is becoming very important for it will gradually eliminate much of the value of a multimillion-dollar investment.

The current assumption is that Tarbela's live storage volume will be depleted at the average annual rates of 0.12 MAF for the first 20 years and 0.17 MAF for the following 30 years, corresponding to an average silt load of the Indus at Tarbela of 440 million tons. As indicated in Table 5–11, these rates of depletion imply that live storage would decline from 8.48 in 1975 to 1.10 MAF in the year 2025.

The rate of siltation, particularly for short spans of years, could be even greater than assumed here. The average rate assumed was calculated on the basis of only a few years' collection of empirical data. Most of the silt load is borne by the summer flood flows, but the recorded data suggest that silt loads are very variable and tend to increase more than proportionately with the higher floods. The variations may be caused in part by erratic geomorphic processes resulting from heavy rainfall, landslides and avalanches. Should there be a succession of years in which these geomorphic processes were particularly active, the usable volume of the reservoir could be depleted at a faster rate than assumed. Another uncertainty relates to bed load, assumed in this Study at 5 percent of suspended sediment load; no reliable methods exist for measuring bed load and opinions differ about its importance on the Indus; but any errors resulting from this assumption are probably small compared with those related to the vagaries of nature.

In the context of the proposed program of surface storage development, reductions in the availability from Tarbela are compensated by successive additions of other projects. If any means could be found of reducing the accumulation of silt in the reservoir, it would clearly make possible very

TABLE 5-11
STORED WATER AVAILABLE FOR IRRIGATION RELEASE AT TARBELA
(MAF)

Storage Release Period	Available Storage	Storage Release Period	Available Storage
1975/76	8.48	1999/2000	5.35
1979/80	8.00	2004/2005	4.50
1984/85	7.40	2009/2010	3.65
1989/90	6.80	2024/2025	1.10

large savings in investment expenditures. The obvious means of reducing the rate of depletion of the reservoir—dredging—is infeasible because of the sheer magnitude of the problem; it may be of some use for keeping channels open (e.g. to the Siran Arm) but it is believed to be no general solution. A thorough survey of the silt problem and of means to overcome it is urgently needed.

Financial Requirements for Tarbela. The $625 million cost figure used in the Study Group's economic analyses of Tarbela covers only the reservoir works and excludes the cost of power facilities and financial charges such as duties, income, excise and sales taxes, interest during construction, provision for inflation, financial contingencies, etc. Table 5–12 relates economic costs—in a slightly different form from Table 5–7—to a total financial figure of about $900 million for the reservoir works plus the civil works and mechanical and electrical equipment for the first eight power units. The figures are the same as those used in the Study Group's report of February 1965 on the Tarbela Project. The Study Group considers that the figure for total financial requirements remains a reasonable estimate. Table 5–13 presents the estimated financial requirements of $816 million for the project's start without power units, but including the powerhouse structure for the first four units. Two other minor changes have been incorporated in Table 5–13. The allowance for precontract costs has been raised in the light of current knowledge; since some of the works covered were previously covered under the contract costs, some slight compensating reduction might be warranted in the latter but the amounts involved are too small and too uncertain to justify the change. A small item has also been included in Table 5–13 for the cost of project supervision, based on the experience of carrying out the Indus Basin Works. Table 5–13 brings out the fact that the estimated value of the civil engineering contract is about $530 million, inclusive of civil works for the first four power units.

THE IN-BETWEEN PHASE

There will be some need for additional storage capacity before the need for a major second-stage project on the Indus. There are two projects considered prime candidates for this role: Sehwan-Manchar and Raised Mangla Sehwan-Manchar, scheduled in the recommended program for completion in 1982, is an example of a scheme whose potential will be closely affected by the existence of Tarbela. Being located in the Lower Indus where evaporation is much higher than in the North, and consisting of shallow basins with broad water surface, it would make only a small contribution to rabi water supply if it had to be operated independently of groundwater development or of other storage on the Indus; independent operation would mean that its water had to be spun out over the whole rabi season. If, on the other hand, it could be operated in conjunction with Tarbela, its water could all be released early in rabi, minimizing loss to evaporation and permitting retention of more water in Tarbela in the early winter so that power capability would remain higher there.

TABLE 5-12
TARBELA PROJECT
ESTIMATED FINANCIAL REQUIREMENTS
(including first eight generating units)
(US$ million equivalent)

		Expenditures			
		Total	Foreign Exchange		Receipts
1. *Precontract Costs*					
From January 1, 1965		16.5		4.7	—
2. *Civil Construction:*					
(a) Dam and reservoir	414.4		284.0		—
(b) Power facilities	55.1[b]		35.7[b]		—
(c) Income tax[a]	61.0[c]		—		61.0
(d) Excise and sales taxes[a]	24.4[c]		—		24.4
(e) Performance bond	3.3[d]		3.3		—
(f) Insurance and miscellaneous	7.5[e]		7.5		—
Estimated bid value		565.7		330.5	
3. Subtotal		582.2		335.2	
4. *Engineering Contingencies* (20%)		116.4		67.0	17.1
5. Subtotal		698.6		402.2	—
6. *Mechanical and Electrical Plant*		35.6[b]		31.7[b]	
7. *Contingencies on line 6* (10%)		3.6		3.2	
8. Subtotal		737.8		437.1	
9. *Import Duties*[a]		48.0[c]			48.0
10. *Engineering and Administration:*					
(a) Dam and Reservoir		36.2		30.0	—
(b) Power facilities		8.4		7.0	—
11. Subtotal		830.4		474.1	150.5
12. *Land and Resettlement*		59.0		—	—
13. Subtotal		889.4		474.1	150.5
14. *Allowance for Inflation*[a]					
(a) 1.5% p.a. on Foreign Exchange Costs		39.8		39.8	—
(b) 2.0% p.a. on Local Currency Costs		43.4		—	—
15. Subtotal		972.6		513.9	
16. *Financial Contingency*[a]					
(a) 5% on expenditure through 1968		14.9		9.2	—
(b) 10% thereafter		54.0		28.7	—
17. Subtotal		1,041.5		551.8	
18. *Expenditures between*					
November 30, 1962 & January 1, 1965[f]		5.8		2.1	—
19. Subtotal		1,047.3[g]		553.9[g]	150.5
20. *Less Receipts*		150.5		—	
21. TOTAL		896.8		553.9	

[a] These items have been included in the cost estimates set out above to arrive at an estimate of the financial requirements. They are excluded from the figures in Table 5-7 because they are not pertinent to an economic evaluation.

[b] First eight units only. Excludes all transmission and distribution.

[c] Based on figures prepared by Coopers & Lybrand.

[d] The cost of this item is given as $4.0 million in Table 5-7 but is a bid item. It has therefore been reduced to $3.3 million so that when contingencies are added back (20%) the total becomes $4 million.

[e] This figure has been reduced from $9.0 million to $7.5 million for the same reason as in ([d]) above.

[f] In Table 5-7 all costs incurred prior to January 1, 1965, have been disregarded. Those incurred prior to November 30, 1962, have been met from the Indus Basin Development Fund.

[g] Makes no provision for interest during construction.

TABLE 5-13
TARBELA PROJECT
ESTIMATED FINANCIAL REQUIREMENTS
(excluding all mechanical and electrical power plant)
(US$ million equivalent)

	Expenditures				
		Total		Foreign Exchange	Receipts
1. *Precontract Costs*					
From October 1, 1965		34.8		13.0	—
2. *Civil Construction:*					
(a) Dam and reservoir	414.4		284.0		—
(b) Power facilities	27.6[b]		17.9[b]		—
(c) Income tax[a]	59.0[c]		—		59.0
(d) Excise and sales taxes[a]	21.0[c]		—		21.0
(e) Performance bond	3.3[d]		3.3		—
(f) Insurance and miscellaneous	7.5		7.5[e]		—
Estimated bid value		532.8		312.7	
3. Subtotal		567.6		325.7	
4. *Engineering Contingencies*		106.2		59.6	16.0
5. Subtotal		673.8		385.3	
6. *Import Duties*[a]		36.0[c]			36.0
7. *Engineering and Administration*		36.5		30.1	—
8. Subtotal		746.3		415.4	132.0
9. *Land and Resettlement*		59.0		—	—
10. Subtotal		805.3		415.4	132.0
11. *Allowance for Inflation*[a]		73.2		34.1	—
12. Subtotal		878.5		449.5	
13. *Financial Contingency*[a]		60.2		32.3	—
14. Subtotal		938.7		481.8	
15. *Supervision*		9.0		7.7	—
16. Subtotal		947.7[f]		489.5[f]	132.0
17. *Less Receipts*		132.0		—	
18. TOTAL		815.7		489.5	

[a] These items have been included in the cost estimates set out above to arrive at an estimate of the financial requirements. They are excluded from the figures in Table 5-7 because they are not pertinent to an economic evaluation.
[b] Civil engineering work only for first four power units.
[c] Based on figures prepared by Coopers & Lybrand for February 1965 report.
[d] The cost of this item is given as $4.0 million in Table 5-7 but is a bid item. It has therefore been reduced to $3.3 million so that when contingencies are added back (20%) the total becomes $4 million.
[e] This figure has been reduced from $9.0 million to $7.5 million for the same reason as in ([d]) above.
[f] Makes no provision for interest during construction.

The Sehwan-Manchar scheme is in fact the most important single irrigation work proposed by the LIP consultants. It is designed to increase water supplies to some of the best agricultural land in the Sind at the lower ends of Rohri and Nara Canals on the left bank of the Indus. The scheme takes advantage of the existence of Manchar Lake some four miles away from the river on the right bank. A 3,500-foot long barrage would be built across the Indus near Sehwan to impound water to a maximum level of 125 feet SPD. The barrage would thus be able to store effectively about 0.8 MAF, which would be released into a new 36,000 cusec feeder canal to the southern parts of the existing Rohri and Nara Commands. An inlet channel from the Indus, upstream of the barrage, would be built to Lake Manchar and the containing bund at the Lake would be raised to permit retention of water to the same level as at Sehwan. Lake Manchar would then have effective storage capacity of about 1.0 MAF; it would be filled partly from the Indus and possibly partly from the Lower Indus Right Bank Outfall Drain also proposed by LIP. The water would be released through an enlarged Manchar Outfall back into the river above the barrage and diverted into the left-bank feeder leading to Lower Rohri and Nara.

The Sehwan-Manchar Project could thus provide total storage of about 1.8 MAF and it is estimated that it would cost in a range of $177—$221 million. As such it would provide relatively expensive storage, but it might also eliminate the need for remodeling the upper portions of the long Nara and Rohri Canals from Sukkur, so that the net cost of storage would be quite low. The scheduling of the project depends on the timing of related irrigation works in the Sind. Under the integrated program, proposed construction would start in 1975, and so it is important to start the necessary preliminary investigations at an early date, particularly regarding evaporation and siltation.

A small possible additional development of the same project, actually scheduled in the recommended program for 1990, would be storage at Chotiari Lake, located on the eastern fringe of Nara Canal Command. The lake would be converted into a reservoir by construction of a 14-mile long bund. Live capacity would be 1.1 MAF and the storage available at canal head would be about 0.9 MAF. The reservoir could be filled either from an extension of the left-bank feeder mentioned above or from the existing Nara Canal. Cost of the Chotiari Scheme is estimated in the range $12–15 million.

The Project for Raising Mangla. The impounding structures of the Mangla Project are designed for raising the dam 40 feet to elevation 1274; this would permit a 48-foot increase in full reservoir level (to elevation 1250 feet SPD)—somewhat greater than the increase in the dam height because the larger surface of the higher reservoir would mean that floods could be handled with a smaller rise in reservoir elevation. Raising the maximum reservoir elevation to 1250 feet would permit an increase in live storage capacity in the neighborhood of 3.5 MAF. Detailed studies have been made of this project; the most recent estimate of cost was $217 million, with $130 million in foreign exchange.

According to the IACA projections of irrigation water requirements, shortages will arise in the canal commands of the eastern Punjab in the 1980's. It is at this time that the areas with groundwater of "mixing" quality—that is, which has to be mixed with surface water before it is usable for irrigation—will be coming under development. IACA recommends construction of a new trans-Punjab link canal, above the TSMB Link, and taking off from the tail reach of the Chasma-Jhelum Link on the Jhelum River; as discussed in regard to irrigation development, this would enable more of the eastern Punjab to be commanded from the Indus and would add significantly to the flexibility of the system. At the same time, as the cropping intensity of the mixing zones grows, the requirement of such areas for rabi surface supplies will increase. Additional storage at Mangla would help to meet this need. It is true, as indicated by Tables 5–1 and 5–2, that the kharif surplus available for storage at this time on the Jhelum will be declining; for instance, according to the IACA projections, it would be possible to fill a reservoir at Mangla only to the extent of 7 MAF even under mean-year conditions at the stage of ultimate development (the reference year 2000). But the capacity of Mangla raised 40 feet, allowing for siltation, would be about 8 MAF by this time. Thus many questions will have to be answered before it is firmly decided to raise Mangla. It may be preferable, as IACA tentatively suggests, to add less than the full 40 feet to Mangla Dam.

On the other hand, by the end of the century the system might be in transition from interseasonal storage, provision of which is the main concern during this century, to over-year storage. It would be quite logical to make the first step towards over-year storage on the very variable Jhelum River; as in the past, the tributaries rather than the Indus itself are still better candidates to inaugurate a new stage of development. Over-year storage would mean storing water from years of high flood for use in low-flow years, and obviously this could only be done with substantially larger storage capacity than necessary for interseasonal transfers alone.

Raising of Mangla will also be intimately related to the construction of the proposed trans-Punjab Link Canal; the latter might postpone the need for additional storage at Mangla for some years, but it might also be operated in such a way as to reduce the load of kharif requirements that had to be borne by the Jhelum and thus leave larger surpluses for storage at Mangla.

Second-Stage Storage on the Indus

According to the IACA projections of stored water requirements, a second major storage project on the Indus will not be required until about 1990, and the tentative program in Table 5–6 does not bring in the second major project on the Indus until 1992. This is partly because the two smaller projects in the Lower Indus area, Sehwan and Manchar, would be introduced around 1980 in connection with canal development there (cf. discussion above). Need could arise for major second-stage storage on the Indus somewhat earlier than projected, particularly if the canal remodeling program is carried less far than suggested by IACA. But even if a second major storage project is not required before about 1990, it is important to formulate views about which project that might be—to give direction to investigation efforts and to ensure that sufficient information is available by the time that the need arises to make a decision. It was apparent in the discussion of Tarbela and Kalabagh that only barely enough data were available for reaching a wise choice.

Further storage development on the Indus will be intimately affected by the prior existence of Tarbela and it will be important to investigate each potential storage site not only for its own direct advantages and disadvantages but also from the point of view of its effect upon and interrelation with Tarbela. One series of potential projects—at sites on the left-bank tributaries of the Indus downstream of Tarbela—will in fact only be feasible because of the prior existence of Tarbela; Indus water would be diverted from Tarbela, in the late flood season after Tarbela had been filled, down long diversion canals discharging at these sites. Projects at other sites on the Indus main stem upstream of Tarbela would likely have a great effect on the rate of siltation at Tarbela, while projects downstream would be to some extent protected from siltation by Tarbela.

Major Alternatives. For large-scale storage development on the Indus after Tarbela, there appear to be four main alternatives, as far as can now be foreseen—Kalabagh, Side-Valley Storage, Upper Indus sites and the Thal Offstream Storage Scheme. Kalabagh was discussed in connection with the choice of Tarbela. A few details of the other three alternatives will be presented here.

In regard to Side-Valley Storage, the possibility of diverting water from Tarbela to storage in either the Soan or the Haro River Valleys—on the left side of the Indus—has for some time been seen as an additional attraction of the Tarbela site. It has been suggested that storage capacity of the order of 30 MAF might be built on these rivers, to be filled almost entirely by diverted Indus flows. Four potential Side-Valley Storage Projects were studied by Chas. T. Main—Gariala and Sanjwal-Akhori on the Haro and Dhok Pathan and Dhok Abbaki on the Soan (see Map 4 at the end of the chapter).

Chas. T. Main concluded that the Gariala site was definitely preferable to the Sanjwal-Akhori site for major storage on the Haro, since a much larger reservoir could be built there, with larger power capability, and the unit cost of storage would be lower. The dam proposed for Gariala by Chas. T. Main would be about 375 feet high and would have a crest length of 40,000 feet. It would contain about 189 million cubic yards of embankment materials, or somewhat more than required for Tarbela. The dam could be constructed all at once or in two stages: a first stage with a live capacity of 4.6 MAF, a second stage adding 3.4 MAF. Of the full capacity of 8 MAF, a modest 0.4 MAF would be derived from the Haro River in a mean year with the rest being diverted from the Tarbela Reservoir, after the floods had brought the water elevation there to about 1550 feet, via a five-mile canal with a capacity of 76,000 cusecs. A power installation at Gariala would only be able to generate part of the year. However, one of the advantages of Gariala would be a long life of useful storage; some 5.4 MAF of capacity would still be available after 100 years of service. No subsurface explorations or detailed mapping have been carried out at the site. The consultants had to base their work on topographic maps, air photographs and one generalized, unsurveyed geological cross section of the dam site. Chas. T. Main estimated the cost of the single-stage project at about $650 million. The Study Group estimates that if conditions were somewhat less favorable than assumed, then the costs could rise to the order of $975 million.

Dhok Pathan and Dhok Abbaki, sites close together on the Soan River, are thought to be capable of supporting similar dams. The projects would be mutually exclusive. Dhok Pathan would probably be the better site for storage of water diverted by gravity from Tarbela, whereas Dhok Abbaki, seven miles downstream, might be preferable as a pumped storage project in connection with a reservoir at Kalabagh. The dam envisaged by the consultant for Dhok Pathan would be an earth and rockfill structure some 275 feet high with a crest length of about 12,000 feet, containing 38 million cubic yards of fill. The reservoir would provide a usable live storage capacity of about 7.5 MAF. Water would be conveyed from Tarbela to the reservoir by a costly 70-mile conveyance system requiring canals with a combined capacity of 76,000 cusecs and auxiliary structures, such as syphons, aqueducts and culverts. A subsidiary dam and reservoir would have to be built at the point where the canals crossed the Haro. Maintenance costs on the long conveyance system would be high because it would only be used for some three months in the year. Engineering and geological data are extremely scant but Chas. T. Main made a rough estimate of costs, as for Gariala, which totaled $1,130 million. The Dhok Abbaki Scheme, in connection with Kalabagh, would provide about the same storage capacity and it would be cheaper in terms of direct construction cost—about $635 million according to Chas. T. Main's estimate —because the long conveyance system from Tarbela would not be needed. The Soan River channel would merely need to be deepened to convey water from Kalabagh to the foot of the dam, whence it would be pumped into the reservoir. The pump turbine units would be reversible, with a capacity of about 2,000 mw on the pumping cycle and 1,900 mw on the generation cycle. To meet the large pumping load the power system would need substantial additional generating capacity which would add significantly to the true cost of the project.

The best of these sites for Side-Valley Storage would therefore appear to be Gariala, though it is possible that Dhok Abbaki might become attractive at a later date after completion of Kalabagh. Gariala would be substantially cheaper than Dhok Pathan but it would still apparently cost at least as much as Tarbela. One of the main difficulties with these Side-Valley Schemes, which adds substantially to the cost, is the very large canal capacity or, in the case of Dhok Abbaki, pumping capacity needed to bring water from the Indus; the large capacity is needed because of the relatively short period, about two months, that would be available for filling the reservoirs, between the time when Tarbela was filled and the end of the flood season. Maintenance of the canals and the power plants, if installed, would be expensive because of little use, and it would be possible to generate power for only about eight months in the year as the reservoirs were being drawn down. One additional disadvantage of Gariala specifically is that it would inundate the town of Campbellpore.

Upper Indus Sites refer basically to the Indus main stem upstream of Tarbela, particularly the 300-mile-long Upper Indus Gorge, and the tributaries of the Indus in this area. Topographically the area would appear quite well-suited for dam construction, particularly for hydroelectric purposes taking advantage of the steep river gradient (about 7,000 feet fall in a 300-mile stretch). There is one site—Skardu, about 315 miles upstream of Tarbela at the head of the Gorge—which, again from a purely topographic point of view, appears especially suitable for construction of a storage reservoir; it might be technically possible to build a reservoir there of some 35 MAF storage capable of regulating the entire flow of the Indus at that point. Thirty-five MAF is also the estimated annual discharge of the Indus at Skardu. However, there is an almost total lack of all the other information required to establish the feasibility of a dam there, and, with present techniques for dam construction, the problem of accessibility would be almost insuperable. The main portion of the Upper Indus Gorge is separated from the rest of West Pakistan by high mountain ranges; access to the area is over the 13,000-foot Babu-Sar Pass, closed by snow for eight months of the year, and thence along rough and generally narrow jeep tracks dug out of the side of the vast piles of glacial debris and silt which form the banks of the rivers.

Chas. T. Main tentatively formulated a project for the Skardu site, consisting of an earth and rockfill dam with concrete gravity spillway, on the basis of aerial photography carried out under the Study, contour maps prepared by the Survey of Pakistan and reconnaissance reports by WAPDA and its consultants. Foundation conditions at Skardu are totally uncertain; the Skardu site was not inspected on the ground in the course of the Study nor has it previously been studied in any detail. For purposes of their desk study, Chas. T. Main made arbitrary assumptions about foundation conditions. They drew rough outline plans for reservoirs of 5.2 MAF and 8.0 MAF capacity, and calculated that the smaller project might, on their assumptions, cost between approximately $425 million and $510 million while the larger one would cost between about $500 million and $590 million. These costs include an allowance of about $110 million for the access road. Power facilities were not included in the project designs because the long distance of transmission over rugged terrain makes it doubtful whether power installations would be justified. On the other hand, regulation of the Indus at this point would considerably increase the value of downstream hydroelectric facilities. No discharge or sediment load data were available for Skardu at the time Chas. T. Main made their study, though WAPDA is in the process of establishing a gauging station there. It is likely that these data, when gathered, will indicate a very much lower sediment transport on the Indus at Skardu than at Tarbela or Kalabagh so that a reservoir of about eight-MAF size should have very much longer life than reservoirs downstream.

The Thal Storage Scheme consists of an enormous shallow reservoir of some 21 MAF gross storage capacity formed by a long semicircular dike or bund around an area of rather poor agricultural potential on the left bank of the Indus in the upper part of Thal Doab. It was proposed by Tipton and Kalmbach (T&K), consultants to WAPDA, in February 1967. The dike would extend in a broad arc from the vicinity of Panjgirain on the left bank of the Indus southward and then across the doab to a point some eight miles from the Jhelum, where it would turn northward and run generally parallel to the Jhelum River, terminating some 15 miles south of the Chasma-Jhelum Link. It would have a crest level at 615 feet elevation and would be some 115 miles long with a maximum height of about 70 feet above existing ground level. The average height would be about 50 feet. T&K propose that the embankment, requiring about 300 million cubic yards of fill, be constructed from local alluvium compacted in layers with a puddled core. Allowing 15 feet for freeboard and assuming a minimum pool elevation of 560 feet, T&K estimate that the live storage capacity of such a reservoir would be about 20 MAF. To fill such a reservoir within two to three months, during the surplus flows on the Indus, would require about 100,000 cusecs of diversion channel capacity. An 80,000 cusec channel, some 12 miles long, would extend from a new barrage on the Indus at Panjgirain, some 35 miles south of Chasma, to the reservoir. An additional 20,000 cusecs of diversion capacity would be provided by a feeder canal, some 17 miles long, taking off from the Chasma-Jhelum Link. Releases would be made into the Jhelum upstream of Trimmu by way of outlet works of about 50,000 cusecs capacity. The cost of the scheme, according to preliminary T&K estimates, is about $590 million.

Though the live storage capacity of the reservoir could be as much as 20 MAF, the actual yield of the reservoir would be substantially less. T&K estimate annual seepage and evaporation losses at 1.7 MAF and 3.5 MAF respectively, but they judge that more than 1.5 MAF of the seepage could be recovered by construction of a drain suitably sited immediately downstream of the dike embankment. Allowing for annual operational losses of about 3.7 MAF, T&K state that the mean annual yield of the reservoir would be about 12 MAF and, with full use of Tarbela regulation, this could be increased to about 14 or 15 MAF.

The scheme, as proposed, appears to have many attractive features but there are clearly many aspects which will require careful and possibly prolonged investigation before final conclusions are possible. If the yield is taken as 13.5 MAF (12 MAF plus 1.5 MAF recoverable seepage) then the cost of an acre-foot of annual yield capacity would be about $44, considerably cheaper than the unit cost of storage behind the high dams discussed above. As off-channel storage, the rate of sedimentation would be low. For power generation at the outlet works, T&K believe that it might be possible to develop some 50 feet of head between minimum pool level and the Jhelum River; but the more important gain to power would be the scope that this large amount of storage capacity might offer for Tarbela to keep its head longer through the winter. However, as a major operational disadvantage of the scheme, unrecoverable losses, though they are hard to predict, will undoubtedly be high; this could be a serious matter in a country where water and not land is the ultimate constraint on irrigation development.

Before the feasibility of the Thal Scheme can be assessed, or its advantages and disadvantages weighed against those of other potential second-stage storage projects, much consideration will need to be given to aspects such as foundation conditions, seepage rates, the suitability of local materials for embankment construction, siltation rates, actual feasible reservoir capacity, and the extent to which water would be lost to evaporation (some might be regained elsewhere in the Province in the form of rainfall). Owing to the great length of the proposed bund, the cost of overcoming foundation or construction material supply problems might prove very high; thus special attention should be given this matter. Another matter which will call for careful study is maintenance of the long bund and seasonally operated channels; costs of such maintenance would tend to be high.

Second-Stage Storage—Assessment The basic conclusion which stands out is that existing knowledge is entirely inadequate for reaching a sound judgment as to which of these alternative projects might be best for second-stage storage on the Indus. The additional information needed is basically of two types. First, more data are required about river stages and discharges, type and quantity of silt load, and evaporation at different locations and different times of year. Collection of these data requires establishment of hydrometric stations at strategic locations and sustained observation of daily conditions over long periods of years. This general type of data is needed to obtain a better understanding of the whole Indus River system—the growth of knowledge and the evolution of water-control techniques may reveal opportunities that are not yet even conceived. Second, more data are needed regarding geologic aspects: foundation conditions, the process of silt generation, the permeability of local materials, etc. This information will be gathered in special surveys and studies. WAPDA's Surface Water Circle has proposed establishment of a number of additional hydrometric stations, particularly in the Upper Indus area, and the Study Group thinks that these should be established as early as possible; the longer the record, the more useful will the data be for decisions regarding second-stage storage—decisions that in fact will have to be taken within the next 10–15 years. As for the more specific studies, the Study Group thinks that priority should be given to (a) further exploratory work at Kalabagh, particularly on the geological side, including drilling of boreholes and adits in the foundation rock, laboratory test of rocks and identification of sources of construction materials; (b) to extensive field investigations and thorough studies of the Upper Indus, particularly the silt problem, studies of the effects of snowmelt and glacial movements, and related work on geological aspects of potential dam sites (which might be developed either on a small scale for purely local purposes or on a large scale for regulation of downstream flows); and (c) to further investigation and consideration of the many uncertain aspects implicit in Tipton and Kalmbach's imaginative scheme for off-stream storage at Thal. Limited field investigations should also be undertaken at Gariala to confirm the feasibility of the project. The basic approach regarding specific project proposals should be first to undertake sufficient field work and laboratory tests to confirm the feasibility of the project and the approximate cost, and then, some five years before construction would begin, to commence an intensive program of detailed investigation and project design work. Five years is by no means too long: after all, for Tarbela it took a year to fix the site, two more years to establish project feasibility with reasonable certainty, three more years to prepare definite plans, and another two years to reach the stage when construction might start.

In its tentative program of surface storage development, the Study Group has included Kalabagh (without sluicing) for second-stage storage on the Indus and it has scheduled it for completion in 1992 in order to meet the IACA "low ultimate" surface storage requirements, taking account of the gradual depletion of storage capacity at Tarbela. There were a number of reasons for this choice. Despite the attractive features of Skardu, such as its suitable topographic formation and its likely low rate of siltation, knowledge about geologic conditions is completely inadequate for saying whether, as related to Kalabagh, savings on construction costs would be great enough to outweigh the very high costs that would be involved in gaining access to the site. As for the interesting Thal Scheme, it has too many novel aspects and there are too many uncertainties about its basic feasibility to warrant its inclusion in a development program; but these aspects should be investigated at an early date to see whether the proposed development program cannot be radically improved by including substantial cheap storage there. For the present, though, the choice would appear to be between Kalabagh and Side-Valley Storage. And of these two, the Study Group believes that the present evidence markedly favors Kalabagh.

The existence of Tarbela will so much reduce the sediment inflow to Kalabagh, if the latter is built within 15–20 years of Tarbela, that it would appear preferable to build Kalabagh, as second-stage storage, as a nonsluicing rather than a sluicing structure. In that case, it would probably be worth installing some 1,125 mw of generating capacity at Kalabagh. The hydroelectric plant would have a firm capability of approximately 350 mw. By about 1990, the power system should be sufficiently large to be able to absorb usefully the contribution of a further hydroelectric project (beyond Mangla and Tarbela) with capability that would fluctuate heavily over the course of the year. Gariala, on the other hand, would have no firm power capability. Secondly, the Study has brought out the very large capacity (about 76,000 cusecs) of the canals that would be required to carry water from Tarbela to Gariala and the consequences of this for the cost of the project. The best available cost estimates indicate about $650–$975 million for the Gariala project against about $540–$735 million for Kalabagh. Thirdly, Chas. T. Main's backwater studies at Kalabagh appear to indicate that the danger of flooding at Attock, which had before been thought to be serious, is likely to be a relatively minor addition to what it would be without the dam. It may prove possible to achieve some reduction in the estimated costs of land acquisition, which are extremely high in the case of Kalabagh (about $200 million). It is true that Gariala might be built with somewhat larger storage capacity than nonsluicing Kalabagh and that its storage capacity would have a considerably longer life. However, as siltation increased at Kalabagh, a pumped storage scheme might be feasible at Dhok Abbaki and, in any case, the contribution that its power plant could make to meeting loads would become more substantial. Moreover, a project on the main stem, with power capability, would be much more flexible than Gariala as a component of an eventual total system that will probably include large-scale low-siltation storage at Skardu, Thal or possibly at Gariala itself.

A first objective of the detailed investigations of the Kalabagh Project, recommended to be undertaken at an early date, would be to check the validity of the Study Group's assumptions; if these assumptions prove significantly invalid, then there should be sufficient time to undertake thorough investigations elsewhere before the need for construction of second-stage storage on the Indus arises. These investigations at Kalabagh should include subsurface exploratory works and seismic studies, detailed survey of the site, access routes and reservoir area, sediment sampling and material analysis.

Other Sites and Projects

Further Storage Projects on Tributaries. As pointed out earlier, the potential for development of surface water storage to serve the main irrigated areas of West Pakistan is heavily concentrated on the Indus River itself. The tributaries are very much smaller and their flows are already, particularly with the completion of Mangla, much closer to full use; moreover, being more heavily dependent on monsoon rains than the Indus, their flows show much greater variability from year to year. There are many opportunities for development of small-scale storage works for local purposes—both agricultural and hydroelectric—but these are excluded from the scope of this Study. There is also a number of opportunities for relatively small-scale storage development in connection with major hydroelectric projects—as, for instance, the Kunhar Project, which will be discussed later in connection with power—and there are possible sites of a somewhat comparable nature on the Indus main stem, as at Bunji and Chilas and elsewhere in the Upper Indus area. Because of the extent to which their flows are already used, and the year-to-year variability of these flows, further storage development of sizable scale on the tributaries will be very closely linked to the irrigation needs of the particular sectors of the overall irrigation system which are served by these tributaries.

The Swat-Ambahar Project. The Swat River is a tributary of the Kabul. Existing developments there include the Upper Swat irrigation scheme, based on the Amandara headworks and the Lower Swat system of canals which draw their water from the Munda headworks. IACA estimated that, at full development, these projects will utilize, in an average year, all but 4.75 MAF of the Swat River flow. Of this, only about 2.0 MAF would be "untimely" and therefore available for storage. There are indications of promising storage possibilities in the Basin, but lack of data on dam sites allowed only an indicative desk study to be made by Chas. T. Main. This was in reference to a possible dam at Ambahar in the Lower Swat Gorge, about 13 miles upstream from the Munda headworks. It would appear possible to construct a very high dam in this area. As outlined by Chas. T. Main, a rockfill dam about 710 feet high would create a reservoir with a gross storage capacity of about 2.4 MAF, of which 2.0 MAF would be live. Large variations in storable runoff could be expected from year to year. There are possibilities that additional water could be brought from the Kabul but the cost would be high. However, the high head available at Ambahar would permit generation of a considerable amount of power even from the relatively small flows available in the Swat River; the project would have value for peaking purposes in the low flow season, although the transmission distances would be substantial. Much necessary data regarding the project, such as sediment records and geological information, are lacking. The inclusion of this project in the program is based on the assumption that further investigations verify the possibilities. Chas. T. Main estimated the cost of the project at $145 million.

Chiniot Project on the Chenab. The Chenab River presents no suitable sites in West Pakistan for large-scale storage development. But there is one possible small project which might help to regulate the operation of the massive link canal system. The project consists of an offstream reservoir, of 1.4 MAF capacity, which might be created in an abandoned channel of the river near Chiniot, some 110 miles downstream of Marala, by construction of extensive earthen dikes. The reservoir would have to be connected to the river by a canal. Water could only be stored there for short periods because of the permeable nature of the reservoir floor and the danger of waterlogging the surrounding farmlands. The costs of the project, over $100 million, would be quite high. It has not been included in the proposed program, but experience in operation of the enlarged canal system might show the need for such a centrally located project, which could be used to take small temporary surpluses in the balancing of month-to-month canal supplies.

C. FINANCIAL REQUIREMENTS OF THE PROPOSED PROGRAM

One of the objectives of the Indus Study is to indicate the order of magnitude of investment needed over the 20-year period 1965–85. This chapter has emphasized the uncertainties involved—not only with regard to actual requirements for surface storage but also regarding the projects which further investigation may show to be most appropriate and their costs. However, a reasonable estimate of financial requirements between 1965 and 1985 can be made for the program of surface storage given in Table 5–6. The Study Group believes that this program is as sound as such a program can be made at this time; it is consistent with the integrated development of all the water and power resources of West Pakistan, as

TABLE 5-14
PRELIMINARY ESTIMATE OF COST OF INVESTIGATION PROGRAM FOR SURFACE WATER STORAGE, 1967/68-1974/75

	US$ Millions
Collection and analysis of basic hydrological and meteorological data	5.9
Identification of second-stage storage	5.5
Detailed investigation of second-stage storage	7.5
Master planning	2.0
	20.9

proposed in this report. This program envisages completion of three surface storage projects, apart from Mangla, within the two decades to 1985—Raised Chasma Barrage, Tarbela and Sehwan-Manchar. However, several additional projects—Raised Mangla, Chotiari and Kalabagh—would be completed shortly after 1985, and expenditures on them would therefore commence within the 20-year period.

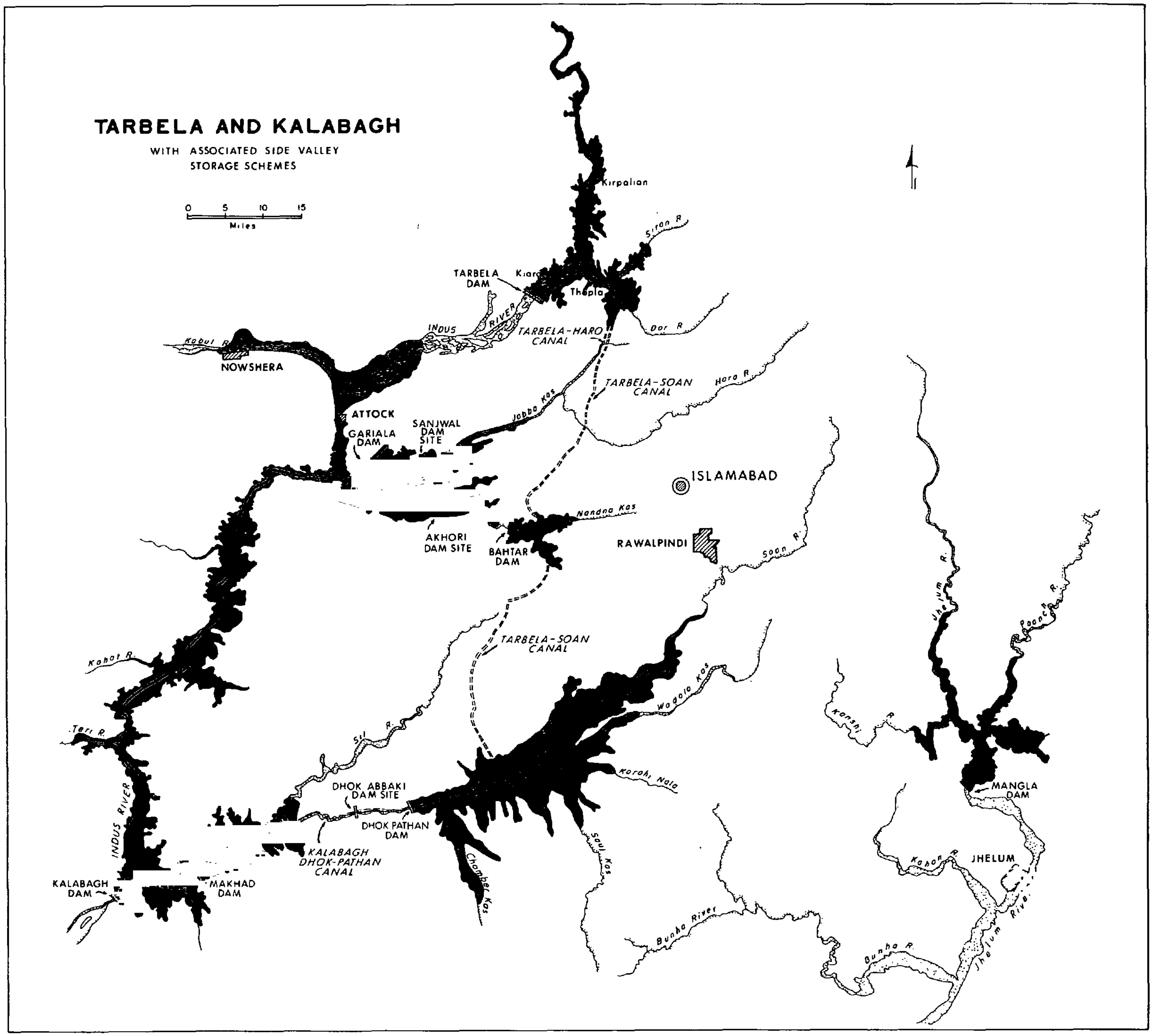
The proposed investigations, particularly with regard to the silt problem on the Upper Indus and identification of the best scheme for second-stage storage on the Indus, will also require expenditures over the 20 years. It is difficult to be precise about the costs involved, but the Study Group has estimated that about $2.5 million (with a 36 percent foreign exchange component), excluding taxes, may be required annually up to about 1970 and $3 million thereafter. Total estimated costs of the investigation program for 1968–75 are shown in Table 5–14. (A breakdown is given in Annex II.) These estimates are not intended to cover the costs of the existing network of hydrometric stations maintained by WAPDA and the Irrigation Department. They are intended to cover the costs of the studies recommended by the Study Group, but the sums required for these investigations may be even higher. The Study Group believes strongly that a substantial allocation for these activities should be included in development budgets in the coming years. Large sums are scheduled to be spent on surface water projects throughout the Perspective Plan period, and the availability of adequate data will enable those sums to be spent much more effectively than would otherwise be the case. Without adequate data and analysis of it, costly mistakes may be made in either selecting future projects or designing too conservatively or too radically for them. A better understanding of the silt problem, for instance, could pay off very handsomely indeed.

Table 5–15 brings together the proposed surface storage projects and investigations program over 1965–85. The first seven columns indicate the estimated economic costs of the projects and investigations program; the figure used for Tarbela is somewhat different in that it includes the allowances for inflation and financial contingency shown in Table 5–13. The eighth column sums them by years; the ninth column indicates the estimated foreign exchange component of the total program. The last two columns show the estimated cost of the whole program, including allowances for duties, taxes and interest during construction, first in US dollars and then in rupees.

TABLE 5-15
ESTIMATED ANNUAL COST 1965/66–1984/85 OF SURFACE WATER STORAGE PROGRAM
(US$ million)

	(1) Raised Chasma (1972)	(2) Tarbela[a] (1975)	(3) Sehwan-Manchar (1982)	(4) Raised Mangla (1986)	(5) Chotiari (1990)	(6) Kalabagh (1992)	(7) Investigations	(8) Total Annual Expenditures: Total	(9) Total Annual Expenditures: F.E.	(10) Interest during Constr.[b]	(11) Estimated Taxes[c]	(12) Total Financial Requirements: $ mlns.	(13) Total Financial Requirements: Rs mlns.
1965/66	0.3	1.4						1.7	0.7		0.3	2.0	9.5
1966/67	0.6	20.4						21.0	7.1		3.4	24.4	116.1
1967/68	3.9	99.4					1.9	105.2	59.2		16.8	122.0	580.8
1968/69	5.6	103.1					2.5	111.2	68.5	0.5	17.8	129.5	616.4
1969/70	3.9	100.3					2.5	106.7	66.2	0.8	17.1	124.6	593.1
1970/71	2.7	98.8					2.5	104.0	61.6	1.0	16.6	121.6	578.8
1971/72	1.1	76.1					2.5	95.4	56.7	1.1	15.3	96.1	457.4
1972/73		71.0					3.0	89.0	53.2		14.2	88.2	419.8
1973/74		68.6	1.0				3.0	77.6	46.7		12.4	75.0	357.0
1974/75		60.4	3.0				3.0	86.8	50.4		13.9	80.3	382.2
1975/76		53.0	6.0				3.0	77.0	43.6	0.5	12.3	74.8	356.0
1976/77		22.5	25.0				3.0	71.5	38.9	1.3	11.4	63.2	300.8
1977/78			35.0				3.0	58.0	29.6	3.2	9.3	50.5	240.4
1978/79			40.0				3.0	48.0	23.2	5.7	7.7	56.4	268.5
1979/80			40.0	0.4			3.0	48.4	21.9	8.4	7.7	59.5	283.2
1980/81			35.0	1.2		0.8	3.0	40.0	18.0	11.2	6.4	57.6	274.2
1981/82			26.0	4.0		2.5	3.0	35.5	16.2	13.4	5.7	54.6	259.9
1982/83			10.0	28.5		4.0	3.0	45.5	22.0	16.1	7.3	68.9	327.9
1983/84				59.5	1.0	10.0	3.0	73.5	38.6	4.5	11.8	89.8	427.4
1984/85				69.0	2.0	16.0	3.0	90.0	48.1	9.3	14.4	113.7	541.2
	18.1	775.0	221.0	162.6	3.0	33.3	50.9	1,386.0	770.4	77.0	221.8	1,552.7	7,390.6

[a] Excludes civil engineering work and all mechanical and electrical items for power plants.
[b] Compound interest at 6 percent per annum, assuming equal monthly disbursements within a year.
Interest during construction included for all projects *except* Tarbela.
[c] Taxes taken at 16 percent of annual expenditures excluding taxes, as implied by Table 5-13.


TARBELA AND KALABAGH
WITH ASSOCIATED SIDE VALLEY
STORAGE SCHEMES
0 5 10 15
Miles
Kirpalian
Siran R.
TARBELA
DAM
Kiara
Thapla
INDUS
RIVER
TARBELA-HARO
CANAL
Dor R.
Kabul R.
NOWSHERA
TARBELA-SOAN
CANAL
Haro R.
Jabba Kas
ATTOCK
GARIALA
DAM
SANJWAL
DAM
SITE
ISLAMABAD
Nandna Kas
AKHORI
DAM SITE
BAHTAR
DAM
RAWALPINDI
Soan R.
Jhelum R.
Poonch R.
TARBELA-SOAN
CANAL
Kohat R.
Wadala Kas
Kanshi R.
Teri R.
Sil R.
Koroh, Nala
MANGLA
DAM
DHOK ABBAKI
DAM SITE
DHOK PATHAN
DAM
INDUS RIVER
KALABAGH
DHOK-PATHAN
CANAL
Soil Kas
Chamber Kas
Kahan R.
JHELUM
KALABAGH
DAM
MAKHAD
DAM
Bunha River
Bunha R.
Jhelum River

VI

Electric Power

The report on power is essentially based on the work and findings of Stone & Webster. But important developments continued to take place after the consultants completed their field work late in 1965, and their report in May 1966. There were substantial changes in the basic data and, in fact, there was every reason to expect further changes in knowledge about fuel reserves, expectations regarding future loads, etc. The Study Group was anxious to develop techniques of evaluation which could be used for future revisions of the power program as well as its own purposes. One particular concern was the question of natural gas; how much might wisely be used for power generation, given the reserves assumed to be available in the Province and the growth of requirements of natural gas for purposes other than power generation. Another concern was to develop techniques for linking the forecast of power loads to the overall Perspective Plan for the growth of the provincial economy. But the greater need was for a pervasive, sectorwide method of analysis. For this purpose, the Study Group developed a computer model which effectively simulates the operation of West Pakistan electric power system, month by month, for the 20 years of the Perspective Plan period, 1965–85. The objectives were to put forward a feasible action program for the decade 1965–75 and a tentative indication of the kind of developments that would seem likely to be appropriate for the decade 1975–85.

A. STRUCTURE AND GROWTH OF THE SYSTEM

West Pakistan is served by four regional power systems (cf. Map 5 at the end of this Chapter). These systems, which are not interconnected, serve the following areas:

The North, an extensive area tied together by a 132-kv grid; it contains all of the hydroelectric capacity in the Province; the capability at maximum hydro output is approximately 522 mw.

The Upper Sind, centering on a gas-fired 50-mw steam station at Sukkur.

The Lower Sind, powered by both gas-fired steam and gas turbine plants; the total capacity is about 30 mw, centered on Hyderabad.

TABLE 6–1
TOTAL SALES OF ENERGY TO THE VARIOUS CLASSES OF CUSTOMERS BY UTILITIES IN 1960 AND 1965

	1960		1965	
Class of Consumer	Million kwh	Percent of Total	Million kwh	Percent of Total
Residential & Commercial	193	16.5	488	15.4
Industrial	576	49.3	1,321	41.5
Bulk and other uses	116	9.9	216	6.8
Agricultural Pumping	87	7.4	538	16.9
Total Sales	972	77.8	2,563	80.6
Losses and Theft	197	22.2	617	19.4
Total Utility Generation (Net)	1,169	100.0	3,180	100.0

TABLE 6–2
ENERGY GENERATED AND PEAK DEMANDS (NET) 1960 AND 1965

	1960		1965	
	Energy mln kwh	Demand megawatts	Energy mln kwh	Demand[a] megawatts
North	777.4	152	2,296.0	409
Sind & Baluchistan	31.9	25	174.0	34
Private Utilities	67.6	—	66.0	—
KESC	292.7	50	644.0	121
Subtotal	1,169.6	227	3,180.0	564
Industrially owned	520.6		544.0	
Total	1,689.6		3,724.0	

[a] Actual demand. The nonsuppressed demands (excluding load shed as a result of shortages of capacity) were estimated as follows: North, 473 mw; Sind & Baluchistan, 44 mw; KESC, 136 mw.

Karachi, West Pakistan's largest city and largest seaport and industrial center; the generating capacity is about 250 mw.

In addition, there are many small isolated generating plants with related distribution facilities, most of them serving individual municipalities or industrial installations. By far the largest of them is a 15-mw coal-fired station at Quetta.

The bulk of power facilities in the North and in the Sind, as well as the 15-mw Quetta plant, are owned and operated by the West Pakistan Water and Power Development Authority (WAPDA), an autonomous Government agency. Karachi is served by the Karachi Electric Supply Corporation (KESC), a stock company in which the Government holds a controlling interest. WAPDA also runs some of the small isolated stations in the Province, while others are in the hands of municipal utilities or private industrial enterprises. In 1965, about 65 percent of the electrical energy generated in West Pakistan was supplied by WAPDA, about 18 percent by KESC, about 14 percent by industrially owned generating equipment, and the remaining 3 percent by privately owned utilities.

As Tables 6–1 and 6–2 show, recent growth of electricity consumption has been rapid. Residential and commercial sales, as well as industrial sales, more than doubled between 1960 and 1965; sales for agricultural pumping in 1965 were about six times what they were in 1960. In the Northern Grid, total sales grew about 25 percent per year; in Karachi, the growth was 18 percent per year. In the North, agricultural pumping grew almost two and a half times as fast as industrial sales. The recorded peak demand on the public utility systems increased from 227 mw in 1960 to 564 mw in 1965.

B. THE LOAD FORECAST

Stone & Webster prepared a detailed 20-year load forecast for each of the four main power markets identified above and for the Quetta system. Great uncertainty inevitably surrounds such long projections into the future. Yet, because Tarbela Dam would take eight or nine years to build and because the generating capacity and transmission lines added during the next few years would soon become part of a power system dominated by Tarbela, 20 years seemed the minimum perspective required for wise decision making.

As a basis for forecasting, Stone & Webster used hypothetical 1965 figures rather than the actual figures cited in Tables 6–1 and 6–2, chiefly because of a downward bias in that year due to load shedding and voltage reduction; 1965 loads met by small independent utilities within the WAPDA service areas were also included in the base year figures because these loads and any increase that takes place in them will be largely met by WAPDA in the future. For each area, basic requirements were projected for various categories of uses—such as industrial, residential, commercial, agricultural—and then peak loads were determined by assigning appropriate hours of use to each category. The agricultural load forecast (i.e. tubewell pumping) was made on the basis of data supplied by IACA regarding number of tubewells to be constructed, average utilization rates, monthly pattern of tubewell pumping, etc. Other categories were forecast on the basis of such factors as historic performance, known loads, and long-term economic growth forecasts.

Table 6–3 summarizes the final forecast as prepared by Stone & Webster of energy and peak loads, both net of station use. Summarized briefly, total net electrical energy requirements are expected to increase from slightly under 4,000 million kwh in 1965 to nearly 30,000 million kwh in 1985. The average increase would be 10.6 percent, ranging from 14 percent during the Third Plan period to 8 percent in 1980–85. Industrial consumption would grow from 1,800 million kwh in 1965 to 13,500 million kwh in 1985, at an average annual rate of 10.5 percent, falling from a 13 percent rate during the Third Plan period to an 8 percent rate during the early 1980's. Residential consumption would grow from about 380 million kwh in 1965 to about 3,700 million kwh in 1985, at an average annual rate of 12 percent, falling from nearly 14 percent early in the period to about 10 percent late in the period. Agricultural consumption would grow from about 570 million kwh in 1965 to about 5,050 million kwh in 1985 or at an average rate of 11.6 percent, falling from 18 percent

TABLE 6-3
FORECAST OF ENERGY AND PEAK LOADS, 1965-85
(excluding industrially owned generation)

Area	1965	1970	1975	1980	1985	Annual Rate of Growth (%)
Energy (million kwh)						
North	2,480	4,606	7,228	10,589	15,063	9.5
Upper Sind	31	271	650	976	1,518	21.5
Lower Sind	152	349	778	1,405	2,309	14.6
Baluchistan	16	43	85	134	210	13.8
Karachi	710	1,675	3,520	6,055	9,300	13.8
Total Utility	3,389	6,944	12,261	19,159	28,400	11.2
Peak Load (mw)						
North	473	889	1,402	2,021	2,878	
Upper Sind	8	45	105	162	250	
Lower Sind	31	73	154	266	424	
Baluchistan	5	12	22	32	48	
Karachi	136	309	642	1,114	1,730	
Total Utility	653	1,328	2,325	3,595	5,330	

per year early in the period to about 7 percent late in the 1980's. In 1965, about 73 percent of the total utility generation was consumed in the Northern Grid, and 21 percent in Karachi. By 1985, the Northern Grid is estimated to consume 53 percent of the total, and Karachi 33 percent. The pattern in 1985 reflects the expected continued rapid development of industry in the South.

As part of its review of the Stone & Webster forecasts, the Study Group considered the consistency of the load forecast with other indications of growth. The Pakistan Planning Commission had prepared a general sketch of how the economy might grow between 1966 and 1985 and, of course, the Study Group had a later understanding of the probable development of irrigated agriculture, based on the final recommendations contained in this report. Since 90 percent of the present and prospective power load is accounted for by three categories—industrial, residential/commercial and agricultural (tubewell pumping)—the Study Group concentrated its efforts on these.

The forecast of pumping load adopted in this report, including its monthly pattern, is consistent with the Study Group's recommendations regarding the installation of public tubewells and the electrification of private wells. The wells installed by WAPDA under the SCARP program have so far generally been shut down daily for two hours at times when generating capacity was short; this has resulted in a reduction of system peak demand by some 20–40 mw. According to studies made by the consultants, these daily interruptions would continue to be physically feasible and economically worthwhile. Interruption of the peak pumping load was, therefore, built into the load forecasts according to the working criteria that drainage wells (i.e. those pumping saline water in excess of 3,000 ppm) would be shut down for the four-hour evening peak, while about 70 percent of the public wells in usable groundwater areas would be shut down for two hours a day, 35 percent in the first two hours of daily peak and 35 percent in the second two hours of daily peak. The pumping load forecasts shown in Table 6–4 below are all given net of this amount of interruption.

In regard to the future residential and commercial load, the expected increase of family incomes will enable additional families to become consumers of electricity and existing electricity consumers to purchase more electrical appliances and increase their consumption of electricity. At the same time, the utilities will be extending the distribution system into new areas. The Study Group tried to evaluate the prospects in these fields in the light of the growth of family incomes projected in the Perspective Plan, the emphasis on agricultural development implied by the Perspective Plan and confirmed by this Study, the prospective development of groundwater pumping in the Indus Basin, and the funds which might be available for extension of the rural distribution system. The Group's studies (described in Supplemental Paper No. 2, Volume Three) led to the conclusion that, if the trained manpower and organizational capability were available to put in the distribution lines, then the number of residential consumers might grow somewhat more rapidly but the average consumption per household somewhat slower than the figures adopted by Stone & Webster. Also, rural electrification would tend to be restricted by the availability of finance. The composite effect might be a slightly slower growth of the residential load, especially in the early years of the 20-year period.

The Study Group's approach to industrial load forecasting was to estimate growth of industrial output and then translate this into power requirements. The rate of industrial growth implied by the Perspective Plan appears to be somewhat below what might actually be achieved, especially in the early years of the perspective period. At the same time, a relatively high proportion of the industrial growth, particularly in the early years, might be in industries which are exceptionally heavy consumers of electric power—for instance it was felt necessary to make separate projections of output in both physical and financial terms for the cement and fertilizer industries. The indicated industrial growth rate is somewhat more than 10 percent per year over 1965–85, but higher initially—about 13 percent in the Third Plan period. The fertilizer industry could average about 15 percent per year over the 1965–85 period and about 30 percent per year in the early years. On the basis of certain power intensities that appear to exist for different industries in West Pakistan—i.e. the amount of electric energy consumed by the industry per Rs. 10 of net output—projections of output have been translated into projections of power requirements. It appears that the overall industrial load in the Province might grow more rapidly than industrial output in the Third Plan because of the importance of power-intensive industries. The growth may average 15 percent for a few years, then drop off to about 10–11 percent during the 1970's and early 1980's. In sum, the industrial load might grow initially slightly more rapidly than Stone & Webster had projected; after 1970, growth in industrial load would be somewhat slower but tailing off less rapidly than the consultants forecast.

TABLE 6–4
ALTERNATIVE LOAD FORECASTS FOR NORTHERN GRID AREA

	1965	1970	1975	1980	1985	Annual Rate of Growth (%)
Main Forecast (million kwh)						
Basic Load	1,820	3,100	4,600	7,040	10,270	9.0
Pumping Load	680	1,514	2,628	3,547	4,793	10.3
Total	2,500	4,614	7,228	10,587	15,063	9.5
Contingency Forecast (million kwh)						
Basic Load	1,820	3,480	5,900	9,596	15,453	11.3
Pumping Load	680	1,514	2,628	3,547	4,793	10.3
Total	2,500	4,994	8,528	13,143	20,246	11.0
Projected Peak Loads (mw)						
Main Forecast	473	889	1,402	2,021	2,878	
Contingency Forecast	473	967	1,591	2,521	3,928	

On the basis of these reviews of the major sectors, the growth of total electric energy requirements as set forth in Table 6–3 appears to be slightly on the optimistic side. Given the long-term capacity planning purposes for which the load forecast was being used, there is good reason to endorse a projection that is slightly on the high side. Geographically it appeared that, while loads might be somewhat differently distributed within the North or the South (e.g. greater growth in Upper Sind due to the fertilizer industry there), the general balance between North and South projected by Stone & Webster seemed reasonable. In other words, loads might be expected to grow exceptionally rapidly in the Sind, and also somewhat faster in Karachi than in the Northern Grid area. Thus the predominance of the Northern Grid area in consumption of utility-generated electricity would tend to fall from about 70 percent of the Provincial total in 1965 to about 55 percent in 1985.

While the forecasts in Table 6–3 are the best that can now be given, power requirements can change rapidly in a country that is developing as rapidly as Pakistan has been doing in recent years. This makes it particularly important to keep the load forecasts under constant surveillance. It also suggests the value of contingency planning—planning against more than one load forecast in order to minimize the chance of being caught unprepared. The Study Group took the view that a tendency to err slightly on the optimistic side was correct, given the long-term capacity planning purposes for which the load forecast was being used. (For more details, see Supplemental Paper No. 2, Volume Three.)

As an illustration of how contingency planning can be helpful, the Study Group would put forward the case for a higher forecast of basic load in the North as an alternative to the forecast given in Table 6–3. There are, for instance, some uncertainties surrounding the major element of demand. The requirements of electric power for construction of Tarbela could be higher than assumed in Table 6–3; the transfer of Government from Karachi to Islamabad could have a greater power impact than expected; so could the Government's emphasis on industrial development outside Karachi. A higher load forecast for the Northern Grid has in fact been made by Harza, not on the basis of individual loads expected, as Stone & Webster did, but simply as a rough extrapolation of load growth (from the base-year figures developed by Stone & Webster for 1965). The Harza forecast, although on a less solid analytical basis, provides a useful means of preparing for any unexpected future load growth. Table 6–4 compares the main forecast adopted by the Study Group (i.e. Stone & Webster's) and the contingency forecast (i.e. Harza's). The pumping loads are the final forecasts which came out of IACA's studies. The Study Group worked primarily in terms of the main load forecast, which it considers sound, but it has also considered the implications of the contingency forecast for some of the major decisions facing West Pakistan in the development of its power system.

C. BULK SUPPLY, 1965–85

For reasons of convenience, bulk supply will be discussed in five phases. First, we will consider developments which are in train during the Third Plan, 1965–70, which was well underway when this was being written. The program for bulk supply proposed by Stone & Webster will be described, followed by a brief explanation of adjustments made by the Study Group. Then the program will be described for each Plan period from 1970 to 1985. Finally, the distribution program will be explained.

Developments in Train, 1965–70

In 1966/67, the Northern Grid area and Lower Sind were confronted with a serious power crisis. There was considerable load shedding and, all in all, power shortages resulted in serious loss of agricultural and industrial production over half a year or more. While the shortage in capacity was expected to be filled in 1967, the circumstances of the shortages illustrate the importance of stable power in West Pakistan; and the plans to overcome them will bring this discussion to a point of departure for a proposed program to meet future demands.

The shortage in the Northern Grid area was especially acute due to unforeseen mishaps to the units at the main thermal station in the North at Multan and delays in the completion of a new thermal station at Lyallpur. By the middle of 1966, WAPDA had a peak capacity of about 550 mw net.[1] Peak demand in August was estimated at about 520 mw net, but the peak which could actually be met was only about 400 mw. Equipment failure at Multan had resulted in outage of one complete unit and reduction in capacity of the three other units. The situation became even worse in the winter of 1966/67, as the normal reduction in river flows restrained hydro capacity. By the end of April 1967, with the increase

[1] 160 mw at Warsak hydro station, 85 mw on eight small hydroelectric stations on rivers and canals, 250 mw in four modern gas-fired steam units at Multan, 26 mw in two new gas turbines at Lahore and about 25 mw in miscellaneous small thermal units.

TABLE 6–5
WAPDA NORTHERN GRID NET CAPABILITY, MARCH 1968
(mw)

Warsak units 1–4	100
Mangla units 1–2	90
Small hydels	75
Multan steam station	250
Lyallpur steam station	124
Lahore gas turbines	78
Miscellaneous thermal	23
Total	740

of flows in the rivers and the reduction in tubewell loads, the worst of the power crisis was over. By the middle of the year, the first two units at Mangla were in operation (minimum combined capacity in March–May about 90 mw and maximum capacity in August–September about 260 mw) and two 66-mw steam units were soon due to be completed at Lyallpur. In the latter part of 1967, four 13-mw gas turbines were to be added to the Lahore station. Assuming repair of the Multan units, the total net capacity on the system by March 1968 would be 740 mw (Table 6–5). The projected load would be about 600 mw on the main load forecast and 620 mw on the contingency load forecast, indicating a reasonable surplus. Both the loads are given net of interruption of public tubewells at the peak.

The Lower Sind system has been overloaded for a number of years. The crisis in 1966 was at least partially due to the failure of a boiler in a new 15-mw unit. Of a peak load of about 38 mw, only about 28 mw was being met. The existing capacity was expected to be increased by about 28 mw during 1967, as a result of final completion of the 15-mw steam unit at Hyderabad and installation of a 13-mw gas turbine at Kotri. WAPDA plans to add two more 13-mw gas turbines at Kotri during 1968; by the middle of that year, a 132-kv transmission connection should be completed between Hyderabad and Karachi. Karachi has a net capability of about 250 mw at the present time, against a 1966 peak load of about 136 mw. The main units on the Karachi system are two 33-mw steam units at West Wharf and two new 66-mw units at Korangi. The Upper Sind system had a capability of about 25 mw in 1966 (in two 12.5-mw steam units at Sukkur) against a peak load of about 8 mw. Two more 12.5-mw steam units were added to the Sukkur steam station in early 1967. The Upper Sind now has a net capability of 50 mw.

For the system as a whole, the supply-demand situation in 1970 could be foreseen. The third unit at Mangla was expected to be ready for service late in 1968 and the fourth unit late in 1969 or early in 1970. Negotiations for supply of two 100-mw steam units from Czechoslovakia, for installation in the Upper Sind area by about 1970 or 1971, were being finalized by WAPDA. A double circuit 132-kv link between the Northern Grid and the Upper Sind was also being completed, so that the Northern Grid would be able to draw about 120 mw from the Upper Sind. A 125-mw

TABLE 6–6
GENERATING CAPABILITY AND PEAK LOADS, 1970
(mw)

			Peak Loads	
		Capability	Main Forecast	Contingency Forecast
Without Transmission Link				
Northern Grid	(March)	830	813	879
Upper Sind	(October)	250	45	45
Lower Sind	(October)	84	73	73
Karachi	(October)	375	309	309
With 132-kv Transmission Link				
North/Upper Sind	(March)	1,080	852	918
Karachi/Lower Sind	(October)	459	382	382

steam unit at Karachi, financed by a World Bank loan to KESC, should be completed during 1969. Table 6–6 compares anticipated capability and anticipated loads in the critical month in each of the four main market areas in 1970, on the assumption that both the Czech units at Mari will be completed by that time, with and without the completion of the 132-kv links as scheduled. Commitments already made appear sufficient to meet all anticipated increases in load; indeed, the second Czech unit in the Upper Sind could be deferred to 1971 if anticipated loads are of the order projected in the main load forecast used here. As regards the South (Karachi/Lower Sind), the capacity additions already described will be sufficient to meet anticipated loads with a reserve of about 80 mw. Such a reserve would be adequate on criteria generally adopted in these studies—12 percent of thermal capability and 5 percent of hydro capability—but it would not be adequate on the largest-single-unit-out criterion since the largest unit on the Southern system at that time would be the 125-mw Korangi C unit. To ensure full security of supply in the South in 1970, it may be advisable to add several gas turbines. The proposed program for 1965–85 includes 26 mw of gas turbines at Hyderabad in 1970, partly with a view to this need for additional reserves in that year and partly because additional gas turbines will subsequently be required in the South to firm up the EHV transmission link between Upper Sind and Karachi proposed below for the early 1970's.

THE STONE & WEBSTER PROGRAM

The program proposed by Stone & Webster (S&W) for evaluation by the Study Group contained four main features. First is the Tarbela Dam. Completion is scheduled for 1975, so its power potential can be gradually realized in the following years. The second important component of the S&W program is a 380-kv transmission interconnection, starting with a line between Mari and Karachi in 1971 and embracing all main load centers by the time that Tarbela comes on line in 1975. Third, and closely linked with the transmission recommendations, is a heavy concentration of thermal development at Mari (Upper Sind area) to provide all main load centers

TABLE 6–7
STONE & WEBSTER'S GENERATION AND TRANSMISSION PROGRAM, 1965–85
(mw)

	Northern Grid Hydro	Northern Grid Thermal	Upper Sind Thermal	Karachi/ Hyderabad Thermal	Total
Generating Equipment					
Existing 1965	155	277	25	275	732
1966–69	197	176	51	101	525
1970–74	277	—	390	250	917
1975–79	598	—	300	325	1,223
1980–84	400	—	540	880	1,820
1985	—	—	240	—	240

380-kv Transmission Equipment

1971	Mari-Karachi single circuit.
1973	Mari-Lyallpur single circuit.
1974	Second Mari-Karachi circuit; Tarbela-Lyallpur single circuit.
1977	Second Tarbela-Lyallpur circuit; Second Lyallpur-Mari circuit.
1982	Third Tarbela-Lyallpur circuit.
1983	Third Lyallpur-Mari circuit.

in the Province with thermal power produced by cheap gas there. The consultant envisaged that all the reserves of the Mari gas field, as estimated at the time they were reporting (five trillion cubic feet), would be committed to supporting 1,500 mw of locally sited generating facilities. The fourth important feature of the program is a continuation of thermal development based on Sui gas at Karachi.

Stone & Webster thus evisaged that all the generating equipment installed by the public utilities between 1965 and 1985 would be either hydroelectric or gas-fired thermal units, with one exception. Their program also makes allowance for installation of a 125-mw nuclear plant by the Atomic Energy Commission in the early 1970's, which would supply power to Karachi. The recommended hydroelectric development, including two additional units (Nos. 5 and 6) at Warsak, eight units at Mangla, and 12 units at Tarbela, would have a firm capability of about 1,450 mw. This was based on the assumption that the Tarbela Reservoir would be drawn down to a minimum level of 1332 feet each year while the Mangla Reservoir would be drawn down to a minimum level of 1075 feet each year. New gas-fired plant would be installed mainly at Mari (about 1,500 mw) and Karachi (about 1,400 mw). Substantial seasonal interchange of power was envisaged, with hydro energy being sent south to the Sind and Karachi in the summer flood months and early winter when the reservoirs were nearly full and with energy generated at Mari being sent to Karachi in most months of the year and to the Northern Grid area in the spring when the reservoirs were at minimum levels. This program was drawn up after consideration of a large number of alternatives including various numbers of units at Mangla and Tarbela and various phasings of their introduction, different drawdown levels and reservoir release patterns at Mangla and Tarbela, alternative sources of thermal generation and alternative transmission patterns. It is explained in detail in Supplemental Paper No. 8, Volume Three.

Table 6–7 indicates the schedule of installation of generation and transmission equipment proposed by S&W. Capabilities of the hydro units are given in terms of the critical 10-day period on the system at the time the units are introduced. Besides the equipment listed in the table, the program also included a further 32 mw of coal-fired thermal plant at Quetta and a 220-kv link between Mari and Quetta in 1981. The consultants also recommended retirement of about 30 mw of small-scale generating equipment in Karachi and the Northern Grid over the next 10 years. Thus West Pakistan would, according to the S&W program, have a power system with a capability of 5,557 mw at the time of minimum hydro capability (May) in 1985. The forecast power demand would be somewhat over 5,000 mw at that time.

Adjustments to Stone & Webster's Program

The bulk power supply program proposed in this report differs in a number of important respects from the program proposed by Stone & Webster, although many of the basic concepts put forward by the power consultant have been retained. The differences arise from a number of sources. After the power consultants had completed their report, one very important change occurred in the basic framework of information within which a power program for West Pakistan has to be drawn up: the best estimate of recoverable gas reserves at Mari was reduced from 5 trillion cubic feet to about 1.8 trillion cubic feet, resulting in a reduction of about 25 percent in the estimated total thermal value of the main usable gas reserves in the Province. This change in knowledge about fuel reserves required reevaluation of some of the most important proposals made by S&W, particularly with regard to transmission; to the extent that indigenous fuel reserves for thermal generation of electric power were scarcer than had previously been supposed, this also had an effect upon the power benefits attributable to the proposed hydroelectric projects. Other important differences arise from changes made in other parts of the Indus Special Study which had been brought further along by the time the Study Group came to finalize its recommendations; this affected the drawdown level at Mangla, the release patterns at Mangla and Tarbela and the growth and monthly pattern of the assumed tubewell pumping load. Also, the Study Group carried out further investigation of certain particular items in the program, sometimes at the specific suggestion of the Government of Pakistan: two results of these studies are (a) substantially different scheduling of the hydro units at Warsak and Mangla and the installation of the 380-kv transmission lines between Karachi and Lyallpur, and (b) some important implications for the extension of the Province's gas pipeline system. Accounting for some other relatively minor changes in the proposed program, commitments for installation of generating equipment over the next few years, made since S&W completed their report, differ from those envisaged by them. Finally, there are some important adjustments which result from a combination of the sources of change mentioned above: an earlier installation of certain transmission lines; a heavier emphasis on nuclear installation following completion of 12 units at Tarbela. Almost all the changes proposed have been tested and examined with the aid of the com-

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FIGURE 10

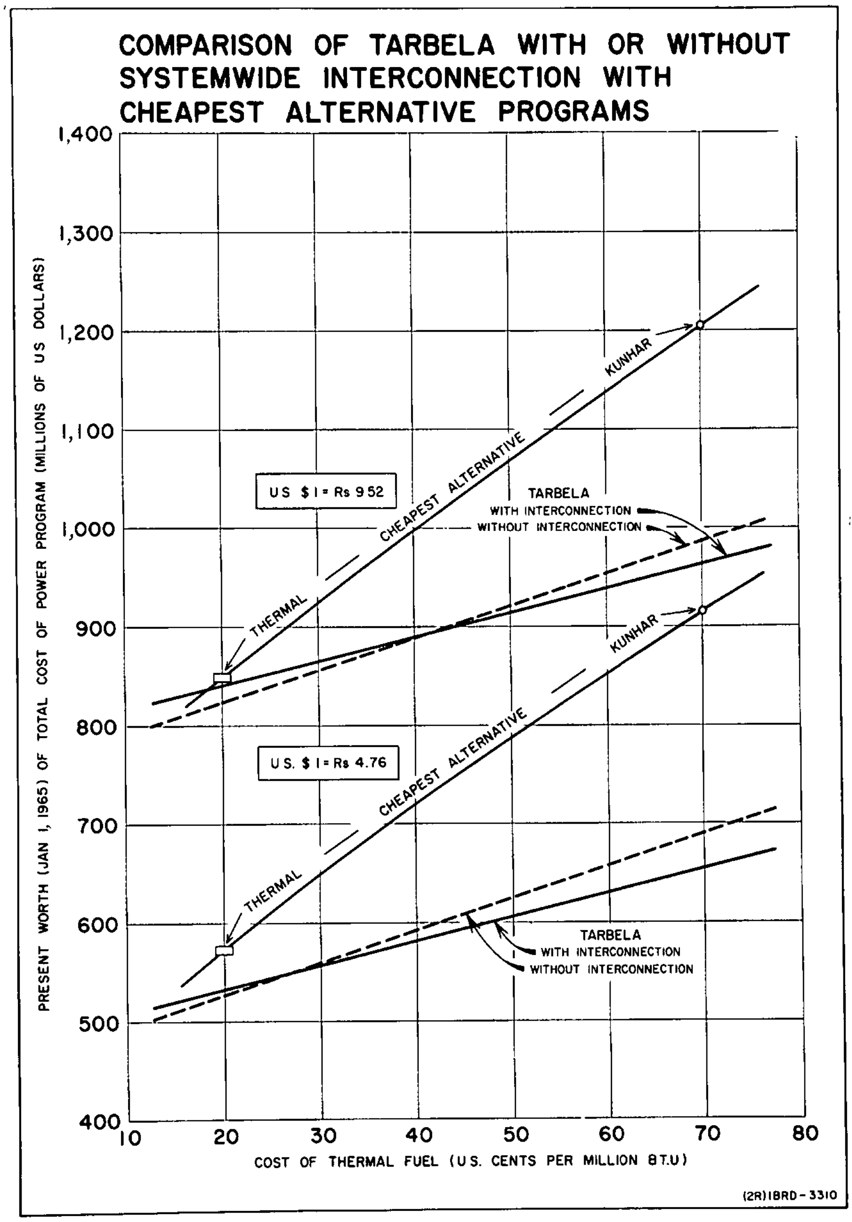

TABLE 6-8
BANK STUDY GROUP'S GENERATION AND TRANSMISSION PROGRAM, 1966-85
(mw)

	Northern Grid Hydro	Northern Grid Thermal	Upper Sind Thermal	Karachi/ Hyderabad Thermal	Total
Generating Equipment					
Existing 1965	155	277	25	275	732
1966–69	135	202	25	187	549
1970–74	225	—	400	151	776
1975–79	664	—	200	325	1,189
1980–84	292	—	700	700	1,692
1985	—	—	—	400	400
380-kv Transmission Equipment					
1971 Mari-Lyallpur single circuit; Mari-Karachi single circuit					
1974 Second Mari-Karachi circuit					
1975 Tarbela-Lyallpur single circuit					
1976 Second Mari-Lyallpur circuit					
1978 Second Tarbela-Lyallpur circuit					
1979 Third Mari-Lyallpur circuit					
1980 Third Tarbela-Lyallpur circuit					

puter model which simulates the operation of West Pakistan's power system.

The bulk power supply program proposed by the Study Group is summarized in Tables 6–8 and 6–9.

THE FOURTH PLAN (1970/71–1974/75)

It has been shown that existing commitments will be sufficient to meet prospective loads up to 1970, so proposals for the Third Plan are not discussed, except it is noted that work should have commenced on a 380-kv link between the Northern Grid and Mari. For the next plan, the Study Group proposes that the 380-kv link be completed in 1971; also, construction should be completed on Mangla Units 4–8 between 1970 and 1974. It also proposes the addition of 400 mw of capacity in the Mari area, about half of it in the form of gas turbines. Depending on a number of factors, particularly whether or not the fifth outlet tunnel at Mangla, now plugged, will be commissioned for irrigation purposes, it may prove economical to install Units 9 and 10 at Mangla in this period, in place of some of the gas turbines at Mari: if commissioned, the Mangla units would be able to operate on base load throughout most of the period of minimum reservoir level under mean-year flow conditions.

The Study Group's program is designed to meet the main load forecast adopted in this report. Provided that both Czech units at Mari can be installed by 1970, the 132-kv Mari-Lyallpur link also completed by then, and the 380-kv Mari-Lyallpur link completed by 1971, the proposed program is also sufficient to meet the contingency load forecast for the Northern Grid through 1971 with ample reserve. By 1972, reserves would appear inadequate, unless the complete Lyallpur-Karachi 380-kv tie is in place by that time. Therefore, the program seems adequate for both

TABLE 6-9

SUMMARY OF PROGRAM

POWER GENERATING EQUIPMENT AND TRANSMISSION LINE INSTALLATION

(mw)

	Generating Equipment						EHV Transmission Line
	Northern Grid		Upper Sind		Lower Sind and Karachi		
1966	Existing	467(Oct)	Existing	50(Dec)	Existing	280(Dec)	
1967	Lyallpur-Steam	124			Hyderabad-Steam	15	
	Mangla 1; 2	90(Mar)			Kotri GT	13	
1968	Lahore GTs	52			Kotri GTs	26	
1969	Mangla 3	45(Mar)			Korangi "C"	125	
1970	Mangla 4	45(Mar)	Mari-Steam	100	Hyderabad GTs	26	
	Mangla 5, 6	90(Mar)					
1971	Retire	(15)	Mari-Steam	100	Karachi-Nuclear	25	Lyallpur-Mari-Karachi (s/c)
1972					Karachi-Nuclear	100	
1973	Mangla 7, 8	90(Mar)			Retire	(15)	
1974			Mari GTs	200			Mari-Karachi (s/c)
1975	Tarbela 1, 2	180(Mar)			Korangi 4	125	Tarbela-Lyallpur (s/c)
1976	Tarbela 3, 4	180(Mar)					Lyallpur-Mari (s/c)
1977			Mari/Sui 5	200			
1978	Critical changes to May						Tarbela-Lyallpur (s/c)
	Tarbela 5, 6	146(May)					
	Warsak 5, 6	80(May)					
1979	Tarbela 7, 8	146(May)			Korangi 5	200	Lyallpur-Mari (s/c)
1980	Tarbela 9, 10	146(May)					Tarbela-Lyallpur (s/c)
	Tarbela 11, 12	146(May)					
1981					Korangi 6	300	
1982			Mari/Sui 5a	200			
			Mari/Sui 5b	200			
1983					Karachi-Nuclear	400	
1984			Mari/Sui 6	300			
1985					Karachi-Nuclear	400	

load forecasts until about 1972/73. In the North, assuming that loads on the Northern Grid were being fully met by the winter of 1967/68, actual sales should begin to provide a better indication of what the demand in the North really is and of how it may grow. There may be time to reassess the prospective loads of the early 1970's. If they are close to the contingency forecasts, an additional 200 mw of capacity at Mari, over and above that proposed in the Study Group's program, will need to be installed in 1973–75.

Development of the Karachi/Hyderabad power system in the Fourth Plan will be chiefly affected by two dates: when interconnection is achieved with the North and when the Karachi nuclear plant becomes available as reliable capacity. It is assumed that 25 mw of its capability will become available as reliable capacity for KESC in 1971 and the remaining 100 mw in the following year. If 26 mw of gas turbines are added at Hyderabad in 1970, and the EHV transmission link with Mari is installed in 1971, there would be sufficient firm capacity available in the South to meet the projected peak. Without the EHV link, local capacity in the South may not be adequate to meet projected loads with full security of supply (i.e. reserves adequate on the single-largest-unit-out criterion); so, if it appears that the EHV link will be delayed beyond 1971, it may be necessary to install gas turbines or to hasten completion of the nuclear plant. The EHV link should anyway be completed by 1974/75. The Study Group's tentative program includes a 125-mw Korangi unit No. 4 in 1975. This unit could be postponed longer, as S&W proposed, if more capability could be conveniently located in the Mari vicinity.

There will be a critical period in the power system in the spring of 1975. This gap should be filled by the timely completion of the first two units at Tarbela. If it proves impossible to meet this schedule, it may be necessary to install additional thermal capacity to cover the loads of that year. This would be unfortunate, since the additional thermal capacity would likely have limited use after the Tarbela units are introduced. Therefore, if a delay on Tarbela appears likely, 1975 may be a year to plan for maintenance of a higher drawdown level at Mangla and the careful screening of projected loads.

THE FIFTH PLAN (1975/76–1979/80)

During 1975–80, three main sets of decisions can be identified: the scheduling of units at Tarbela, the steps that should be taken to expand the EHV transmission system, and the type and location of thermal capability to be provided to firm up the hydroelectric units and help stabilize the transmission system. How the capacity at the Tarbela units should be brought in will depend on details of the load growth that cannot be foreseen with sufficient accuracy at the present time to make a firm judgment. Various schedulings of the Tarbela units, tested on the power simulation model, suggest that, with a drawdown level of 1332 feet, the best schedule might be to bring in the first four units in 1975 and 1976 and to postpone the remaining eight for the introduction of two per year in 1978 and 1979 and the last four in 1980 when the capacity of the interconnected system to absorb additional supplies of energy will have grown. The inexpensive units at Warsak could be added in 1977–79 to provide useful peaking capability once the critical period has become May. (See Supplemental Paper No. 9, Volume Three.)

The expansion of the 380-kv transmission system during 1975–80 would consist mainly of construction of lines from Tarbela to Lyallpur and the addition of further links between Lyallpur and Mari. These lines will not have sufficient capacity to carry the full potential output of Tarbela in the summer months; neither could the Northern Grid absorb the full potential of Tarbela in these months. To find a use for the full output of Tarbela in the summer, it would be necessary to increase considerably the transmission line capacity all the way to Karachi. This expense would not be justified for such a short period. According to the main load forecasts, an additional 400 mw of thermal capability will be needed in the system besides the 125-mw Korangi Unit 4 at Karachi in the Fifth Plan period, even if all 12 units at Tarbela are installed. The additional thermal capacity will add capability at a low load factor, to provide megawatts when the reservoirs are fully drawn down, and in addition it will provide capability at both ends of the EHV transmission line to help stabilize it. Thus in the period 1975–80 the Study Group envisages the installation in the North of 12 units at Tarbela, two units at Warsak, 200 mw at Mari/Sui and 200 mw in Karachi.

The Sixth Plan (1980/81–1984/85)

After the completion of 12 units at Tarbela there are two possible hydroelectric developments that might be brought in within the Perspective Plan period—first, Kunhar and, second, raising Mangla for power programs. As far as can be foreseen, neither of these would be attractive in the early part of the 1980's. A sizable portion of their energy would be available in the summer flood months and, with Tarbela still producing more energy than could be absorbed, this capability would not yet be needed.

By the early 1980's, there is likely to be a strong case for extensive nuclear development in the South. An earlier installation of nuclear plant does not look very attractive for a number of reasons. Before 1980, nuclear equipment, even in Karachi, would have a load factor of only about 50 percent because the base load would be preempted in most months by energy from the North and supplies from the small Atomic Energy Commission nuclear plant. And such a low load factor would place a heavy burden on nuclear plant operations—because so much of the cost of nuclear equipment occurs in the form of fixed charges. This load factor consideration would postpone nuclear plant in the North even longer, because even after 1980 the load factor attainable on nuclear plant there would still be only about 20–30 percent. But in the South, loads should be adequate by the early 1980's to give a 400-mw nuclear unit a load factor of better than 80 percent; by 1985, a second 400-mw nuclear unit could have a load factor of nearly 70 percent. Present technological trends in nuclear development suggest that 400–500 mw may be the minimum size at which substantial economies will be obtainable. By the early 1980's, loads on an interconnected system would be growing rapidly enough to absorb units of this size reasonably quickly; the technology and capability of the world nuclear industry and the industrial base in West Pakistan should also have developed far enough to make it possible to construct nuclear units of 400-mw size at reasonable cost in the Karachi area. In considering nuclear development, it must be borne in mind that technology is developing extremely rapidly in this field; the views expressed here, though intended to be optimistic, may prove within a few years to have been shortsighted.

There will be need to install additional thermal capacity in the late 1970's or early in the 1980's to firm up the capability of the Tarbela units in the season of minimum reservoir levels. It is expected that this will best be accomplished with additional gas-fired plant. However, there is a possibility that the gas reserve situation might prove stringent enough at that time to make a mine-mouth plant at the Lakhra coal field appear attractive. A coal-fired plant would be considerably more expensive than a gas-fired plant, in capital costs as well as operating and maintenance costs, but if coal were available at a price sufficiently below the scarcity price of gas at that time, then generation on the basis of coal might be worthwhile. On assumptions favorable to coal, it appears that coal would have to be available at a price per Btu about 20 percent below the price of gas to make coal attractive. In terms of economic prices, coal might become competitive about 1980 if gas reserves turn out to be no larger than the lowest of current estimates of reserves.

The gas-fired thermal plant foreseen for the early 1980's, in the vicinity of the Mari and Sui gas fields, will not have a guaranteed supply of gas for lifetime operations at high load factor. Of course, more gas may be discovered over the intervening 15 years. But if gas reserves appeared to be becoming short, adjustment would have to be made. It would be possible to keep the load factor on the Mari/Sui units down by developing further hydro plants or nuclear installations to meet base load. However, even if gas reserves available for power use were completely exhausted, the Gudu location would be quite suitable for generation on the basis of imported fuel oil to meet seasonal peaks in the North. Conversion of gas-fired plants to the use of oil would not be expensive, and generation at Gudu instead of in the Northern Grid area itself would save a lengthy rail haul.

The exact proportions of plant that should be based on gas, imported oil or coal, or combined oil and gas use will of course depend on many unforeseeable factors. The tighter the gas situation, the more attractive it would be, for instance, to use Lakhra coal for thermal generation for Karachi and the Sind intermediate between base load and peak load. Nevertheless, the presumption of thermal development in the Mari/Sui area makes the most economic use of known resources in West Pakistan, while providing a high degree of flexibility for meeting future contingencies.

Distribution

To serve the new domestic, commercial and industrial customers projected over the years, and to permit the proper growth of tubewell operations, Stone & Webster estimated that WAPDA alone would have to construct at least 20,000 miles of new distribution line by 1970 and another 35,000 miles by 1975. The consultants were doubtful whether WAPDA would be able to achieve these targets. They felt that the Power Wing of WAPDA had concentrated most of its efforts towards large projects involving power generation, to the neglect of the electric distribution system. The distribution system has borne a high proportion of budget cuts; the training of technicians for distribution line work has lagged. Achievement in terms of miles of line construction during the Second Plan period may have been somewhat better than implied by the figures available to S&W. However, the WAPDA figures are not wholly reassuring. The rate of connection of public tubewells appears to have declined from 1,000 in 1960/61 to 138 for the two years 1963/64 and 1964/65; and the rate of village electrification had also declined from the levels achieved during the earlier years of the 1960's. It would seem, therefore, that whatever the performance in the field of urban distribution, there remains a real difficulty in making rural connections, either under the village electrification program or under the tubewell program. The combining of these two programs would probably result in a higher rate of village electrification. Nevertheless, there is no question but that electrification in general, and electrification of tubewells in particular, will make great demands on the finance and trained manpower available to WAPDA. Metaphorically, however, the effort will be worth the candle.

D. THE ECONOMICS OF INVESTMENT DECISIONS IN POWER

The Evaluation of Tarbela

The central position in the power program is occupied by the Tarbela Dam. The power benefits of the dam, which had been evaluated in the first phase of the Indus Study in 1964/65, had to be reconsidered in the broader context of an integrated water development program. One aspect of joint power and irrigation benefits of the dam, already discussed, is that postponing completion of the dam from 1975 to 1985 would be clearly disadvantageous. The logical next question is: what would be the value of the power benefits accruing from construction of the dam by 1975, as opposed to its not being constructed at all? The net power benefits of Tarbela are defined as the savings that would result from meeting projected power loads with a program including Tarbela rather than one excluding it. As part of the earlier study of Tarbela, an alternative program excluding Tarbela had been prepared for the Northern Grid area. This program included a hydroelectric project on the Kunhar River (a tributary of the Jhelum). The present worth (at an 8 percent discount rate) of the cost (operating and capital) of this alternative program—considered the most favorable for meeting system demand for both energy and power—amounted to about $206 million; this is about $80 million more than the present worth of the cost of the program including Tarbela. Costs of the program including Tarbela, incidentally, excluded the costs of the main reservoir structures, because these costs were all assigned to the irrigation side of the ledger.

Finally, how sensitive are the power benefits under different assumptions regarding the scarcity value of thermal fuel and foreign exchange? This test of benefits was broadened by using a variety of programs excluding Tarbela. As it turns out, the net power benefits of Tarbela are not very sensitive to changes in assumption regarding the value of foreign exchange. But, as illustrated by Figure 10, they are very sensitive to changes in assumption regarding the price of thermal fuel. With calculations using the current foreign exchange rate, benefits range from about $40 million at a fuel price of 20 cents per million Btu to about $220 million at a fuel price of 70 cents. At current financial fuel prices, the net benefits attributable to Tarbela power were in the neighborhood of $110–120 million. (For details, see Supplemental Paper No. 7, Volume Three.)

The Scarcity Value of Thermal Fuel

As stated above, the power benefits of Tarbela are very sensitive to changes in the scarcity value of thermal fuel; also, many other decisions depend intimately on the value attributed to the Province's fuel reserves—for instance, the scheduling of the introduction of the hydro units and transmission lines and the type of thermal equipment that should be installed. Thus the real economic value of thermal fuel in West Pakistan is a matter of no small importance. Evaluation involves the estimated reserves of natural gas, coal and oil, and the likely growth of demand for these fuels for purposes other than power generation—particularly for major alternative uses such as fertilizer production. Estimated indigenous reserves of oil are very small; known coal reserves are of relatively low thermal value and mostly located in places where exploitation would be costly; this explains the main concern with natural gas reserves. Gas is concentrated chiefly in the Upper Sind region, particularly in the Sui field, with estimated reserves of 6 trillion cubic feet, and in the Mari field, with currently estimated reserves of 1.8 trillion cubic feet. There are also a number of other significant fields: Sari Sing near Karachi, Khandkot and Mazarani in Upper Sind and Dhulian in the Potwar Plateau in the North.

The reserves in all the gas fields were considered together and compared against the projected growth of nonpower uses of natural gas. Some reserves have already been committed to other uses, and these decisions are taken to be irrevocable. If all the natural gas currently estimated to be available, and not already committed, were reserved for purposes other than power generation, then they would be exhausted about the year 2000. Therefore, to the extent that they were used in the interim for power generation, they would be exhausted earlier. Furthermore, for purposes of analysis, it can be assumed that once gas reserves are exhausted,

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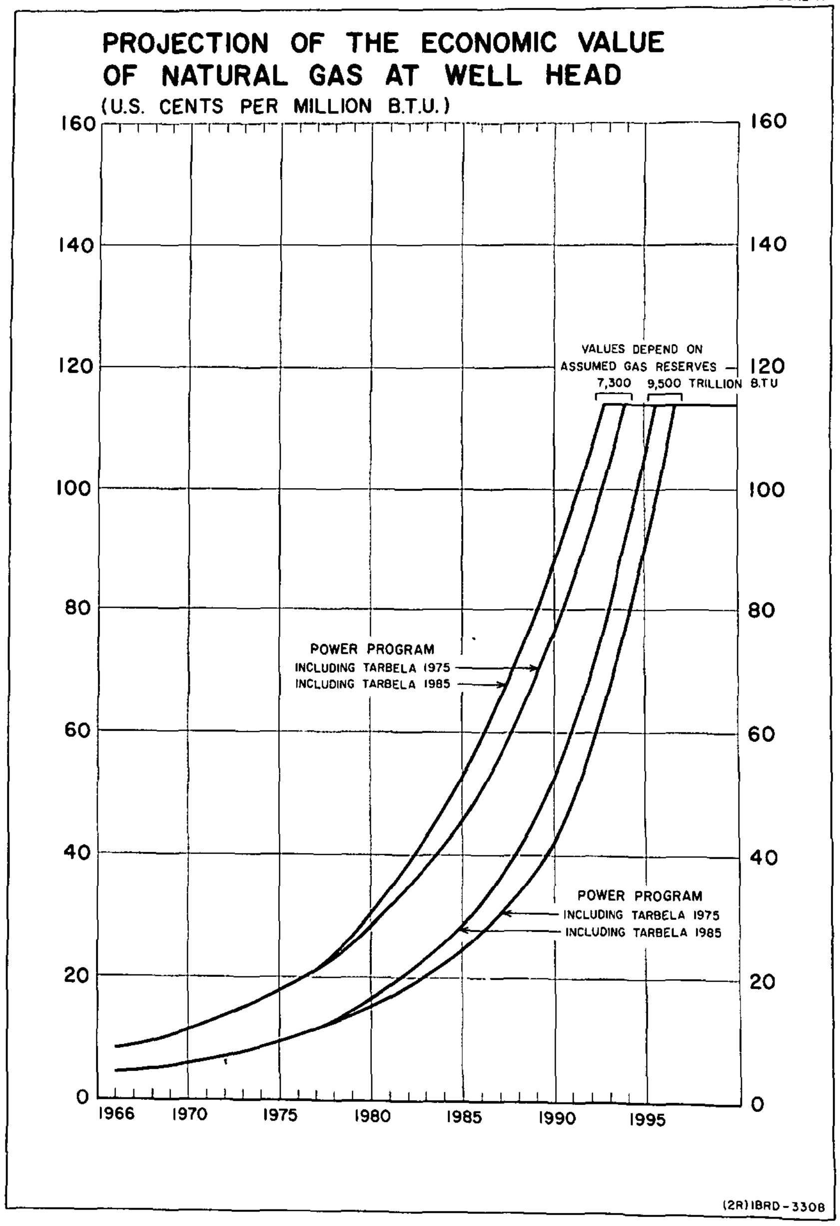
FIGURE 11



fuel needs would be covered by imported liquid fuels. Thus, to formulate a reasonable policy for rationing gas reserves in the interim, the economist would focus attention on the turn of the century. What would be the international price for liquid fuel in the year 2000? More crucial, foreign exchange available to West Pakistan at that time might be scarce, and then the real burden on the Pakistan economy would be the scarcity value of the foreign exchange used to import fuel supplies once gas reserves were exhausted.

The figure finally adopted for this purpose for the reasons set out in Supplemental Paper No. 6 was $1.14 per million Btu of imported fuel, delivered to the Upper Sind in the year when gas reserves were exhausted (i.e. around 2000). In previous years, the sacrifice involved by using gas for power generation, instead of conserving it for nonpower uses, would be the discounted present worth of the foreign-exchange burden in that year. Taking account of the gas required for power generation in a program including Tarbela, and applying this approach to current estimates of gas reserves, it was found, for instance, that the economic value of gas at well head would be approximately 8 cents per million Btu in 1965, 11 cents in 1970, 18 cents in 1975, 28 cents in 1980 and 45 cents in 1985. If Tarbela were to be eliminated from the program or postponed to 1985, then the draft on the natural gas reserves for power generation would be substantially higher, the reserves would be depleted more rapidly, and hence the economic value of thermal fuel would be higher in the later years of the Perspective Plan period. Various assumptions can be tested in this manner, and Figure 11 shows the results of some calculations under different estimates of the size of gas reserves and the timing of Tarbela.

This analytical framework was used to verify the various components of the recommended power program—the units at Mangla and Tarbela and the transmission lines, etc., and the proposed timing of their installation. It is roughly estimated that the net power benefits of Tarbela, estimated at about $110–120 million on the basis of current financial fuel prices, would be at least $150 million if thermal fuel was attributed its real scarcity value.

Interconnection

The value of natural gas has a bearing on the interconnection investment. Both Stone & Webster and WAPDA's consultants, Harza, based their recommendations regarding linkage of the major markets—interconnection by the early 1970's—to a significant extent on the assumption that substantial reserves of natural gas were available at Mari with little use for purposes other than power generation. When it became known that Mari gas reserves might in fact be only a fraction of what had been previously estimated, Stone & Webster expressed strong doubts as to whether EHV interconnection should still be introduced at the time they had recommended.

The issue boils down to consideration of alternative power programs with and without interconnection and with different amounts of thermal development in the Mari vicinity. At one time, it had been suggested

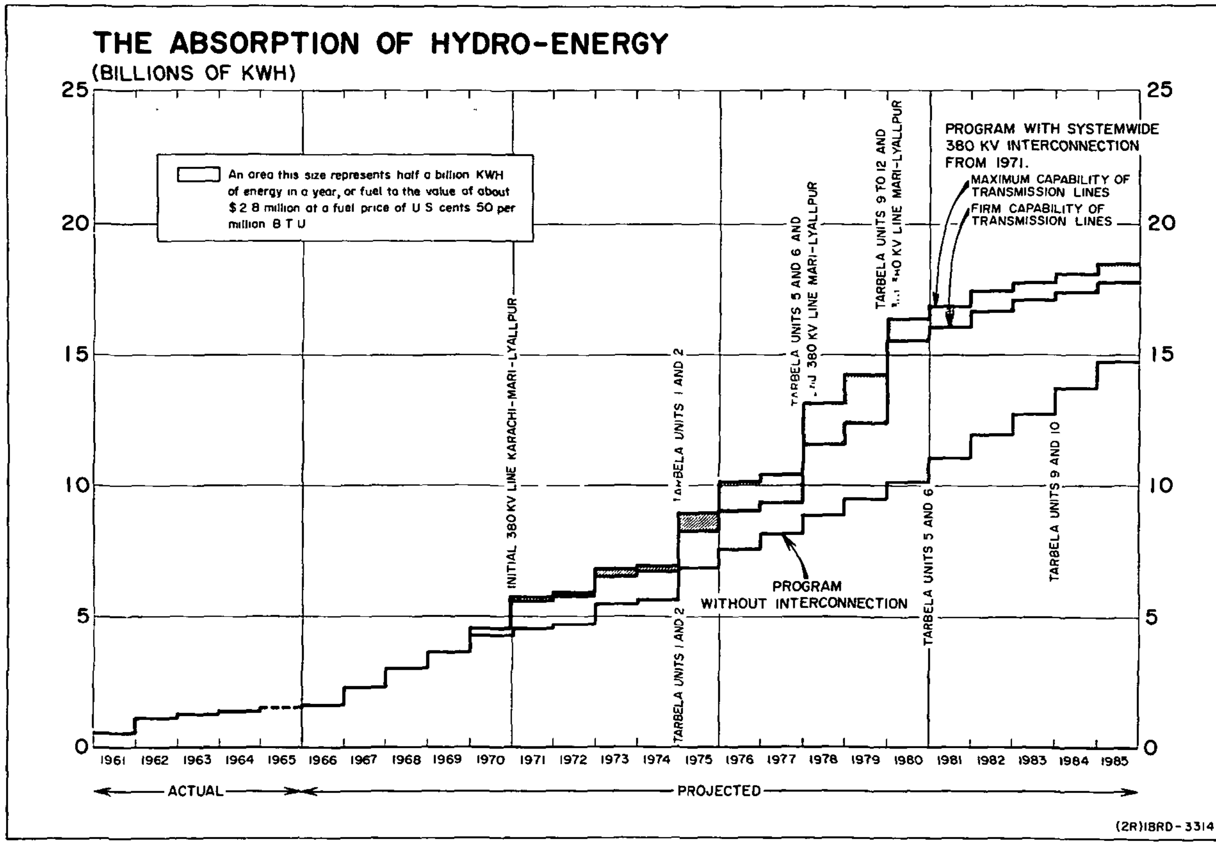


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FIGURE 12

that thermal development at Mari be limited to 400 mw; in this context, in terms of both current financial and projected economic prices for natural gas, doubts regarding EHV interconnection were verified by the Study Group's analysis. However, a different picture emerges if a large thermal plant is assumed for the Mari vicinity, but fired with Sui gas. First of all, the scarcity-value approach to the price and use of natural gas reserves suggests that, with reserves as currently best estimated, it would appear reasonable to use substantial amounts of Sui gas over coming years for thermal power, which is a necessary complement to Mangla and Tarbela as a source of electric energy. Secondly, the site provisionally selected by WAPDA's consultants for generation on the basis of Mari gas was at Gudu, close to the Indus River and almost equidistant from the Mari and Sui fields. The Study Group, therefore, tested a power program including interconnection and 1,100 mw at Gudu—requiring in total during 1965–85 about one trillion cubic feet of Sui-quality gas (for generation in Karachi and the North as well as at Gudu). Such a program would have significant advantages over a program excluding interconnection. The two programs would differ markedly in terms of hydro energy absorption (Figure 12). By making more hydro energy available in the South, interconnection would make possible savings in thermal fuel requirements. There would also be a reduction in generating capacity reserves and a saving in pipeline capacity for gas transmission. The program including interconnection showed present-worth savings over the best program without interconnection of the order of $20–25 million when foreign exchange costs were valued at the current exchange rate and about $10–15 million when foreign exchange was valued at a shadow rate of twice the official rate. (For further details see Supplemental Paper No. 6, Volume Three.)

These savings "with interconnection" would be offset to some extent by the costs of gas pipelines to carry fuel from Mari and Sui to the Gudu site; but there are other advantages to interconnection which were not taken into account in the quantitative analysis. In the first place, if the Northern Grid has to generate all its own power requirements in the pre-Tarbela years, thermal fuel will probably be more costly than assumed in the quantitative calculations, since either additional gas pipeline capacity will have to be installed or expensive imported fuel oil will have to be used to meet peak fuel requirements. In the second place, the quantitative comparisons between the with and without programs were made in terms of the same series of economic prices for natural gas; in fact, since a program excluding interconnection would involve a heavier draft on natural gas reserves than one including it, the shadow fuel prices applicable to the "without" program would be somewhat higher. In the third place, the EHV transmission lines may be able to carry somewhat more hydro energy southward than was assumed in the quantitative analysis; this possibility is illustrated by the hatched blocks in Figure 12. Finally, there are more general and intangible though none the less important advantages to interconnection, such as the flexibility it will add to the overall power system.

The Timing of Interconnection. Among the programs considered by the Study Group, the main comparisons were all based on the assumption that, if 380-kv interconnection were introduced, then a complete link from Lyallpur to Mari to Karachi would be available by 1971. Short-term comparisons on different schedulings verify that there are advantages to completing EHV interconnections in the early 1970's, say 1971 or 1972, but these advantages would be particularly strong in the case of the link between Mari and Lyallpur. Therefore, in contrast to Stone & Webster, the Study Group would attach higher priority to the Lyallpur-Mari line than to the Karachi-Mari line. Nevertheless, the Karachi-Mari line should be completed by 1975 at the latest, for a large part of the benefit of the whole EHV system occurs in the form of thermal fuel savings in the South, resulting from the availability of hydro-energy there, and these savings will become particularly important when the Tarbela units begin to be installed. The main disadvantages from postponement of the EHV link between Mari and Lyallpur beyond 1971/72 are (a) additional thermal capacity may then have to be installed in the Northern Grid area, which would be relatively little used for a decade or more after completion of Tarbela Dam and (b) special difficulties would arise in meeting peak requirements of thermal fuel in the North in the early 1970's. If these loads are closer to the contingency than the main load forecasts, the case for early EHV interconnection between Mari and Lyallpur will be reinforced.

Thermal Fuel Supply. As the impact of Mangla and later of Tarbela is gradually spread throughout the power system by EHV interconnection, what would be the best means of supplying thermal fuel in the different areas of the Province? For the South, there will be an interim period of a decade before EHV is available. The choice would be either to expand the capacity of the gas pipeline from Sui sufficiently to meet peak requirements or to restrict expansion of the pipeline and meet peaks with fuel oil. Taking into account the scarcity value of natural gas and foreign exchange, the expansion of the gas line appears the better proposition. This conclusion might be altered under three sets of circumstances: (a) if the peak requirements were very sharp and expected to be very short-lived; (b) if it appeared that the more convenient Sari Sing field would be likely to prove an economic source of fuel supply for Karachi; or (c) if Sari Sing is not a productive field, if it can still be developed as a gas storage reservoir. Under these circumstances, it might prove economical to meet peak fuel requirements on a short-term basis with fuel oil. Once EHV interconnection between the North and the South becomes available, KESC's thermal fuel demands will have a much lower annual load factor than they do now. Moreover, hydro energy and Mari energy would continue to make sizable contributions to meeting the load in the South through the 1970's and nuclear power would become important in the early 1980's; if the recommended program is adopted and loads in the South are of the order projected here, KESC's peak requirements for thermal fuel may not, within the Perspective Plan period, rise substantially above the level reached immediately prior to interconnection. Following interconnection, the storage potential of Sari Sing might become particularly valuable, and even if it proves infeasible to develop Sari Sing for storage, it might become worthwhile at that time to meet KESC's peak requirements of thermal fuel with oil and to release to other consumers a portion of the pipeline capacity previously committed to supplying KESC with gas.

In the North, if electrical interconnection is completed in 1971/72 and thermal development is concentrated in the Mari vicinity, peak day requirements of thermal fuel for meeting the forecast main load probably would not increase above their 1966/67 level before about 1980. If loads turned out to be closer to the contingency load forecast, then peak day fuel requirements might rise somewhat above their 1966/67 level—perhaps to about 95 MMcf/day. However, the overall annual load factor on thermal plant in the North appeared likely to be quite low over the next 10–20 years—not usually above 30 percent on the main load forecast or 40 percent on the contingency forecast even on the most economical plant (Lyallpur steam units). Moreover, the load would be heavily concentrated in a few months of each year (in the spring), implying that any firm base load on the plants throughout the year would be small. Thought should be given to the possibility of meeting peak fuel requirements in the North with imported fuel oil and releasing the gas pipeline capacity presently committed to WAPDA for serving other consumers rather than expanding the gas pipeline to Multan and Lyallpur to meet WAPDA's needs. (For further details, see Supplemental Paper No. 8, Volume Three.)

E. FINANCE AND ACCOUNTS

In recent years, load growth has been curtailed in all four major power systems by shortages of capacity, particularly in the Northern Grid area and Lower Sind, and by the lag in expansion of the distribution system. Maintenance has also been inadequate. Thus backlogs have grown—deferred maintenance, customers awaiting connection, and shed loads awaiting more generating capacity. These requirements are to some extent being met in the Third Plan, already well underway as this is written.

The proposed program has some immediate consequences for finance, as for instance the heavy cost of the EHV transmission system recommended for commencement prior to 1970. The proposed program would cost Rs. 3,017 million over the five years, 1965–70. These capital requirements are substantially above the Rs. 2,178 million allocation initially made for the power sector in the Third Plan. A revision raised the allocation somewhat to about Rs. 2,400 million, but there was still a sizable financial gap to be filled before the end of the decade.

The cost of the proposed program would rise further, in rounded figures, to Rs. 3,500 million in the Fourth Plan, Rs. 3,700 in the Fifth, and Rs. 4,000 in the proposed Sixth Plan. As a percentage of total investment, public and private, investment in power would increase in the Third Plan, against the Second, from 5.7 percent to 10.5 percent, but then would gradually decrease to a level of about 6 percent again in the 1980's. The

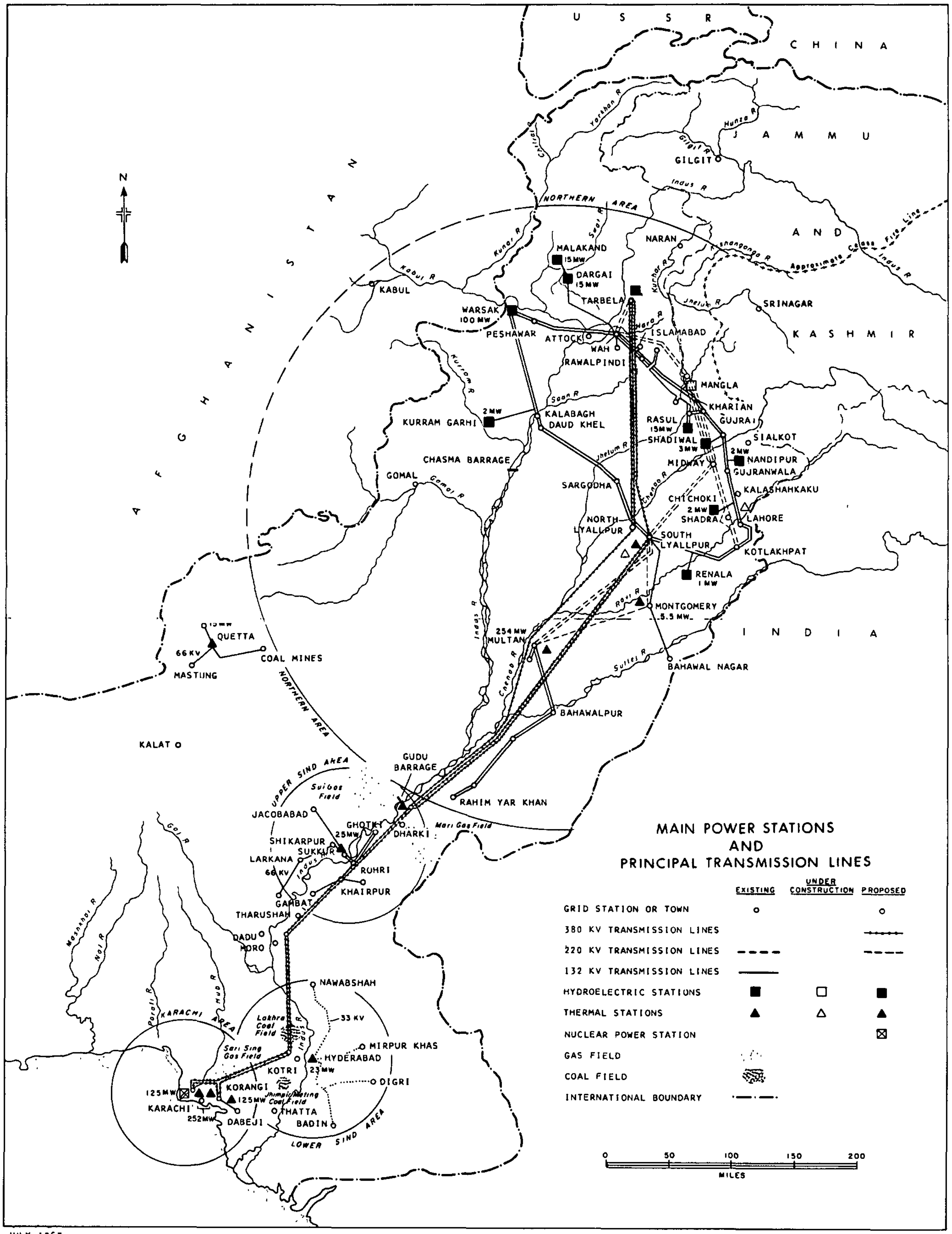
MAIN POWER STATIONS
AND
PRINCIPAL TRANSMISSION LINES
EXISTING
UNDER CONSTRUCTION
PROPOSED
GRID STATION OR TOWN
380 KV TRANSMISSION LINES
220 KV TRANSMISSION LINES
132 KV TRANSMISSION LINES
HYDROELECTRIC STATIONS
THERMAL STATIONS
NUCLEAR POWER STATION
GAS FIELD
COAL FIELD
INTERNATIONAL BOUNDARY
0
50
100
150
200
MILES
U S S R
C H I N A
J A M M U
A N D
K A S H M I R
A F G H A N I S T A N
I N D I A
NORTHERN AREA
UPPER SIND AREA
KARACHI AREA
LOWER SIND AREA
GILGIT
NARAN
SRINAGAR
KABUL
MALAKAND 15 MW
DARGAI 15 MW
TARBELA
WARSAK 100 MW
PESHAWAR
ATTOCK
WAH
ISLAMABAD
RAWALPINDI
MANGLA
KHARIAN
GUJRAT
RASUL 15 MW
SHADIWAL 3 MW
SIALKOT
2 MW
NANDIPUR
GUJRANWALA
MIDWAY
KALASHAHKAKU
CHICHOKI 2 MW
SHADRA
LAHORE
KOTLAKHPAT
NORTH LYALLPUR
SOUTH LYALLPUR
RENALA 1 MW
MONTGOMERY 5.5 MW
BAHAWAL NAGAR
2 MW
KURRAM GARHI
KALABAGH
DAUD KHEL
CHASMA BARRAGE
GOMAL
SARGODHA
254 MW
MULTAN
BAHAWALPUR
QUETTA
66 KV
MASTUNG
COAL MINES
KALAT
GUDU BARRAGE
RAHIM YAR KHAN
Sui Gas Field
Mari Gas Field
JACOBABAD
GHOTKI
DHARKI
SHIKARPUR
25 MW
SUKKUR
LARKANA
66 KV
ROHRI
KHAIRPUR
GAMBAT
THARUSHAH
DADU
MORO
NAWABSHAH
33 KV
Lakhra Coal Field
MIRPUR KHAS
Sari Sing Gas Field
HYDERABAD
23 MW
KOTRI
DIGRI
125 MW
KORANGI
125 MW
Jhimpir Meting Coal Field
KARACHI
252 MW
DABEJI
THATTA
BADIN
Yarkhun R
Hunza R
Gilgit R
Indus R
Chitral R
Kunar R
Swat R
Kabul R
Kishanganga R
Approximate Cease Fire Line
Jhelum R
Kunhar R
Haro R
Kurram R
Soan R
Gomal R
Chenab R
Ravi R
Sutlej R
Gaj R
Mashkai R
Hab R
Porali R

TABLE 6–10
ACTUAL AND PROJECTED INVESTMENT IN POWER COMPARED TO TOTAL INVESTMENT (PUBLIC AND PRIVATE) IN WEST PAKISTAN, 1960–85
(Rs millions)

	Investment in Power[a]	Total Investment[b]	Power as a % of Total
Actual			
1960/61	208	3,023	6.8
1961/62	273	3,528	7.7
1962/63	213	4,410	4.8
1963/64	258	4,753	5.4
1964/65	242	5,260	4.6
Subtotal Second Plan	1,194	20,974	5.7
Projected			
Third Plan	2,849	27,250	10.5
Fourth Plan	3,468	38,200	9.1
Fifth Plan	3,676	53,200	6.9
Sixth Plan	4,031	68,000	5.9

[a] Public sector only.
[b] Public and private.

relatively heavy burden proposed for the Third and Fourth Plan periods represents a measure of the catching-up that needs to be accomplished. Table 6–10 compares actual capital expenditure on power with the total investment in each year of the Second Plan, along with proposed figures for each Plan period through 1985. The estimates of total investment were made available by the Pakistan Planning Commission. The table covers only public sector investment in power (i.e. excluding industrially owned).

The size of these capital requirements and the shortage of funds for parts of the program in the past emphasize the importance of keeping the level and structure of tariffs in West Pakistan under constant review. WAPDA's rate of return on net fixed assets in operation averaged 7.58 percent for the four years 1960/61 to 1963/64.[1] The latest year for which financial information was available to the Study Group, 1964/65, showed WAPDA's rate of return declining to 5.83 percent. The large capital expenditure which will be required for system expansion and the recent decline in WAPDA's rate of return suggest that there is need for revision in the level and structure of WAPDA's tariffs.

In 1965, the Harza Engineering Company, in their capacity as consultants to WAPDA, made a study of WAPDA's tariffs. Harza did not recommend any major changes in the tariff structure but proposed the elimination of certain anomalies and inequities in that structure. Their report focused more on the reduction of losses by improving administration rather than on revising the tariffs. In recent years, very large amounts of

[1] The Study Group recalculated WAPDA's rate of return in a manner that is more standard among electric utilities around the world. Returns were taken as consisting simply of funds available for interest payments and allocation to surplus, i.e. excluding depreciation. The capital base, average investment in plant in service, was taken after deduction of depreciation for the year in question. The ratio between these two items is the rate of return normally used by the Bank.

energy have been lost between generation and sales and, as Harza pointed out, these energy losses represent substantial losses in revenue. If in 1963/64 the lost and unaccounted-for energy had been held to about 15 percent of the total sent out, the improvement in income would have been about 50 percent of actual net earnings in that year. Thus there is an obvious need for a major effort to reduce losses. Also, improvement of WAPDA's accounting and recording procedures should be aimed at providing management with up-to-date financial and statistical statements that would permit analysis of operating results, trends, and the responsibility for successes and failures.

The agricultural tariff is a good illustration of the case for restructuring tariffs. According to Harza, bills under the agricultural tariff were 37 to 44 percent lower than bills which industrial consumers would pay for the same load and consumption. Harza recommended that sales to agricultural consumers under the present agricultural tariff should be available only to those who agree to discontinue the operation of their pumps during the critical load periods. This change of practice was not accepted by WAPDA. In effect, therefore, other consumers still bear the burden of the subsidy which is granted to agricultural pumping by these noncompensatory rates. Pumping requirements are expected to increase substantially in the next decade. The Study Group believes that it will be necessary for WAPDA to raise agricultural pumping rates, to raise rates to some or all nonagricultural customers, or to ask that the subsidy be covered by allocations from the Government. The Study Group believes that WAPDA should aim for a rate of return of not less than 8 percent, as calculated on average net fixed assets in operation.

KESC had a study of its tariffs made in 1964/65 by Gilbert Associates. Gilbert pointed out that KESC's present tariffs are extremely complex, hard to understand, and difficult to use in calculating bills. Some of the rates are based on horsepower of demand and some on kilowatts of demand. Some of the rates run to five decimal places. Some rates are gross with a discount for prompt payment and others offer no discount. The fuel adjustment is a large portion of an industrial consumer's bill because the present base was established some years ago when fuel was cheaper. The changes proposed by the consultant would simplify all of the rates mentioned above and reduce the existing 11 rates to seven. There would be total elimination of free energy, kilowatts would be used instead of horsepower, several tariffs for residential and commercial consumers would be replaced by one tariff through one meter. The fuel adjustment would bring it into line with the present costs of fuel and there would be a uniform discount for prompt payment of all bills. On the whole, the new tariffs might yield about 5 percent more than the existing tariffs.

KESC's rate of return on average net fixed assets in operation ranged between 10.6 and 13.4 percent over the years 1960 to 1964, but it declined to 10.2 percent in 1965. KESC declared cash dividends of 10 percent for a number of years; in 1963 and 1964, stock dividends were declared; in 1965, a combination of 6 percent cash and a 4 percent stock dividend was declared. KESC's financial position has been sound in the past but the cost of doing business has recently risen, while the average revenue received per kilowatt-hour has declined. The generous tax exemptions allowed KESC on its new facilities have been helpful but these exemptions may sometime in the future be withdrawn. KESC should be permitted to charge tariffs aimed at maintaining revenues sufficient to provide an annual rate of return of at least 8 percent (on average net fixed assets in operation). This would ensure that KESC would continue to obtain from internal cash generation the local currency for its expansion program.

F. OPERATIONAL PROBLEMS

MANGLA AND TARBELA

For purposes of power planning, the Study Group has used the final monthly release patterns developed by IACA. The needs of power and irrigation are reconciled to the extent possible, but irrigation requirements in fact dominate. However, by emphasizing the use of tubewells in the early part of the rabi season, when the heads on the turbines are higher, better advantage can be taken of hydropower in this period; also, more water can be retained in the reservoir until later in rabi, thereby increasing the capability of the hydro units and ensuring against a deficiency in irrigation water during these low-flow months. The patterns of release for Mangla and Tarbela (as previously noted in Table 5–8) based on these considerations, are given in Table 6–11. In practice, there will be deviations from these release patterns, depending on the natural flows available in each year, the available tubewell pumping capability, etc., but small changes in the release patterns will have the effect only of transferring the availability of hydro energy from one month to another and possibly requiring compensating changes in the amount of thermal energy produced.

The most critical aspect of reservoir operation, from the point of view of power planning, will be the levels to which the Mangla and Tarbela Reservoirs are drawn down each spring. The drawdown level will have a substantial effect on the capability of hydroelectric stations in this period; it will consequently affect the amount of complementary thermal capacity required to meet loads. Raising the minimum drawdown level of Mangla from 1040 feet to 1075 feet would sacrifice some 400,000 acre-feet of potential rabi irrigation supplies, but it would also result in raising the head on the Mangla turbines throughout the critical period by 35 feet and would consequently increase the firm capability of 8 units by about 140 mw. At Tarbela, the firm capability of 12 units can be increased by about 270 mw by sacrificing some 700,000 acre-feet of potential initial live storage capacity and keeping the minimum reservoir level up to 1332 feet. Changing the drawdown levels on the reservoirs would also have some effect on the energy available from the hydroelectric units, particularly in the season of minimum drawdown. Maintenance of the higher drawdown level at Mangla would increase the total amount of energy available in the mean year by an estimated 250 million kwh, while maintenance of

TABLE 6-11

TARBELA AND MANGLA RELEASE PATTERNS

(% of live storage)

(positive figures: releases; negative figures: storage)

	Mangla	Tarbela
October	23	0
November	15	8
December	10	11
January	10	21
February	24	26
March	18	19
April	0	10
May	−24	5
June	−36	−45
July	−31	−55
August	−9	0
September	0	0

the higher drawdown level at Tarbela would increase mean-year energy output by about 300 million kwh.

In practice, of course, the minimum drawdown level at Mangla or Tarbela is a continuous variable. Attention is focused on two discrete alternatives for each reservoir because the consequences indicate the relative order of priority that should be attached to the needs of agriculture and power in long-term planning. The comparison is made in terms of the power and agricultural benefits associated with a policy of high or low drawdown levels pursued over the 20-year planning period. The power benefits can be derived from a comparison of alternative power programs, analyzed with the aid of the power system simulation model, with one program assuming the reservoir would be drawn down each year to the lower level, the other assuming the higher level. The "higher drawdown" program would require less companion thermal capacity. This saving, plus related fuel savings, accounts for the difference in present-worth costs of the two programs. Extra agricultural benefits would attach to drawing down to the lower level; these were derived by linear programming analysis of investment in irrigation and agriculture on the assumption that release of the additional irrigation water would follow the release patterns assumed for the two reservoirs. The analysis indicated the marginal values of small increments or decrements to the annual supply of irrigation water in two 10-year periods, 1965–75 and 1975–85, and is presented in Supplemental Paper No. 7, Volume Three.

The comparison between power and agricultural benefits is in terms of the marginal benefits to be derived from allocating a little more water to power (i.e. retaining it in the reservoir) or to agriculture (i.e. releasing it). These benefits are quite close. But in line with the results of other studies, a high marginal value is indicated for supplies of irrigation water in the period 1965–75. In the case of Mangla, the marginal value to irrigation of the last 400,000 acre-feet in this decade appeared to be greater than the value of the higher drawdown level to power, thus suggesting in general that greater benefit would be derived from drawing down Mangla fully to 1040 until 1975. After Tarbela is completed in 1975, the marginal value of additional irrigation supplies will be considerably less, partly because of the sizable addition to rabi water supplies made by Tarbela itself and partly because of the substantial opportunities that will then exist for increasing irrigation supplies by overpumping in the public tubewell fields. As far as can now be foreseen, an appropriate general presumption would be that Mangla might generally continue to be operated to the lower drawdown level during 1975–85 but that Tarbela should probably be operated to 1332 feet, at least in that decade.

Operating Under Conditions of Uncertainty

While the comparison of benefits above indicates the general priority attaching to irrigation and power claims on storage capacity, it fails to show how priority claims will fluctuate from year to year under varying conditions. There are some reasonably predictable elements, of course, such as likely demands for irrigation water and power, and the availability of alternative supplies—tubewells for irrigation water and thermal equipment for power. But benefits associated with such "predictable" elements will fluctuate from year to year. For instance, scheduled additions to the power system in some years (e.g. hydro units) will be much more expensive than the additions in other years (e.g. gas turbines) and, as a consequence, the postponement of a step in power system development, made possible by maintaining a higher drawdown level, will therefore bring much greater savings to the power sector in some years than in others.

There are other aspects of operation which will be much less predictable —for instance, flows may not always be high enough to maintain the higher drawdown level without detriment to the agricultural sector; there is always a chance of serious outages of thermal equipment or transmission equipment. Recognition must be given to the losses that would be incurred by WAPDA and by the Pakistan economy should these uncertain factors turn out at their worst. Where possible, probabilities should be taken into account—e.g. the probability that flows will not be sufficient to permit the higher drawdown level without detriment to irrigation supplies. Reasonable estimates of probable losses, given a particular "disaster," can be very helpful in planning annual operating decisions. For example, how large would losses be assuming an unexpected requirement to draw down to 1040 feet at Mangla, for instance, instead of 1075 feet? There is evidence to suggest that the losses would not be very large. In certain years, the benefits associated with maintenance of the higher drawdown level—adding to the reservoir only the amount required to maintain the drawdown level—might well be sufficient to outweigh the chance of loss if drawing down further proved necessary. Thus losses would need to be weighted by an appropriate probability factor. Moreover, it may be possible to develop rate structures for large industrial loads with a built-in provision for occasional peak shaving; this could further reduce the losses that would arise from an unexpected shortage of capacity. By such means as these, planning can be based on maintenance of a higher drawdown level in certain years than would otherwise appear prudent. Thus operational decisions can be consciously related to an optimal water release pattern, similar to the prototype given in Table 2–8.

In establishing operational policies, the mechanics of the power system must be kept in mind. Mangla will introduce an entirely different type of generating plant into the power system of West Pakistan. If the Mangla Reservoir is drawn down each year to 1040 feet, the capability of each unit will fluctuate between about 45 mw at minimum drawdown and about 130 mw at full reservoir; even with a minimum drawdown level of 1075 feet, the capability of each unit will still fluctuate between about 60 mw and 130 mw over the course of the year. But given adequate reserve capacity to meet loads in the period of minimum drawdown, maintenance of a reasonable release pattern will mean that generating capacity reserves will be very ample or even excessive throughout most other months of the year. The possibility of a power crisis of the proportions and duration experienced in 1966/67 would then be remote. The same will be all the more true after the power units begin to be installed at Tarbela.

Peaking at Mangla and Tarbela

Peaking at Mangla and Tarbela will essentially involve storing some water over a day and then releasing a large quantity in a short space of time, as contrasted with maintaining an even discharge over the day. Tarbela is sufficiently far upstream of irrigation structures, and the Bong escape and Rasul Barrage provide sufficient re-regulation capacity at Mangla, that there would appear to be no danger of sharp fluctuations in discharges causing scouring or other damage downstream. At Mangla, it will probably be necessary to maintain a constant minimum discharge sufficient to meet the irrigation requirements of the Upper Jhelum Canal, but this will preempt only a portion of flows, so that remaining flows can still be used for peaking purposes if required. The possibilities for using reservoirs as pondage for peaking purposes will need continuing study.

The Peaking Role of Thermal Plant

The heavy seasonal fluctuation in power output at Mangla and Tarbela will greatly affect the role which will be played by thermal equipment on the system. If the system is run in the most economical way, the service role of the thermal units will be much more in the nature of peaking than formally. This will apply especially to the thermal units in the Northern Grid, as units are added at Mangla, but it will also apply to the Mari units and, when the South is linked by EHV transmission to the Northern Grid, it will also apply to many of the units there. These considerations have an important effect upon the selection of thermal equipment and also on the means that should be adopted to meet the fuel requirements of the thermal plants.

One of the main reasons for pressing ahead with early EHV interconnection between Lyallpur and Mari, as previously discussed, was to avoid the need for installation of additional thermal equipment in the North, because Tarbela would make it somewhat redundant. Thermal capacity installed in the vicinity of Mari would be able to play a triple role—helping to meet local loads, loads in the South, and loads in the North during the short period in each year when hydro capacity is at a minimum. However, the load factor on thermal equipment installed in the Mari area still appears likely to be relatively low. The Study Group's simulation exercise indicates that thermal capability in the Upper Sind will, when required to meet Northern Grid loads, be brought into play in the critical months between base load (met by hydro) and peak load (met by local thermal generation). To a much greater extent—in most months of most years—it will supply power to help meet loads in the South but there, too, its contribution will generally be utilized between base load met by hydro energy from the North and nuclear energy, on the one hand, and peak load met by local thermal generation on the other. Partly with a view to the load factor, Stone & Webster recommended that the first 150 mw of thermal plant installed at Mari (coming on line in 1969–71) should be gas turbines and that the next plant should be an extended-rating steam turbine. The Study Group's adjusted program includes about 400 mw of thermal capacity in the Upper Sind area during the period 1970–74. The equipment should be suitable for heavily fluctuating operation and a relatively large proportion of it should be in the form of gas turbines.

VII

Implementation and Impact on Planning

A. ORGANIZATIONAL NEEDS

THE INSTITUTIONAL FRAMEWORK

The Water and Power Development Authority (WAPDA) will bear responsibility for planning and execution of most of the major investment schemes recommended in this report—in particular the Tarbela Dam, the public tubewell projects, and the main power generation and transmission projects. It is already responsible for execution of the major construction work under the Indus Basin Project. Since its inception in 1958, WAPDA has had dynamic leadership and has successfully borne a large responsibility. In 1959 it also was given full responsibility for the operation of the power system, including the reclamation tubewells which were expected to become a very important part of the total power load; operational responsibility for the irrigation system has remained with the Irrigation Department. WAPDA has demonstrated the wisdom of creating a flexible body outside the regular administration. Not being restrained by normal departmental regulations, WAPDA has been able to attract and absorb funds needed for the implementation of large projects. All divisions of the agency have regularly enlisted expatriate and local consultants for the study, planning and supervision of projects. But despite its leadership and the quality of much of its top staff, WAPDA has inevitably had growing pains, given the large volume of work it was called upon to perform. In particular, the execution of the public tubewell program has been a source of difficulty. During the Second Plan, only about 2,100 public wells were installed: about 1,000 were installed in one year, 1960/61, but less than 200 were installed in fiscal 1964/65 and 1965/66, respectively, against a target in the WAPDA Master Plan of over 2,000 wells for 1966 alone. The Third Plan target for groundwater from WAPDA projects is 14 MAF by 1970; about 2.5 MAF was achieved during the Second Plan. As another example of the difficulties WAPDA has faced, the power crisis of 1966/67 was partly the result of plant breakdown, the consequences of which were aggravated by the delay in completion of the new Lyallpur plant.

Some responsibility for construction work on irrigation schemes, and a great deal of responsibility for their successful operation, will lie with two traditional line departments of the West Pakistan Government—the Irrigation Department and the Agriculture Department. Both of these bodies have responsibilities spanning the Province. The Irrigation Department's primary responsibility within the Basin area is the day-to-day operation of the entire surface water distribution system, including collection of irrigation revenue. As such, it has built up a cadre of engineers in its upper levels with great experience in water use and supply. Because canal remodeling work must be very closely integrated with the operation of the canal system, to minimize interruption of supplies, IACA recommends that responsibility for most of this work should be borne by the Irrigation Department.

The Agriculture Department has extremely wide responsibilities, covering virtually all aspects of agriculture (including animal husbandry) throughout the Province. Its activities are closely related to the productive return on water use—to appreciate its role, one need only recall that agriculture represents more than 40 percent of provincial income. The Agriculture Department will play a critical role in enabling the farmers to derive the results which are projected from the programs recommended here. Specifically, its main contributions will be in three areas: (a) research to identify new crop varieties, pesticides and other inputs, and to discover the best practices for their application; (b) extension work to spread existing knowledge and the results of further research work among the farmers; and (c) services to the livestock sector, which is expected to play such an important role in future agricultural development in West Pakistan. The Department will not be able to fulfill these roles effectively unless a wholehearted effort is made to strengthen it. The Department has suffered seriously in the past from shortage of well-qualified staff. Careers in agriculture have not carried prestige, salaries have been low, opportunities for advancement limited, and working conditions poor. Field Assistants are expected to cover 15,000 acres and Agricultural Assistants, at the first supervisory level, 60,000 acres; but neither are provided with adequate transportation facilities to enable them to work effectively. Field assignments usually require living in areas where housing and school facilities for families are poor—but officers posted to extension services usually receive neither housing nor a housing allowance. Trained research staff are not provided with adequate assistance or facilities—and they gravitate to more remunerative administrative work which makes less than best use of their training. Sustained and rapid progress in agriculture will not take place without a vast improvement in these critical services. Primarily, this will involve substantial improvement in the pay, conditions, and facilities offered to employees.

Two other agencies will play a major role in the recommended tubewell project areas: the Agricultural Development Corporation (ADC) and the Land Water Development Board (LWDB). Both of these agencies were established largely to overcome the rigidity and lack of coordination among the line departments. ADC, formed in 1961 on the recommendation of a Food and Agriculture Commission, has responsibility for supply of certain inputs throughout the Province and specific responsibility for water supply, agricultural inputs and extension work in four areas that are being brought under surface-water irrigation: Thal, Taunsa, Gudu and

Ghulam Mohammed commands. It has dynamic leadership, and coordination of effort has been greatly improved in the areas where ADC has worked, but it lacks adequate numbers of experienced agricultural staff. The LWDB is an even newer body, established in 1964 at the suggestion of the US-sponsored Revelle Panel specifically to promote development in the SCARP areas. It is chaired by the Provincial Chief Secretary and has as members the secretaries of all Government departments concerned with agriculture; it meets only about once every two months. In the first few years of its existence, the LWDB's main area of activity was SCARP I. It appointed a Project Director with overall command of developmental activities and supplied him with staff seconded from the regular departments; these personnel carry out extension, reclamation, input supply and irrigation activities. In comparison with the situation elsewhere, the extension coverage in SCARP I appears to be somewhat more intensive. The Study Group endorses the idea of making all officers concerned with agriculture and irrigation within an integrated project program responsible to a Project Director.

While most of the new inputs have been channeled to the farmer via one or another of the official agencies discussed above, there is a gradual growth of private enterprise activity in support of agriculture. These private channels could become very important in future years. But conditions in the agricultural economy are a crucial factor to private enterprise. Recent growth can be linked with a limited liberalization of external economic relations and a continuing improvement of agriculture's terms of trade with other sectors of the economy—farmers have had somewhat more earnings to reinvest in agriculture and somewhat more incentive to do so. Another factor has been the availability of imported raw materials. Private enterprise has played a major role in drilling private tubewells and manufacturing and installing pumps, casings and engines. Distribution of fertilizer was also handed over to private enterprise for a brief period in 1964 and 1965; this arrangement was withdrawn because, in a way, it was too successful: stocks were run down so fast that a shortage, and consequently a black market, developed; while the shortage lasted, the Government felt it could secure more equitable distribution through official channels.

Private enterprise can play a key role in development because, as is natural for a country undertaking a rapid development effort, all Government departments suffer from a severe shortage of qualified staff, especially at the lower levels. With good Government officers in short supply, the available ones should concentrate on the overall supervision of market operations and on the work which generally cannot be handled by others—such as education, and development and introduction of new inputs and new practices. But even with maximum dependence on marketing channels, there will be a need to improve public support of the private effort. In some recent years, for instance, there has been a Governmental effort to economize on current expenditures in order to maximize public savings and investment. However, the consequent shortage of funds for agricultural staff could lead, and probably has led, to false economy in some activities:

agricultural education and extension work, where inadequate support tends to lessen the ability of the farmer to respond to investments in water and other inputs; maintenance of the irrigation system, where it leads to gradual deterioration and eventual need for much more extensive repairs than would have been necessary had maintenance been regular; and investigations, such as groundwater quality studies and monitoring of project development, where it leads to lack of sufficient data for planning purposes and consequent mistakes which have later to be remedied, with much delay and added cost. Thus the additional amounts needed to maintain an adequate level of Government current expenditure, aimed at providing capable staff for the department concerned with agriculture and irrigation development, could have high returns to the economy.

Interagency coordination remains another problem for agriculture. The involved agencies, in addition to those already mentioned, include other important bodies such as the Agricultural Development Bank (ADB), which is playing an increasingly important role in provision of credit, and the Cooperative Development Board. Two of the agencies discussed earlier, the ADC and the LWDB, were established specifically with a view to overcoming the problem of coordination, and they have been successful to a limited degree in the project areas where they have operated. Nevertheless, the problem of coordinating Government policy and its implementation remains serious. IACA reports that, on occasions, two agencies have initiated planning independently of each other for the same area. And where responsibility for planning is centered in one agency, the judgment and experience available in other agencies is not always consulted: in particular, until recently the Agriculture Department seems to have been drawn little into WAPDA and Irrigation Department project planning. Also differences of opinion during early stages of planning may be suppressed, making reconciliation of views at later stages more expensive.

By coordination is meant the creation of a common developmental front. Perhaps there will always be some conflicts of institutional interests, narrowly construed, but the broad purposes of the organizations are not in conflict. WAPDA builds the main water development projects, the Irrigation Department distributes much of the water from them, and the Agriculture Department is concerned with effective final use of the water. The difficulties encountered by the ADC and the LWDB—in establishing effective working relationships with the existing administrative structure—may be attributed to their being new agencies. But there appears to be a need for additional coordination of agricultural planning and policy implementation. The logical body to undertake this task would seem to be the West Pakistan Planning and Development Department, which is already responsible for keeping under review the Development Plans. At present, the Department has insufficient technical and professional staff to perform such a role effectively. But the problem is particularly important, and the savings to be had from more effective deployment of human and financial resources are sufficiently large, that the coordination function should be put on the priority list for manpower requirements.

IMPLEMENTATION CAPACITY

Administrative capacity, in a general sense including highly skilled manpower, has been a recognized constraint on development in the past, and it would be expected to continue to be a determinant of how much development can be accomplished over the next 20 years. As an unavoidable element in preparing a plan of action that would be feasible of execution, the Study Group and its consultants attempted the difficult task of estimating the approximate rate of progress that might be achieved in each direction of activity, assuming a major effort. While this report cannot offer the last word on such matters of judgment, the Study Group emphasizes that "implementation capacity" is a scarce resource, there are administrative and organizational limits to the pace of development, and to gloss over these facts would be more conducive to wishful thinking than to effective planning.

It is also emphasized that all estimates of progress rates in this report are regarded as being on the side of optimism. For planning purposes, that is, implementation capacity has been set at a level that, if judged solely in the light of past experience, should be termed unrealistic. The progress rates assume a much more massive effort than has so far been made to promote agricultural development. The required effort can be anticipated only because the Government's declared policy is to eliminate dependence on food supplies from abroad and to make "high priority for agriculture" a reality rather than an intention.

Where possible, estimates or impressions have been offered as to the extent of change required in expenditures, status and attention accorded to agricultural extension, education and research. But it is difficult to express the required effort meaningfully in quantitative terms, because so much depends on the quality of the service and the inputs provided. Improved seed is a case in point. The target of the Second Plan was to cover 50 percent of the area under major crops with improved seed by 1964/65; actual achievement was, according to the Second Plan Evaluation, 11 percent or not greatly more than the area covered at the start of the Plan. The 1975 targets assumed in the Study Group's projections are 40 percent of the rice acreage, virtually the entire cotton acreage, and 50 percent of the wheat acreage; this would imply an increase over the 10-year period of more than 400 percent in the area planted with improved seed. While the quantities projected assume a significant improvement in services to farmers, the more significant factor in the Study Group's assessment of progress rates is the assumption that the improved seed will be of high quality and high germination rate and will not be adulterated as it often is now. This will require a very substantial expansion of seed multiplication farms under Government supervision and much more effective quality control than has so far been maintained.

It is not only in the purely agricultural field that the recommended program is administratively ambitious. As was pointed out in the chapter on power, in 1965/66 WAPDA actually electrified less than 10 percent of the number of wells envisaged in the Master Plan target for that year. Fulfillment of the Action Program will mean completing in almost each year of the Fourth Plan as many public tubewells as were completed in the whole of the Second Plan, or about 10 times the recent annual achievement. Furthermore, this large tubewell effort would take place at a time when a goodly amount of WAPDA's engineering talent would still be burdened with the completion of the IBP works and with the construction of Tarbela. The recommended canal remodeling program—about a million acres by 1975—would be no small job for the Irrigation Department either.

And the administration burden imposed by the power program should not be underestimated. During the Second Plan, WAPDA more than doubled its number of customers and built about 15,000 miles of distribution line; the heavy concentration on new large-scale power projects and on connecting new customers led to some neglect of maintenance. During the current plan and the Fourth Plan, this backlog in maintenance has had to be made up and, at the same time, according to the Study Group's estimates, about 60,000 miles of new distribution line will be required. The recommended program also envisages a very substantial investment over the next decade in 380-kv EHV transmission, a field new to West Pakistan, and an approximate trebling of the utilities' installed generating capacity between 1965 and 1975. WAPDA takes the view that the load growth may be even higher than projected by the Study Group. Whichever magnitude turns out to be right, it is clear that planning and construction will have to be enormously expanded and greatly improved if West Pakistan is to build a power system commensurate with its needs.

Implementation Bottlenecks

The main foreseeable bottlenecks in planning and implementation of projects are related to manpower and procedures. Schedules are often not met because procedures are still too loose to ensure the smooth flow of needed construction materials. But procedures in the larger sense includes the mounting of field missions, cooperation between departments, etc. The manpower bottleneck is more precisely a shortage of engineers. The educational backlog can to some extent be alleviated by continued use of foreign contractors and consultants, but the number of engineers needed cannot be adequately supplied in this fashion: there can be no replacement for sufficient numbers of Pakistani engineers, permanently employed and experienced in local conditions.

Engineering education has expanded rapidly in recent years, but still the output of graduate engineers during the Third Plan will be only about 3,800 against a requirement, according to the Third Plan document, of an additional 7,000 engineers between 1965 and 1970. By 1975, IACA estimate that the public tubewell program will require an additional 1,000 engineers for project planning and construction alone. In addition, supervision and operation of completed tubewell projects will by that time require about 300 more engineers. The Study Group adds that the critically important task of managing the tubewell projects will require staff with administrative as well as engineering ability, and finding this management cadre will require special attention. In comparison with the total need for engineers, formal education facilities in engineering cannot be expanded fast enough without sacrificing quality, because of the shortage of good teachers. More on-the-job training is required for recent graduates. On-the-job training could also be used to upgrade promising young men who may lack full formal training in engineering; such men could be used in supervisory positions where technical training is less important than good general experience in construction, operation, or maintenance. More use could probably be made of consultants for on-the-job training purposes.

Improved procedures are essential if the large tubewell program is to be executed as envisaged. There is need for a major tightening and routinization, as much as possible, of procedures for investigation, design, land acquisition, contracting, supplying components, and designing and building the electricity distribution system. The public tubewell projects proposed here are of considerably smaller size than the ones built hitherto; they average about half a million acres each. The smaller size for public projects will leave the maximum scope for private development in areas where private tubewell growth shows promise. This would reduce the burden on the public authorities. The smaller scale would also make construction and operation of the projects considerably more manageable. Construction stages would be shorter; thus the projects should come into operation more rapidly. Delays can be minimized by good initial investigations of the physical conditions—groundwater, topography, electrification problems, etc.—in the area to be covered, by better scheduling of procurement, and by improved coordination both within departments (e.g. between WAPDA's Power and Water Wings) and between departments. With one SCARP project completed and four underway, enough experience should have been gained that potential bottlenecks can be foreseen and the requisite steps taken at each stage of a project to see that bottlenecks do not recur.

There have been suggestions that execution of the program will require the establishment of new organizations, in particular changes in the institutional structures related to the tubewell projects and the power field. One specific suggestion is that some of the responsibilities of WAPDA's Power Wing be transferred to a new organization. The Study Group is not convinced that this would be a prudent move at the present time. The Power Wing has done a reasonably good job under rather difficult circumstances and, through trial and error, has gained much valuable experience. Establishment of a new organization would not ease the basic problem, the shortage of qualified and experienced people. Indeed, creating a separate management hierarchy would more likely exacerbate the shortage of qualified staff and intensify the procedures problem as well—more people in both the new and old organizations would have to devote time to ensuring proper coordination between them. Recently formed organizations, such as municipal power distribution agencies, might encounter even more difficulties than WAPDA does in securing adequate financing for distribution work, because they would not have the backing of WAPDA's general financial strength. The reassignment of responsibilities in different organizations at this time would tend to delay, rather than expedite, the expansion of the distribution and transmission systems needed for the tubewell program and to connect large numbers of new customers anticipated. It would be more prudent to concentrate on strengthening the Power Wing. The Study Group believes this conclusion, to concentrate on strengthening existing organizations, applies to the tubewell projects and to the implementation structure as a whole.

Problems for Management

Efficient operation of the evolving water system may soon prove to be a more serious problem than actual project construction. Over the two decades to the mid-1980's, but especially in the next few years, the irrigation system of West Pakistan, having remained basically a system for diversion of natural river flows for a century, will be going through a critical transitional phase. Established rights to surface water, and the procedures that have been used for allocation of the annual flows, will no longer give the greatest benefit from the water supplies that will be available. However, it will be necessary to continue to allocate water each year largely on the basis of predetermined requirements, rather than on a basis of demand, because of system rigidities. These requirements will need to be reviewed annually in the light of interim system development. Management of the system will need to take into consideration a varied combination of flexible and rigid elements. For instance, while most of Mangla's storage will go to replace the rabi flows of the eastern rivers, the regulation capacity of the dam will make it possible to fit flows better to seasonal crop needs than has been possible in the past. Completion of the link canals from the Indus will add to the flexibility of bulk water allocations between areas, but new diversions will be required to enable them to provide enough water to replace Sutlej and Ravi flows. Increasing quantities of groundwater becoming available with the gradual spread of tubewell fields will complicate calculations of surface-water requirements; in some cases, first probably in SCARP IV, groundwater will be able to substitute for some of the current surface supplies, releasing them for use elsewhere. Tarbela will further alter the nature of the system, adding substantially to total rabi water availability and providing more capacity for fitting water supplies to crop needs. Thus the water system will be evolving rapidly and major new policy decisions will be required.

To give adequate recognition to the broad range of administrative, legal, sociological and technical considerations that should be brought to bear in formulation of these evolving policies, the Study Group believes that a Provincial Irrigation Authority should be constituted at the highest level. This body would be responsible for basic decisions on barrage allocations, reservoir release patterns and drawdown levels and other major policy issues, such as the use of tubewell fields in relation to surface water deliveries; it would be concerned with both power and irrigation aspects of system operations. While the Authority would ensure the cooperative formation of new policies and water allocations, it would not itself be expected to undertake the detailed analyses of water distribution. An effective mechanism for technical analysis could be set up in the form of a semi-independent study group or working party, or whatever such a body might be called, staffed by, say, the Irrigation and Power Department, WAPDA, Agriculture Department and the Planning and Development Department. The staff technical officers should be fully conversant with the practical problems of operating the irrigation system and the needs of the farmer, as well as being competent in technical analysis.

Another important problem area for management concerns the Power Wing. This organization will continue to carry out management functions not directly related to water resources. These administrative duties are in vital need of improvement. The chief dispatchers of the power systems must be clothed with sufficient authority to direct the flow of electricity from generating stations to load centers, as required, and to order the starting up or closing down of generating stations to meet fluctuating demands. After the North and South are interconnected by EHV transmission lines, a central dispatching station will be needed. The Power Wing's billing, collecting and accounting procedures need improvement. The accounting system needs updating into a management tool. Statistics should be convertible into operating results and trends, enabling management to know where to place responsibility for successes and failures. The electricity "losses" on the WAPDA systems needs to be reduced. With unbilled energy accounting for about 20 percent of total generation, even a small reduction could lead to substantial increase in net income. But a sizable reduction should be possible with improvement of the distribution system, better meter reading and billing procedures, and more efficient operation of a denser transmission and distribution network.

Maintenance is another area that requires special management attention. As the complexity of the irrigation and power systems increases, the need for programmed maintenance will increase. The importance of maintenance will need to be stressed. The neglect of power maintenance in the past, due partly to shortages of personnel and partly to lack of adequate financial provisions, has led to some serious deterioration of works, sometimes with disastrous consequences, as in the case of the Multan power plant. The distribution network on WAPDA's power system has deteriorated, leading to excessive accidents and accounting in part for the large distribution losses on the system; it is urgent for WAPDA to increase its manpower in this field and to allocate sufficient funds for renovation of the distribution network. The problem exists similarly in the field of irrigation. More attention there must be given to canal maintenance. For many canals, further deterioration could result in extensive and costly repairs. Routine maintenance of the canals will become increasingly important as the irrigation system evolves. To give one reason why: because the water will have deposited most of its silt load in the reservoirs, there will be greater danger of scouring damage to the canals; but a more pervasive reason is that reliable operation of the canals will be critical in a tightly integrated system. Canal maintenance will have to be carefully scheduled and fitted in with the program for tubewell maintenance to ensure the availability of irrigation supplies from one source or another in accordance with crop requirements.

As each public tubewell project is completed, the two critical tasks for management will be to master the problems of supplying groundwater in the context of the integrated system and, secondly, to ensure the availability of complementary agricultural inputs. Concerned about the need for efficient management on the water side, IACA felt that integration of surface and groundwater supplies required that the Irrigation Department also take over responsibility for operation of the tubewell fields. Private enterprise would be expected to promote and provide the complementary inputs. The Study Group disagrees with this concept of management on two grounds. First, it believes the Irrigation Department has too many responsibilities to give sufficient attention to the tubewell fields. Second, the Study Group has doubts that private enterprise would come into a project area fast enough, in sufficient force, to promote and provide inputs that had been relatively little used before. An integrated project management, fully responsible for all aspects of project operation, seems to be required to get public tubewell projects off to a good start. The existing concept of ADC and LWDB appears to be sound. Emphasis should therefore be placed on strengthening and improving these relatively new organizations. They would provide a Project Director, with full responsibility for the overall success of the project; the staff of engineers, extension workers, etc., would be seconded from the line departments and be fully responsible to the Project Director. This approach would help to ensure that sufficient emphasis is given to improved farm practices and to use of more material inputs as well as to water. An important task of the project management should be, as IACA pointed out, monitoring project development starting with the pre-project condition of agriculture: lack of sufficient data on agriculture in West Pakistan is an obstacle to effective project planning, and the execution of a project provides a good opportunity to help remedy this deficiency. The integrated project management would in no sense discourage the development of private enterprise for supplying inputs, nor would it replace the activities of the regular line departments in the area. Once the project is well underway and major changes have been accomplished, the appointed manager concept could give way in favor of an organization more representative of the local farmers.

Finally, the potential contribution of the private sector, an aspect of water development policy which has received considerable emphasis throughout this report, has some important implications for institutional management. The Study Group sees public and private tubewells as essentially complementary, since neither alone can meet the urgent need for greater amounts of irrigation water. Public tubewell projects have been proposed for areas where a public program has a clear advantage over private development and/or where private investment is not likely to be very significant. When a detailed feasibility study is made for a public project, the assumed degree of private development should be closely examined: could greater parts or possibly all of a proposed project area be wisely left to private initiative? Over the next decade, in particular, private investment could make an extra contribution by freeing public funds for activity elsewhere. It must be borne in mind that scheduling an area for public development will discourage some of the private development that would otherwise have taken place there; if the public project then gets seriously delayed, an important and avoidable loss of production will have been sustained. Thus a policy of keeping public tubewell programs to a manageable size should be considered an incentive for investors in private tubewells. The Government also should take other measures to stimulate private water development. Many of the private tubewells presently installed have technical deficiencies which could have been avoided. Technical advice should be readily available to farmers and landowners on procurement and construction matters, types of equipment available, water quality, irrigation requirements and water management. Such advice would cover not only tubewells but also other water works such as small dams and watercourse alignment; increasingly, advice and assistance may be required to help organize cooperative use of facilities. The extension service should be alert to helping enterprising farmers—those who are enterprising enough to install their own irrigation works—to make the best use of them. The Study Group strongly advocates measures of this sort, i.e. direct help in the form of technical advice and services that will not otherwise be provided. Credit may also become more important as the further spread of private tubewells comes to depend more on the smaller farmers. Increasing the impact of credit, as a stimulating influence on development, may require a more aggressive credit policy on the part of the Agricultural Development Bank and sustained increases in its lending resources.

Promoting Better Agriculture

To achieve the increases in agricultural production envisaged in this report, very great stress will have to be placed on the adoption of improved farm practices and greater use of agricultural inputs other than water. The "stressing" will have to be done by administrative units connected with agriculture and by private enterprise. For the project areas, the line departments will have to provide the personnel for promoting improved farming, and the Project Directors, assuming this management concept is followed, will have overall responsibility for performance. However, even if the whole public tubewell program can be completed by 1975, Project Directors will be responsible for only about 10 million acres. Promotion of new inputs in the remaining three quarters of the farm area, both irrigated and unirrigated, will be the responsibility of the Agriculture Department staff, the ADC, and private enterprise. It is one of the most important conclusions of this report that such areas can profitably absorb large quantities of new inputs and adopt improved practices even before additional water is provided. Moreover, a sizable portion of this area should see rapid development of private tubewells for increasing water supplies. Thus, from the viewpoint of public administration, the nonproject areas represent a responsibility of great magnitude, which in turn underlines the need for the vast improvement in the Agriculture Department called for earlier. Even for the project areas, the Agriculture Department will largely be the source of extension staff; and it will be responsible for the research work necessary to test and develop the new inputs and to evolve cultural practices that will produce the best results from the inputs.

As with water development, the public sector should give maximum encouragement to private enterprise in supplying and promoting agricultural inputs. The disposition of public resources will be an important concern of policy. Public resources should be allocated to maximize the return on the combined public and private investment—the investment of effort as well as finance in promoting better agriculture. As in water development, again, there will be many areas of activity where private enterprise probably will not come in rapidly and the Government must take a strong lead.

There are four main aspects to the work involved in promoting widespread adoption of an input; and, because promotion of better agriculture must be a continuing process, they must all be carried on simultaneously. The first stage is research and testing of new inputs, and this must remain very largely a Government responsibility in West Pakistan. The second aspect is making sure that supplies are widely available—this is where private enterprise should be able to make the largest contribution. The third part of the effort must be provision of incentives for the farmer to adopt the new inputs. Incentives fall largely in the area of policy: the overall price structure for agricultural goods, which must be conducive to investment of farmers' effort and savings in agriculture, and subsidies for specific inputs and provision of credit for purchase of such inputs. And fourthly, extension work—showing the farmer what is available and how to use it—may be the most important part of promoting new inputs; though private enterprise can help, the main extension task will remain with the Government.

The emphasis in research must be put on practical problems which are directly related to progress in agriculture. Applied research is vitally needed to develop new and improved crop varieties, more efficient plant protection methods and better understanding of soil, crop, water and fertilizer relationships. But, as presently set up, the research service is not capable of making the needed contributions. It suffers from the lack of qualified personnel and supporting facilities noted earlier for the Agriculture Department as a whole. It tends to be overly academic and isolated from the farmers' day-to-day problems. Building an efficient and contributing research branch will take more than the addition of a few more staff members or some new equipment. The critical needs for improvement of the research service are generous financial support, patience and understanding of the uncertainties which are a necessary part of research, the infusion of a spirit of service to the agricultural community, dedicated leadership, and a conscious orientation towards the problems facing West Pakistan's agriculture today.

A massive expansion of the distribution network for agricultural inputs is clearly called for. At present, the ADC and the cooperatives bear the main responsibility for fertilizer distribution. This input probably could be very effectively handled by private enterprise, provided that fertilizer is made available in adequate quantities. For the short-term, action has already been taken to increase supplies, by the allocation of large amounts of foreign exchange. On the horizon is a massive increase in domestic production. One commercial enterprise with a plant under construction announced its intention to set up its own sales organization; other large producers, expected soon to set up shop in West Pakistan, may do the same. Production and distribution of improved seed are likely to require substantial Government supervision. In the past there has been severe adulteration of improved seed stocks by growers and distributors. To maintain the quality of the seed, there will need to be a planned multiplication of registered growers, supplied with nucleus stock, under close Government supervision. If quality is not maintained—if the germination rate falls—this can have very serious effects on the readiness of the farmers to use the new varieties. Private suppliers, under Government supervision, may gradually be able to take over a major part of the burden. The realization of reasonably large yield increases through the use of fertilizer and better seed is likely to be a prerequisite to adoption of plant protection measures; simplified techniques, developed through research, is another crucial factor. In terms of organizational responsibility for the inputs, effective plant protection depends so much on application at the right time that the farmer should be closely associated with procurement of the materials. At present, the extension service carries almost the entire responsibility for plant protection, and, according to IACA's observations, it is not very effective. Gradually transferring plant protection to private enterprise would give the extension service more time for other activities. Farm mechanization and the spread of improved hand tools and animal-drawn equipment are other fields where private enterprise, with Government supervision, could play a bigger role than it does now. Some sort of standards will have to be set to ensure adequate spare parts and servicing facilities; some control may also be necessary on the variety of equipment made available. But the rapid growth of domestic production and servicing facilities for private tubewells suggests that private enterprise could handle the distribution and servicing of farm machinery effectively.

Maintenance of a strong price framework for agricultural commodities, giving proper rewards to the farmers, may be the decisive factor in promotion of new inputs, as for promotion of improved agriculture in general. The price framework in turn involves a variety of financial measures which, in the last analysis, must take into consideration a balance of various interests. In terms of agricultural objectives, it is relevant to note that a gradual improvement in effective prices paid for commodities played a significant part in stimulating greater interest in agriculture during the Second Plan. There still would appear to be some room for further improvement in the price paid to the farmer for selected farm products. In the course of the Third Plan, the official support price of wheat was raised to Rs. 17 per maund. This price appears to be somewhat above the international market price for wheat at the current exchange rate but substantially below the international price at a shadow rate which the

Study Group suggests may be more relevant (say, approximately double the official rate). Apart from a favorable price structure for farm products, the Government should in each case carefully consider whether greater benefit would be forthcoming by measures to subsidize the use of inputs. Specific subsidies dedicated to specific objectives will continue to offer a proved way to encourage use of inputs. Current subsidies on fertilizer, plant protection, and improved farm machinery, which appear to play an important promotional role, will need to be retained until the value of these inputs is so widely recognized by farmers that they are prepared to buy adequate quantities at unsubsidized prices. All subsidies should be reviewed from time to time, looking to the day when they can be dispensed with. A closer look might now be taken at the subsidized rate for electricity used for pumping purposes; the Study Group believes this to be of dubious value. It appears to have played little role in promoting private tubewells—the more important factor has been the sheer availability of electricity. Since lack of finance is one of the major factors limiting the expansion of the distribution system, and since the Power Wing's rate of return on capital invested is already below what the Study Group would consider a reasonable level, serious consideration should be given to raising the price charged the farmer for electricity. The Study Group would also urge a thorough study of water charges, for raising them could be a means to alleviate the budgetary stringency on the execution of development programs. The role of water as an input is widely understood by the farmers, so increased water charges should have no disincentive effect; indeed, charges more commensurate with the costs of building and operating the irrigation system could help to improve the utilization of water—just as the much higher costs of private tubewell water have apparently led to more careful and productive use of water obtained from that source.

The credit system in general is very inadequate in terms of input use, especially for inputs like seed and fertilizer. In terms of their effective support to agriculture, credit channels may become a serious block to progress unless special measures are taken to improve them. Credit on reasonable terms, generally from the Agricultural Development Bank and from the commercial banks, is available only to the larger farmers. The majority of credit made available comes from merchants, zamindars, etc., sometimes at high interest rates, and most of it is spent not on farm inputs but to meet social and subsistence needs; this heavy demand for credit for nonagricultural purposes tends to raise the price of credit in general. Measures are needed to improve the availability of credit and the operation of the cooperative system, which will be one important channel of credit, but such measures cannot have a rapid effect. In the meantime, main reliance for credit will have to continue to be placed on noninstitutional sources.

Finally, the extension service is at present entirely inadequate to provide the educational effort that will, in the last analysis, be crucial to promotion of the new inputs. General problems of recruitment were referred to previously. The lack of facilities, such as transport, further limits the effectiveness of the available officers: many farmers seldom have an opportunity of meeting an extension worker. Much time of the extension service is devoted to administrative chores and to rather ineffective plant protection work. The low status of the extension personnel, and the Field Assistant in particular, makes it difficult for them to contact and work with the more influential farmers in a community. The general ineffectiveness of many extension workers can be simply stated: backed by weak research support, and having a limited base of practical training and experience, they are often not in a position to offer advice of real value to farmers. Yet it is this extension service which must carry the main responsibility for showing farmers how to use fertilizer to best advantage under specific conditions, for demonstrating the best cultural practices that go along with new seed varieties, etc. The extension service must have the capability of advising the most progressive farmers, who are moving on to insecticides and farm machinery. A concentrated extension effort is essential to enable the farmers to make best use of the added irrigation supplies as water becomes available. Also, rapid development of the livestock sector, essential in face of the increasing demand for meat and milk, is not likely to happen by itself; animal husbandry will have to be closely coordinated with crop production in diversified farms. The agricultural extension service must develop the capability to provide advice about livestock management and improved feeding practices.

There will need to be a substantial expansion of the extension service. Over the short run, however, the uncertain quality of the advice offered now is such a problem that the strategic decision should be to concentrate on recruitment of better personnel and improvement of training, rather than trying to meet theoretically desirable personnel targets. It is estimated that the essential requirements of the Government agricultural services for university graduates could be met by an increase of about 1,600 between 1965 and 1975; taking account of the needs of other departments such as Irrigation, WAPDA and the Education Department, present plans for expansion of the agricultural universities appear fully adequate. For Field Assistants, IACA recommended that the number be approximately doubled by 1975: an increase from 3,000 to 6,000. It would not be difficult in a physical sense to meet this target, as an additional six training colleges are projected for the Fourth Plan period. But whether this full expansion could be carried out simultaneously with a major effort to accept only qualified candidates and to improve the instruction afforded them is open to question. The Study Group would put emphasis on quality rather than quantity. The recent increase in the length of the course for Field Assistants from one year to two, including six months of supervised field work, should help greatly in upgrading the extension services. There should be continuing efforts to make the training more meaningful in the practical terms required for effective work with the farmers.

B. IMPACT ON MACROECONOMIC PLANNING

Development Objectives

In the years to come, implementation of the proposed program for harnessing Indus Basin water will constitute the largest element of West Pakistan's development effort. Increased agricultural output and energy production will be the direct results of this effort. But these sectors are not the only economic activities of importance in the Province; the Province itself is but one of two in Pakistan; and, in the last analysis, proposals for water resources development must be related to the concerns of the Central Government—such as, on a mundane scale, allocating fiscal resources and conserving foreign exchange and, on a higher scale, improving living standards and building the strength of the nation as a whole.

National development planning at the working level is the responsibility of the Planning Commission, which serves as the President's Secretariat. Membership of the Commission includes direct representatives of the agricultural and water resource (including power) sectors of the economy.[1] Economic policy recommendations made by the Commission are incorporated into a Plan document, covering five years, which is submitted for endorsement by the National Economic Council; the final step is official adoption of recommended policies as part of the national development effort. Pakistan's Five-Year Development Plans have come to play an increasingly important part in the total development effort of the country. The Plans are concerned with setting the overall financial and economic framework, establishing specific financial and physical targets, allocating Government development expenditures, and proposing policies that will promote economic growth. The First Plan, covering 1955–60, had disappointing results. The Second Plan, covering 1960–65, was given much greater emphasis by the Government in terms of policy recommendations adopted.

In the course of preparing the Third Plan, the Planning Commission felt the need for a longer term framework. It was recognized that many short-term decisions can critically confine or expand the scope for later choices, and furthermore, the results of short-term decisions cannot be judged without a longer term view. Considerable effort was therefore devoted to formulation of a 20-year Perspective Plan, built around major economic and social goals. It was envisaged that, gradually, the development potential of each sector would be filled out into long-term Master Plans. The objectives of the Perspective Plan for 1965–85 are mainly national objectives covering both wings of the country. Specific targets mentioned are a doubling of per capita income between 1965 and 1985; parity in per capita incomes between East and West Pakistan by 1985; full employment at earliest achievable date; more equitable income distribution, especially raising the lowest 25 percent of the population; universal eight-year education by 1985; elimination of net capital inflows on public account by 1985.

The objectives in general can be interpreted as being dependent on rapid economic growth to generate the projected increased incomes and fiscal revenues. With reference to West Pakistan, the objectives also imply a policy of institutionalizing the growth process, in the sense of making it increasingly dependent on its own resources of savings, skills, and industrial production. These policy objectives are in keeping with the proposed program for development of water resources.

[1] *Development Planning; Lessons of Experience*, Johns Hopkins, 1965, p. 658.

Assuming a population growth of 2.8 percent, which is somewhat higher than the figure used by the Planning Commission, a doubling of per capita income in West Pakistan would require more than tripling the Gross Provincial Product (GPP). The existence of such a target implies the necessity of a rigorous development effort. This in turn underscores the importance of a continuous review of economic priorities, the careful consideration of organizational needs as discussed previously, and a responsive attitude toward the financial requirements of agricultural programs. The priority attached to agriculture is of especial concern.

Over most of the post-World War II period, the importance of agriculture in West Pakistan's economy has been obscured by the growth of manufacturing industry, the most dynamic sector of the economy. Modern large-scale industry has shown dramatic growth; it has been built up from almost nothing in 1950 to about 12 percent of total output in 1965. It grew at about 16 percent per year during the Second Plan period (1960–65). Early growth of the large-scale manufacturing sector was largely in industries producing substitutes for imports. It was stimulated by the existence of a high protective tariff on consumer-goods imports, as well as direct quantitative controls on all imports. Over the last decade industry has come to make an increasingly important contribution to exports —chiefly in textiles, but also in fields such as light engineering goods, rubber and leather products—encouraged by positive Government measures. Table 7–1 shows the structure of the large-scale manufacturing sector in 1964/65. But the importance of agriculture, even in this context, begins to reemerge when one considers the extremely important position of agricultural processing industry in West Pakistan; in particular, the industry based on domestically produced cotton (cotton-ginning and most of the textile industry) alone accounted for about a third of large-scale manufacturing output in 1964/65. Also, agricultural machinery has been one of the mainstays of the expansion of investment goods industry.

TABLE 7–1
STRUCTURE OF THE LARGE-SCALE MANUFACTURING SECTOR, 1964/65
(% of total value added in sector)

Consumer Goods	52.8
Sugar	5.0
Tobacco	2.3
Textiles (80%)	21.3
Board, Paper	1.0
Other	23.2
Intermediate Goods	28.2
Fertilizer	1.1
Cement	2.1
Textiles (20%)	5.3
Cotton-ginning	7.7
Chemical and Refining	7.0
Other	5.0
Investment Goods	19.0

All in all, agriculture still remains very much the dominant sector of the economy. There are about five million farms—most of them at least partially irrigated—and on these farms live nearly three-quarters of the Province's 55 million people. Much of the activity elsewhere in the economy is intimately linked to agriculture, in the form of providing services to the agricultural sector, processing the agricultural commodities produced or distributing them. Exports of agricultural commodities, in raw form, made a more than proportionate contribution to the increase in exports during the Second Plan, rising from Rs. 320 million in 1959/60 to Rs. 620 million in 1964/65. Cotton manufactures also made a significant contribution to exports.

The importance of agriculture has been reemphasized to Pakistani planning experts by the rising imports of food stuffs in recent years—imports into a traditionally surplus economy. Exports of agricultural commodities, in raw and processed form, are not increasing fast enough to displace the importance of food production for domestic consumption. Thus for some time it has been an important policy objective to encourage self-sufficiency in basic agricultural commodities.

Agriculture's Contribution to GPP

One of the chief targets of both the Perspective Plan and the Third Five-Year Plan is to achieve an average annual growth rate in agriculture in the neighborhood of 5–5.5 percent. This was an ambitious target in the light of past experience: between 1950 and 1965, agricultural production grew at less than 2.5 percent per year. However, annual growth of some 3.8 percent was achieved during the Second Plan period and the outlook was for a similar improved performance in the Third Plan, if sufficient incentive were given to the farmers and they were provided more water, fertilizer, insecticides, etc. The target rate of growth for agriculture has, as a general magnitude, appeared essential if growth of the provincial economy as a whole were not to be restrained. Planning Commission Studies showed that an agricultural growth rate of some 4.5–5.0 percent per year was essential to support the 6.0–6.5 percent growth rate in GPP required to meet the target of doubling per capita income between 1965 and 1985.

On the assumption the development program advocated here will be adopted, a projection of agriculture's contribution to GPP has been built up beginning with the production response estimated in this report. For the canal-commanded areas of the Indus Basin, the gross value of agricultural production[1] might well grow at 5.2 percent per year over 1965–75 and 6.4 percent per year over 1975–85.

In terms of agriculture's contribution (i.e. in value added) to GPP, these figures for Indus Basin agriculture would be 4.5 percent for 1965–75 and 5.5–6 percent for 1975–85. Thus, the outlook would be for only a very slight shortfall in 1985 output below the official planning target.

But the actual growth rate achieved will, of course, depend on policy factors, for instance in regard to such matters as self-sufficiency in food

[1] In current "farm gate" prices. For details see Supplement Paper No. 1, Volume Three.

grains. The dynamics of possible growth will be discussed in due course. Suffice it to say here that, assuming that an export-import parity in basic farm commodities is pursued and achieved by, say, the mid-1970's, the agricultural growth rate of 4.5 percent per year (again, value added) projected in this report (cf. Chapter IV) would be fully consistent with a growth rate in GPP of about 5.7 percent per year. This estimate is based on the assumption that the marginal savings rate implied in the Perspective Plan—about 24 percent between 1965 and 1975—will be attained. A higher growth of, say, 6 percent is conceivable, but the Study Group prefers to accept for planning purposes the more conservative projection.

Self-Sufficiency in Major Commodities

The Third Plan in its original form, before it was revised late in 1966, gave high priority to agricultural production. But an even greater sense of urgency has been added in the revised document: "The importance of this sector is already recognized in the Third Plan but the need for attaining self-sufficiency in food in the shortest possible time has been sharpened by the growing uncertainty and more difficult terms of PL-480 supplies."[1] While food self-sufficiency had been a longer term target, the Government of West Pakistan developed and adopted a major program designed to eliminate dependence on imported wheat by the end of the Third Plan, that is, by 1970. The key element in the program is higher-yielding wheat varieties introduced from Mexico. Ambitious targets were set for use of Mexican wheat seed; absorption targets for fertilizer were greatly increased, etc. High priority was placed on measures to increase irrigation supplies, particularly from public and private tubewells.

These late revisions in targets, and particularly the immediate objective of wheat self-sufficiency by 1970, could not because of timing be taken into consideration in the Action Program proposed herein. This report rather reflects what the Study Group and its consultants considered practically achievable and consistent with available resources at the time it carried out its analyses. Production was projected on the basis of detailed analysis of areas studied rather than against particular demand targets. Moreover, to retain the focus on the technical aspects of development proposals, prices of commodities were, for the most part, held constant for analytical purposes. To put the matter into the context of this report, the developing irrigation system was intended to have sufficient flexibility to cope with deviations in supply and demand, but Government price and marketing policies would have to encourage the necessary shifts in cropping patterns.

But the flexibility of the system to meet planning contingencies—i.e. short-term changes in production targets—may be considerably reduced if the growth rate for agriculture falls much below 4.5 percent. An earlier "most likely" projection of future supply and demand, to determine whether the Program might meet West Pakistan's requirements, was made

[1] PL-480 refers to United States foreign aid legislation which authorized sales of commodities to recipient countries for local currency. A 1967 revision called for the elimination of "soft currency" sales.

by IACA on the basis of agriculture growing at only 3.5 percent per year through 1975. Though there would be surpluses in some crops at this rate of growth, there would likely be significant domestic shortages in output of food grains. It is only at a higher rate of growth—4.5 percent or higher—that the surpluses and deficits projected for different crops could be completely overcome by appropriate adjustments to the cropping patterns. Self-sufficiency at least by about 1975 in the major agricultural commodities taken together is thus consistent with all the analyses carried out in this study.

The Dynamics of Growth

While self-sufficiency in all crops in general and wheat in particular is a sensible goal, it is reasonable to ask: what would be the requirements for achieving such a policy objective? And to broaden the discussion, what would be the implications of carrying out the proposed water development program, under various assumptions in regard to this objective as well as other macroeconomic magnitudes? To obtain relevant comparisons with Perspective Plan data, the Study Group investigated the growth dynamics of the agricultural sector with the aid of an economic model for West Pakistan similar to the one used for the national economy by the Planning Commission in preparing the Third Five-Year Plan. The projection for West Pakistan is described in Supplemental Paper No. 1, Volume Three. The Study Group settled on a 12-year projection, over the period of 1962/63–1974/75; the base year was selected because it is the only year for which an input-output table is available for West Pakistan. As noted earlier, there are differences of opinion on matters related to projections, such as, for instance, what agricultural demand will be. Much more light needs to be shed on the key variables for which the Study Group's basic analysis differs from the Third Plan projections. The rate of population growth is anticipated to be in the range of 2.6–3 percent per year, but these estimates of future population could turn out to be considerably inaccurate. The estimates used here are 67 million for 1975 and 89 million for 1985. Thus, it is important to keep in continuous review the assumptions used in projecting demand and other critical variables.

The model used in these calculations, of the linear intersectoral type, relates macroeconomic magnitudes, such as the overall growth rate or the savings rate, to a sectoral growth pattern which balances the supply and demand relationships between sectors. The model has a built-in mechanism for adjusting a surplus or deficit on balance-of-payments current account to equal the difference between projected savings and investment; the adjustment mechanism is import substitution. Thus, the model shows the values of import substitutes which must be produced domestically in the year projected if the assumed savings level is to be attained. (For more details see Supplemental Paper No. 1, Volume Three.)

The broad implications for economic planning in West Pakistan are illustrated in Figure 13. With this figure, it is possible to trace the consequences of various levels of imports and exports of farm commodities in 1975. The rupee figures represent changes between the base year and

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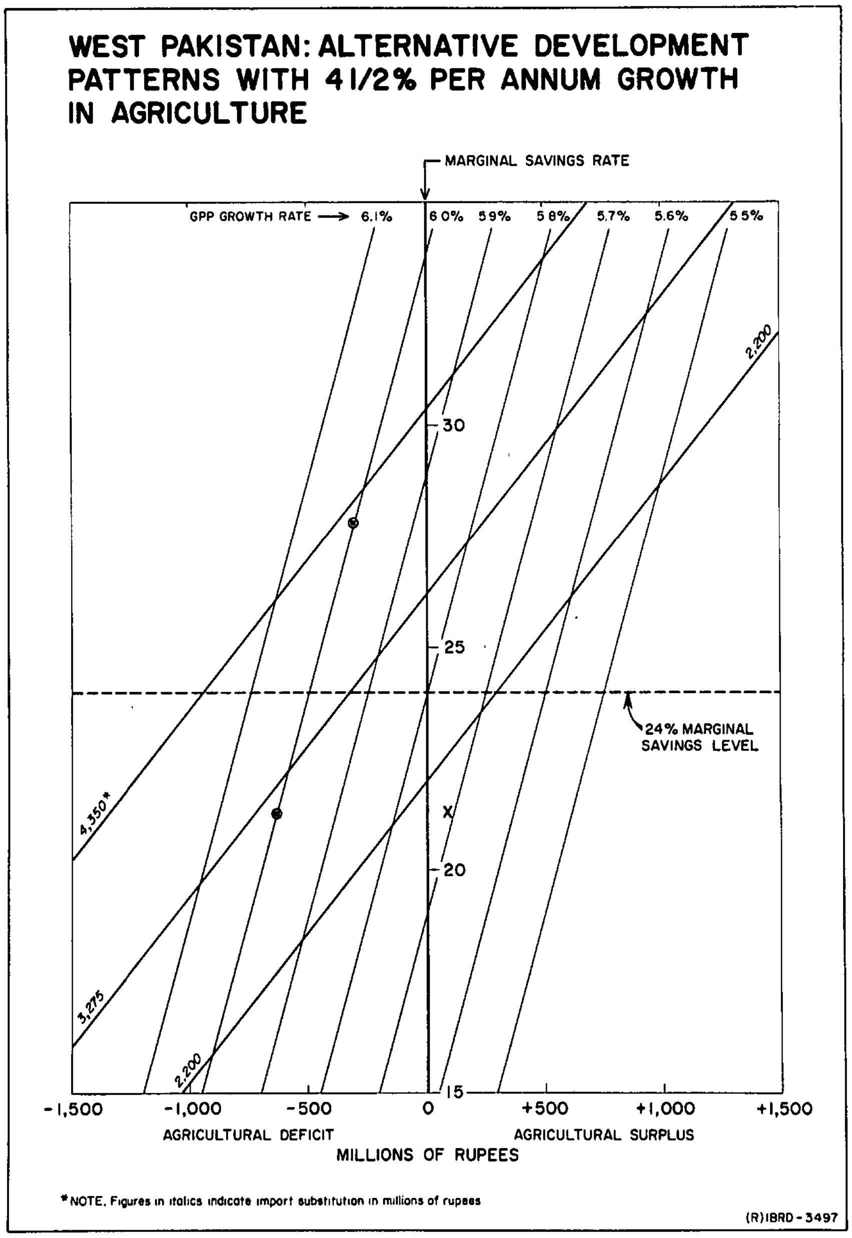
FIGURE 13



1974/75, rather than absolute quantities. The underlying projections were made on the assumption that GPV of agriculture would grow at an average rate of about 5.2 percent per year and that value added in agriculture would grow at 4.5 percent per year. The vertical axis, representing the marginal savings rate, divides the horizontal axis into agricultural surpluses and deficits in 1975: to the right the quantity of agricultural production in excess of domestic requirements, and therefore available for export in that year, and to the left the agricultural deficit in that year. The sharply sloping, lighter lines in the center indicate combinations of agricultural surplus/deficit and marginal savings rate which would be consistent with a particular growth rate in GPP. The more gently sloping, heavier lines indicate the corresponding import substitution necessary to bring the Foreign Exchange Gap into balance with the Savings Investment Gap in 1974/75. Thus, with a marginal savings rate of about 24 percent and an overall growth rate of 5.7 percent per year, an agricultural surplus of about Rs. 250 million could be achieved, sufficient to offset the Rs. 250 million of wheat imports in the base year. There is another effect which derives from the logic of the model, which equates the Foreign Exchange Gap with the Savings-Investment Gap: though not shown on Figure 13, since there had already been a deficit of Rs. 350 million in the base year, there would have been an accompanying net improvement in the balance of payments on current account of the order of Rs. 600 million. This of course would be due to the amount of investment required to support the specified growth rate in 1974/75 being less than the domestic savings achieved in that year with the assumed 24 percent marginal savings rate in the interim. While this would mean self-sufficiency in wheat, there would be shortfalls below Perspective Plan targets in other respects—an overall growth rate of 5.7 percent between 1965 and 1975 against a Plan target of over 6 percent and an improvement in the balance of payments of only half the size of that implied by the Plan.

However, the choice of growth patterns is not restricted to this single one. Higher rates of growth in GPP would be possible, but they would require some continuing or even increasing imports of agricultural products and larger amounts of import substitution. Two alternative cases have been studied as examples, each with an overall growth rate of 6 percent but with 21 percent and 28 percent marginal savings rates respectively. These cases are marked on Figure 13 with circles on the "6% growth" line. At the lower savings rate, needed imports of agricultural commodities are large, greater import substitution is required and the improvement in the balance of payments is small, less than Rs. 100 million as compared with the case discussed above with 5.7 percent overall growth rate. At the higher savings rate, a much larger amount of import substitution would be required, but there would also be a slight surplus on the current account balance of payments by 1975. The higher import substitution requirements mean that higher growth is required in the sectors where import substitution is assumed to occur—manufacturing of consumer goods, intermediate goods and capital goods. Such requisite growth rates, however, do not appear unreasonable by comparison with those attained in the past or those projected in the Perspective Plan for these sectors.

The analysis further shows that with slight changes in several key assumptions, it is possible that a 6 percent growth in GPP would be compatible with food self-sufficiency, a substantial improvement in the balance of payments, and a relatively small amount of import substitution. This result can be produced by using the elasticity of demand for agricultural products as assumed by the Planning Commission in preparing the Third Five Year Plan. Figure 13 assumed an elasticity for directly consumed foodstuffs in the neighborhood of 0.85, including an elasticity for food grains of 0.55. These elasticities are in line with the analysis made by IACA; they are also consistent with those used in some Planning Commission documents. However, a substantially lower figure—0.67—was used in the preparation of the Third Five Year Plan; it was derived on the basis of estimated historical experience in Pakistan during the Second Plan. The Study Group tested the effects of assuming this lower demand elasticity. It found that it had the effect of reducing the agricultural deficit or increasing the agricultural surplus projected, using the Study Group's coefficients, by some Rs. 700 million. In terms of Figure 13, it would shift the line representing a 6 percent growth rate of GPP over into the right-hand half of the figure; as indicated by an x-mark, even a 21 percent marginal savings rate would produce reduction in agricultural imports between 1962/63 and 1974/75 of over Rs. 100 million; at higher marginal savings rates there would be potential increases in agricultural exports.

What this analysis suggests is that the growth rate will be closely allied to (1) how fast demand for food actually grows, and (2) the marginal savings rate achieved. If demand for food grows only at the rate assumed in the Third Plan, it would be possible to achieve food self-sufficiency with a 6 percent growth rate and also a balance of payments improvement nearly two-thirds of that projected in the Perspective Plan, provided that the planned marginal savings rate of 24 percent is achieved. However, if demand for agricultural products grows at the higher rate, then, according to the Study Group's analysis, it will not be possible to reach both self-sufficiency in agricultural products and a 6 percent overall growth rate. Since substantial imports of capital goods will be needed, it would also be difficult under these circumstances to achieve the improvement in the balance of payments projected in the Perspective Plan. The extent of improvement possible would depend on the marginal savings rate achieved and the growth of import-substituting industry. But as an inescapable conclusion, the Study Group's analysis reconfirms the Planning Commission's conclusion that achievement of a high rate of growth in agriculture is very important to attainment of Pakistan's objectives.

Growth of Nonagricultural Sectors

As stated earlier, manufacturing industry has been the most dynamic sector of the economy of West Pakistan, having doubled its share of GPP—from 8.5 to 17.5 percent—between 1950 and 1965. Other notable trends since 1950 have been a sharp growth of construction as a proportion of total activity (an increase from 1.5 to 4 percent of GPP), a relative stability of transport (about 5 percent), and a small but noticeable fall in the share of Government (from 5 to 4.4 percent). As a bench mark, agriculture's share of GPP fell from 54.3 to 41.8 percent over the 15 years.

Projections for nonagricultural sectors are included in the Perspective Plan, and so it is relevant to point out two noteworthy differences between these forecasts and the Study Group's projections, and some of the ramifications. Considerably more rapid growth in the transport industry is projected by the Study Group than by the Perspective Plan—about 7 percent per year as against less than 6 percent. This result further confirms the great stress that the Study Group would place on expansion of the transport network—both arterial links and farm-to-market roads—as a critical element in attainment of a high agricultural growth rate and a high overall growth rate. The Government appears to be aware of this need. In recognition of the importance of rural farm-to-market roads, it was stipulated that half of the funds earmarked for the Rural Works Program in 1964/65 had to be spent on local road construction. Plans are underway for substantial expansion of the capacity of the railway and of Karachi Port. However, execution has not always come up to expectations: less than half the funds allocated for Rural Works in 1964/65, for instance, were actually spent on roads, and there have been very serious delays in procuring the additional locomotives required by the Pakistan Western Railway. The Government's plan for wheat self-sufficiency in 1970 correctly identified transport as a major potential bottleneck in getting the requisite amounts of fertilizer to the farmer and wheat to the towns.

The second noteworthy difference concerns growth of consumer goods manufacturing. The Plan projects a growth rate in the neighborhood of 3 percent. Study Group projections imply a growth rate in the neighborhood of at least 6 percent. Studies suggest that one aspect of the improvement in the relative price situation facing farmers, which was such a crucial factor in inducing the agricultural successes of the Second Plan, was the increasing availability of domestic manufactured goods at slightly declining prices through the late 1950's and early 1960's. The importance of adequate incentives and rewards to the farmers was stressed earlier in this Chapter. The availability of manufactured consumer goods, at reasonable prices relative to farm product prices, on which farmers can spend their increasing incomes, should be regarded as one of the factors making for maximum farmer response to opportunities. The growth rate in consumer goods manufacturing implied by the Study Group's projections is slightly in excess of projected growth in total consumption in the economy.

The growth rate of consumer goods manufacturing also has an important bearing on the power load forecasts used for industry. As noted in Chapter VI, the Study Group assumed that the overall industrial growth rate actually achieved might be somewhat above that implied by the Perspective Plan. On that basis, it concluded that the projection of industrial load included in the main load forecast used for the power studies seemed reasonable for 1970 and might be a little on the high side by 1975. The macroeconomic projections now made with the aid of the Planning Commission's model suggest that the growth assumed for consumer goods manufacturing in the power studies may have been a little on the low side while that for other types of manufacturing was likely somewhat too high. The effect of these different industrial growth rates on the power load forecast has not been checked in detail because macroeconomic projections of sectoral growth rates are not considered to be sufficiently precise or reliable. Nevertheless, it would appear, in general terms, that the aggregate growth of the industrial sector broadly defined—large-scale manufacturing, small-scale manufacturing, mining and utilities—might, according to Study Group projections, lie somewhere between the 8 percent per year projected by the Perspective Plan and the 10 percent assumed in the power studies. This would in turn imply that the main load forecast remains a reasonable projection, erring on the optimistic side and thus including some contingency for unanticipated developments.

The Growth of Employment

The Planning Commission estimated that agricultural work available in 1965 was equivalent to about 7.6 million man-years. In the light of data gathered by its consultants, the Study Group concluded that the basis of the estimate, 395 man-hours per cropped acre, was on the high side. A figure of about 300 hours seemed more appropriate.

The adjusted figure of 6.6 million man-years provides the starting point for estimating the amount of employment that might be available in agriculture if production grows at the rates projected in this report, allowing for increasing mechanization. It is assumed the total labor force will remain unchanged at about 31.6 percent of total population; this is the Planning Commission's figure. The population is assumed to be 67 million in 1975 and 89 million in 1985. Table 7–2 shows the projected growth in agriculture and the employment estimates derived therefrom.

TABLE 7–2
Estimate of Employment in Agriculture, 1965–85

	1965	1975	1985
Crops			
Cropped Acres (millions)	40.72	47.84	54.30
GPV of Crops per Acre (Rs)	133	184	260
Employment (mln. man-years)	4.7	5.8	6.9
Livestock			
Gross Production Value (Rs mln.)	3.3	5.6	9.8
Employment (mln. man-years)	1.9	2.7	3.9
Total Agricultural Employment	6.6	8.5	10.8
Total Labor Force	16.2	21.2	28.1
Agriculture as % of Total	40.7%	40.1%	38.4%

Agricultural employment may increase by about two-thirds between 1965 and 1985, equivalent to an annual growth of 2.5 percent. The proportion of the labor force employed in agriculture would remain little changed. However, it should be borne in mind that these are provincial average figures and there may be considerable variations in the growth of agricultural employment in different parts of the Province.

The objective of full employment at the earliest possible date, adopted in the Perspective Plan, was modified by the hope that unemployment would be no higher than 5 percent in West Pakistan by 1975. The mid-1960's level of unemployment was believed to be about 16 percent though labor force data are very sparse. It should be clear from the foregoing that reductions to the unemployment level will have to be sought elsewhere than in agricultural employment.

Agricultural Investments and Planning

In the past, it has sometimes been thought that one of the advantages of giving a large role to agriculture in the development plans was that this sector could provide large increases in output and large increases in employment for relatively low inputs of capital investment—in other words, that it had a low capital-output ratio. The employment potential is not all that great, as just discussed. Also, the Study Group found that the capital-output ratio in agriculture implied by its projections was considerably higher than might be expected on the basis of past experience. For instance, the ratio between total investment in irrigation and agriculture during the Second Plan (excluding the Indus Basin Works) and the increase in agricultural output over that period has been estimated by the Planning Commission at about 1.9. The Study Group found that the comparable ratios implied by its program, and assuming a rate of growth in agriculture of 4.5 percent, would be about 2.7 for the Third Plan and 3.8 for the Fourth Plan period. These are considerably higher than the ratios implicit in the Perspective Plan. Taken at face value, they might appear to imply that less scarce investment capital should be allocated to agriculture and a lesser role should be given to agriculture in the future than hitherto planned. A growth path involving less emphasis on agriculture and relying to a greater extent on industrial import substitution might be envisaged.

However, the Study Group believes that such a conclusion would be erroneous. It is essential to give to agriculture the high priority role attributed to it in the Perspective Plan, and to allocate the funds needed to support the most rapid development that agriculture can sustain. The general need for high agricultural growth, and more explicitly the objectives of the Pakistan Government with regard to food self-sufficiency, have been discussed. In addition, agricultural growth can play a major role in reducing the foreign exchange shortage that has severely hampered Pakistan's development efforts. As for the need for large quantities of capital, the nature of investment in irrigated agriculture should by now be recognized in West Pakistan: partly because it involves slow gestation projects with long-term benefits, irrigated agriculture necessarily tends to be relatively capital intensive. The heavy effect of irrigation works on the capital-output ratio is illustrated most dramatically by the relation of Tarbela to the Study Group's projected ratio for the Fourth Plan. Instead of 3.8 as quoted above, it would be 2.9 if the Fourth Plan expenditures on Tarbela are not counted, on the grounds that the dam will not begin to yield benefits until the very end of the Plan period. Even 2.9 is a moderately high capital-output ratio. But the "highness" of the ratio must be weighed against the essential role these irrigation projects have in the development of a modern agriculture, as well as the relatively high rates of return which were shown in Chapter IV to be typical of the proposed irrigation projects—rates between about 12 and 25 percent. These returns compare favorably with the return on a wide range of major industries in West Pakistan; a recent survey showed returns averaging about 14 percent per year on total capital invested, although some industries had higher returns. While the figures are not really directly comparable, they suggest that the proposed surface water development and the public tubewell projects appear to be very paying propositions. Also, as an added correction to the apparent low returns on irrigation works, it is noted that the domestic price structure may weigh against agriculture in return-on-investment calculations. The capital-output ratios and rates of return on the proposed irrigation projects are calculated chiefly in terms of actual financial prices of 1962/63 and average farm prices over 1960–65. There is strong evidence to suggest that the price structure in West Pakistan has been and still is less favorable to agriculture than in many other countries, despite improvements during the Second Plan period. Thus, if the capital-output ratios and rates of return on different types of project were calculated in terms of international prices for investments and for products, the rates of return on the irrigation projects would certainly appear even more favorable relative to projects in other sectors; and the capital-output ratios in irrigation and agriculture would appear lower.

The Study Group's analyses also shed light on investment requirements as related to targeted growth rates. Specifically, the analysis of GPP growth rates, marginal savings rates, etc., was aimed at indicating whether possible policy and macroeconomic assumptions would be consistent with a 4.5 growth rate in agriculture. Table 7–3 shows estimates of total investment on the basis of a 6 percent growth rate in GPP, in tandem of course with a 4.5 percent growth in agriculture. The total investment requirements over the Third and Fourth Plan periods, derived from the Study Group's macroeconomic projection to 1975, are compared with the investment costs of the proposed programs. The indication is for about 36 percent of in-

TABLE 7–3
MODEL PROJECTION OF INVESTMENT REQUIRED FOR SIX PERCENT GROWTH IN GPP
(Rs millions, 1964/65 prices)

	Third Plan	Fourth Plan
Total Investment	31,175	43,050
Proposed Programs	11,196	15,819
Proposed as % of Total	36%	36.7%

vestment going into the sectors of concern here. This compares with an actual proportion of some 24 percent estimated for the Second Plan.

The heavy capital costs of the proposed programs account for some of the increase in total investment, but the projection indicates that "other-than-proposed-program" investment will be growing rapidly, as the proportion of the proposed program to the total remains fairly constant. The projected totals of about Rs. 31,000 million in the Third and Rs. 43,000 million in the Fourth are somewhat higher than the totals implied in the Perspective Plan documents, as will be compared in due course. (See Supplemental Paper No. 1, Volume Three.) In terms of broad planning implications, the proposed program implies some increases in total development expenditures, but the most significant shift will be in the proportion of investment going to the three sectors under discussion here from their Second Plan levels.

C. FINANCIAL REQUIREMENTS

The Proposed Investments

The investment implications of the proposed program are given in further detail in Table 7–4, along with actual figures for investment during the Second Plan. To illustrate the impact on investment plans, the Study Group estimates for the Third and Fourth Plans are set against the total investment implied in the Perspective Plan document. In other words, assuming no change in the total allocation, how much of the total investment would go to the three sectors of major concern here? In comparison with the Second Plan, the proportion of investment going to agriculture, irrigation, and power would increase from some 24 percent to over 40 percent over 1965–75, if the Perspective Plan projections were followed, and to 36 percent in the Study Group's projection. The increases would

TABLE 7–4
Investment in Agriculture, Irrigation and Power, 1960–75
(Rs million[a] and percent)

	Second Plan	Third Plan[b]	Fourth Plan[b]
	(est. actual)	(projected)	(projected)
Private—Agriculture and Irrigation	1,500 (7.1)	2,330 (8.5)	4,120 (11.0)
Public—Agriculture	625 (3.0)	1,640 (6.0)	3,200 (8.6)
Irrigation	1,658 (7.9)	2,461 (9.0)	2,836 (7.6)
Surface Storage	–	1,916 (7.0)	2,195 (5.9)
Power	1,194 (5.7)	2,849 (10.5)	3,468 (9.3)
Total	4,977 (23.7)	11,196 (41.0)	15,819 (42.4)
Indus Basin Works	2,910 (13.9)	3,500 (16.7)	–
Total Investment (Plan Documents)	20,973	27,250	37,300
Total Investment (Projected on basis of 6% growth of GPP)		31,175	43,050

[a] Current prices for the Second Plan period and 1964/65 prices for Third and Fourth Plan. Percentages in parentheses relate to total investment (Plan Documents).
[b] Investment in agriculture, irrigation and power as projected by the Study Group.

occur in all sectors, but they would be particularly substantial in public investment in agriculture and electric power; surface storage works, mainly Tarbela, would represent about 6.5 percent of total investment over the Third and Fourth Plan periods, and part of this investment would be attributable to the irrigation sector, part to power.

The Public Sector

The public sector financial requirements, as shown in Table 7–5, include interest during construction at 6 percent on all investment projects except Tarbela Dam, a substantial part of which is substantially financed out of the sums remaining in the Indus Fund. Comparisons are in order.

In absolute terms, public sector development expenditures on agriculture, water and power more than doubled between the First and Second Plan. Allocations in the Third Plan, as recently revised, were about 80 percent above those achieved in the Second Plan. The allocation to agriculture was twice what was actually spent in the Second Plan. Power was 15 percent of the total, as in the Second Plan, but water's share was reduced from about 21 percent achieved in the Second Plan to 15 percent for the Third Plan. Allocations for the three sectors together represent about 43 percent of total revised Third Plan public sector expenditures, or somewhat less than in previous Plans.

Comparisons with the revised Third Plan allocations are shown in Table 7–6. The combined costs of Rs. 7,807 million—excluding Tarbela, for which no financial provision was made in the Third Plan documents —would represent about 54 percent of total public development expenditures as projected. Allocations for expansion of transport facilities, which as pointed out are essential to support the projected development of agriculture, would be additional.

The largest shortfall in the Plan allocations occurs in the electric power sector, despite the fact that the revised Plan increased the allocation to power by some Rs. 250 million. The program's estimate does include about Rs. 115 million for Mangla Units 1, 2 and 3, which may not be covered under the Plan allocation, but even with deduction of this amount the difference between the figures clearly remains large. The reasons for the larger allocations were discussed in Chapter VI.

The shortfall on agriculture is also large. The program figure corresponds closely to the original Third Plan allocation, but the revision of the Plan lowered allocations for fertilizer subsidies, plant protection, mechanization and extension services. However, the crop production targets were not reduced during the revision, and targets for fertilizer absorption and production of foodgrains were actually increased, as mentioned before. Apparently the revised allocation would make available no more than Rs. 400 million for fertilizer subsidies, compared with an original Third Plan figure of Rs. 678 million. The adequacy of this reduced allocation for supporting the higher consumption targets now projected will have to be kept under close surveillance. The Study Group considers that the allocations for the extension services are of sufficiently high priority to warrant their maintenance at the original level.

TABLE 7–5

FINANCIAL REQUIREMENTS OF PROPOSED PUBLIC SECTOR PROGRAMS BY PLAN PERIODS[a]

(Rs. millions)

Third Plan Period		Fourth Plan Period	
	AGRICULTURE		
Fertilizer Subsidies	500	Fertilizer Subsidies	700
Plant Protection Subsidies	300	Plant Protection Subsidies	500
Extension and Research	180	Extension and Research	260
Mechanization	214	Mechanization, Forestry, Others, etc.	2,835
Soil Conservation	105		
Animal Husbandry	112		
Colonization	117		4,295
Forestry and Fisheries	304	Capital Liability for Credit	350
Others	364		
			4,645
	2,196		
Capital Liability for Credit	178		
	2,374		
	IRRIGATION & DRAINAGE		
Ongoing Public Tubewell Projects	873	Ongoing Public Tubewell Projects	118
New Public Tubewell Projects	286	New Public Tubewell Projects	975
Canal Remodeling & Other Irrigation	600	Initial Work on Further Wells	315
Surface Drainage	373	Canal Remodeling & Other Irrigation	402
Tile Drainage	39	Surface Drainage	527
Investigations	191	Tile Drainage	184
Flood Protection	74	Investigations	240
Miscellaneous	25	Flood Protection	75
	2,461		2,836
	SURFACE WATER STORAGE		
Raised Chasma	85	Raised Chasma	31
Tarbela	1,793	Tarbela	2,065
Investigations	38	Sehwan-Manchar	22
		Investigations	77
	1,916		
			2,195
	ELECTRIC POWER		
Generating Units Completed or under Construction	356	Proposed New Generating Units	1,017
Proposed New Units	697	Transmission Lines	525
Transmission Lines	590	Distribution Lines & Connections, etc.	1,890
Distribution Lines & Connections, etc.	1,180	General	36
General	26		3,468
	2,849		

[a] Including taxes and duties and interest during construction at 6 percent per annum except on Tarbela.

No official estimates are available for Fourth Plan public sector development expenditures. But it is clear from Table 7–4 that the public sector investment requirements for irrigation, agriculture and power are unlikely to represent a lesser burden percentagewise than in the Third Plan; in absolute terms they will be substantially greater. Quite apart from the capital funds, increasing expenditures will be required for operating and maintaining the completed projects if maximum benefits are to be derived.

TABLE 7-6

COMPARISON BETWEEN PUBLIC SECTOR COSTS OF PROPOSED PROGRAMS AND THIRD PLAN ALLOCATIONS

(Rs. millions)

	Third Plan Revised	Proposed Programs
Agriculture	1,186	2,734
Electric Power	2,176	2,849
Irrigation and Drainage / Surface Storage (excl. Tarbela)	2,211	123
Subtotal	6,203	7,807
Tarbela Dam	-	1,793
		9,600

In the past, some critically important services, like education and extension work and maintenance of the irrigation system and the power distribution system, have sometimes been made to bear the brunt of budget cuts. The services depend primarily on rupee budgetary resources and relatively little on foreign exchange. The Third Five-Year Plan document projects an increase in current Government expenditure of about 7 percent per year. This may be on the low side if full benefit is to be derived from the human and material capital resources which Pakistan has already built up. According to IACA projections, current expenditures of the departments responsible for the irrigation and agriculture development program may increase at a rate above 13 percent per year (Table 7–7).

To meet the capital costs and the increasing current costs of the proposed programs large additions to revenues will be required. Thus, the recommendations in this report aimed at increasing revenues should be given careful consideration. In regard to power, for example, it was suggested that WAPDA's Power Wing should aim for a rate of return (net of depreciation allowances) of 8 percent on plant in service and that, in particular, this might involve increasing the tariffs on electricity sold to farmers; such an increase would still leave water pumped by electric wells substantially cheaper than water pumped by diesel wells, but it would reduce the existing large disparity. As a general point of departure, charging the farmer more for water may be the best way to increase Government revenues from agriculture.

TABLE 7-7

CURRENT EXPENDITURES FOR AGRICULTURE AND IRRIGATION DEVELOPMENT PROGRAM

(Rs. millions)

	1965	1970	1975
Agriculture Department	36	77	231
Land and Water Development Board	10	28	60
Irrigation Department Establishment	36	54	81
Irrigation System Maintenance	138	244	386
	220	403	758

At present, the agricultural sector, despite its size, makes an extremely small contribution to Government revenues. By Study Group estimates, tax revenues from farmers (net of Government subsidies to them) fell from about 3 percent of value added in agriculture at the beginning of the Second Plan period to about 1.5 percent—or Rs. 175 million—at the end of the Plan period. Nevertheless, the case for increasing taxation on agriculture is much more complex than this bald statement would imply, primarily because of the way in which the price structure has been somewhat biased against agriculture, as was pointed out earlier in connection with the capital-output ratio. While there is a good case for increasing taxation on agriculture, which would be the chief immediate beneficiary of the large works proposed, the measures chosen should be very carefully selected. The context must be a coordinated structure of financial incentives which make it profitable for farmers to engage in activities that enhance economic growth and nonprofitable for them to engage in activities that absorb resources without contributing substantially to growth. Irrigation water is a suitable vehicle for raising revenue from the farmer because, unlike fertilizer or insecticides, its value is already very widely appreciated. There is evidence (from the private tubewell surveys) to suggest that higher charges for irrigation water could lead to better and more careful usage. Cognizance of the scope for charging farmers more for water was taken in the Second Plan which pointed out that "a large subsidy has been implicit in the provision of water" for irrigation. Water rates were increased, but they still seem to be very low by comparison with the costs of making water available and even lower by comparison with the benefit that can be derived from water. This source of revenue could make a sizable contribution to the financial effort required to meet the costs of the development program.

Order of Priorities

Nevertheless, there may be shortfalls in the availability of finance for executing the programs proposed. The guiding principle in allocation of available funds should be the relative priority which attaches to different components of the programs. With financing for Tarbela Dam assured and its high priority established, it should be carried through to completion according to schedule; the only other major surface storage work for the first decade, Chasma Barrage, is already underway. On the irrigation side, there is a clearcut view regarding the priority position of the three public tubewell projects scheduled for commencement in the Third Plan; the four projects proposed for Bari Doab—or at least parts of them—might be deferred in favor of continued reliance on private tubewell development in these areas. An approach has been suggested whereby each of the 12 proposed tubewell project areas should be examined in detail before the public project is started, to see if there is scope for reducing the scale of the project by relying more on private enterprise. There may be some scope, too, for cutting back on the canal remodeling program: the proposed program includes remodeling of canals serving some 330,000 acres in Khairpur East during the Fourth Plan, but it would be possible to phase this out more into the Fifth Plan, following the LIP program; it would also probably be possible to postpone temporarily the canal remodeling proposed for 330,000 acres in Ravi Syphon-Dipalpur Link without involving more than a small amount of underwatering or some minor adjustments in cropping patterns. The area where any proposed cuts should be scrutinized most carefully, and avoided if at all possible, is the program for agricultural development, including expansion of extension and research and promotion of new farm inputs; a maximum effort here is essential both for immediate production increases and to prepare the way for deriving maximum benefit from Tarbela.

On the power side, the goal of the program is to provide a considerably more reliable and adequate power supply service than has been available in the past. The Group has tried to allow for a level of generating reserves consistent with this principle and it has included transmission-line capacity that is also appropriate for attaining a high degree of reliability in power supply. Reduction of planned generating and transmission reserves would be possible, but it would be at the cost of quality of service. However, in the Northern Grid, the sacrifice in quality of service would be less than what it has been in the past because of the existence of the Mangla hydroelectric station. Thus, there is some scope for cutbacks on the power side, apart from the obvious but undesirable alternative of reducing the rate at which new customers are connected. For instance, the proposed program includes about Rs. 90 million of expenditure in the Third Plan period on the first Karachi-Mari 380-kv transmission line. This could be postponed into the Fourth Plan.

Private Investment

Very little information is available regarding past private investment in irrigation and agriculture. What information there is suggests that private investment may have been running around Rs. 300 million per year, or about 3–4 percent of value added in agriculture; the figure given in Table 7–4 was based on this assumption. Private investment in irrigation and agriculture was projected in that table to increase rapidly, rising from some 7 percent of total investment during the Second Plan to 11 percent of the figure implied by the Perspective Plan for total investment in the Fourth Plan period. The amounts covering private tubewells are based on the IACA projection of private tubewell growth. Because it may be possible to reach a higher rate of achievement in private tubewell installations, and because in the long term it should be possible to reach a rate of private investment in agriculture of around 10 percent, the figures in Table 7–4 should be taken as minimum targets.

Rough estimates suggest that savings from direct agricultural incomes may have been in the order of Rs. 700 million in 1963/64. Investment may account for perhaps Rs. 400 million of these savings: private investment in irrigation and agriculture was estimated above at Rs. 300 million, and about Rs. 100 million would appear to have been going annually into farm dwellings. These figures suggest that substantial transfers of savings out of agriculture—perhaps of the order of Rs. 300 million per year—have been taking place. They also suggest that, if appropriate incentive policies are adopted, farmers should be quite capable of reinvesting in agriculture much larger amounts than they do currently.

In addition to the fundamental need for a sound financial framework for farming, three specific steps appear necessary to mobilize rural private resources to the maximum possible extent for investment in agriculture and irrigation. First, measures are needed to help channel available savings from savers to investors and to expand the availability of credit for farmers to use along with their own savings for investment. The Agricultural Development Bank should play an increasingly important role in this, with a growing number of branches, and it should be enabled to follow a more expansionist credit policy. Second, increased Government attention to the provision of services will play a particularly important role in mobilizing private resources. What we have in mind are such services as rural workshops, extension and mechanical facilities and more ample financial allocations to current expenditures to support them, as called for above. Improved technical assistance to private tubewells, for instance, will require government expenditures. Third, and possibly the most important policy recommendation, is provision of sufficient foreign exchange to ensure the availability of imported inputs and materials needed in agriculture. The liberalization of imports during the Second Plan played an important role in promoting private tubewells. Pumps and engines for private wells were already manufactured in Pakistan, but the gradual freeing of imports of the basic commodities (such as pig iron and steel) meant that the small shops which produce the equipment could increase their output. The availability of tubewell equipment in itself represented an opportunity for investment which would not otherwise have been there; this opportunity in turn encouraged interested farmers to save. Thus, provision of foreign exchange had the double effect of promoting both investment and saving.

Foreign Exchange

For the years ahead, the agriculture sector represents a high priority area for foreign exchange allocations. This conclusion was confirmed by the linear programming analysis of investment in irrigation. What would be the value, in terms of increased agricultural production, of the foreign exchange required for the proposed development program? This would represent the economic value of the imported component of capital and current expenditures on improved irrigated agriculture. It was found that, at the margin, the value of this designated foreign exchange was of approximately the same scarcity value to West Pakistan as foreign exchange in general (estimated by the Study Group to be about Rs. 9.52 = US$ 1.00). This suggests that the size and composition of the proposed program is appropriate to the foreign exchange situation existing in Pakistan. Thus, irrigation development should have a very competitive call on the amounts of foreign exchange required to execute the program.

Estimates of foreign exchange requirements for the proposed program are inevitably rather rough. There is uncertainty, for instance, about how

TABLE 7–8
FOREIGN EXCHANGE REQUIREMENTS FOR AGRICULTURE, IRRIGATION AND POWER DEVELOPMENT, 1965–75
(Rs millions, 1964/65 prices)

	Third Plan	Fourth Plan
Private—Agriculture and Irrigation	340	1,050
Public—Agriculture	340	400
Irrigation	850	870
Surface Storage	960	1,280
Power	1,530	1,630
Total	4,020	5,230

import-substitution policy will relate to production of equipment and inputs for the specific projects and programs proposed. However, the Study Group's analysis indicates that the foreign exchange requirements of the private sector in agriculture will increase much more rapidly than for any of the other categories studied. This need bears out the emphasis put on this factor in the previous section. Table 7–8 summarizes the estimates for private and public development needs in connection with the proposed programs. The projected private sector requirements include Rs. 450 million for fertilizer imports in the Fourth Plan period, and it is possible that domestic production of fertilizer might expand rapidly enough to reduce this need. However, the remainder covers such import requirements as farm-mechanization, plant protection, and private tubewells. Also, because the private sector could outpace the projections of private investment in this report, if given proper incentives, more foreign exchange may be required to support this investment.

Finally, in considering the allocation of foreign exchange to the agricultural sector, it would be well for the authorities to bear in mind the very important contribution that the sector makes to export earnings. A large increase in export earnings was one of the main successes of the Second Plan. Visible exports increased from about Rs. 760 million in 1959/60 to about Rs. 1,140 million in 1964/65. Exports of agricultural commodities, in raw form, made a more than proportionate contribution to this increase, rising from Rs. 320 million in 1959/60 to Rs. 620 million in 1964/65; cotton and rice were the main contributors. Over the Plan as a whole, agricultural commodities in raw form accounted for some 63 percent of visible exports and cotton manufactures, made from domestic cotton, for another 16 percent. Also, it should not be forgotten that West Pakistan may need to import increasing amounts of agricultural commodities if provincial income grows at 6 percent or more. Nevertheless, this would not exclude simultaneous increases in exports of those commodities, such as cotton and rice, in which the Province has comparative international advantage.

VIII

Summary of Findings and Principal Recommendations

BROAD OUTLINE OF PROPOSED DEVELOPMENTS

This report has dealt with the development prospects of agriculture and electric power in West Pakistan. It may be useful to recapitulate briefly the broad findings of the Bank Study Group. The most crucial conclusion is that agriculture remains the most important single sector in the economy. It is responsible for nearly 45 percent of the output and 75 percent of the foreign exchange earnings of the Province, and about 70 percent of the population are directly dependent on it for their livelihood. Much of the industrial activity in the Province is concerned with processing the products of agriculture and, to an increasing extent, with manufacturing farm inputs. Growth of the agricultural sector has in the past lagged seriously behind the growth of other sectors of the economy. Increasing amounts of food have had to be imported and agricultural exports have grown slowly. Total agricultural output grew between 1950 and 1960 at about 1.5 percent per year; population was growing faster, probably at about 2.5 percent per year. During the Second Plan (1960–65), agriculture's performance improved sharply, reaching an annual average growth rate of 3.8 percent; and agricultural exports grew from about Rs. 500 million at the beginning of the 1960's to about Rs. 800 million at mid-decade. Nevertheless, at that time, agricultural production per head of provincial population was still below what it had been 15 years earlier.

The power sector is, in comparison, small in its contribution to the total provincial output, but electric energy is essential to much of the economic activity of the Province; farming is beginning to become dependent on electricity for tubewells. Although output of electricity has grown rapidly—at an average rate in excess of 20 percent per annum between 1950 and 1965—electricity has been almost continuously in short supply, so that load shedding and heavy voltage fluctuations have been commonplace. These shortages of electricity have constrained the growth of industrial and agricultural output.

West Pakistan is aiming for an annual growth rate of about 6 percent in total provincial output. This implies a need for at least 4.5 percent annual growth in gross value added by agriculture—and more if agriculture is to make any contribution to easing the acute foreign exchange stringency from which the economy suffers. Regarding power, the 6 percent overall growth target implies a need for about 13 percent annual growth in generation of electricity by public utilities over the 1965–75 decade. Over a 20-year span, West Pakistan is aiming to have total provincial output triple, almost doubling current per capita income levels; agricultural output would have to nearly triple, and electricity production increase eight times over. Sustained performance in agriculture of this magnitude is almost without precedent. Its achievement, however, is a necessity if major crises in food supplies are to be avoided.

Growth anywhere near the scale required cannot be achieved without the highest possible efficiency in utilization of economic resources. The proposed program is dedicated to this end, based on a realistic appraisal of possibilities. It is recognized that the basic resources, soils, climate and water, are capable of supporting a program even more ambitious than the one presented here. Availability of funds will always be a problem but money does not appear to be the most stubborn constraint. The key consideration is capacity as it relates to policy implementation, construction and operation of projects, and the development of institutional support to provide goods and services to back up the program.

The program proposed is heavily dependent upon public sector investment. The Study Group attaches great importance to the careful monitoring of progress and, in the light of experience, ensuring that preoccupation with the public sector is not allowed to damp down the vital contribution which can and must be made by the private sector. Fundamentally, it is the farmer who will decide whether agricultural production grows at 3 percent or 5 percent and hence whether per capita provincial income will stagnate or will double in the next 20 years. Only if the farmer has the incentives, the supplies and the knowledge together with confidence and conviction will he produce the results desired. Policy, prices, and market opportunities must be kept under constant review.

The growth of agricultural production is severely hampered by shortage of irrigation water and by husbandry standards. Slight use is now made of yield-increasing inputs such as fertilizer, good seeds, and insecticides. However, the more progressive farmers have shown themselves ready to adopt means to increase production when they appear profitable. To achieve higher yields across the Basin, the farmer needs increased attention from extension services and greatly improved supply channels for the various inputs (as well as incentives to use them). It is not possible, on a general basis, to identify water or any other single input as being most critical. Most of the inputs are in short supply in most parts of the Province, including the irrigated areas which account for about 80 percent of agricultural production. Rapid progress in one—be it water or any of the modern production aids—would only show up more acutely the lack of the others. There are also technical, administrative and social limits to the rate of progress that can be achieved on any single front: a concerted effort is needed. Thus, the proposed program takes into consideration a proper balance between progress on the agricultural front (i.e. better farming, more agricultural inputs, etc.) and further water development.

The centerpiece of the proposed programs is the Tarbela Dam on the Indus. Completion of this dam by 1975/76 is a crucial element in the recommended strategy for meeting West Pakistan's need for additional supplies of irrigation water and electric power. The detailed programs proposed have been built on the assumption that the dam would be completed on schedule. The importance of the project is so great that this expectation has influenced and conditioned almost all the other proposals. The Tarbela Dam is estimated to cost the equivalent of about $775 million, excluding duties, taxes and interest during construction, and also excluding the costs of power plant and its housing. The main purpose of the dam would be to store water from the summer flood season, when Indus discharges are greatly in excess of the amount that could be used for irrigation purposes (even with an expanded canal system). The water would be used, for the most part, during the rabi (winter) season when the main food crops are grown, but when natural river flows are low and variable and irrigation deliveries consequently unreliable. At its initial capacity, the Tarbela Reservoir will store sufficient water to increase rabi river flows on the Indus in a mean year by about a third and those in a dry year by about half.

It is extremely difficult to quantify the contribution that Tarbela will make to increased production. To the extent that it is measurable, a conservative range for the rate of return would appear to be about 9–13 percent. The cost of delaying Tarbela was weighed by comparing the costs of the recommended program with the costs of a hypothetical alternative—the analysis assumed a 10-year lack of Tarbela water, made up by the use of groundwater mining techniques that have potential in Pakistan but have not yet been tested there. The alternative program, which was the cheapest of several alternatives considered, worked out to be $50 million more expensive in terms of the present worth of economic costs and, furthermore, it could not provide the degree of security provided by a program including Tarbela in 1975.

The Study Group's estimates suggest that about three-quarters of the benefits of Tarbela would accrue to agriculture. Deliveries direct from Tarbela storage would, in 1985, account for more than 10 percent of total rabi supplies of irrigation water, and in terms of additional supplies made available, Tarbela would account for about 25 percent of incremental deliveries for farmers in rabi. The availability of additional surface water in rabi is particularly important to further development in those areas which are not underlain by fresh groundwater—about 40 percent of the Punjab and 80 percent of the Sind. Additional rabi canal supplies are a sine qua non of further irrigation development in areas with the most saline groundwater (about 11 million acres or about 35 percent of the canal irrigated area) and, in the 15 percent of canal irrigated area underlain by groundwater of intermediate salinity, additional rabi canal supplies can be mixed with pumped groundwater and can thus have a multiplied effect on total rabi water supplies in such areas. Nevertheless, the addition to rabi deliveries is only one part of the benefits for agriculture. Existence of a large reservoir on the Indus will make it possible to regulate, to a significant extent at least, the time pattern of river discharges. The result will be to match canal deliveries, in combination with supplies pumped from the groundwater aquifer, to the rather inflexible time pattern of crop-water requirements in a way that has not been possible in the past.

The remaining quarter of the total benefits of Tarbela relate to the hydroelectric potential of the dam. The proposed program calls for installation of 12 turbine generators, each of nominal rating 175 mw, over the years 1975–80. With this development of its hydroelectric potential, Tarbela will contribute more than one-quarter of the total amount of electric energy required by West Pakistan over the decade 1975–85. By 1985, Tarbela should be contributing some 10 billion kwh or more than one-third of the Province's total annual requirements of electric energy at that time. Under mean year flow conditions, 12 turbines would be capable of generating 12 billion kwh, and the additional 2 billion kwh, which would be produced almost entirely in the summer flood months, would be absorbed gradually after 1985 as loads on the power system grow. As opposed to a 10-year postponement, completion of Tarbela in 1975 would save some 700 trillion Btu of natural gas—or about 10 percent of West Pakistan's known usable reserves of gas—that would otherwise have to be devoted to generation of electric power; such a saving is important because known gas reserves are limited and gas is required as feedstock for the production of badly needed fertilizer.

Because Tarbela will have a very large impact on the irrigation and power systems of West Pakistan, the systems in existence by 1975 must be prepared to absorb the irrigation and power supplies from the dam as quickly and as effectively as possible. This will require careful advance planning. The scale of the project alone emphasizes the need for a very active development effort to prepare the way for Tarbela. The project is also very expensive. Tarbela irrigation supplies will cost Pakistan about three times as much per acre-foot as water pumped from the groundwater aquifer within the limit of annual recharge. Theoretically, substantial additions to rabi water supplies could be made at lower cost for a number of years by pumping beyond this level, but this technique would not serve to increase water supplies so rapidly as surface storage, it would be less flexible, it might be hazardous, it would be inconsistent with the optimum integrated pattern of water-resource development, and in the long run it would be more expensive. Thus, any substantial addition to rabi irrigation supplies would inevitably be costly. This emphasizes the need to make sure that water is used to the greatest possible advantage. The time required for construction of Tarbela—the interim to 1975—also underlines the need for other immediate efforts to improve agricultural productivity. Increased production of food and fiber are required before Tarbela begins to help.

The 10-year "Action" segment of the proposed program spans the Third and Fourth Plans (July 1, 1965 to June 30, 1975). The public sector costs of the program are based, as far as possible, on cost concepts similar to those used in Pakistan's Five-Year Plans, so that the figures will be directly comparable. Construction of the main reservoir structures at Tarbela, excluding interest during construction, would represent about 17 percent of the total public sector costs over the 10 years. Another expense category would be the allocations to agriculture, mainly the Department of Agriculture, necessary to implement the proposed program. Other expenditures would cover water and power development works undertaken largely by WAPDA and by the Irrigation Department, except for the cost of a nuclear power plant being built by the Pakistan Atomic Energy Commission outside Karachi.

AGRICULTURAL DEVELOPMENT, 1965–75

Expenditures on agricultural development represent the largest single block—more than 30 percent—of the total Program costs for the public sector (an annual average of nearly $150 million equivalent). This is consistent with the very great emphasis that, in the opinion of the Study Group, should be placed on this aspect of the development effort. It would serve two purposes. First, it could lead to immediate and rapid growth of agricultural production. Second, it represents the most vital part of the job of preparing the way for Tarbela. Only if farming standards are greatly improved before 1975 will the large agricultural benefits anticipated from Tarbela in fact be realized. Increase of water supplies alone, upon which so much emphasis has been placed in the past, will do no more than extend and prolong the traditional agriculture of low productivity; technological improvement in farming, on the other hand, could, with a large enough effort to spread it widely, raise agriculture in West Pakistan to an entirely new plane of productivity.

Existing water supplies could be used to much greater advantage than they are now if they were combined with better irrigation farming practices and more physical inputs such as fertilizer, improved seed and plant protection. Because application of improved methods depends on the farmers themselves, it is vital that knowledge of modern agricultural technology, on which the farmer's ability ultimately depends, be disseminated within the farming community. This puts those concerned with training, education, and extension service in a position of the utmost importance. The Study Group believes that the status of the men serving the farming community in these ways must be raised to a level commensurate with the responsibility they carry and that they must be provided with more material support if the requisite improvement in general farming standards is to be achieved.

Among the physical inputs required for increased production, fertilizer has the greatest immediate potential. The Study Group is firmly convinced that substantially larger amounts of fertilizer could be beneficially applied in conjunction with the existing water supplies. Every effort should be made to make available to farmers, at reasonable costs and in timely supply, all the fertilizer that they can absorb. Fertilizer consumption in the mid-1960's was estimated at about 90,000 nutrient tons per year. An offtake target of 700,000 nutrient tons in 1974/75 would appear feasible, provided that appropriate institutional arrangements are made. The 1975 target includes about 470,000 nutrient tons of nitrogen and 230,000 nutrient tons of phosphate. The target is about double those adopted by the Special Study consultants and represents rates of increase in the use of fertilizer of about 30 percent per annum through the Third Plan and 15

TABLE 8–1
PUBLIC DEVELOPMENT EXPENDITURES FOR PROPOSED PROGRAM, 1965–75[a]
(Rs million)

Tarbela Dam[b]	3,862
Other Surface Storage Projects—Raised Chasma	116
Sehwan Manchar[c]	22
Surface Storage Investigations	115
	4,115
Irrigation and Drainage Projects[d]—	
Ongoing Public Tubewell Schemes	991
Proposed New Public Tubewell Schemes	1,563
Canal Remodeling and Other Irrigation	1,002
Surface Drainage	900
Tile Drainage	223
Investigations	431
Flood Protection	149
Miscellaneous	25
	5,284
Agriculture—	
Fertilizer Subsidies	1,200
Plant Protection Subsidies	800
Extension and Research	440
Mechanization, Forestry, Others, etc.	4,051
Capital Liability for Agricultural Credit	528
	7,019
Electric Power[e]—	
Generation	2,070
Transmission	1,115
Distribution	3,070
General	62
	6,317
Total	22,735

[a] Including duties, taxes and interest during construction at 6 percent per annum, where appropriate. Interest during construction is not included in the figure for Tarbela.
[b] Costs through 1974/75 only, and excluding civil engineering and all mechanical and electrical items for power plant.
[c] Expenditures commence at the end of decade, but project not scheduled for completion until 1982.
[d] See details in Table 8–2.
[e] See details in Table 8–3.

percent per annum through the Fourth Plan. The large allowance shown in Table 8–1 for fertilizer subsidies assumes the price of fertilizer to the farmer will not be allowed to increase significantly from its present subsidized level, although the amount of subsidy per ton will fall as a result of reduced procurement costs.

Improved seed material, particularly of superior varieties of wheat, cotton and rice, constitute a second major agricultural input which could have significant impact within the next decade. High yielding varieties of wheat and rice have reached an advanced stage of development, but further research is still required on these crops and on others. Achievement of productivity increases from this source will depend on the establishment of effective multiplication and distribution networks. To the fullest possible extent, private entrepreneurs should be encouraged to participate in the multiplication of improved varieties, under Government supervision. The Study Group has assumed that about 50 percent of the wheat acreage (about six million acres) and one million acres of rice will be covered by improved varieties by 1975. Seed experts in Pakistan have predicted faster rates of growth, which would be highly desirable if they could be achieved without sacrifice in seed quality, but the Study Group feels that achievement of its projections would represent a very important advance in terms of organization.

Effective plant protection could increase current yields significantly. An estimated 15 percent of potential production is lost due to lack of plant protection. Because timeliness of application is critical to obtaining good results from insecticides, much depends on the farmers' awareness of the problems, their cooperation, and the availability of effective service. Plant protection services are rendered free through the Governmental extension service; the existing system is inadequate, lacks efficiency and diverts scarce extension personnel from their important functions of disseminating agricultural knowledge. The private sector could play an increasingly effective role in providing protection materials because the interests of the suppliers and the needs of the farmers would merge. As the importance of plant protection is not yet widely accepted, subsidies will probably need to be continued for some years. Other important Government contributions would be research to develop simple, practical procedures for the farmers and continuation of aerial spraying against epidemic attacks such as from locusts. Since protective measures will probably not improve much before the use of fertilizer and better husbandry become more general, there are not likely to be large increases in the acreage sprayed until after 1975.

Mechanization of farm operations will be closely related to progress towards more intensive and highly commercialized agriculture. But even before farmers reach the stage of mechanizing their operations, they could be assisted by improved hand tools and animal-drawn equipment. A larger research and promotion effort is needed for these. Encouragement should be given to the spread of mechanization in the form of credit, advice on suitability of machinery for particular conditions and purposes, instruction in operation, ensured supplies of machinery and parts, and adequate service facilities. Mechanization will continue to be adopted mainly by the larger farms. However, in view of the preponderance of small farms, careful consideration should be given to the stimulation and support of contract mechanization service and the cooperative use of farm machinery.

Animals will continue to be the main source of power on the farm for a long time to come. Livestock products, which now account for some 35 percent of total agricultural output, will be increasingly important—demand for milk and meat is likely to grow more rapidly than demand for other agricultural products. Despite the very great importance of the livestock sector, very little is known about its development potential. The Study Group's consultants have drawn an outline of a massive program of artificial insemination designed to build up an improved Zebu milk herd to replace the existing buffaloes as the main source of milk, but even with an early start on this program large-scale results are not expected to occur until well after 1975. The livestock sector is so little understood that the Study Group suggests it be made the subject of a special comprehensive study to provide a basis for deciding the requirements for future development.

Irrigation and Drainage Works, 1965–75

Expenditures on irrigation and drainage projects represent about 23 percent of the total public sector costs of the Action Program, averaging about $110 million equivalent. The main emphasis in irrigation development in the years up to 1975 is to get more water onto the land. The drainage effect of public tubewells will be important; in some areas, the groundwater table needs to be lowered before additional surface supplies from Tarbela can prudently be absorbed. But the past preoccupation of public tubewell development with reclamation of saline and waterlogged lands should be reduced in favor of efforts to exploit groundwater resources for irrigation purposes. At the same time, public tubewell development should not be undertaken in large areas where private wells are spreading rapidly. The public tubewell program tries to steer a middle course, including projects in areas which are predominantly underlain by fresh groundwater and where the reclamation problems are not the most severe, but excluding areas where conditions are most favorable to continued rapid growth of private tubewells. Extensive surface drainage schemes, included in the program, will help to lower the water table and thus provide valuable support to tubewells, whether private or public, and enable additional surface supplies from Tarbela to be absorbed subsequently. The public tubewell projects generally cover substantially smaller areas than those of the past.

Nearly 50 percent of the public sector expenditures on irrigation and drainage works in the recommended program are allocated to public tubewells. The program foresaw the installation and energizing of some 6,700 public tubewells between July 1, 1966 and June 30, 1970. About 5,900 of these wells would be in the four projects that WAPDA has underway, while the remainder would be in four high priority projects—Wagah, Shorkot-Kamalia, Rohri North and Panjnad-Abbasia—that the Study Group recommends for early initiation. Wagah is a small project, identified but not studied in detail by IACA, in an area which will cease receiving surface supplies once the Indus Treaty is fully implemented and where tubewells would therefore be fulfilling a replacement function. The other three projects belong to a group of 12 for which the Special Study consultants prepared detailed project feasibility reports and the Study Group made project reviews. These projects, which were identified on the basis of a survey of all canal commands, cover some 5.8 million acres. Most of the work on them would be undertaken during the Fourth Plan in the course of which a total of about 11,000 public tubewells would be installed under the recommended program. This program excludes SCARP V, a major tubewell project proposed by WAPDA, because there are good prospects of strong private tubewell development continuing over most of the area

TABLE 8-2

IRRIGATION AND DRAINAGE PROGRAM, 1965–75

Completion Date		Canal Commanded Area ('000 acres)	Cost (Rs mlns.)[a]
	Ongoing Public Tubewell Projects		
1971	SCARP II (Chaj Doab) (2510)[b]	1,600	281
1970	SCARP III (Thal Doab) (1470)	900	165
1973	SCARP IV (Rechna Doab) (3270)	1,700	366
1969	Khairpur (568)	300	179
		4,500	991
	New Tubewell Projects Proposed in Program		
1969	Wagah	50	13
1970	Shorkot-Kamalia (426)	294	53
1974	Rohri North (1580)	598	156
1973	Panjnad-Abbasia (1623)	878	190
1973	Dipalpur above B-S Link (630)	372	75
1973	Shujaabad (725)	379	84
1974	Ravi Syphon-Dipalpur Link (780)	595	109
1976	Bahawal Qaim (924)	522	107
1975	Fordwah Sadiqia (665)	359	79
1977	Rohri South (1,500)	528	136
1977	Sukkur Right Bank (820)	273	82
1977	Dipalpur below B-S Link (850)	611	103
1976	Begari Sind (880)	349	92
	Other small tubewell projects		36
	Project investment after 1975[c]		−67
	Initial work on further projects		315
		5,808	1,563
	Canal Remodeling and Other Irrigation		
	Khairpur East and West	454	54
	Panjnad-Abbasia	100	63
	Ravi Syphon—Dipalpur Link	330	48
	Lower Bari Doab	70	8
	Shorkot Kamalia (Haveli)	60	8
	Other irrigation works in canal commands		482
	Other irrigation works outside canal commands		337
		1,014	1,000
	Surface Drainage		
	Sukh Beas Scheme		191
	Lower Indus Left Bank Outfall (start)		374
	Other smaller schemes		335
			900
	Tile Drainage		
	Shorkot Kamalia (Haveli)	40	16
	Lower Bari Doab	70	46
	Tando Bago	90	96
	Khairpur East	30	45
	Kalri Baghar (Ochito and pumps) (start)	120	20
		350	223
	Investigations		431
	Flood Protection		149
	Miscellaneous		25
	Total		5,284

[a] Costs including taxes, duties and interest during construction at 6 percent per annum.
[b] Figures in parentheses represent number of wells to be completed from July 1, 1966.
[c] Investment required after 1975 to complete the listed tubewell projects.

covered, the small portion where hydrological conditions are more difficult is included in one of the recommended smaller public projects.

The Study Group found that all the 12 projects proposed would yield high rates of return. All of them are included in the recommended program, although some would not be completed until after the end of the Fourth Plan. Particular priority is attached to eight of the projects. The remaining four, all in the Bari Doab, have only marginal advantages over the alternative of continued private development. The indications are that the substantial private development in the Bari Doab will continue in the absence of public tubewell projects—and it is likely to be sufficiently dense to provide some drainage effects. Therefore, this may well be an area where economies can be made in the public development program. Since designation of an area for public tubewell development naturally tends to discourage installation of private wells—even though the first water from the public wells may not materialize for some years—the Study Group feels strongly that these areas in Bari Doab should not be announced as public tubewell areas until there is complete assurance that WAPDA will be able to carry through all or at least most of the recommended tubewell program.

The public part of the recommended program is believed to be at the limit of administrative feasibility, and it alone will not suffice to support the increases in agricultural production that are needed. Policies conducive to rapid private development would serve as insurance against shortfalls in public sector performance. The program assumes that the private wells in operation would rise from about 34,000 in 1965 to some 55,500 by 1970 and then decline slightly to 52,500 by 1975 if the public tubewell program maintains the schedule called for. However, it is likely that, given appropriate incentives, the private sector could sustain a higher installation rate than this and would do so in certain areas if public projects were not going forward. Most recent information suggests that the installation of private wells has continued to accelerate so that they might well grow to about 66,500 by 1970. It is important that, until the successful implementation of consecutive public well fields appears assured, private development be given proper encouragement, even in areas that may later be scheduled for public development.

Following the public and private tubewells, the Study Group attributes most importance to some of the drainage works proposed, especially the Sukh Beas Nalla Drainage Scheme. This project originally formulated by the Government of Pakistan and substantially revised by the Study Group's consultants, comprises a 327-mile drain using mainly the old Beas River bed and having a catchment area of 3.3 million acres in the Bari Doab. It would reduce flood damage in one of the most productive agricultural areas in the Province and also reduce the recharge to the aquifer, thereby contributing to control of the water table in a large part of the Bari Doab. Work also should be started at an early date on the Lower Indus Left Bank Outfall Drain. The Drain, which would be 267 miles long and have a mamixum discharge of 15,000 cusecs, is expected to take 16 years to build; its purposes would be partly to drain away surface runoff but mainly to remove to the sea saline subsoil water from most of the irrigated area on the left bank of the Indus below Khairpur. Commencement of construction was recommended for 1968. The Action Program includes a number of other smaller drainage schemes, besides Sukh Beas and the Left Bank Outfall Drain, primarily in the Rechna Doab and in the Sind.

Under "canal remodeling and other irrigation works," the recommended program includes a number of schemes—both inside and outside the canal-irrigated area—which WAPDA and the Irrigation Department already have underway. But about Rs. 200 million of the proposed allocation under this head would be devoted to enlargement of canals serving altogether about one million acres. Most of the areas proposed for canal remodeling are parts of the areas covered by ongoing and recommended tubewell projects where the underlying groundwater is brackish, so that additional surface water is needed to increase irrigation supplies and to enable the cropping intensity to be raised there. Generally, it is the distributaries and minors which require remodeling rather than the main canals.

The program also includes five small tile drainage projects, chiefly in the Sind. These projects, which cover about 350,000 acres in all, are mainly intended as pilot projects. Tile drainage may subsequently become an important mode of development in the saline groundwater zones.

Surface Water Storage—Other Than Tarbela

Apart from Tarbela, there are two small but important components to the proposed program for surface water storage development up to 1975: raising of Chasma Barrage to provide storage of 0.5 MAF, and a major program of investigation of the siltation problem and identification of the best site for second-stage storage development on the Indus. Expenditures would also commence within the Fourth Plan on the Sehwan-Manchar Project, which would provide a small amount of interseasonal storage in the Sind.

Chasma Barrage is being built on the Indus, nearly 200 miles downstream of Tarbela, as part of the Indus Basin Works to divert water into the Chasma-Jhelum Link Canal. The project included in the recommended program covers only the costs of building the barrage structure some six feet higher than necessary simply to serve the Link and extending bunds. This will serve to provide some 0.5 MAF of storage at relatively low cost. The project should be completed in 1971.

There are four projects which, on the basis of present knowledge, can be considered contenders for second-stage storage development of the Indus—Kalabagh, Gariala, Skardu and the Thal Scheme. Though the best of these appears to be Kalabagh, with a conventional structure and firm power capability of about 350 mw, insufficient data are available on the four alternatives to permit a firm judgment at this point. The need for major second-stage storage on the Indus may be expected to arise during the late 1980's or early 1990's. Since it may take seven years or more to construct the necessary structures and because, if one site proves to have significantly less favorable conditions than now believed, there must be time to investigate other sites before construction of second-stage storage has to be commenced, the Study Group recommends early efforts to carry investigations further. Skardu should be studied in connection with the Upper Indus investigations. The Thal Scheme is little more than a concept at present; the Study Group thinks it would be worth giving some early attention to general investigations to provide a firmer idea of the feasibility of the concept. More detailed investigations should be undertaken at Kalabagh, at latest early in the Fourth Plan.

Maintenance and expansion of the network of stations for gathering basic hydrological and meteorological data is of utmost importance, for the storage sites which now seem to be the most attractive for further development may not prove to be so. Techniques of dam design will continue to develop and a great deal more information will be forthcoming about geological conditions along the rivers. There is an urgent need to start investigations of the siltation problem, for calculations show that all but one MAF of Tarbela's live storage will be depleted within 50 years.

The Sehwan-Manchar Project is not scheduled in the recommended program for completion until 1982, but intensive investigations and initial works would have to be started about 1974 in order to meet this schedule. The project is, in fact, the most important single irrigation work proposed by the LIP consultants. It is designed to increase water supplies to some of the best agricultural land in the Sind at the lower ends of Rohri and Nara Canals on the left bank of the Indus. It would comprise a new barrage, providing about 0.8 MAF storage, bunds around the existing Lake Manchar, some four miles away on the right bank of the river creating storage capacity there of about 1.0 MAF, expanded channels linking Lake Manchar to the river, and a large 36,000 cusec feeder canal to carry water from Sehwan to the Rohri and Nara Canals.

Electric Power Development

Proposals for electric power development account for about 28 percent of the cost of the Action Program for the public sector; the annual average is the equivalent of about $130 million. These proposed allocations appear to represent a significantly higher proportion of total plan investment than has been devoted to the power sector in the past. This is accounted for by several factors. First, the power system has been expanding so fast in recent years that serious shortcomings have arisen in the distribution network; second, in view of the planned completion of Tarbela in 1975, an early start is recommended on the installation of a 380-kv transmission system to interconnect all the main power markets of the Province; and third, the program includes sufficient generating plant to raise the margin between generating capacity and anticipated loads to a more adequate level. The plans are generally based on provision of about 10 percent reserve generating capacity in the 10-day period when the hydroelectric plants reach their lowest capability.

The main power system in West Pakistan is in transition. The first units at Mangla will have greatly fluctuating capability over the course of the year, depending mainly on the height of water in the reservoir. As a result, if reserves are established to be reasonably adequate at the time when the reservoir level is at its lowest, then they will be ample at other times in the year. While the Bank Study Group believes that the level of reserves recommended is appropriate, the reserve problem should be further considered in light of events and the increasing importance that will attach to the tubewell pumping load.

The peak power loads on the public utilities in the main power markets of the Province are projected to rise from a combined total about 560 mw in 1965 (650 mw, had there been no load shedding) to about 2,300 mw in 1975. The Special Study power consultant thought that load growth would be more rapid in the South of the Province than in the North. Despite the rapid development of tubewells anticipated in the North, the effect of this on total loads would be outweighed by faster growth of industrial loads in Karachi and the Sind. The Study Group, concurring with the power consultant, has adopted a main load forecast rising, in the Northern Grid, from a nonsuppressed peak of 473 mw in 1965 to about 1,400 mw in 1975 and in Karachi from 136 mw in 1965 to 640 mw in 1975; load growth in the Sind would be even more rapid than in Karachi, but loads are presently very small there and they would remain less important in the overall picture. These peak loads are all calculated on the assumption that most of the public tubewells would be shut off in the evening hours of peak load, which would serve to reduce peaks in 1975 by about 100 mw from what they would otherwise be. It is noted that, for a number of reasons, the situation in the North is rather uncertain. A careful reappraisal of prospective loads in the early 1970's should be undertaken. In the meantime, an alternative contingency load forecast for the Northern Grid, leading to a peak of about 1,600 mw in 1975, some 200 mw higher than the figure used in the main load forecast, is put forward for planning purposes.

The Study Group believes that, provided existing construction schedules are adhered to, then loads in all areas can be adequately covered between 1968 and 1970 inclusive, whether loads in the Northern Grid are at the higher or the lower of the two levels projected. The top portions of Table 8–3 list the main generating units which are under construction or which are recommended in the proposed program. The third unit at Mangla is expected to be ready for service late in 1968 and the fourth unit late in 1969. Negotiations for supply of two 100-mw steam units from Czechoslovakia for installation in the Upper Sind about 1970 and 1971 are being finalized by WAPDA. A double circuit 132-kv link between the Northern Grid and Upper Sind is also being completed so that the Northern Grid would be able to draw about 120 mw from the Upper Sind. The World Bank has recently approved a loan to Karachi Electricity Supply Corporation (KESC) for addition of a 125-mw steam unit at Karachi, which should be completed by mid-1969. The main point is that by the critical period on the northern system, at the time of lowest reservoir level at Mangla, in March 1970, the minimum requirement is that either Mangla Units 5 and 6 or both the 132-kv line between the Northern Grid and Upper Sind and the first 100-mw Czech unit should be fully completed. Either of these sets of installations would provide sufficient capacity to meet loads projected on the main load forecast with adequate reserves and enough to cover those projected on the contingency load forecast, though with

TABLE 8–3

POWER PROGRAM, 1965–75

Completion Date		Installed Capacity (mw)	Cost[a] (Rs mlns.)
	Electrical Generation: Units Completed or under Construction		
1966	Lahore Gas Turbines	26	15
1967	Sukkur Steam Units	25	17
1967	Lyallpur Steam Units	124	44
1967/69	Mangla Units 1, 2 and 3	300	115
1967	Kotri Gas Turbine	13	10
1968	Lahore Gas Turbines	52	37
1968	Kotri Gas Turbines	26	19
1969	Korangi Unit 3 ("C" station)	125	99
1971/72	Karachi Nuclear Station	125	286
			642
	Electrical Generation: Units Proposed		
1970	Mangla Units 4, 5 and 6	300	100
1970	Mari Steam Unit I	100	98
1970	Hyderabad Gas Turbines	26	19
1971	Mari Steam Unit II	100	98
1973	Mangla Units 7 and 8	200	86
1974	Mari Gas Turbines	200	146
1975	Tarbela Units 1 and 2	350	278
1975	Korangi Unit 4	125	99
1974	Quetta Units	19	31
	Initial Work on further units		473
			1,428
	Electrical Transmission (lines only)		
1969	220 kv Mangla-Wah		33
1968/72	220 kv Mangla-Midway		68
1968/72	220 kv Midway-Lyallpur		31
1969	220 kv Midway-Kotlakhpat		11
1969	220 kv S. Lyallpur-Montgomery		11
1975	220 kv Montgomery-Multan		23
1969/73	220 kv Wah-Tarbela		12
1971	380 kv Lyallpur-Mari		99
1971	380 kv Mari-Hyderabad-Karachi		101
1974	380 kv Mari-Karachi		65
1975	380 kv Tarbela-Lyallpur		61
	Other (line Terminals, Transformers, 33, 66 and 132-kv lines)		600
			1,115
	Distribution (400-v/11-kv lines, customer connections, etc.)		
	Third Plan Period		1,180
	Fourth Plan Period		1,890
			3,070
	General[b]		62
	Total		6,317

[a] Including taxes, duties and interest during construction at 6 percent per annum.
[b] Including buildings, offices, miscellaneous equipment, etc.

inadequate reserves. The Study Group's recommended program includes more than this bare minimum—Mangla Units 5 and 6 as well as the 132-kv link and the first Czech unit—which would provide sufficient capacity to meet the highest anticipated loads with adequate reserve. If Mangla Units 5 and 6 cannot be completed by the spring of 1970, then completion of the second Czech unit in the Upper Sind probably would be warranted by that time. In the South, the situation would be somewhat similar: assuming that the 132-kv line between Karachi and Hyderabad was completed on schedule in 1968, and generating plant is installed as noted in Table 8–3, then projected 1970 loads could be covered; but the proposed program includes an additional 26 mw of gas turbines in order to raise reserves to a more adequate level, close to the size of the largest single unit on the system at the time (125 mw).

A critical project for the Fourth Plan is 380-kv transmission interconnection between all main power markets; the earlier this can be completed after 1970, the better—which means that work on these lines should have been initiated well within the Third Plan. Provincewide EHV interconnection will be especially valuable in enabling more rapid absorption of Tarbela's hydroelectric potential. It will also serve to reduce the amount of gas-pipeline capacity which must be installed to provide fuel for thermal generation. The Study Group considers that there would be advantages in having a complete EHV line between Lyallpur in the Northern Grid and Karachi in the South by 1971 or 1972. However, highest priority for early completion attaches to the northern section of the line between Lyallpur and the Upper Sind because it would enable concentration of thermal capacity at the gas fields in Upper Sind and it would reduce problems that would otherwise arise in supplying large quantities of fuel—gas or fuel oil—to plants in the Northern Grid for short periods during the year. Nevertheless, the Study Group recommends that the southern half of the proposed EHV line, between the Upper Sind and Karachi, should also be installed at latest by 1975, and preferably earlier, because without it West Pakistan will lose some of the main potential benefits of the proposed system—such as consolidation of Provincewide generating reserves, reduction of reliance on gas (with its significant opportunity cost) and fuel oil (with its heavy foreign exchange component) and rapid realization of the power benefits of Tarbela.

The main additions to generating capacity during the Fourth Plan would be at Mangla and at the Mari/Sui gas fields. Mangla Units 5–8 are scheduled for early completion because they would provide much base-load power for the Northern Grid and, once the EHV interconnection was in place, excess energy could be exported to the South. Thermal units at the gas fields would provide supplementary power for the Northern Grid and semi-peaking capacity for the South, where the base load would be met by the Atomic Energy Commission's nuclear plant and hydroelectric energy from the North and peak load met by local thermal units in Karachi and Hyderabad. Concentration of thermal development on the gas fields would eliminate the need for expansion of the gas pipelines to meet the needs of other power plants after 1970; it would facilitate the operation of the EHV transmission interconnection; and it would usefully complement the proposed hydroelectric developments. A relatively large proportion of the generating capacity installed during the Fourth Plan—possibly as much as one-half—should be gas turbines.

Nearly half the cost of the proposed Action Program for electric power relates to distribution lines, customer connections, meters, etc. These allocations are vital: this side of development neglected in the past, making for, among other disadvantages, wasteful delays between the time when tubewells are installed and the time they become operational. According to the Study Group's projections, WAPDA needs to connect about 516,000 new customers before the Third Plan is over (including 16,000 public and private tubewells) and about 725,000 new customers during the Fourth Plan (including 25,000 public and private wells). This will involve construction of an estimated 23,000 miles of 11-kv and 400-volt distribution line during the Third Plan and 35,000 miles during the Fourth Plan, compared with an actual achievement of about 15,000 miles during the Third Plan. Performance in the construction of distribution lines can be improved by: first, adequate funds; second, an improved system of inventory control; and third, more emphasis to practical training of labor for distribution-line work.

Organization and Implementation

Although implementation capacity is accepted as a major constraint on the size of the recommended development program, the targets adopted are ambitious. They will not be realized without substantial improvements in organization and management. The necessary improvements will be achieved most quickly and effectively by adjusting the existing organizational structure and improving coordination among its parts rather than by establishing wholly new organizations or other radical structural change.

But much more effective coordination among the entities working in related fields is required in all phases of the development effort. This applies especially to the public tubewell projects, which must necessarily be cooperative efforts—installation of wells under WAPDA's Groundwater and Reclamation Division, electrification of wells by WAPDA's Power Wing, operation of wells by the Land and Water Development Board or the Agricultural Development Corporation, coordination of surface water supplies under the control of the Irrigation Department, concentration of extension effort by the Agriculture Department and distribution of farm inputs by various of these public agencies and by private enterprise. The need for coordination in planning also applies to the power sector; WAPDA load forecasting and system planning should be much better coordinated both with similar work in KESC and with general economic planning and forecasting. Because plans must be constantly revised and updated, long-term relationships are needed among these various bodies. The Planning and Development Department, which has overall responsibility for the development effort, needs strengthening.

All phases of tubewell project work, from initial identification and preparation to final connection of the wells with the distribution system, must be streamlined. The experience that has now been gained in execution of public tubewell projects should make it possible to develop a standard routine for organizing much of the work. The smaller scale of the projects recommended, as compared to those undertaken in the past, should also make their construction and completion on schedule more manageable. Great importance should be attached to the development of management cadres and organizational structures for each tubewell project, aiming at putting the wells into effective operation immediately upon completion; management difficulty may in fact prove a more serious obstacle to progress than the difficulties on the construction side. For the initial development effort, the Study Group strongly favors integrated project management with direct and undivided responsibility for increased supply of both water and other inputs like fertilizer and correct use of them. Project Directors should be appointed early, so that they can monitor progress starting with the pre-project conditions; extension officers and technical specialists would be seconded from other Government Departments. Once a project is operating smoothly, the organization could become more representative of the farmers; then support functions would be performed by the line departments directly.

The agricultural extension service has suffered from inability to attract and hold well-qualified personnel. University facilities appear adequate under current expansion plans; expansion of the training colleges for Field Assistants should be assessed in terms of the quality of education rather than maximum output. The Agriculture Department must be able to offer better career opportunities, involving more status, better pay and better working conditions. Relief from some tasks, such as the actual handling of plant protection materials, and provision of improved facilities such as transport, could greatly increase the effectiveness of this service. A dynamic research program is needed to deal with varietal improvement, more efficient treatment of insect infestation and plant disease, better understanding of soil, crop, water and fertilizer relationships, and improvement of farm implements. Immediate steps towards securing a greater contribution from research would be better pay and conditions, as with the extension service, and better coordination with the extension service in order to focus attention on the urgent problems of the farm community.

There is an acute shortage of engineers. The Special Study consultants have estimated that, by 1975, the recommended program of irrigation and drainage development will require 1,000 engineers for project planning and construction activity and 300 engineers for supervision and operation of tubewell projects. Rapid expansion of engineering education is difficult. The shortage of engineers for the program could be reduced by more on-the-job training of promising young nongraduates. Foreign consultants and contractors cannot fully make up for the lack of people with extensive local experience, but continuing heavy reliance will have to be placed on them.

The shortage of good civil-service staff does emphasize the need for making as much use as possible of private enterprise. It is very important that public agencies do not try to undertake more than they can really achieve because, besides overextending their staff resources and making them less effective, they also thereby reduce the scope for private enterprise, whether in groundwater development or in promotion of agricultural inputs. Subsidies will probably continue to be needed on fertilizer and plant protection materials, to encourage their adoption, but they should be arranged in such a way as to minimize the administrative burden on government agricultural officers.

The Study Group also recommends a positive Government effort to promote private tubewells. In particular, farmers and landowners should be able to get advice easily regarding procurement and construction matters, types of equipment available and suitable, quality of groundwater underlying their farms, irrigation requirements and water management. The need for advice about ways to organize cooperative installation and use of wells will become more important as continued growth of private tubewells comes to depend more on the smaller farmers; credit will equally become important and a more aggressive credit policy on the part of the Agricultural Development Bank would help. The extension service should give special attention to farms with private wells, to help the farmers make best use of additional water supplies.

The price structure for farm products should provide adequate returns to farmers for their effort and risks. Rather than a reduction in subsidies on the new inputs or in farm product prices, a more appropriate way to increase public savings would be increased water charges. Water is an accustomed input, the critical importance of which is already widely understood by the farmers, so that increased water charges should have no disincentive effect. Indeed, higher charges for water could help to improve the utilization of water just as the much higher costs of private tubewell water have apparently led to more careful and productive use of water obtained from that source. It would also help the Power Wing to achieve a more satisfactory rate of return on investment.

Broad policies affecting the distribution of available water supplies have remained little changed for decades, but it is essential to subject them to thorough review in light of existence of Mangla Dam, the forthcoming completion of the IBP works, changes in the design discharges of canals and gradual expansion of the public tubewell system. These policies will need to be continually adjusted as the complex irrigation system evolves. The Study Group recommends that a Provincial Irrigation Authority be constituted at the highest level to give adequate recognition to the broad range of administrative, legal, sociological and technical considerations related to water resource policy. This body would be responsible for basic policy decisions on barrage allocations, reservoir release patterns and drawdown levels and other major policy issues such as the use of tubewell fields in relation to surface water deliveries, and it would be concerned with both power and irrigation aspects of these matters. Stored surface water will yield highest benefits if it is released and allocated on the basis which recognizes the advantages accruing to power from keeping up the level of water in the reservoir for as long as possible, which considers irrigation releases in terms of the actual needs for canal commands rather than theoretical historic allocations, and which takes account of the extent to which these irrigation needs in different months can be met by groundwater pumping.

The Provincial Irrigation Authority could be serviced by a semi-independent working party staffed by, say, the Irrigation and Power Department, WAPDA, the Agriculture Department and the Planning and Development Department. It may require assistance from consultants during the early stages.

WAPDA's Power Wing must be clothed with sufficient authority to direct the flow of electricity from generating stations to load centers as required and to order the starting up or closing down of generating stations to meet fluctuating demands. After the power systems in the North and the South are interconnected by EHV transmission lines, a central dispatching station will be needed. The Power Wing's billing, collecting and accounting procedures need improvement. Losses on the WAPDA systems are presently unduly high, and a sizable reduction should be possible with improvement of the distribution system, better meter reading and billing procedures, and more efficient operation of a denser distribution and transmission network.

Irrigation and Agriculture Development after 1975

Parallel improvements in the supply of water and of other agricultural inputs should continue after 1975. There will remain substantial scope for increasing productivity by such means as greater use of fertilizer, development and widespread adoption of effective plant protection measures. Mechanization should take place at an increasing rate.

With completion of Tarbela in 1975, full integration of groundwater and surface water supplies should be achieved in the decade 1975–85. It is at this stage that coordinated control of the tubewell fields will become important. The existence of effective water-table control by means of public tubewells will make it worthwhile to expand the canal enlargement program substantially. As more areas with brackish groundwater are brought under development, there will be increasing need for drainage works.

Virtually the entire area underlain by usable groundwater could be covered with public tubewell projects by 1980, if this proves desirable. This would mean construction of public projects covering about seven million acres between 1975 and 1980, additional to the twelve million acres covered by 1975. But the need to replace private wells with public wells in all areas, to achieve sufficiently integrated operation of the system, remains to be seen. Once the usable groundwater areas needing public tubewells have been covered, then the tubewell construction program would shift to the saline groundwater areas. In some areas surface or subsurface drainage will be called for. In most of the areas where limited use can be made of groundwater for irrigation purposes, the canals will need to be expanded to carry sufficient surface supplies. The long-term program envisages completion of canal remodeling in five million acres over the decade 1975–85 and a further ten million acres before the end of the century. By the early 1980's, an additional link canal across the Punjab may be required to deliver water from the Indus to the expanded canals in areas with saline groundwater in the eastern Punjab.

In the Lower Indus, the main work in the decade after 1975 would be canal remodeling, in connection with the expansion of tubewells and tile drainage in saline groundwater zones, and surface drainage works. Canal enlargement here hinges essentially on the Sehwan Barrage Project, construction of which is recommended to begin late in the Fourth Plan period. As now proposed, the Sehwan Barrage and Sehwan-Rohri Feeder are scheduled for completion in 1982, and the Rohri-Nara Feeder is scheduled for completion after 1985. The very large Left Bank Outfall Drain, if started in the Third Plan period, should be brought to completion around 1985. A parallel drain on the right bank, which would drain the effluent of the Gudu and Sukkur Right Bank areas, would be built over the years 1980–90.

As regards surface storage, following completion of Tarbela in 1975, additional capacity probably will not be required until the 1980's. Sehwan-Manchar could then add some 1.8 MAF of capacity. Around 1985, further large-scale capacity will be needed to meet growing irrigation needs and to help replace capacity lost by siltation at Tarbela. The need might be met by raising the Mangla Dam. Alternatively, it may then be best to go straight to second-stage storage on the Indus, which will anyway be required by the early 1990's. The amount of additional surface storage capacity required in this period will depend on the extent to which inter-seasonal underground storage, which would require canal remodeling in fresh groundwater zones, is found to be a feasible alternative.

Power Development After 1975

The Study Group's projections suggest that it would be worthwhile installing all 12 units at Tarbela by 1981. By that time, there should be three 380-kv transmission lines between Tarbela and the Upper Sind. These lines will not carry the full potential output of Tarbela during the flood months, but the excess energy would have to be taken to Karachi to find a market, and it probably would not be worth installing additional lines for this purpose. Some years later the extra energy produced in the flood months could be absorbed locally or in the Northern Grid, as further 380-kv lines are installed.

Additional thermal capacity will be needed to provide megawatts in the spring when the reservoirs are fully drawn down and to help stabilize the EHV transmission line. This thermal capacity will operate at low load factor and, as far as can now be foreseen, this capacity would best be based on natural gas. The outline program for the post-1975 period includes additional thermal capacity on the gas fields in the Upper Sind and in Karachi, where it would be fired by Sui gas. It is doubtful whether the scarcity of natural gas by this time will be sufficient to warrant a change to coal-burning power plant with its higher capital and operating costs.

By the early 1980's, there will be a strong case for extensive development of nuclear generation in the South, despite its relatively high foreign exchange costs. Loads in the South would be adequate by then to give a 400-mw nuclear unit a load factor of better than 80 percent; moreover, by the middle of the 1980's, loads on an interconnected system would be growing fast enough to absorb reasonably quickly output from another 400 mw, which may be the minimum size at which substantial economies will be obtainable from nuclear plant.

ANNEX 1

Engineering Aspects of Tarbela and Related Projects[1]

INTRODUCTION

The Tarbela Dam site (see Maps 1.2 and 1.5) was selected by WAPDA as a result of detailed studies of three potential sites in a 17-mile stretch of the river that commenced in 1955. Investigations and engineering planning have been carried out for WAPDA by Tippetts-Abbett-McCarthy-Stratton International Corp. (TAMS) of New York.

The project comprises essentially a major earth and rockfill dam of 159 million cubic yards, rising 485 feet above ground level, with a crest length of about 9,000 feet, and an impervious blanket extending 5,000 feet upstream; two auxiliary earth and rockfill dams; two chute spillways; four outlet tunnels each 45 feet maximum diameter; and a power station with initially four generating units rated at 175 mw each and subsequent extensions for eight more units giving a total installation of 2,100 mw rated capability. The reservoir will contain initially 11.1 MAF of gross storage, giving 9.3 MAF of live storage at a minimum level of 1300 feet and 8.6 MAF of live storage at a minimum level of 1332 feet.

The major drawback of Tarbela is that the useful life of the reservoir will be rather short—on the order of 50 years—because of rapid sedimentation. Although sluicing might conceivably be possible, the shape of the reservoir and the type of dam are not conducive to this mode of operation; and, in addition, the power potential would be severely affected. Because of the overall economic effects and technical problems involved, Chas. T. Main concluded that sluicing would not be practicable.

Whatever its limitations, Tarbela is the only major storage project which has been investigated thoroughly, whose technical feasibility has been firmly established, and which can be completed by the middle 1970's—at which time the mean-year demand for stored water is estimated by IACA to be approximately five MAF. Also, its location is favorable for diversion by gravity flow to side-valley reservoirs, in which sedimentation would take place very slowly. Thus as Tarbela depletes, its value to power would

[1] The information incorporated in this Annex is based for the most part on reports prepared by Chas. T. Main and Sir Alexander Gibb.

increase and its storage for irrigation supplies could be replaced by side-valley reservoirs and/or another dam on the Indus main stem, say at Kalabagh, which would also benefit from Tarbela's trapping of sediment. This Annex is divided into two parts, the first part devoted to Tarbela itself, the second to associated side-valley projects.

A. TARBELA

THE SITE

The Tarbela Dam site is situated at the downstream end of the Indus River gorge, immediately above the junction between the main Indus valley and the Vale of Peshawar. It is six miles downstream of Tarbela Village and about 33 miles upstream of Attock. The Indus River at this point occupies a broad flood plain some 6,000 feet wide, above which the valley sides rise steeply.

The stretch of river between the villages of Bara and Kirpalian (Map 1.5) has been thoroughly investigated since 1959 to ascertain the most advantageous reservoir site on this promising segment of the Indus. In 1962, TAMS submitted a report which concluded that the Bara site (essentially the Tarbela site and hereinafter referred to as Tarbela) would afford the best location for a dam on the Indus in that general area. The Bara site was compared to two alternatives, one at Kirpalian, the other at Kiara. The choice of Bara was based on the following facts and observations:

1. The Kirpalian site, 17 miles upstream of Tarbela, was judged to have a maximum practical gross storage potential of 4.3 MAF. An additional 1.3 MAF of gross storage could be added by diverting water by gravity flow from the Kirpalian reservoir, through a conveyance canal, to a reservoir formed by a dam to be constructed at Thapla on the Siran River. The estimated cost per acre-foot of usable storage at the Kirpalian site was found to be greater than the comparable storage at the Tarbela site. The cost of the conveyance system and the Thapla dam would further increase the overall average cost of storage at Kirpalian in comparison to that at Tarbela.
2. The Kiara site, only two miles upstream of Tarbela, has a storage potential about 10 percent less than that of Tarbela. Also, the physical attributes of the site are not as favorable as those of Tarbela. The estimated cost of storage at Kiara is more than that at Tarbela.
3. The Bara site (Tarbela) proved the most promising of the three, primarily because of a geologically ancient stream bed, at the left abutment of the proposed dam, which would facilitate the construction of a spillway.

The TAMS report listed comparative costs per acre-foot of live storage capacity (Table A1–1). All sites listed as alternatives to Tarbela would equally permit gravity diversion of Indus water to the side-valley storage on the Haro and Soan Rivers.

TABLE A1-1
THE COMPARATIVE COST PER ACRE-FOOT OF LIVE STORAGE CAPACITY AT SITES ALTERNATIVE TO TARBELA

	Percentage of Cost of Bara Site
Kirpalian site	149
Kirpalian including Thapla dam and conveyance structure	168
Kiara	111
Tarbela (Bara site)	100

GEOLOGY

Geological data are found in the report on the Tarbela Project of November 1966, by Sir Alexander Gibb and Partners. The following statements are taken from that report:

The foundations of the various structures present a variety of conditions which call for a range of foundation treatments. Foundation materials vary from hard rock to completely decomposed rock and alluvial deposits.

The rocks of the dam site are predominantly low-grade metamorphic and intrusive material, and, although thought to be from the same formation, the beds on the two sides of the river differ in some respects. Those on the right bank are more strongly metamorphosed than on the left bank, and differences are observed in rock types. On the right bank the principal rock types are schists, limestones, and basic intrusives with minor beds of quartzite and gypsum. On the left bank they are predominantly metamorphosed thinly bedded marly limestones and slatey mudstones. Considerable jointing and minor faulting has occurred. The geological structure is completed, with folding in two directions together with local doming.

An important feature of this dam site is the presence of deep pervious alluvial filling across the river flood plain. The depth of bedrocks ranges generally from 200 to 400 feet. The maximum measured at one location is nearly 600 feet. The bedrock below the alluvium has a very irregular profile and is thought to contain an inactive fault along the right side of the valley. The alluvium is predominantly boulder-gravel with elongated stones set in a sand filling.

The dam site is in a zone with occasional seismic activity for which due allowance is made in the design of both the main embankment dam and its auxiliary structures.

HYDROLOGY

The hydrology of the Indus River's system as a whole, as well as that of the Indus itself, with its large floods and seasonal fluctuations, results from the annual meteorological cycle. This cycle is characterized by four periods:

October to November: Following the humid summer heat a persistent high-pressure system gradually develops over the Indus Plains. It is generally a period of settled fine weather.

December to March: By midwinter, areas of low pressure from the Mediterranean occasionally gain sufficient strength to carry over the land masses and mountains to the west, forming a steady procession of secondary lows. These give rise in the northern part of the country to overcast conditions with steady mild rain for several days at a time. The southern part of the country remains clear.

April to June: The principal meteorological disturbances are local convective thunderstorms. Few of them, however, produce rain and then only in small widely scattered areas.

July to September: A persistent area of low pressure develops over the northern central plains and humidity rises. The monsoon rains occur during this season. The southeast monsoon moves up the Indo-Gangetic Plain from the southeast, but by the time it reaches the Punjab Plains it is nearing the end of its travel and is consequently unpredictable as to the amount of rain it may produce. The southwest monsoon, which moves up the lower Indus Valley, is more reliable but weaker at its source. Occasionally, moist air masses from both sources converge over the Punjab and the headwaters of the Indus system. This results in intense and sometimes prolonged rainfall.

It is in this last period, the July to September monsoon period, that most of the annual precipitation occurs. Torrential rains may produce a third of the year's rainfall in a day. (The mean annual precipitation on the plains ranges from less than four inches in parts of the Sind in the South to more than 30 inches at the foothills of the mountains.)

The hydrological character of the Indus River's system is also influenced by the fact that the Indus and its principal tributaries, the Kabul, Jhelum, Chenab, Ravi, Beas and Sutlej (as shown on Map I.2), all have their sources at elevations exceeding 15000 feet.[1] Precipitation on the mountain ranges accumulates in the form of snow, particularly during the winter. The snowmelt, resulting from the rising temperatures in spring, causes an early rise in the flow of the rivers, and accounts for a considerable proportion of their annual discharge. A study of the hydrographs of the Indus at Darband has led to the tentative conclusion that about half of the total annual flow is derived from snowmelt.

The runoff from the monsoon rain is superimposed on the basic flows derived from snowmelt. This results in high discharges on all rivers during July, August and early September.

Discharge Measurement and River Flows

These river flows have fortunately been measured over a considerable period of time. The first records of gauge height were made on the Indus at Attock in 1868; the next were on the Chenab at Alexandria Bridge in 1879. Regular discharge measurements were undertaken later by the Irrigation Department at the various barrages on the plains as they were

[1] All levels are in feet above Standard Pakistan Datum (SPD), which is based on mean sea level, Karachi.

TABLE A1-2
ANNUAL DISCHARGE OF THE INDUS
(MAF)[a]

River	Location	Discharge Mean	Minimum	Maximum
Indus	Attock	93	72	110

[a] Million acre-feet.

completed. The most important gauging stations for which extensive records exist are the so-called "rim" stations at points where the rivers leave the hills and enter the plains. These records have been analyzed by the Study Group's consultants, who have concluded that the discharge figures prior to 1922 are probably less accurate than those for subsequent years. Therefore, for purposes of this study, the years 1922 through 1963 have been used.[1] This 41-year period is considered to be adequate as a basis for planning purposes. The network of gauging stations is being rapidly extended: 61 new stations having been installed since 1960, so that valuable information on the secondary rivers will become available in due course.

On the basis of the rim station measurements, the average annual discharge of the Indus is shown in Table A1–2. Also shown are the maximum and minimum yearly flows of record. Hydrographs of the mean monthly discharges of the Indus River over the years 1922–63 are shown in Figure 2, Chapter 3 of this volume. The high summer flows are the result of a combination of snowmelt and monsoon rainfall. Since the monsoon rainfall is extremely variable, there is considerable year-to-year variation in discharge. The Indus, with a high proportion of snowmelt runoff, has a relatively modest variation in annual yield in comparison to other Pakistan rivers, although a very large proportion of the annual flow still occurs in the four months June to September. In the mean-year case, as noted at the outset, this is 72 percent, representing approximately 67 MAF (out of 93 MAF recorded at Attock).

The Indus measurements at Attock (Table A1–2) include the flow of the Kabul River and other upper tributaries. They do not, however, provide information as to the degree of that contribution. Though neither the Indus nor the Kabul River has been gauged at their confluence, regular readings of the Indus at Darband, some 50 miles upstream of the confluence, were started in 1954. These readings, which have been used to assess the flows at Tarbela, comprise stage records from 1954 to 1958 and discharge measurements since 1960. (No readings were taken between 1958 and 1960.) By comparisons with concurrent flow data of the Indus below Attock, synthetic records for the two rivers have been computed independently, as shown in Tables A1–3 and A1–4. The estimated annual contribution of each of the rivers to the surface water supplies of the Indus Basin in West Pakistan is given in round figures in Table A1–5.

[1] Unless otherwise noted, hydrological years, which extend from October 1 to September 30 of the following year, have been used.

TABLE A1-3
DERIVATION OF MEAN INDUS DISCHARGE AT TARBELA
(MAF)

	Indus at Darband[a]	Siran[b]	Indus at Tarbela
Jan.	1.07	.04	1.11
Feb.	1.02	.04	1.06
Mar.	1.42	.08	1.50
Apr.	2.02	.09	2.11
May	4.36	.07	4.43
June	10.22	.03	10.25
July	16.70	.10	16.80
Aug.	15.85	.11	15.96
Sep.	6.66	.09	6.75
Oct.	2.71	.03	2.74
Nov.	1.54	.03	1.57
Dec.	1.24	.03	1.27
Total	64.81	.74	65.55

[a] Calculated from the Indus flows at Attock for the period 1922 to 1963, by application of the Attock/Darband ratios during concurrent period of record 1954–58 and 1960–64.
[b] Based on records 1959–64.

TABLE A1-4
INDUS DISCHARGE ABOVE AND BELOW ATTOCK
(MAF)

	Indus at Tarbela	Kabul above Attock[a]	Indus at Attock
Jan.	1.11	0.60	1.71
Feb.	1.06	0.56	1.62
Mar.	1.50	0.95	2.45
Apr.	2.11	2.19	4.30
May	4.43	3.95	8.38
June	10.25	5.24	15.49
July	16.80	5.77	22.57
Aug.	15.96	3.85	19.81
Sep.	6.75	1.90	8.65
Oct.	2.74	0.88	3.62
Nov.	1.57	0.57	2.14
Dec.	1.27	0.60	1.87
Total	65.55	27.06	92.61

[a] Obtained from difference between Indus flows at Attock and Tarbela.

TABLE A1-5
AVERAGE ANNUAL CONTRIBUTION OF PRINCIPAL RIVERS

	Contribution	
	(MAF)	(percent)
Indus above Attock	66	45
Kabul above Attock	27	18
Total Indus below Attock	93	63
Jhelum at Mangla	23	16
Chenab at Marala	26	18
Others	5	3
	147	100

SEDIMENT MOVEMENT

Any plan for the construction of reservoirs in Pakistan must consider the problem of sedimentation. This is particularly true for reservoirs on the Indus. For out of approximately 700 million tons of sediment transported by the river system, to or through the plains each year, the Indus River itself carries nearly 540 million. (This compares with the estimated load of the Missouri River at Kansas City of 131 million tons a year, and of the Mississippi River below New Orleans of 600 million tons a year.) Given this fact, it must be recognized that a large loss of useful capacity by sedimentation will occur in any reservoir on the Indus. It must also be recognized that only a continuing program of silt measurement can serve to determine the precise dimensions of this problem and provide a basis for its solution.

Because the rate of sedimentation will have such a profound effect on the life of an Indus reservoir, it has been necessary to make the most of all available data—hoping thereby to establish a basis for a defensible judgment about the useful life of Tarbela, as well as other possible reservoirs of the system. Following is a brief analysis of the known situation and a summary of the broad conclusions that can be drawn from it.

The information used dates from 1960. Before then, records of sediment measurements are considered unreliable because of the sampling techniques employed. Since 1960, however, a fairly extensive network of sampling stations has been established, on the Indus River in particular. At Darband, 5,000 samples of water have been taken, using up-to-date methods. The results of this field work are shown in Figure A1–5, and summarized in Table A1–6, which together clearly indicate the rapid rise in rate of sediment transported with increase in flow. On the basis of this work, and the synthetic record of historic flows at Darband, the average annual suspended sediment load was estimated to be about 420 million tons.

One further reservation relates to bed load. No reliable methods are available for measuring bed load and, in the case of the Indus, opinions differ as to its importance. For the purposes of the study, it is estimated at 5 percent of the suspended load. Any errors resulting from this, according to IACA, probably will be small compared with those resulting from the possible vagaries of nature.

Since the sediment load varies with discharge, seasonal differences occur in one as in the other. It is estimated that about 90 percent of the total annual sediment load is carried by the river during the period between the middle of June to the middle of August as summarized in Table A1–7.

The average annual sediment transport of the Indus at Darband has been estimated at 440 million tons a year. Sediment deposited in Tarbela Reservoir is expected to consolidate a final density of about 85 pounds per cubic foot. This rather high value is estimated because of the predominance (about 60 percent) of fine sand in the suspended sediment and the absence of clay. At 85 pounds per cubic foot, 440 million tons is equivalent in volume to 238,000 acre-feet. On the basis of these estimates, Tarbela Reservoir may be expected to silt up at the rate of approximately

TABLE A1-6
ESTIMATED SEDIMENT TRANSPORT OF INDUS RIVER AT DARBAND
(19 miles above Tarbela Dam)

Flow (cusecs)[a]	Approximate % of Time Flow Equalled or Exceeded	Suspended Sediment (thousand tons per day)[b]	Approximate % of Total Sediment Transported by Flows in Range Noted
0	100	0	
			8
100,000	31	400	
			5
150,000	23	1,200	
			9
200,000	17	2,400	
			39
300,000	5	6,600	
			35
400,000	0.3	13,000	
			4
500,000	0.02	23,000	
600,000	0.00	36,000	

[a] Cubic feet per guard.
[b] Sediment measurements for different flows vary considerably; for example, at a flow of 300,000 cusecs the range is from 3.2 million to 13 million tons per day (see Figure A1-5).

TABLE A1-7
MEAN-YEAR SEDIMENT TRANSPORT OF INDUS RIVER AT TARBELA DURING FLOOD SEASON

Period	Mean Flow Attock (thousand cusecs)	Ratio Tarbela to Attock Flow	Mean Flow Tarbela (thousand cusecs)	Sediment Load (million tons per day)	Approximate Percentage of Total Annual Sediment Load[a]	
					Per Period	Cumulative
June						
1-10	226	0.65	147	1.1	3	3
11-20	276	0.68	187	2.0	6	9
21-30	301	0.68	205	2.7	8	17
July						
1-10	340	0.74	251	4.0	12	29
11-20	365	0.74	270	5.0	15	44
21-31	369	0.76	280	5.5	16	60
August						
1-10	368	0.8	294	6.0	18	78
11-20	324	0.8	259	4.7	14	92
21-31	260	0.8	208	2.8	8	100
Total Sediment Flow for Period				338	100	

[a] May and September sediment flow and bedload, accounting for 2, 5 and 5 percent respectively of average annual sediment transport, are omitted for simplifying reasons. The mean-year flow does not adequately reflect peak flows, which account for disproportionate amounts of sediment transport; hence, in the peak flow months, the sediment transport above is understated. Average annual sediment transport is estimated to be 440 million tons.

TABLE A1-8
QUANTITIES OF STORED WATER AVAILABLE FOR RELEASE AT TARBELA

Storage Release Period	Available Storage (MAF)	Storage Release Period	Available Storage (MAF)
1975/76	8.48	1999/2000	5.35
1979/80	8.00	2004/2005	4.50
1984/85	7.40	2009/2010	3.65
1989/90	6.80	2024/2025	1.10

2 percent per year. As noted earlier, initially, the Tarbela reservoir would have a gross storage capacity of 11.1 MAF. Of this, 8.6 MAF would be live storage. Because of the high sediment load, the reservoir would be fully depleted to a final volume of one MAF after about 50 years. Figure A1–6 demonstrates the projected pattern of sediment deposition.

Taking into account the reservoir depletion, the quantities of water available for irrigation releases at reference years would be about the same as in Table A1–8. This Table is basic to the analysis of Tarbela and has been included in the main text on pp. 136 (Table 5–11).

It should also be noted that, in the case of the Indus, variations in the total suspended sediment load have occurred. These variations may have been caused in part by erratic geomorphic processes resulting from heavy rainfall, landslides and avalanches. The statistically random nature of these occurrences gives rise to the possibility that sediment actually deposited in a reservoir at Tarbela could, over a number of years, vary substantially from that assumed in the studies which are based upon a rating curve, as shown in Figure 3. Should there be a succession of years in which geomorphic processes were particularly active, the usable volume of the reservoir could be depleted at a much faster rate than has been assumed.

FEASIBILITY OF SLUICING

Because the sediment inflow to Tarbela Reservoir will be very high, the dam site consultant investigated the feasibility of providing sluiceways to pass the heavily charged waters of the monsoon season, principally during June and July when over 50 percent of the annual load is carried. It is clear that sluicing would serve to increase the useful life of the reservoir, otherwise estimated at 50 years, to some indeterminable degree. Three schemes were studied in detail, one based on the present design and two on modifications.

The dam site consultant concluded, however, that effective sluicing at Tarbela is precluded by the nature of the site. Owing to the broad valley and the great depth of alluvium underlying the dam, enough outlets cannot be provided. The four tunnels included in the present design appeared to be the maximum practicable for installation. Sluicing through these tunnels during the critical months of June and July as the head increased would be hazardous because of the high resultant tunnel velocities, some of which are indicated in Table A1–9.

TABLE A1-9
TARBELA: VELOCITY IN TUNNELS IF USED FOR SEDIMENT SLUICING
(mean-year conditions)

	Mean Inflow at Tarbela (cusecs)	Reservoir Elevation (feet SPD)	Velocity in Tunnels (feet/second)
June 1–10	147,000	1185	23
11–20	188,000	1230	30
21–30	204,000	1245	32
July 1–10	252,000	1310	40
11–20	270,000	1335	43
21–31	280,000	1350	44

The generally accepted design practice for large steel-lined conduits carrying substantial quantities of sediment is to limit velocities to something less than 20 feet/second to avoid excessive damage by abrasion. It follows that any plan involving tunnel velocities of more than twice the safe figure would be unacceptable.

While this would seem to constitute a sufficient reason in itself for discarding any hope of profitable sediment sluicing at Tarbela, the detrimental effects on power production confirm the conclusion. Power generation capabilities would be eliminated for upwards of 60 days each year. For both reasons, therefore, the dam site consultant concluded that sluicing would be impracticable. The Study Group concurs in this view.

FLOODS

The Indus and its tributaries are subject to severe floods. These generally result from rainfall of high intensity sometimes combined with snowmelt. They may also be caused or aggravated by the breaching of natural dams formed by glaciers or landslides. In this Annex, floods are considered only as they affect the design of dam and spillway structures. In the case of Tarbela, adequate spillway capacity is essential because of the catastrophic consequences in terms of damage and loss of life that would result from a failure of the earth and rockfill dam in the event of its being overtopped during a massive flood.

For the Indus, therefore, detailed meteorological investigations were undertaken to ascertain what might be the maximum probable flood arising from the most adverse conditions. The maximum flood of record on the Indus at Tarbela was recorded at Attock in August 1929: 875,000 cusecs. The maximum flood assumed for design purposes was 2,127,000 cusecs, which has been derived by TAMS from three components: (i) maximum flood due to snowmelt, estimated from a study of recorded flood hydrographs to be 600,000 cusecs; (ii) maximum flood due to monsoon rainfall, estimated from synthetic unit hydrograph and probable maximum storm studies to be 1,080,000 cusecs (subsequently slightly revised by TAMS to 1,173,000 cusecs); and (iii) maximum flood due to the breaking of a natural dam, estimated from the flood hydrograph of August 18, and 19, 1929, when a glacial dam on the Shyok was breached, to be 354,000 cusecs.

The first and second factors together produce a "maximum probable flood" of 1,773,000 cusecs and (i), (ii) and (iii) together give a "maximum combined flood" of 2,127,000. While a combination of the first two is quite probable, the concurrence of all three is extremely unlikely. However, prudence dictates the acceptance of the possibility of an exceptional flood.

Status of Project

Between 1959 and 1965, more than $19.5 million was spent on intensive site investigations, preliminary works and design for the Tarbela Project. Subsurface investigations included 560 bore holes, totaling about 100,000 feet, more than 25,000 feet of tunnels and 4,184 feet of trenches, varying in depth from 10 to 80 feet. In addition, more than 1,000 test pits have been dug.

Further investigations continue. Drilling has been carried out in the alluvial foundation for the main embankment to obtain further information regarding its structure, composition, and permeability. Immediately after the main contract has been let, deep bores will be taken to confirm more accurately the depth of alluvium overlying bedrock. The foundations for the spillway flip buckets are being explored by means of tunnels and shafts. Exploratory tunneling is continuing in the diversion tunnel area, particularly in the vicinity of the powerhouse foundations where a gypsiferous deposit may be a potential hazard to concrete structures.

Hydraulic model tests have been made and are continuing. Natural and distorted scale models of the Indus River in the vicinity of the Tarbela Dam site, and of the spillways and outlet works stilling basins, have been built and are being tested at the Irrigation Research Station at Nandipur, West Pakistan. Model tests of the performance of the tunnels, both under diversion and normal operating conditions and during filling of the reservoir and tunnel closure, have been conducted at the Colorado State University Hydraulic Laboratory near Fort Collins, Colorado. Further tests will be necessary to verify certain aspects and their performance.

The consultants (TAMS) for the Water and Power Development Authority of West Pakistan have completed final designs and the tender documents for the project had been issued at the time this report was prepared. This work has been reviewed by the Study Group's consultants, Sir Alexander Gibb & Partners.

Design

The plan and sections of the Tarbela project as finally presented for tender are as shown in Figure A1–3 and the major characteristics are listed in Table A1–10.

Embankments

The main dam with a total volume of fill amounting to 159 million cubic yards will be the most massive of its kind in the world. Seepage through the foundation of the main dam will be controlled by an impervious earth blanket covering the valley floor under the dam and extending about

TABLE A1-10

TARBELA PROJECT STATISTICS

Reservoir	
Retention level	1550 feet SPD
Drawdown level	
Design	1300 feet SPD
Assumed for reservoir operation	1332 feet SPD
Storage volume:	
At elevation 1550 feet	11.1 MAF
At elevation 1332 feet	2.5 MAF
At elevation 1300 feet	1.8 MAF
Length of reservoir	48 miles
Maximum width of reservoir (excluding Siran arm)	3 miles
Maximum depth	450+ feet
Main Dam	
Type—Earth and rockfill with impervious cores; foundation seepage control by upstream impervious blanket and downstream relief wells	
Crest elevation	1565 feet SPD
Crest length	9,000 feet
Maximum height	485 feet
Side slopes	
Upstream	1 in 2.65
Downstream	1 in 2
Volume	159 million cubic yards
Auxiliary Dam No. 1	
Type—Earth and rockfill founded on alluvium with sloping impervious core and blanket extending to bedrock	
Crest elevation	1565 feet SPD
Crest length	2,340 feet
Maximum height	345 feet
Side slopes	
Upstream	1 in 2.65
Downstream	1 in 2
Volume	18 million cubic yards
Auxiliary Dam No. 2	
Type—Earth over rockfill founded on rock with impervious core to bedrock	
Crest elevation	1565 feet SPD
Crest length	860 feet
Maximum height	225 feet
Volume	1.7 million cubic yards
Spillways	
Type—Two gated channels forming service and auxiliary spillways will be excavated in the rock on the left bank; they will be concrete-lined from their crests to flip-buckets, the remaining length of the channels to the river being unlined	
Crest level	1492 feet SPD
Gates	
Service spillway (7)	50 feet wide by 58 feet high
Auxiliary spillway (9)	50 feet wide by 58 feet high
Discharge capacity at elevation 1550 feet	
Service spillway	615,000 cusecs
Auxiliary	795,000 cusecs
Design Flood	
Maximum inflow	2,127,000 cusecs
Maximum outflow	
At elevation 1550 feet	1,410,000 cusecs
At elevation 1556.8 feet	1,670,000 cusecs
Maximum flood of record	
(August 27–30, 1929 at Attock)	875,000 cusecs

TABLE A1-10—(Continued)

Outlet Works	
Four concrete-lined tunnels, each 45 feet diameter up to gate structures	
Emergency gates—two 13.5 feet by 45 feet fixed-wheel gates in each tunnel plus two bulkhead gates of same size upstream of emergency gates	
Tunnels 1, 2 and 3 steel-lined downstream of gate structure 43.5 feet diameter	
Tunnel 4, steel-lined downstream of gate structure, 36 feet diameter	
Tunnel 4 controlled for irrigation releases by two 16 feet wide by 24 feet high radial gates at downstream end. Tunnel 3 will be similarly controlled until power units 9 to 12 are installed	
Intake sill level (final construction stage)	
Tunnels 1 and 2	1225 feet SPD
Tunnels 3 and 4	1160 feet SPD
Estimated discharge capacity of Tunnel 4	
At elevation 1300 feet	62,500 cusecs
At elevation 1332 feet	66,500 cusecs
Estimated discharge capacity of each of three power tunnels (controlled by four turbine-bypass valve units)	
At elevation 1300 feet	15,200 cusecs
At elevation 1332 feet	17,200 cusecs
Release capability full development one irrigation tunnel plus 12 turbine-bypass valve units	
At elevation 1300 feet	107,000 cusecs
At elevation 1332 feet	118,000 cusecs
At elevation 1492 feet	171,000 cusecs
Power Plant	
Ultimate Installation—12 turbine generator units, 4 each on Tunnels 1, 2 and 3 with total rated capacity of 2,100 mw	
Turbines —Francis type, to be designed for best efficiency at 333 feet net head and to have guaranteed outputs at 376 feet net head of 241,000 hp and at 417 feet net head of 281,000 hp	
Generators —Rated 175 mw but capable of 15 percent continuous overload	
Maximum normal tailwater elevation—1115 feet	
Minimum tailwater elevation (1 unit)—1100 feet	
Maximum net head—437 feet	
Minimum net head—183 feet	

5,000 feet upstream and by a system of drainage wells in the alluvium at the downstream toe of the dam. Two saddle dams of similar design, but with impervious membranes extending to bedrock, close two gaps in the topography of the left bank. One of these dams is in itself a large structure with a maximum height of 345 feet and volume of 18 million cubic yards. The other is a relatively small structure 225 feet in height with a volume of 1.7 million cubic yards. Each of the three dams is designed as a zoned rockfill embankment with a blended core of silt and angular gravel set within the dam section. Suitably graded filter zones are provided on each side of the impervious core. The embankments are being designed so that materials from required excavation could be moved directly to embankment sections with a minimum of rehandling.

As mentioned before, the site is located in a region of seismic activity. In view of this condition, five feet of the 15 feet normal freeboard on the dams has been provided as insurance against abnormal earthquake-induced subsidence. In addition, the impervious core and the adjacent filter zones will be constructed from materials that will tend to be self-healing in the event differential settlement or subsidence is sufficiently severe to cause cracking. The materials composing the impervious core will be blended during construction as necessary to assure high shear resistance and impermeability.

During construction the river would be diverted through a channel excavated on the right bank with a capacity of 750,000 cusecs. For final diversion, the outlet tunnels would be used.

SPILLWAYS

Two gated spillway structures on the left bank would discharge excess floodwaters through concrete paved chutes into a common discharge channel to be excavated along the course of a natural channel (the Dal Darra). One, the service spillway, would be operated every year, the other, the auxiliary spillway, would be used only in the case of unusually high floods. The spillway gate structures and chutes are to be founded on rock throughout. Flip buckets at the downstream ends of the spillway chutes are designed to throw the water into the air clear of the concrete structures. Energy of the water, which will leave the flip buckets at velocities as high as 130 feet per second, will be dissipated partly in the air and partly by turbulent interaction with the water in the pools that will be scoured in the discharge channels to depths of some 200 feet by the falling water. Present designs envisage that the flip buckets for the service and auxiliary spillways will be about 70 and 40 feet, respectively, above the bottom of the discharge channel. The discharge channel would be constructed with its bed at a level of 1160 feet, which is about 70 feet above the bed of the river. The approximate length of this channel from the intersection of the two spillways to the river is 1½ miles.

The combined discharge capacity of the spillways is:

(i) 1,410,000 cusecs at normal retention level,
(ii) 1,490,000 cusecs with surcharge of 2.2 feet, and
(iii) 1,670,000 cusecs with surcharge of 6.8 feet.

Flood routing studies have shown that, after allowance for a flow of 132,000 cusecs through the tunnels, (ii) is sufficient to pass the "maximum probable flood" of 1,773,000 cusecs and (iii) the "maximum combined flood" of 2,127,000 cusecs.

The great volume of water discharged at high velocities and falling on erodible materials will cause significant maintenance problems. Some damage to the concrete chutes from cavitation and abrasion will occur, and this will increase as the reservoir volume becomes depleted and the water flowing over the spillway becomes more sediment-laden. Also, the flip bucket foundations will be exposed to erosive action and will require corrective work at some point. Careful operation will be necessary to minimize damage due to erosion and frequent inspection will be advisable to detect conditions requiring repair in their early stages.

Outlet Works

The outlet works would consist of four tunnels each 45 feet in diameter upstream of the gate shafts and 43.5 feet in diameter downstream, except for Tunnel 4 which has a 36-foot diameter downstream. These tunnels would be used for diverting the flow of the river during the later phases of constructing the embankment. One of the four tunnels is to be used permanently as an irrigation outlet. The other three will, at various stages, each be connected to four generating units.

To minimize water hammer, to permit fast response to load variations, and to assure uninterrupted irrigation releases in the face of changing power loads and emergency power shutdown, a bypass valve will be installed at each generating unit with its inlet ahead of each turbine. These valves will open as the turbine gates close to maintain preset discharge rates that are independent of turbine load. Each valve will have a discharge capacity of about 3,800 cusecs when the reservoir level is at elevation 1300 feet.

The four tunnels during diversion will be capable of discharging about 430,000 cusecs with the reservoir level at elevation 1345 feet (recent model tests indicate a slightly higher figure). This discharge will be reached during diversion if the construction-design inflow flood (805,000 cusecs peak), which has an estimated probability of being equaled or exceeded once in one hundred years, occurs.

Until the conversion of Tunnel 3 to power, the two irrigation release tunnels will have a combined minimum release capacity of 125,000 cusecs (recent model studies indicate this may in fact be 136,000 cusecs), and the two power tunnels could provide an additional 30,000 cusecs, all at a drawdown level of 1300 feet.

The combined outlet capacity at Tarbela will reduce to about 107,000 cusecs at reservoir elevation 1300 feet and 118,000 cusecs at elevation 1332 feet at the time 12 generating units are installed and Tunnel 4 is the only irrigation tunnel. Consequences of limited outlet capacity in later years are described subsequently.

The Tarbela Drawdown Problem

WAPDA's planning is based on a 1300 feet SPD drawdown level for Tarbela. The IACA program assumes that Tarbela Reservoir would be drawn down to a level of 1332 feet SPD each year about the middle of May and that the natural river flow will then be passed downstream until about the middle of June. At this time, flow in the Indus will begin to exceed irrigation requirements, and impounding will start.

These irrigation requirements (for the months of June, July and August) are presented in Table A1–11. Requirements for 1985 are given, and also for the year of ultimate development. As indicated previously, the program developed by the power consultants for the integration of hydroelectric and thermal generating capacity into the grid system includes 12 generating units to be installed at Tarbela by 1985. The discharge capacity of the outlet structures with these units installed would be as in Table A1–12.

TABLE A1-11

TARBELA: AVERAGE MONTHLY IRRIGATION RELEASE REQUIREMENTS DURING IMPOUNDING PERIOD

(cusecs)

	1985	Ultimate Development (2000)
June	84,000	156,000
July	24,000	92,000
August	39,000	99,000

TABLE A1-12

TARBELA: DISCHARGE CAPACITY OF OUTLET STRUCTURES

Reservoir Elevation (feet SPD)	1 Irrigation Release Tunnel (cusecs)	12 Turbines (3 Power Tunnels) (cusecs)	Total (cusecs)
1300	64,000	43,000	107,000
1332	69,000	49,000	118,000
1350	70,000	54,000	124,000
1400	78,000	65,000	143,000
1500	92,000	81,000	173,000

The inference that must be drawn from inspection of Tables A1–11 and A1–12 implies some modification of the basic IACA program described above. For, while the minimum drawdown level of 1332 feet will be sufficient to meet the irrigation releases of 84,000 cusecs that will be required in June of 1985, only a reservoir level of about 1450 feet will be sufficient to meet the irrigation releases of 156,000 cusecs that will be required in June of 2000. This is a situation which involves both the power and the agricultural benefits.

The advantages for power are discussed fully in subsequent supplements but a preliminary indication may be seen from an inspection of Tables A1–13 and A1–14, which show the effect of different minimum reservoir levels on the power capability and energy availability. This rough calculation indicates that the value to power of water retained in the reservoir is around $6 per acre-foot at the 1332 feet level and around $8 per acre-foot at the 1350 level. IACA has estimated the net addition to agricultural production attributable to Tarbela over the life of the project discounted at 8 percent to 1965. The resultant estimate of net production value per acre-foot of water stored in the project over its life is $17. This is clearly substantially greater than the figure for power estimated above. However, the IACA figure is an average value and does not indicate the marginal benefits attributable to the release, for irrigation purposes each year, of the 0.6/0.7 MAF lying between 1332 feet and 1300 feet.

The Study Group has attempted to measure the marginal values for power and for agriculture fairly precisely for the period 1975–85 of the 0.6/0.7 MAF lying between 1332 feet and 1300 feet. These analyses show quite clearly that advantage lies on the side of retaining the higher drawdown level at least during the first 10 years of the life of Tarbela. (See

TABLE A1–13

ILLUSTRATION OF EFFECT OF DIFFERENT DRAWDOWN LEVELS ON FIRM CAPABILITY OF TARBELA

(1985 conditions: 12 units installed)

Minimum Reservoir Level—feet	1300	1332	1350
Water Released from Storage—MAF	7.9	7.3	6.9
Difference from Minimum Level (1300)	0	0.6	1.0
Capability at Critical Period—mw	487	730	896
Increment	0	243	409
Annual Energy Available—million kwh	11,694	11,944	12,221
Useful Energy[a]—million kwh	6,833	7,063	7,294
Gain in energy—million kwh	0	230	461

[a] During July, August and September, the amount of usable energy is the same for all cases. If the potential energy generated in those months is omitted, it is estimated that the amounts which remain could all be used in the system.

TABLE A1–14

ILLUSTRATION OF EFFECT ON POWER BENEFITS FROM DIFFERENT DRAWDOWN LEVELS AT TARBELA

(US$ million equivalent)

Drawdown Level—feet	1332	1350
Incremental Gain in Capability (mw) over 1300 drawdown	243	409
Capital Construction Costs:		
alternative thermal generating plant	23.1	56.7
alternative transmission	5.0	12.4
Annual Costs:		
plant @ 8.58%	2.0	4.8
transmission @ 8.174%	0.4	1.0
operation and maintenance	0.3	0.6
fuel @ US¢ 30 per million Btu	0.8	1.5
Total Annual Value	3.5	7.9
Quantity of Water Retained in the Reservoir between 1300 feet and Drawdown Level (MAF)	0.6	1.0
Value of Power per acre-foot of Water Retained in the Reservoir	$5.8	$7.9

Supplemental Papers No. 6 and 7, Volume Three for further details.) The benefits to power of maintaining the higher drawdown level arise largely in the form of postponement of the need for further additions to generating capacity. Some benefit also arises in the form of reduced fuel costs due to the greater energy output of Tarbela in the critical period at the higher drawdown level. On the basis of its systems analysis, the Group finds that the savings to power which result from maintenance of the higher drawdown level over the period 1975–85 have a present-worth value at 8 percent in the neighborhood of $19 million. The exact size of this figure depends on a number of things, in particular the price attributed to thermal fuel in this period; since the Study Group feels that present prices tend to underestimate the true scarcity value of fuel that looks likely to prevail in the period 1975–85, it considers the $19 million a minimum estimate. The Group's linear programming analysis of agricultural investment suggests that the net benefits to agriculture that would arise from providing 0.6/0.7 MAF of rabi irrigation water over 1975–85, in addition to that available from Tarbela with a drawdown level of 1332 feet, also have a present worth value of the order of about $19 million. (See Sup-

TABLE A1-15
TARBELA: STORAGE CAPACITY IN MAF

Useful Storage Capacity above Level	Year		
	1975	1985	2000
1300	9.3	7.9	5.6
1332	8.6	7.3	5.5
1350	8.2	6.9	5.4
1400	6.7	6.1	5.0
1500	2.7	2.5	2.4

plemental Paper No. 4, Volume Three.) This makes the marginal value of small amounts of Tarbela water for agriculture and for power seem very close. However, in contrast to the power figure, the agricultural benefit figure must be considered a maximum. The value of an additional 0.6/0.7 MAF of rabi supplies in this period should really be considered in terms of the costs of making this water available by other means. By 1975, very substantial tubewell fields will be in existence and so large amounts of water could be made available by overpumping. Valued in these terms, i.e. the alternative cost of producing the same quantity of irrigation supplies over the period 1975–85, the water lying between 1300 feet and 1332 feet has a present worth value of about $11–$15 million. Since it will take some years after completion of Tarbela to achieve high agricultural benefits on marginal additions to the 7–8 MAF that will be available from Tarbela drawn down to 1332 feet and since, especially in the later years, there will be large possibilities of adding to irrigation supplies by temporary overpumping, the Study Group feels strongly that present evidence recommends a 1332 drawdown level at Tarbela over 1975–85.

Over the longer term, the relative merits of different drawdown levels will depend greatly on what additions to the power system and the surface storage system are made in the meantime or are in prospect. The loss of water to agriculture resulting from maintenance of a higher rather than a lower drawdown level will in fact fall considerably over the years as sedimentation reduces storage capacity. For instance, it is estimated that, by the year 2000, the loss of winter irrigation supplies resulting from maintenance of a drawdown level of 1350 feet rather than 1300 feet would be on the order of only 0.2 MAF (see Table A1–15). The fact that storage supplies available for irrigation will decline faster at lower than at higher drawdowns may mean that the use of Tarbela water for agricultural purposes should be reduced more rapidly than would physically have to be done as the direct result of sediment depleting the live storage capacity of the reservoir. This would emphasize the marginal analysis of storage utilization.

It may, in addition, become necessary over the years to maintain a higher minimum reservoir level, say up to 1450 feet, in order to permit adequate discharge through the outlet structures during the month of June. The Study Group has therefore concluded that a gradual raising of the minimum drawdown level at Tarbela from 1332 feet to perhaps 1350 feet or higher may very well yield substantial economic benefit, taking power and the value to agriculture of full June irrigation releases together, than operation at a permissible level of, say, 1300 feet. The Study Group would recommend that this preliminary conclusion be subjected to further detailed investigation.

Program for Construction

The Indus Basin Fund is at present financing the foreign exchange component ($13 million) of certain preliminary work to be undertaken in the period 1965–67, the total cost of which is estimated at $34.8 million equivalent. Costs incurred by WAPDA prior to this period, principally on initial site investigations, were approximately $19.5 million equivalent, of which $7.1 million involved foreign exchange. Work in progress in June 1967 included the following:

Construction of access road and railway to the project site.
Construction of an access bridge across the Indus downstream of the dam site.
Additional quarters and offices for WAPDA personnel.
Replacement of intake works for the right bank Pehur Canal, whose present intake will be blocked by construction of the dam.
Additional tunneling and core drilling on the right bank.

The project is intended to start impounding water, with a restricted retention level, towards the end of the flood season of 1974, so that a limited amount of storage may be available for the release period 1974/75. Impounding to top water level (1550 feet) is scheduled for 1975, with full use of storage during the release period 1975/76.

The main dam across the Indus will be constructed in three major stages, dictated by the river diversion problems, particularly during flood seasons. Construction work must have reached a definite point of completion of one stage for the next stage to proceed without an intolerable risk of severe damage by floods. The period of construction envisaged to the start of impounding is seven years. To complete the project, including the installation of the first four generating units, will take a further 18 months.

Stage I. A working area on the right bank of the river will be cofferdammed, inside which the diversion channel and buttress-type closure structure will be completed, and dam and blanket construction started. Excavated material will be stockpiled for future use. Cofferdams will be built around the power station and outlet tunnel stilling basins and work on the power station and tunnels commenced. Excavation for the spillways and drilling of relief wells at the toe of the main dam will start.

This stage is scheduled to take three years, leading up to diversion of the river into the diversion channel after the flood season of 1970. In view of the large amount of work involved, this part of the program is particularly critical.

Stage II. With the river diverted, cofferdams will be constructed across the river, inside which construction of the main dam and blanket can proceed. Work on the spillways and the right-bank dam and power station will continue and the tunnels will be substantially completed.

This stage is also scheduled to take three years, and will be completed after the flood season of 1973, when river flows are diverted from the diversion channel into the right-bank power and irrigation tunnels. Completion of the tunnels up to the state that they can be used for river diversion is the most critical factor during this stage.

Stage III. Following the closing of the gates in the buttress-type closure structure, the downstream end of the diversion channel will be cofferdammed, and the closure of the main dam across the channel commenced. To ensure its safety during the flood season of 1974, the schedule calls for the dam to be at least at elevation 1450 feet by that time. Rapid completion of the closure section is thus essential and is the most critical factor during this stage.

The substructure and superstructure for the first four units of the power station are scheduled for completion by July 1974. The first two generating units will be ready to run when penstock connections are completed and at the same time erection of the third and fourth units will be well advanced. If the dams have reached safe elevations and the spillways are completed by August 1, 1974, the plan is to close the two power tunnels (Nos. 1 and 2) and store water on the receding flood flow. Immediately following closure of these tunnels, tunnel No. 1 will be connected to the four units of the power station, the first two units of which are scheduled to be ready for commercial operation by June 1975.

Cost Estimates

Cost of the project as estimated during the first part of the Study, including the first eight generating units at 1964 prices and excluding Pakistan duties and taxes, was the equivalent of $739 million. Although minor changes may affect individual items, the Study Group sees no reason as this is written to alter the estimates, given in Table A1–16.

The project is physically adaptable to construction in more than one stage. The following estimates relating to a two-stage project, assuming that the dam would be constructed initially to impound water to an elevation of 1500 feet and would be raised subsequently to permit impounding to elevation 1550 feet, are based on information obtained from TAMS by the dam site consultant.

As indicated in the first phase of the Indus Study, the construction of Tarbela by stages would be relatively costly and not economically viable. This position was confirmed by the more detailed studies of the Comprehensive Basin Study on the basis of the rate of growth of the demand for stored water as projected by IACA.

TABLE A1-16
ESTIMATED COST OF THE TARBELA PROJECT[a]
(US$ million equivalent)

	Total		Foreign Exchange	
Reservoir Works				
Precontract Costs[b]	16.5		4.7	
Net Contract Costs	414.4		284.0	
Contingencies (20%)	86.2		57.7	
Engineering and Administration	36.2		30.0	
Insurance and Miscellaneous	9.0		9.0	
Performance Bond	4.0		4.0	
Land Acquisition and Resettlement	59.0		-	
		625.3		389.4
Power Facilities (Units 1 to 8 inclusive)				
Civil Engineering Works	55.1		35.7	
Contingencies (20%)	11.0		7.1	
Mechanical and Electrical Equipment	35.6		31.7	
Contingencies (10%)	3.6		3.2	
	105.3		77.7	
Engineering and Administration	8.4		7.0	
Total units 1 to 8		113.7		84.7
Reservoir Works	625.3		389.4	
Power Facilities	113.7		84.7	
Estimated total project cost including first 8 units	739.0		474.1	

[a] As stated in the text, the costs are for the purposes of economic analysis and comparison and exclude provision for inflation, financial contingencies, Pakistan duties and taxes and interest during construction, etc. They do not, therefore, represent a full assessment of the financial resources that might be required to carry out the project (see Chapter VII).

[b] Excluding costs incurred prior to January 1965.

TABLE A1-17
ESTIMATED COST OF PHASED CONSTRUCTION OF THE TARBELA PROJECT: RESERVOIR FEATURES ONLY
(US$ million equivalent)

Cost of initial Tarbela, FSL 1500	588
Cost of subsequent raising for FSL 1550	64
Cost of two-stage Tarbela	652
Cost of single-stage Tarbela	625

B. SIDE-VALLEY PROJECTS ASSOCIATED WITH TARBELA

In recognition of the high rate of depletion of storage capacity at Tarbela, various proposals have been put forward by the Pakistan authorities for auxiliary (side-valley storage) reservoirs on the Haro and Soan Rivers which would be filled by the diversion of Indus River waters through canals from Tarbela Reservoir. It has been indicated that the potential capacity of reservoirs on these rivers is in excess of 30 MAF. A study of the proposals, however, suggests that the costs of dams, considered in connection with the cost of conveyance canals, would make construction of side-valley storage projects as expensive as reservoirs on the main stem of the Indus.

For any such undertakings, Tarbela would have to be built to elevation 1565 feet in order to facilitate the transference of water across the divide. Also, because diversions would be possible only when the Tarbela Reservoir might be full or nearly full, it would be necessary to fill Tarbela as soon as possible each flood season. This would provide sufficient time to fill the side-valley reservoirs before drawdowns for irrigation. Three potential side-valley projects, Gariala, Dhok Pathan and Sanjwal-Akhori, were studied in detail by the dam site consultant and discussed in an earlier Tarbela Report. A summary of the results is described in the following paragraphs.

The Gariala Site

For side-valley storage on the Haro River, the dam site consultant came to a conclusion that an earth dam at the Gariala site would provide the most suitable solution. Such a dam would be about 375 feet high and have a crest length of 40,000 feet. It would contain about 189 million cubic yards of embankment materials. The normal high water elevation behind the dam would be 1250 feet and, with a minimum drawdown level of 1020 feet, would provide a live reservoir capacity of 8.0 MAF. This would be filled in a mean year by diverting 7.6 MAF from Tarbela Reservoir, the Haro River itself contributing 0.4 MAF to storage.

To convey the Indus water from Tarbela to Gariala, a canal some five miles long, with a capacity of 76,000 cusecs, would be constructed from the Siran arm of the Tarbela Reservoir to the Jabba Kas River, a tributary of the Haro (see Map I.5). Few details are known of the geology of the area through which the canal would pass, but the entire length is expected to be in easily excavated, water-deposited silt and sand, with bedrock generally well below invert grade. A control and drop structure at the end of the canal would be required to regulate the releases of water into the Jabba Kas down which it would flow to the Gariala Reservoir.

Four reinforced concrete conduits, 26 feet in diameter, used to divert the flows of the Haro River during construction, would provide the necessary water release capacity for operation of the reservoir. These conduits would be the only water release structures and would, when operating at full discharge, be used in conjunction with the capacity of the reservoir between full supply level and the design-flood freeboard on the dam, to deal with the assumed peak flood inflow of 386,000 cusecs. An emergency spillway would be provided. The consultant's studies indicate that this arrangement would be the most economical.

The installation of turbines at the downstream end of the release structures would permit the generation of power, but only during the storage release period. Because there would be no discharge for several months of the year, the dam site consultant did not carry out detailed studies to determine what the optimum installation might be, but as a matter of judgment decided that three of the four release tunnels might each serve

TABLE A1-18
POSSIBLE COST OF A DAM AT GARIALA[a] WITH CONVEYANCE CANALS
(US$ million equivalent)

	Total		Foreign Exchange	
Conveyance System				
Precontract Costs	3.5		2.4	
Net Contract Costs	86.0		59.7	
Contingencies	26.6		18.8	
Engineering and Administration	9.2		6.5	
Insurance and Miscellaneous	1.9		1.9	
Performance Bond	0.9		0.9	
Land Acquisition and Resettlement	0.4		-	
Subtotal		128.5		90.2
Gariala Dam				
Precontract Costs	11.9		8.7	
Net Contract Costs	295.5		212.9	
Contingencies	91.5		66.8	
Engineering and Administration	31.7		23.1	
Insurance and Miscellaneous	6.6		6.6	
Performance Bond	3.0		3.0	
Land Acquisition and Resettlement[b]	82.4		-	
Subtotal		522.6		321.1
Total		651.1		411.3

[a] Excluding power facilities.
[b] The town of Campbellpore, site of a large military cantonment, would be inundated by the reservoir: the cost of relocation of the facilities and resettlement of the people, as estimated by WAPDA, is included.

two generating units. Each unit would have a rating of 85 mw with a capability for sustained overload of 15 percent. Since the main question is whether any installation could be justified, further studies do not appear warranted at this time.

Basic data for the preparation of feasibility designs and cost estimates are presently limited. Information available to the consultant has consisted of 1:15,000 scale topographic maps, G.T. sheets of the area at a scale of one inch to one mile, air photographs and one generalized, unsurveyed, geological cross section of the dam site. No subsurface explorations have been made or detailed mapping carried out to date.

The dam site consultant, on the basis of a desk study, estimated that a project of the scale envisaged would cost the equivalent of $651 million, made up as in Table A1–18. The estimate given is the best that can be prepared at this time. In view, however, of the lack of necessary engineering data it indicates no more than an order of magnitude. For reasons previously stated the Group has assumed that, although the consultant's cost estimate of about $650 million was a reasonable start for planning purposes, should unforeseen difficulties and serious problems arise, the costs could rise to the order of $975 million.

The consultant appraised the feasibility of phasing the construction at Gariala, on the assumption of an initial live storage of 4.6 MAF, which would be increased subsequently to 8.0 MAF by raising the dam. Two-stage development, however, would cost some $28.6 million more than construction under a single contract. The reduction in initial investment cost was estimated to be $54.9 million.

The Dhok Pathan Site

In the course of the earlier Tarbela investigations, as an alternative to side-valley storage on the Haro River, consideration was given to storage on the Soan River and, for this, a site at Dhok Pathan appeared particularly attractive (see Map I.5). The project envisaged is shown in Figure A1–9, although the canal and pumping/power plant indicated relate to a pumped storage project which might be associated with the Kalabagh Project. Study was also made of an alternative site at Dhok Abbaki with the possibility of a similar development in mind. Details are incorporated in the report on the first part of the Study and a summary of the results is described in subsequent paragraphs. The Makhad dam site, some 30 miles downstream from Dhok Pathan, would be inundated by the possible future development of a reservoir at Kalabagh.

The dam at Dhok Pathan envisaged by the consultant would be an earth and rockfill structure, some 275 feet high, with a crest length of about 12,000 feet, containing about 38,000,000 cubic yards of fill material. The normal top water level of the reservoir would be at elevation 1225 feet which, with a minimum drawdown to 1110 feet, would provide a usable live storage capacity of about 7.5 MAF. Two 30-foot diameter conduits, to be used for diversion during construction would be provided at the right abutment to serve as water release outlets. The conduits could also be used as power penstocks in the event that the installation of generating units became justified. The design flood of 560,000 cusecs, with a total inflow of 1.66 MAF and outlets discharging to full capacity, would raise the reservoir level by 14 feet. Since the provision of this freeboard would be cheaper than a service spillway, the consultant concluded that only an emergency spillway would be needed to prevent overtopping in the event of a catastrophic flood.

To convey water from Tarbela to Dhok Pathan Reservoir, three parallel canals, each about 70 miles long, with a combined capacity of 76,000 cusecs, would be required along with ancillary structures, including dams, syphons, aqueducts and culverts. The canals would traverse several different types of terrain, including sandy, silty alluvium, limestone, sandstone and shales. The most important ancillary structure would be a dam at Bahtar, where the canal alignment crosses the Nandna Kas. This dam would add about 0.8 MAF of useful storage to the project and involve about 44 million cubic yards of fill. The operation of the conveyance system would be complicated by the fact that it would be empty for some nine months in each year. Maintenance costs would be particularly heavy. Further studies would appear essential to confirm operational feasibility.

The engineering and geological data available to the dam site consultant for study of the project was very scant, consisting of a prefeasibility report dated 1957, a geological map to a scale of 1:4,800 based on field investigations carried out in 1960 supplemented by two boreholes, and a geological report dated 1964. Special topographic maps of the area of the proposed reservoir and canal routes thereto at a scale of 1:15,000 and

TABLE A1-19
POSSIBLE COST OF A PROJECT AS DESCRIBED AT DHOK PATHAN
(US$ million equivalent)

		Total	Foreign Exchange
Conveyance Structure			
Precontract Costs	14		
Construction Costs[a]	700		
Land Acquisition and Resettlement	8		
Subtotal		722	476
Bahtar Dam			
Precontract Costs	3		
Construction Costs[a]	135		
Land Acquisition and Resettlement	3		
Subtotal		141	92
Dhok Pathan Dam			
Precontract Costs	5		
Construction Costs[a]	218		
Land Acquisition and Resettlement	45		
Subtotal		268	149
Total Project Costs		1,131	717

[a] Including an allowance of 30 percent for contingencies and 8 percent for engineering and administration.

contour intervals of 10 feet were made for the Study to aid in preliminary design. The consultant's order-of-magnitude estimate of cost (Table A1–19) has been prepared on the same basis as the estimate for Gariala and, in the light of the present very limited knowledge of the two sites, it appears that Dhok Pathan would cost considerably more than Gariala.

The power output of a development at Dhok Pathan would be negligible for a considerable period of the year when no releases of stored water could be made. It was the opinion of the consultant that an installation of six 75-mw units might be possible, provided the storage release patterns were found compatible with the pattern of electrical demand.

THE SANJWAL-AKHORI SITES

To check whether a project involving a dam at Sanjwal-Akhori locations on the Haro River and its tributary, the Nandna Kas, might be developed to serve as an alternative to a high dam at Gariala, or perhaps to supplement the storage created by a low dam at the same place, the consultant made a preliminary study of structures that would impound 3.3 MAF of water (see Map I.5). A detailed discussion of this project was also incorporated in the earlier Tarbela Report. In the course of that evaluation it became evident that an inordinate amount of earth moving would be involved and that serious foundation problems would be encountered at each site. Cut off grouting would be required along the axis of Sanjwal Dam, the embankment of which would be 12.5 miles long, and extensive treatment would also be required at Akhori. In view of this and other considerations, the project was deemed less favorable than Gariala.

TABLE A1–20

TARBELA DAM

ESTIMATED CONTRACT COSTS FOR ECONOMIC ANALYSIS

(Pakistan taxes, duties, etc., excluded)

Cofferdam Stage	Work Item	Unit	Quantity	Unit Price $	Unit Price Rs	Item Total $	Item Total Rs	Total Equivalent $
	CONTRACT COSTS							
	DIVERSION & CARE OF WATER							
	Steel Cellular Cofferdams	L.S.				2,324,400	4,457,700	
	Cofferdams	c.y.	720,000	.7638	1.0425	549,900	750,578	
1	Excavation, Common, Channel	c.y.	10,165,000	.4695	.6747	4,773,077	6,858,326	
	Excavation, Rock, Channel	c.y.	5,936,000	1.1135	2.3344	6,610,210	13,857,054	
	Concrete, Diversion Structure	c.y.	325,100	15.14	55.35	4,923,639	17,995,584	
	Appurtenances, Diversion Structure	L.S.				8,554,000	14,242,800	
	Cofferdams	c.y.	1,020,000	.7637	1.0424	779,025	1,063,319	
2	Excavation, Common, Channel (plugs)	c.y.	2,429,000	.4696	.6747	1,140,560	1,638,846	
	Excavation, Rock, Channel (plugs)	c.y.	334,000	1.0144	2.2708	338,806	758,460	
	Excavation, Common River Alluvium	c.y.	2,200,000	.7379	1.0060	1,623,336	2,213,354	
3	Borrow Area Spoil	c.y.	3,450,000	.1040	.1560	358,800	538,200	
	SUBTOTAL					31,975,753	64,374,221	45,499,749
	EMBANKMENT & BLANKET							
	Abutment & Foundation Preparation Embankment	L.S.				2,090,400	10,692,240	
1	Contact & Foundation Preparation Blanket	L.S.				213,200	751,400	
	Pervious Zones	c.y.	11,538,000	.0390	.1170	449,982	1,349,946	
&	Impervious Zones	c.y.	1,271,000	1.1618	1.4314	1,476,658	1,819,346	
	Transition Zones	c.y.	537,000	.4810	.6630	258,297	356,031	
2	Drainage Blanket	c.y.	422,000	.0390	.1170	16,458	49,374	
	Impervious Blanket	c.y.	5,565,000	1.0874	1.4339	6,051,611	7,979,748	
	Abutment & Foundation Preparation Embankment	L.S.				2,090,400	10,692,240	
	Contact & Foundation Preparation Blanket	L.S.				1,309,100	4,616,300	
	Pervious Zones	c.y.	64,395,000	.0952	.1918	6,133,484	12,351,352	
	Impervious Zones	c.y.	8,722,000	.9517	1.3035	8,300,987	11,369,212	
	Transition Zones	c.y.	1,798,000	.5131	.7223	922,651	1,298,684	
	Drainage Blanket	c.y.	1,460,000	.0390	.1170	56,940	170,820	
	Impervious Blanket	c.y.	17,471,000	.7358	1.0319	12,855,160	18,029,022	

3	Foundation & Preparation Embankment	L.S.				1,135,560	5,717,140	
	Pervious Zones	c.y.	18,685,000	.5326	.7600	9,952,348	14,200,034	
	Impervious Zones	c.y.	2,158,000	1.0050	1.3399	2,168,853	2,748,168	
	Transition Zones	c.y.	540,000	.4810	.6630	259,740	358,020	
	Impervious Blanket	c.y.	692,000	1.2296	1.5013	850,930	1,038,947	
4	Abutment Preparation Embankment	L.S.				325,000	1,731,600	
	Pervious Zones	c.y.	17,982,000	.5642	.8088	10,146,578	14,543,577	
	Impervious Zones	c.y.	2,249,000	1.1511	1.4215	2,588,935	3,197,064	
	Transition Zones	c.y.	350,000	.4810	.6630	168,350	232,050	
	Waste	c.y.	1,000,000	.4955	.7257	495,560	752,700	
	SUBTOTAL					70,317,182	126,045,015	96,797,227
	AUXILIARY EMBANKMENTS							
	Excavation, Common & Rock	c.y.	7,639,000	.5922	.9276	4,524,227	7,086,058	
	Abutment & Foundation Preparation	L.S.				1,287,000	8,009,300	
	Cutoff at Upstream End Impervious Blanket	L.S.				89,700	470,600	
	Pervious Zones	c.y.	13,088,000	.4631	.7133	6,060,528	9,335,800	
	Impervious Zones	c.y.	2,305,000	1.1758	1.4189	2,592,678	3,128,784	
	Transition Zones	c.y.	599,000	.4810	.6630	288,119	397,137	
	Impervious Blanket	c.y.	3,380,000	.9778	1.2335	3,305,105	4,169,262	
	Waste	c.y.	2,140,000	.4955	.7527	1,060,498	1,610,778	
	SUBTOTAL					19,207,855	34,207,719	26,394,350
	SERVICE SPILLWAY (LEFT BANK)							
	Excavation Common	c.y.	38,933,000	.5717	.8016	22,258,298	31,207,801	
	Excavation Rock	c.y.	12,803,000	1.0568	2.5405	13,529,883	32,525,782	
	Foundation Preparation & Misc. Items	L.S.				4,134,000	9,328,800	
	Concrete	c.y.	659,700	12.42	51.38	8,190,175	33,892,747	
	Crest Gates and Hoist	L.S.				1,561,300	1,149,200	
	SUBTOTAL					49,673,656	108,104,330	72,384,650
	AUXILIARY SPILLWAY (LEFT BANK)							
	Excavation, Common	c.y.	400,000	.7072	1.0465	282,880	418,600	
	Excavation, Rock	c.y.	1,970,000	1.1807	2.6773	2,325,900	5,274,378	
	Foundation Preparation & Misc. Items	L.S.				1,821,300	4,748,900	
	Concrete	c.y.	481,500	12.61	51.18	6,071,715	24,643,651	
	Crest Gates and Hoists	L.S.				2,007,200	1,478,100	
	SUBTOTAL					12,508,995	36,563,629	20,190,429

(Continued)

TABLE A1-20 (Continued)

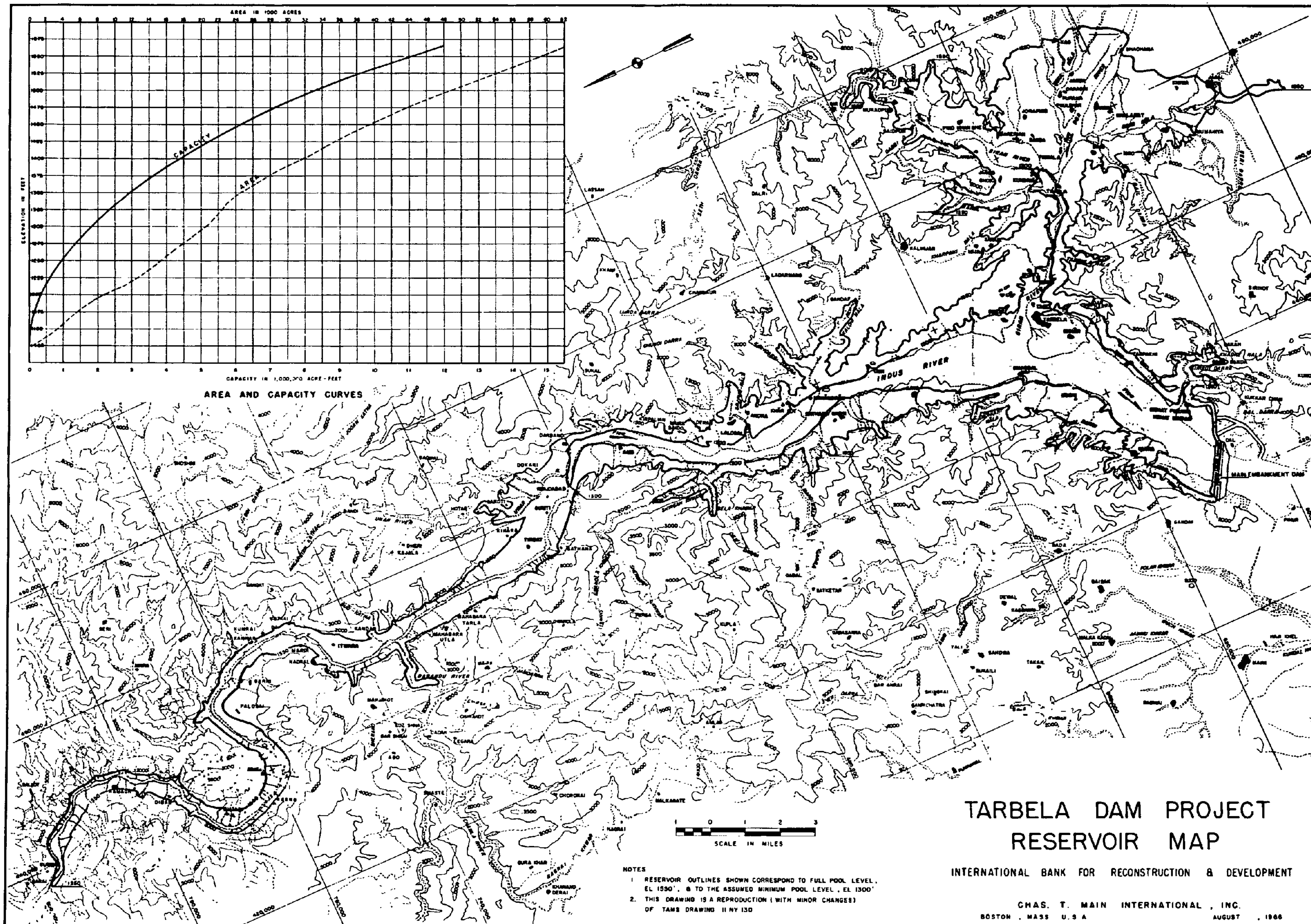
Cofferdam Stage	Work Item	Unit	Quantity	Unit Price $	Unit Price Rs	Item Total $	Item Total Rs	Total Equivalent $
	DIVERSION AND IRRIGATION TUNNELS AND PROVISIONS FOR FUTURE POWER							
	Excavation, Open Cut, Inlet, Common	c.y.	199,000	.7678	.9422	152,785	187,514	
	Excavation, Open Cut, Inlet, Rock	c.y.	6,171,000	1.2974	2.8761	8,006,090	17,748,534	
	Excavation, Open Cut, Outlet, Common	c.y.	1,255,000	.7661	.9395	961,442	1,179,084	
	Excavation, Open Cut, Outlet, Rock	c.y.	3,596,000	1.2995	2.8761	4,672,929	10,342,527	
	Excavation, Tunnels	c.y.	822,000	12.40	24.75	10,193,586	20,343,570	
	Excavation, Shafts, Open Cut	c.y.	46,000	.7995	.9947	36,777	45,758	
	Excavation, Shaft	c.y.	162,000	18.59	37.09	3,011,580	6,008,418	
	Concrete Tunnel Lining & Shafts	c.y.	541,200	15.71	56.28	8,499,005	30,457,112	
	Concrete in Intakes	c.y.	337,000	21.23	74.91	7,154,173	25,243,322	
	Concrete in Outlets and Stilling Basins	c.y.	826,200	11.79	48.46	9,741,724	40,040,957	
	Steel Liners	lbs.	33,408,000	.2795	.3602	9,337,536	12,030,220	
	Gates and Hoists	L.S.				7,697,300	6,185,400	
	Grouting and Drainage	L.S.				1,560,000	9,903,400	
	Foundation Preparation & Misc. Items	L.S.				14,836,200	26,283,100	
	SUBTOTAL					85,861,127	205,998,916	129,138,210
	CONTRACT COSTS					269,544,568	575,293,830	390,404,615

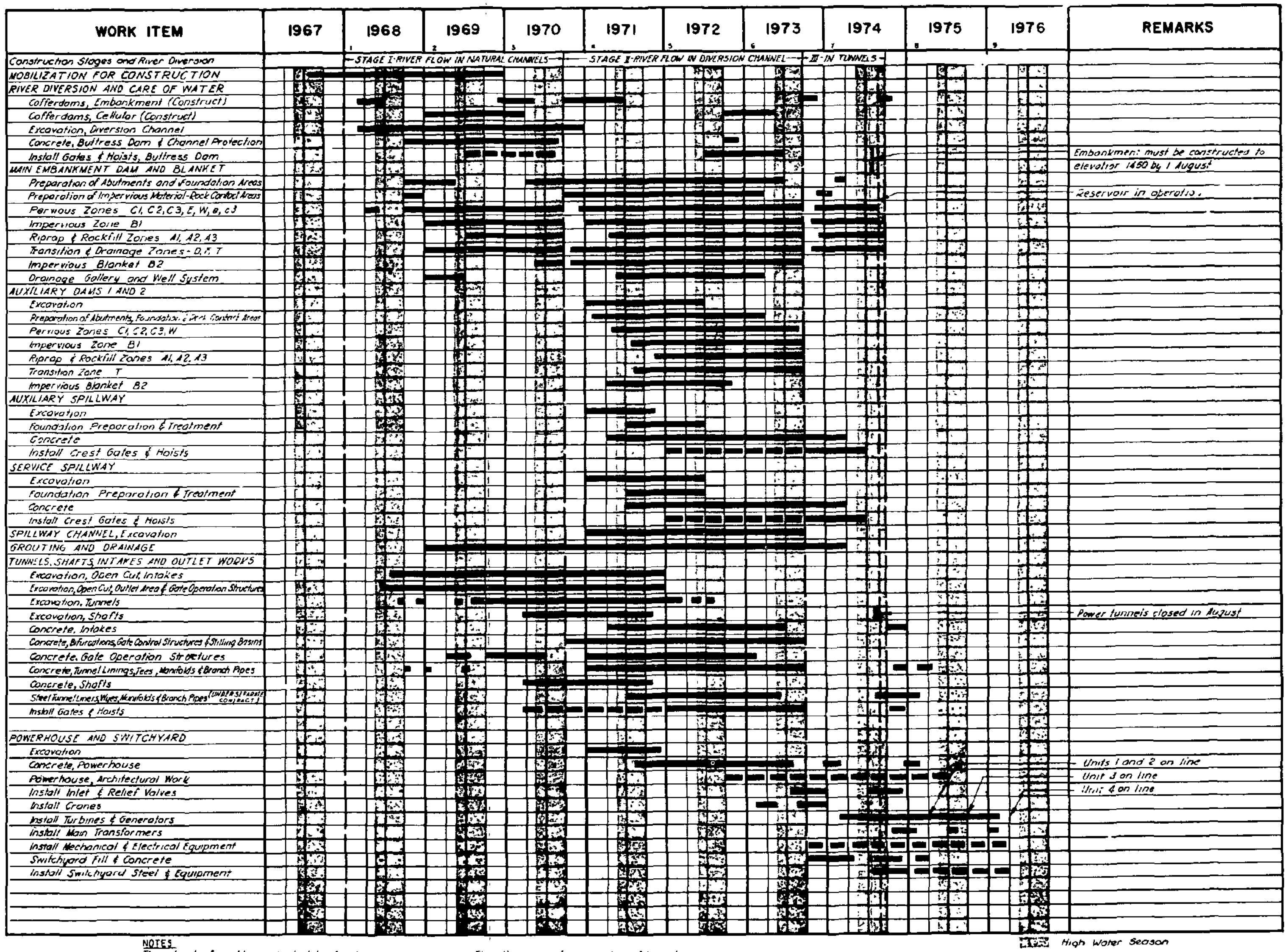
[a] Contract Costs include a markup of 30% to cover indirect costs (see text). July 1964 costs, prices, wage rates and general conditions assumed to prevail for duration of job.

TABLE A1-21
TARBELA DAM COST ESTIMATE FOR ECONOMIC ANALYSIS

	Foreign Exchange $	Total Cost Equivalent $
1. Precontract Costs	4,700,000	16,490,000
2. Contract Costs	269,545,000	390,404,615
3. Precontract Plus Contract Costs (Main—Tarbela Report)	274,245,000	406,894,615
Direct Costs	(210,957,700)	(312,995,858)
Indirect Costs (30% of direct)	(63,287,300)	(93,898,757)
4. Adjusted Precontract Plus Contract Costs (IBRD—Tarbela Report)		
Direct Costs (main)	210,957,700	312,995,858
Additional Direct Costs		
Excavation and Fill	5,190,000	7,700,000
Concrete	1,550,000	2,300,000
	6,740,000	10,000,000
Adjusted Direct Costs	217,697,700	322,995,858
Indirect Costs (main)	63,287,300	93,898,757
Additional Indirect Costs	9,435,900	14,000,000
Adjusted Indirect Costs (33.4% of direct)	72,723,200	107,898,757
Direct Plus Indirect Costs (adjusted)	290,420,900	430,894,615
Use		(430,900,000)
Precontract Costs (after May 1966)	4,700,000	16,500,000
Contract Costs	284,000,000	414,400,000
5. Contingencies (20% of 4.)	57,700,000	86,200,000
6. Precontract Costs, Contract Costs and Contingencies	346,400,000	517,100,000
7. Engineering and Administration (7% of 6.)	30,000,000	36,200,000
8. Insurance & Miscellaneous Plus Performance Bond (2.52% of 6.)	13,000,000	13,000,000
Insurance and Miscellaneous	(9,000,000)	(9,000,000)
Performance Bond	(4,000,000)	(4,000,000)
9. Land and Resettlement (WAPDA)	—	59,000,000
10. Total (6 + 7 + 8 + 9)	$389,400,000	$625,300,000
Use	$390,000,000	$625,000,000

NOTE: The total cost here excludes Pakistan taxes, duties, etc., estimated to be U.S. $106.9 million, equivalent, and interest during construction estimated at 6%, to be $215.1 million equivalent, with foreign exchange component of U.S.$138.6 million equivalent.


AREA IN 1000 ACRES
ELEVATION IN FEET
CAPACITY
AREA
CAPACITY IN 1,000,000 ACRE-FEET
AREA AND CAPACITY CURVES
INDUS RIVER
MAIN EMBANKMENT DAM
SCALE IN MILES
NOTES
1. RESERVOIR OUTLINES SHOWN CORRESPOND TO FULL POOL LEVEL, EL 1550', & TO THE ASSUMED MINIMUM POOL LEVEL, EL 1300'
2. THIS DRAWING IS A REPRODUCTION (WITH MINOR CHANGES) OF TAMS DRAWING 11 NY 130
TARBELA DAM PROJECT
RESERVOIR MAP
INTERNATIONAL BANK FOR RECONSTRUCTION & DEVELOPMENT
CHAS. T. MAIN INTERNATIONAL, INC.
BOSTON, MASS U.S.A
AUGUST, 1966



NOTES
The estimate of quantities and schedule of work shown on this drawing are given only to assist the Contractor in planning the work and are not contractual obligations except as follows:

1. The Indus River must be diverted from the natural channels into the right bank diversion channel at the date shown.
2. The gates of the buttress dam must be closed and Indus River waters diverted through the tunnels at the date shown.
3. Stage III embankment must be constructed to El. 1450 by the date shown.
4. The diversion closure gates of tunnels 1 & 2 must be closed at the date shown.
5. Powerhouse generating units must be on the line at the dates shown.

NOTE
SCHEDULE REPRODUCED FROM TAMS DWG II NY 1000 (UNDATED, RECEIVED FROM TAMS APRIL 27, 1966)

TARBELA DAM PROJECT

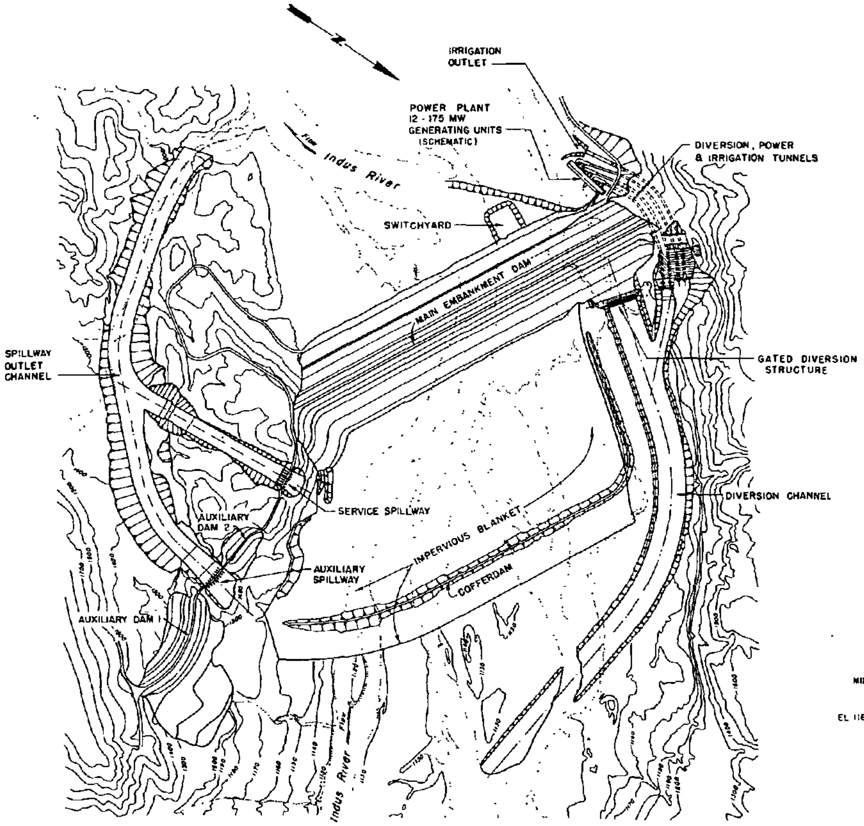
TENTATIVE CONSTRUCTION SCHEDULE

SUMMARY

TARBELA DAM PROJECT
PLAN & SECTIONS

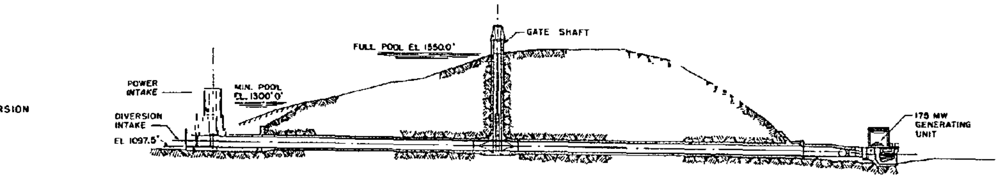
CHAS. T. MAIN INTERNATIONAL INC.
BOSTON, MASS. U S A AUGUST, 1966

SOURCE OF DATA -
JANUARY, 1964 DRAWINGS - WEST PAKISTAN WATER & POWER DEVELOPMENT AUTHORITY - TARBELA DAM PROJECT - CONSULTING ENGINEERS - TIPPETS - ABBETT - MC CARTHY - STRATTON INTERNATIONAL CORP (TAMS) - GHAZI, HAZARA DISTRICT, WEST PAKISTAN & LATER REVISIONS OBTAINED FROM TAMS, N.Y.C.

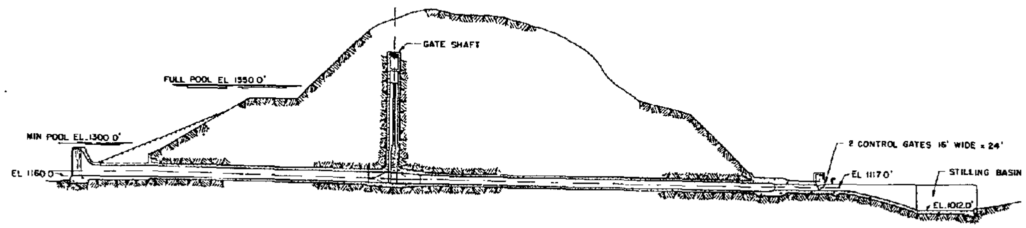


PLAN

1000 0 1000 2000
SCALE IN FEET

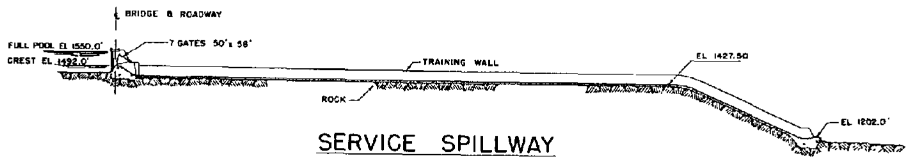


DIVERSION & POWER TUNNEL

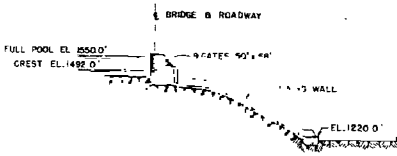


IRRIGATION RELEASE TUNNEL

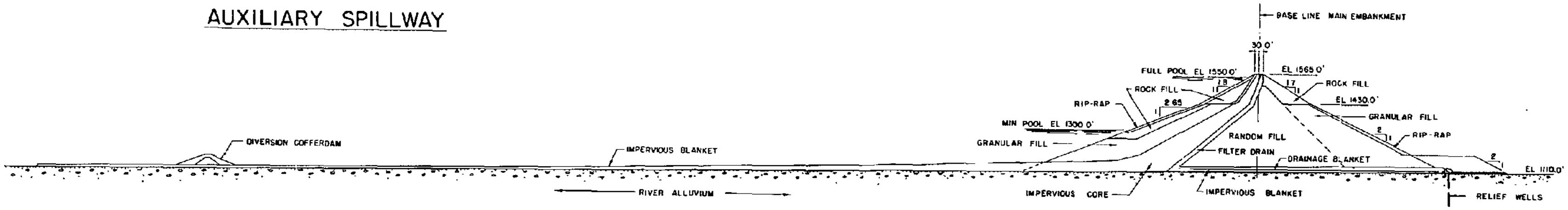
200 0 200 400
SCALE IN FEET



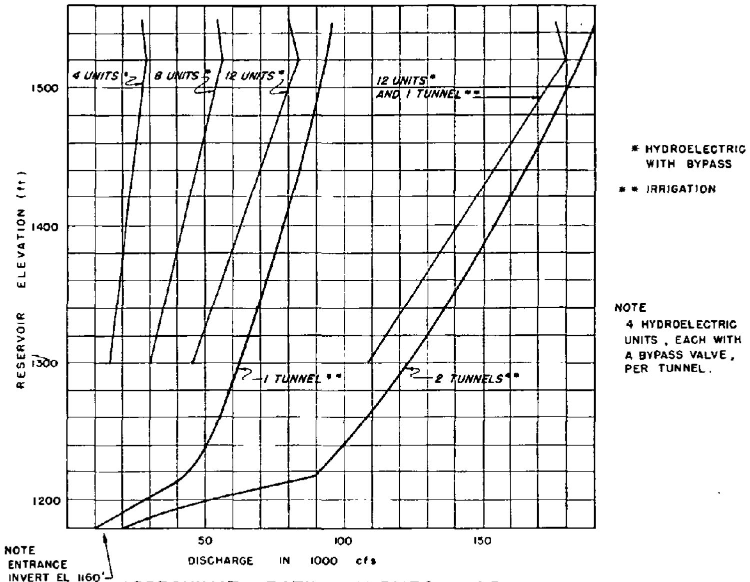
SERVICE SPILLWAY



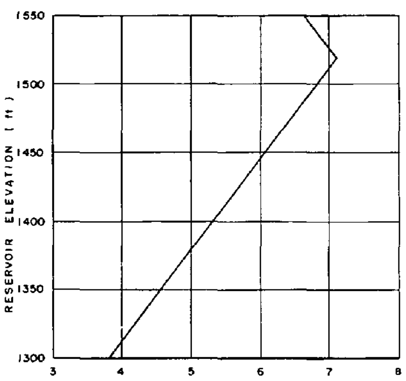
AUXILIARY SPILLWAY



SECTION OF MAIN EMBANKMENT & IMPERVIOUS BLANKET

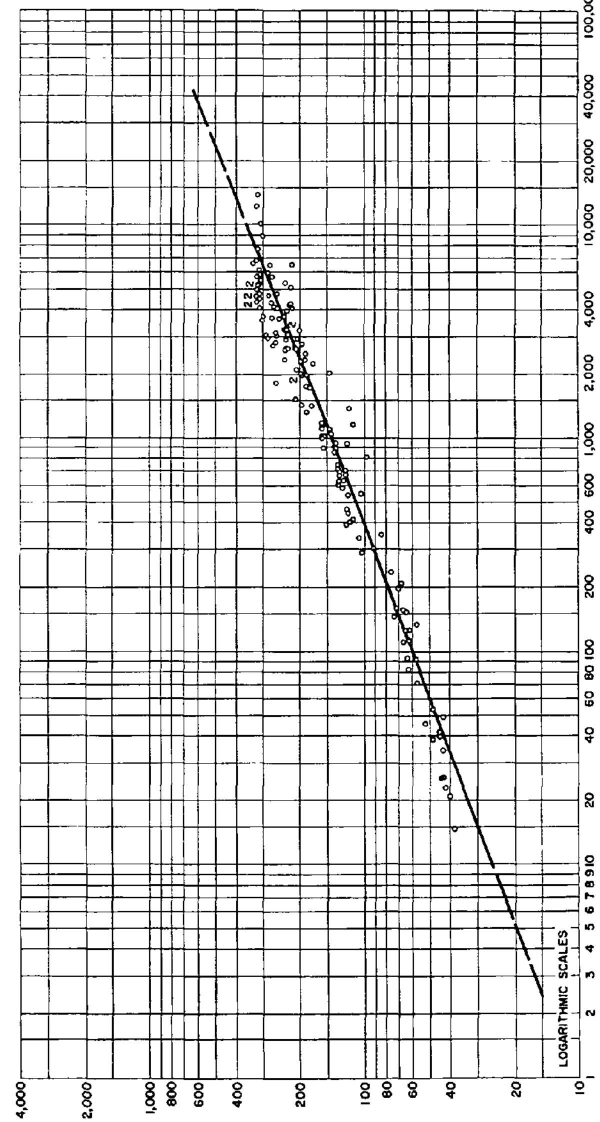


APPROXIMATE RATING CURVES FOR TUNNELS



APPROXIMATE RATING CURVE
FOR ONE HYDROELECTRIC UNIT

TARBELA DAM PROJECT OUTLET RATING CURVES
CHAS T MAIN INTERNATIONAL INC BOSTON, MASSACHUSETTS U.S.A.
DATE AUGUST, 1966



ESTIMATED AVERAGE SEDIMENT TRANSPORT OF INDUS RIVER AT DARBAND*

*Based on the year 1961 as confirmed by measurements 1962-1964 From TAMS drawing 15NY500

AMBAHAR

The existing data available for studying Ambahar Project are completely inadequate for preparing designs, determining the economic size of structure and for preparing accurate cost estimates. Means of access will require special study. Chas. T. Main proposes that hydrographic work started in the river basin should be continued and expanded. The flows of the Swat River at Amandara headworks and the diversions to the Upper Swat Canal need to be known more accurately. Discharge measurements of the Panjkora River should be continued. Discharge measurements should be taken accurately and systematically at the Munda headworks and at the confluence of the Kabul and Swat Rivers. Accurate measurements of all canal diversions from the river from Amandara headworks downstream to the mouth of the Swat River are required. Systematic studies of the areas being served by the several canal commands should be made periodically to update estimated future needs for surface water when the lands are brought to full development.

Investigations should be carried out to the extent necessary to select the optimum site for storage in the Lower Swat Gorge; then that site should be investigated sufficiently to determine its feasibility. Studies should cover the complete range of reservoir sizes likely to be needed, including study of storage space for imported water. The preliminary investigations should include study of surface geology of the site supplemented by subsurface explorations as needed to define fully the problems of design. Sources of materials should be located. Studies should include consideration of the site selected for various types of dam structures.

Other dam sites should be investigated to the extent necessary to identify those justifying further exploration. In every case, however, before the site itself is studied in detail, and certainly before any considerable program of subsurface exploration is commenced, it will be desirable to give thorough consideration to the problem of access. This will be best accomplished by a ground reconnaissance party, sent to explore the possibility of the route close to the river but above maximum flood level. If the preliminary investigation and study of alternative approaches reveal that access costs are likely to be reasonable, more detailed investigations may be justified.

Chas. T. Main has recommended that investigations be made to determine the depth and character of overburden at all dam sites selected for more detailed study. Test pits should be dug and borings made to determine potential sources of materials for construction and to provide estimates of quantities of materials available. Detailed studies should be made of the inhabited land affected by the project, of potential lands in the area that may be developed for relocating the people affected, and of the effects the project will have on the economy of the region.

GENERAL CONSIDERATIONS AND CONCLUSIONS

Although the proposals for investigation are considerable, it is reemphasized that initially the full program for each site is not required.

Sufficient work should be done to confirm the immediate order of development and then the detailed program for each site should be started some four to five years before construction is scheduled to begin.

The program of general investigation, however, should be a continuing one. In particular, in the upper reaches of the Indus River and its tributaries, a great deal of investigation and exploration remains to be done. The scant literature of the area and a few superficial observations suggest that some tributaries are heavily silt laden even at times of the year when others flow relatively clear. These reports require confirmation and explanation. If some tributaries contribute a disproportionate element of the silt load of the Indus, means should be investigated to reduce the load. Any measurable reduction in the rate of siltation at Tarbela would justify considerable effort.

As soon as it is established that a particular project is feasible and likely to be constructed in the foreseeable future, steps should be taken to curb development in the area, so that unnecessarily expensive compensation is avoided. Such arrangements would involve a notification to Government departments and other agencies that might have plans for the area, e.g., Buildings and Roads Department, West Pakistan Railway, etc., and possibly legislation to stop or at least restrict private development.

Chas. T. Main recommended that WAPDA be assigned the task of collecting and analyzing the data needed to implement the development program. The Study Group concurs in this suggestion. Specifically, the Surface Water Circle should establish the new gauging stations and intensify measurements at the existing stations. The systematic collection of other data required in the Upper Indus region, such as glacier and snow course observations, and vigilance for landslides, should begin. An engineering group should be established to develop flow forecasting procedures and to study sediment control and the operation of the present and future system of reservoirs for optimum benefits. Procedures for surveying and determining rates of sedimentation in reservoirs should be established. Investigations of proposed storage sites should be undertaken to permit the preparation of preliminary designs and cost estimates sufficient to confirm the general feasibility of the sites.

The success of the tubewell programs and the efficient operation of the irrigation systems are of paramount importance. It is worthy of note that a 3 percent improvement in the efficiency of the delivery of water at the watercourse would be equivalent to half of one major dam project. Likewise, two tubewell projects equivalent to SCARP I yield at the watercourse the water equivalent of a major dam project. For this reason, the search for improvements in operation of existing and new works must also have a place in the program.

The findings of all investigations and the conclusions of all studies will require assessment in relation to the Master Planning being conducted by WAPDA. It is recommended that this planning should continue; though once the broad framework has been established, it should be fairly straightforward to take account of the results of investigations.

Over the next eight years, the cost of implementing these proposals for investigations is estimated to average about $2.5 million a year, of which

TABLE A2–1
PRELIMINARY SCHEDULE OF COSTS OF INVESTIGATION PROGRAM FOR SURFACE WATER STORAGE
(US$ million equivalent)

	1967/ 1968	1968/ 1969	1969/ 1970	1970/ 1971	1971/ 1972	1972/ 1973	1973/ 1974	1974/ 1975	Total
Collection of Basic Data (hydrological, meteorological, etc.)	0.5	0.7	0.7	0.8	0.8	0.8	0.8	0.8	5.9
Identification of Second Stage Storage	1.0	1.5	1.5	1.0	0.5	–	–	–	5.5
Detailed Investigation of Second Stage Storage	–	–	–	0.5	1.0	2.0	2.0	2.0	7.5
Master Planning	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.2	2.0
	1.9	2.5	2.5	2.5	2.5	3.0	3.0	3.0	20.9

about a third would be devoted to the general program of basic data collection planning and two-thirds to the study of specific projects. A preliminary schedule of costs is given in Table A2–1. It may take a year or two to recruit and train the size of staff required for the investigations; some of the work involves special skills. The preparation of records of work done is a vital part of the investigations and information must be retained in the state that will permit intelligent study by others in the future. Once the team is established, it is essential to maintain the impetus and not to lose the experience gained. If promising results are obtained, particularly in such a field as sediment control in the Upper Indus region, it may be desirable in a few years' time to review and increase the program and consequently the cost. Expenditure on investigations is an investment in the future; it provides greater returns than almost any other work undertaken and to defer or restrict it is to show a lack of faith in the prospects of continued development.

TABLE A2–2

SUMMARY OF PRINCIPAL STORAGE PROJECTS

River Location	Project Location	Live Capacity (MAF)	Cost Range[a] (US$ millions)	Comments
Middle Indus	Tarbela	8.6	625	Extensively studied. Feasible of completion by 1975. Useful life limited to 50 years, due to siltation.
	Attock	—	—	Cannot be considered feasible, due to number of people and land affected by reservoir inundation.
	Kalabagh (nonsluicing)	6.4	540 to 700	Limited field data. Extensive further investigation required to confirm feasibility and cost. Could not be completed by 1975.
	Kalabagh (sluicing)	8.0		
Side-Valley Haro	Gariala (High)	8.0	651 to 975	Side-valley storage scheme associated with Tarbela. Very little field data. Long-term project.
	(Low)	4.6	596 to 800	
	Sanjwal-Akhori	3.3	490 to 735	Side-valley storage scheme associated with Tarbela. Very little field data. Not competitive with Gariala.
Soan	Dhok Pathan	8.3	1,000 to 1,500	Side-valley storage scheme associated with Tarbela. Very little field data. Not competitive with Gariala.
Upper Indus	Skardu	8.0	588 to 900	Reconnaissance data only. Not feasible of execution in foreseeable future.
	Bunji	—	—	Power project not feasible of execution in foreseeable future.
	Chilas	—	—	—Same as above—
Indus Plains	Chasma (incremental storage)	0.5	32[b]	Construction of barrage due to commence 1967 with completion scheduled 1971. Storage features being provided as an addition to basic design.
	Sehwan/Manchar	1.8	177 to 221	Feasible timing of execution dependent on canal remodeling in Lower Sind; possible completion date 1982.
	Indus Plains (Thal Doab)	Uncertain	Uncertain	Off-channel storage. Only very preliminary study. Long-term project.
Jhelum	Mangla	5.2	534[b]	Under construction. Completion scheduled 1967.
	Raised Mangla	3.5	216[b]	Project would involve raising Mangla Dam.
	Rohtas	5.8	—	Side-valley storage scheme associated with Mangla. Very little field data.
Chenab	Chiniot	1.4	100 to 125	Need for storage on Chenab questionable.

(Continued)

TABLE A2-2—(Continued)

River Location	Project Location	Live Capacity (MAF)	Cost Range[a] (US$ millions)	Comments
Kabul-Swat	Ambahar	2.0	145 to 215	No field data available. Representative of developments on Swat River. Capacity limited by water availability.
	Warsak Diversion	—	—	Project to increase water availability in Swat Basin for storage therein by pumping from the Kabul. Would require 3,600 mw of installed pumping capacity. Doubtful feasibility.
	Chitral Diversion	—	—	Project to increase water availability in Swat Basin for storage therein by pumping Kabul. Doubtful feasibility.

[a] Economic costs, without provision for inflation or financial contingencies.
[b] Includes income tax on contractors' profits.

FIGURE A2-1

Inventory of Possible Dam Sites in West Pakistan

Legend Zone: N—North; S—South
Type: E—Earthfill; R—Rockfill; G—Gravity; A—Arch
Purpose: I—Irrigation; P—Power; M—Multipurpose; W—Water Supply
R—River Regulation; F—Flood Control; S—Sediment Control
Present State: O—in operation; C—under construction; P—in planning;
F—for future; S—superseded or abandoned

	Location				Characteristics					Power Capacity (mw)			
Name of Dam	Zone	Region	Basin	Nearest City	Type	Height (ft.)	Length (ft.)	Gross Capacity of Reservoir (MAF)	Purpose	Initial or Installed	Ultimate	Notes	Present State
Adam Kot	N	West Side Tributaries	Gomal	D.I. Kkan								See Khajuri Kach	P
Ahnai Tangi (or Ahnai Kili)	N	West Side Tributaries	Tank	D.I. Khan								Superseded by Hinnis Tangi	S
Akhori	N	East Side Tributaries	Nandna Kas	Attock	Ė	250	15,800	3.6	I			Superseded by Gariala	S
Aktar Kili	N	West Side Tributaries	Zhob	Fort Sandeman								Superseded by Khajuri Kach	S
Ambahar	N	Kabul River	Swat	Peshawar	R	920	850	7.9	I P		1,270		P
Anambar	S	Kacchi Plains	Anambar	Sibi	E	80	2,600	0.055	F				F
Attock	N	Upper Indus	Indus	Attock	E			30	I P R			Superseded by Kalabagh	S
Babar Kach I	S	Kacchi Plains	Sangan Khwar	Sibi	R	180	400	0.715	I P F		15		P
Babar Kach II	S	Kacchi Plains	Beji	Sibi	R	120						Abandoned	P
Badin Zai	N	West Side Tributaries	Zhob	Fort Sandeman								Superseded by Khajuri Kach	S
Bahtar	N	East Side Tributaries	Nandna Kas	Rawalpindi	E	235	7,500	0.9	I				P
Bakhuwala	N	East Side Tributaries	Taba Kas	Rawalpindi	E	80	2,500		I				P
Bandagai	N	Kabul River	Panjkora	Saidu Sharif					P				F
Banda Saidu	N	East Side Tributaries	Siran	Mansehra	G	210	500	0 003	I				
Banda Tanda	N	West Side Tributaries	Kohat Toi	Kohat	E	115	2,340	0.078	I			See Tanda Dam	C
Bara	N	Kabul River	Bara	Peshawar								See Miri Khel	
Bara Tanda	N	West Side Tributaries	Baran	Bannu								See Baran	
Barahotar	N	East Side Tributaries	Soan	Islamabad		150		0.007	P W			Superseded by Chaniot	S
Baran	N	West Side Tributaries	Baran	Bannu		120	3,475	0.098	I				O
Basund	N	East Side Tributaries	Siran	Mansehra		271	750	0.075	I P				
Bazargai	N	Kabul River	Swat	Peshawar	E R	960		8.0	M		1,140		F
Beji Diversion	S	Kacchi Plains	Beji	Sibi	R	120	750		F				P
Bhaun	N	East Side Tributaries	Ling	Rawalpindi	E R	206	2,050	0.026	I				P
Bhogarmang	N	East Side Tributaries	Siran	Muzaffarabad									
Bolan	S	Kacchi Plains	Bolan	Sibi	E			0.06	I				O
Boya Post	N	West Side Tributaries	Tochi	Bannu		300		0.28				See Tochi	

Bunha I	N	Jhelum	Bunha	Jhelum				2.8					
Bunha II	N	Jhelum	Bunha	Jhelum		250		4.6					
Bunji	N	Upper Indus	Indus	Gilgit					P		2,000		F
Burj Zam	N	West Side Tributaries	Daragan	D.I. Khan	E	168		0.171	I P	1.8			P
Butta	N	East Side Tributaries	Nandna Kas	Attock									
Chaniot	N	East Side Tributaries	Soan	Islamabad	G	176	675	0.0095	P W		1,536		P
Chaphar Rift	S	Kacchi Plains	Khost	Sibi		185		0.079	I W	1			F
Charah	N	East Side Tributaries	Soan	Islamabad	G	175	832	0.067	I W				P
Chasma Barrage	N	Upper Indus	Indus	Mianwali	G			0.51	I				O
Chaudhwan Zam	N	West Side Tributaries	Chaudhwan	D.I. Khan	E	262		0.150	I P	2.24	5.1		P
Chicholi Pass	N	West Side Tributaries	Chicholi	Kalabagh								Abandoned	
Chilas	N	Upper Indus	Indus	Chilas					P				F
Chiniot	N	Chenab	Chenab	Chiniot				1.4	I				P
Chitral	N	Kabul River	Chitral	Chitral					P				F
Choti	N	West Side Tributaries	—	D.G. Khan									
Chutiatan	N	Kabul River	Panjkora	Saidu Sharif					P		12		F
Dabar	N	Kabul River	Swat	Saidu Sharif									F
Dadar	N	East Side Tributaries	Siran	Muzaffarabad	G	260	1,620	0.028	I P W		4		F
Dagarai	N	West Side Tributaries	Tochi	Bannu		230		0.10	I				
Dara Tang	N	West Side Tributaries	Kurram	Mianwali		130	8,500						F
Daraban Zam	N	West Side Tributaries	Daraban	D.I. Khan		100/175		0.03/0.15	I			See Burj Zam	P
Darazinda	N	West Side Tributaries	Daraban	D.I. Khan								Superseded by Burj Zam	S
Darwat	S	South Tributaries	Baran	Hyderabad		110		0.073	I			Infeasible	
Data Khel	N	West Side Tributaries	Kaitu	Bannu		200		0.35	I			See Tochi	
Dau	S	Kacchi Plains	Barri	Sibi									
Dhaabi	N	East Side Tributaries	Ghambhir	Rawalpindi		77		0.012	I				
Dhaimgrah	N	Chenab	Chenab	Raisi					P				F
Dhamtour	N	East Side Tributaries	Dar	Abbottabad		225	780	0.027	I P W		15		F
Dharyal Weir	N	East Side Tributaries	Siran	Mansehra		42	920		I				
Dhok Abbaki	N	East Side Tributaries	Soan	Kalabagh	E R	295	24,000	9.0	P		105		P
Dhok Ham	N	East Side Tributaries	Ankur Kas	Kalabagh	G	131	700	0.013	I				P
Dhok Mila (Power Plant)	N	East Side Tributaries	Indus-Soan Canal	Kalabagh					P		1,200		P
Dhok Pathan	N	East Side Tributaries	Soan	Kalabagh	E R	275	12,120	8.5	I				P
Dhok Sial	N	East Side Tributaries	Dhrab	Kalabagh	G	72	360	0.012	I				P
Dhrabi	N	East Side Tributaries	Ghambhir	Kalabagh	E	77	985	0.02	I				P
Domanda	N	West Side Tributaries	Chaudhwan	D.I. Khan								See Chaudhwan Zam	
Drosh	N	Kabul River	Chitral	Chitral		300	1,700		P				F
Dulhal	N	East Side Tributaries	Dulhal Kas	Rawalpindi		70	3,000						
Fort Sandeman	N	West Side Tributaries	Gomal	D.I. Khan								See Khajwri Kach	
Gahirat	N	Kabul River	Chitral	Chitral		100			P				F
Gaj (Gaja Nai)	S	South Tributaries	Gaj	Dadu		300	120	0.150	I F				P
Gambila	N	West Side Tributaries	Gambila	Bannu									P
Gandalat Tang Weir	S	Kacchi Plains	Sukleji	Kalat		10							
Gariala	N	East Side Tributaries	Haro	Attock	E	375	40,000	8.2	I		110		P
Ghatti Bridge	S	Kacchi Plains	Beji	Sibi									—

(Continued)

Figure A2-1—(Continued)

Name of Dam	Location: Zone	Location: Region	Location: Basin	Location: Nearest City	Characteristics: Type	Characteristics: Height (ft.)	Characteristics: Length (ft.)	Characteristics: Gross Capacity of Reservoir (MAF)	Pur-pose	Power Capacity (mw): Initial or Installed	Power Capacity (mw): Ulti-mate	Notes	Pres-ent State
Ghaziabad	N	East Side Tributaries	Haro	Attock								Infeasible	—
Giddar Pur	N	East Side Tributaries	Siran	Mansehra	E	52	1,124	0.004	I				
Gomal Zam	N	West Side Tributaries	Gomal	D.I. Khan								See Khajuri Kach	
Gomal Zam Weir (Murtaza)	N	West Side Tributaries	Gomal	D.I. Khan								See Mian Nur	
Gul Kach	N	West Side Tributaries	Gomal	D.I. Khan	G	195		0.50	I F				F
Haranbar	N	West Side Tributaries	Sangrah Nala (Luni)	D.G. Khan									
Havelian	N	East Side Tributaries	Siran	Abbottabad	E	173	6,600	0.018	I				
Hinnis Tengi	N	West Side Tributaries	Tank	D.I. Khan		236		0.068	I P		0.015		F
Hub	S	Marraw Coast	Hub	Karachi	E	153	22,900	0.606			20		C
Jaro	N	Kabul River	Swat	Saidu Sharif	G	350							
Jathaput	N	Jhelum	Jhelum	Rawalpindi				2.7				Superseded by Mangla	S
Jhelum	N	Jhelum	Jhelum	Jhelum									
Kaham	N	West Side Tributaries	Kahu	D.G. Khan									
Kalabagh	N	Upper Indus	Indus	Kalabagh	E R	285	6,900	8.0	I P		1,125		P
Kalam	N	Kabul River	Swat	Saidu Sharif		480		0.363	I P		110		F
Kalangai	N	Kabul River	Swat	Saidu Sharif	G/E R	580		6.5	I P		750		F
Kamalan Kach	S	Kacchi Plains	Lahri	Sibi	R	200			I F				F
Kanshi	N	Jhelum	Kanshi	Jhelum		270		1.1	S				P
Kesu	N	Kabul River	Chitral	Chitral					P				F
Khairi Murat	N	East Side Tributaries	Sil	Rawalpindi	E	220		0.021	I				P
Khajuri Kach	N	West Side Tributaries	Gomal	D.I. Khan	A/G	500	630	2.15	I P	127			P
Khajuri Post	N	West Side Tributaries	Tochi	Bannu		150		0.130	I				
Khanpur	N	East Side Tributaries	Haro	Islamabad	E	137	1,310	0.059	I P		8		C
Khapulu	N	Upper Indus	Shyok	Skardu		600		10	I P F R		600		P F
Kharikan Kas	N	East Side Tributaries	Kharikan Kas	Kalabagh	E	230	9,750	0.13					
Khazana	N	Kabul River	Panjkora	Saidu Sharif	E R	520		.03	M		170		F
Khirgi Weir	N	West Side Tributaries	Tank	D.I. Khan					P				F
Khushhalgarh	N	Upper Indus	Indus	Kalabagh					M			Superseded by Kalabagh	S
Khwaja Khizar	N	West Side Tributaries	Kohat Toi	Kohat	E/R	100	400	0.14	I			See Yozara	
Kirpalian	N	Upper Indus	Indus	Attock					I P			Superseded by Tarbela	S
Kot Fateh	N	East Side Tributaries	Sil Kas	Rawalpindi	E	80	8,000	0.016	I				P
Kotkai	N	Upper Indus	Indus	Abbottabad					M			Superseded by Tarbela	S
Kotli	N	Jhelum	Punch	Rawalpindi	E	320		0.3	I P S	220			
Kud	S	Marran Coast	Kud	Kandrach				0.047	I F				

Kunbat	N	Kabul River	Chitral	Chitral					P				F
Kurram Garhi	N	West Side Tributaries	Kurram	Bannu					I P	4			O
Kurram Tangi	N	West Side Tributaries	Kurram	Bannu	E	300		1.50	I F P				P
Ladoo	S	Kacchi Plains	Khatan	Sibi		80			F				
Lohar Gali	N	Jhelum	Kunhar	Muzaffarabad	G	530		0.8	I P				P
Lohi Bhir	N	East Side Tributaries	Kurang	Islamabad									
Lower Taba Kas	N	East Side Tributaries	Taba Kas	Rawalpindi		170	4,000						
Main Swat	N	Kabul River	Swat	Saidu Sharif		500			I P				F
Makhad	N	East Side Tributaries	Soan	Kalabagh		280		6.0	I P		700	Superseded by Kalabagh	S
Mangla	N	Jhelum	Jhelum	Jhelum	E/R	380	11,000	5.88	M	400	1400		C
Mastuj-Lutkho	N	Kabul River	Chitral	Chitral		200			P				F
Miannur	N	West Side Tributaries	Gomal	D.I. Khan	E	77	3,460	0.089	I F				P
Mile 46	N	West Side Tributaries	Chaudhwan	D.I. Khan								Superseded by Domanda	S
Mina Bazar	N	West Side Tributaries	Zhob	Fort Sandeman		90	660					Superseded by Khajuri Kach	S
Mirabandi	N	East Side Tributaries	Siran	Muzaffarabad		375		2.38	I				
Miri Khel	N	Kabul River	Bara	Peshawar									F
Mirkhani	N	Kabul River	Chitral	Chitral		400		0.58					
Morgah Weir	N	East Side Tributaries	Soan	Rawalpindi	G	49	0.016		I				P
Munda	N	Kabul River	Swat	Peshawar	E R	660		2.0	I P	370	760		P
Murtaza Weir	N	West Side Tributaries	Gomal	D.I. Khan					I P	8		Superseded by Mian Nur	S
Namal	N	East Side Tributaries	Golar Nullah	Mianwali	G	85	153	0.022	P I W				C
Naran	N	Jhelum	Kunhar	Muzaffarabad	G	410	1,360	0.28	I P	50			P
Nari Bolan	S	Kacchi Plains	Bolan	Sibi	E	68	1,750	0.325	I F				C
Naulung	S	Kacchi Plains	Mula	Sibi	R	185		0.306	I				P
Nawan	N	Jhelum	Jhelum	Islamabad		650		2.6				Superseded by Mangla	S
Nazarai	N	West Side Tributaries	Zhob	Port Sandeman								Superseded by Khajuri Kach	S
Nili Kach	N	West Side Tributaries	Gomal	D.I. Khan	E	77		0.018	I P				
Pak-Afghan	N	Kabul River	Kabul	Peshawar					I P R				F
Panjar	N	Jhelum	Jhelum	Islamabad				3.0	P		1.500		
Papin	N	East Side Tributaries	Wadala Kas	Rawalpindi	E R	100	300	0.053	I				P
Paras	N	Jhelum	Kunhar	Muzaffarabad								Infeasible	—
Pashtkhand (Raiko)	S	Kacchi Plains	Mula	Kalat		190		0.244				Superseded by Maulung	S
Pishi	N	West Side Tributaries	Vider	D.G. Khan									
Porali	S	Marran Coast	Porali	Kandrach									
Rajdhani	N	Jhelum	Punch	Rawalpindi	E	325		0.86	I P		40	Superseded by Mangla	S
Rasul	N	Jhelum	Jhelum	Jhelum				10.0	I P	300		Superseded by Mangla	S
Rawal	N	East Side Tributaries	Korang	Islamabad	G	80	700	0.0475	I W				O
Rohtas	N	Jhelum	Kahan	Jhelum		25		1.90	I P		60		P
Saggar Kas	N	East Side Tributaries	Sil Kas	Kalabagh	E	230	9,500	0.77	I P				P
Sanjwal	N	East Side Tributaries	Haro	Attock	R	165	5,800	0.177			2,250	Superseded by Gariala	S
Sapiala Kas	N	East Side Tributaries	Sapiala Kas	Rawalpindi		130	7,000						
Sawawan	S	Marran Coast	Sawawan	Kandrach									
Sehwan Barrage	S	South Tributaries	Indus	Dadu			3,500	0.8 (2.7)	I				P
Shadi Kar	S	Marran Coast	Shadi	Kandrach									
Shah Bilawal	N	East Side Tributaries	Gabhir	Kalabagh	E	73	1,300	0.021	I				P

(Continued)

Figure A2-1—(Continued)

Name of Dam	Location: Zone	Location: Region	Location: Basin	Location: Nearest City	Characteristics: Type	Characteristics: Height (ft.)	Characteristics: Length (ft.)	Characteristics: Gross Capacity of Reservoir (MAF)	Purpose	Power Capacity (mw): Initial or Installed	Power Capacity (mw): Ultimate	Notes	Present State
Shah Pur	N	East Side Tributaries	Shah Pur Kas	Rawalpindi									
Shakista Nala	N	East Side Tributaries	Shakista Nala	Attock	E	187	11,900	6.25					
Sheikh Haider Zam	N	West Side Tributaries	Sowan	D.I. Khan	E	186		0.0687					P
Sheikh Mela	N	West Side Tributaries	Shingai Nula	D.I. Khan								Superseded by Domanda	S
Shinki Post	N	West Side Tributaries	Tochi	Bannu		250		0.23	I				
Singur	N	Kabul River	Chitral	Chitral					P				F
Sinly	N	East Side Tributaries	Soan	Islamabad	E	215	900	0.020	W				C
Skardu	N	Upper Indus	Indus	Skardu	R	310	3,700	8.0	R				P
Spin Karez	S	Interior Baluchistan	Nar Murdar	Quetta	E	70	2,490	0.0055	I P W				O
Spli Toi	N	West Side Tributaries	Shahur Nula Tank	D.I. Khan								Superseded by Hinnis Tangi	S
Suki Kinari (Power Plant)	N	Jhelum	Kunhar	Muzaffarabad					P	500			P
Surgul-Chambai	N	West Side Tributaries	Kohat Toi	Kohat								Superseded by Tanda	S
Takari Kili	N	West Side Tributaries	Zhob	Fort Sandeman								See Khajuri Kach	
Talli Tangi	S	Kacchi Plains	Talli (Chalar)	Sibi	G	195	150	0.1385	I F				P
Tanda	N	West Side Tributaries	Kohat Toi	Kohat	E	137	2,150	0.079	I				O
Tarbela	N	Upper Indus	Indus	Attock	E R	465	8,700	11.1	I P R	840	2,500		RC
Thalian	N	East Side Tributaries	Sil Kas	Rawalpindi									
Thapla	N	Upper Indus	Siran	Abbottabad		210		0.27	I P			Superseded by Tarbela	S
Tochi	N	West Side Tributaries	Tochi	Bannu								See Data Khel	
Torder	N	Kabul River	Chitral	Chitral					P				F
Total Nala	N	East Side Tributaries	Total Nala	Attock	E	148	14,500	6.25	I P				F
Tung	S	Kacchi Plains	Beji	Sibi									
Tungi	N	West Side Tributaries	Tochi	Bannu					I				P
Turan China	N	West Side Tributaries	Shahur Nula (Tank)	D.I. Khan								Superseded by Hinnis Tangi	S
Upper Sukleji	S	Kacchi Plains	Sukleji	Kalat								See Gandalat Tang	
Upper Taba Kas	N	East Side Tributaries	Taba Kas	Rawalpindi		60	2,000					See Gandalat Tang	
Wadala	N	East Side Tributaries	Wadala Kas	Rawalpindi									
Wali Tangi	S	Interior Baluchistan	Wali Tangi	Quetta	R	75	200	0.0004	F				O
Warsak	N	Kabul River	Kabul	Peshawar	G	250	650		M	160	240		
Wucha Sesta	N	West Side Tributaries	Chaudhwan	D.I. Khan	E				I			Superseded by Domanda	F
Yozara	N	West Side Tributaries	Kohat Toi	Kohat	E/R	100	400	0.14	I				P
Zhair Narai China	N	West Side Tributaries	Zhob	Fort Sandeman								Superseded by Khajuri Kach	S

Glossary of Terms

Active flood plain:	A strip of land beside a river or stream which is flooded at least once during most years, and is capable of being reworked subject to frequent deposition.
Aquifer:	A water-bearing stratum of permeable rock, sand or gravel.
Area, assessed:	An area irrigated on which water rates are levied. Rates vary according to the cropping period.
canal-commanded:	The area which it is possible to irrigate by flow from a given outlet on a canal, whether the whole area is actually irrigated or not.
cropped:	The sum of areas under kharif and rabi crops plus twice the area under perennial crops.
cultivated:	Land which has been under annual or perennial crop within the previous 18 months.
culturable: (CA):	The sum of the cultivated area plus the culturable wasteland.
culturable commanded (CCA):	That portion of the culturable area which is commanded by canal irrigation.
gross (GA):	The total area within extreme limits set by a project, system or canal.
gross commanded (GCA):	That portion of the gross area which is commanded by canal irrigation. GCA includes villages, canals, roads, and some desert wasteland as well as CCA.
irrigated:	That part of the farmlands within an irrigation system on which water is applied during a cropping season.
perennial:	An area which has been designated to receive allocations of canal water throughout the year.
Authorized full supply (AFS):	The maximum discharge (usually the design capacity in cusecs) authorized for an irrigation channel.

Balanced recharge:	A term used in reference to groundwater pumping meaning that the amount of water pumped out of the aquifer over a period is equal to the amount which seeps in.
Barani:	An Urdu term describing rainfed agriculture.
Barrage:	A gated diversion structure across a river. This structure is a part of the headworks of an irrigation canal.
Base load:	That part of the total power load at the base of the load curve which is continuous, as distinguished from that which fluctuates as the total system load changes from hour to hour or seasonally.
Bund:	A large artificial embankment which retains water, or protects agricultural lands from river floods. The term is also applied to small earth ridges separating two fields or sections of fields.
Canal capacity (irrigation):	Size of a canal, expressed as the volume of water that it can carry at any specified point.
Canal-commanded area:	See under Area.
Capability (maximum):	The maximum demonstrated continuous dependable output of a generator under routine operating conditions, expressed in kilowatts or megawatts.
Critical water year:	The year when the sum of flows from October through May of the Chenab, Indus and Jhelum Rivers measured at Marala, Attock and Mangla was minimum between 1922/23 and 1962/63. The critical water year was 1954/55.
Cropping intensity:	The cropped area expressed as a percentage of the CCA.
Cropping pattern:	The sequence in which crops are grown in any given area during a single year and the proportion of cropland devoted to each crop during the year.
Dead storage capacity:	That portion of the reservoir capacity which is not used for operational purposes. Dead storage means the corresponding volume of water.
Dead storage level:	The level of water in a reservoir below which the reservoir does not operate.
Delta:	Tract of alluvium formed at the mouth of a river.
Delta (irrigation):	The depth of water applied to cropland.

Demand (electrical):	The amount of electric power required (or delivered) at a given moment at any specified point or points in a system, usually expressed in kilowatts or megawatts. Often used in the report synonymously with maximum demand.
Design intensity:	The cropping intensity for which the irrigation system in an area is designed to provide adequate water supplies.
Discharge factor:	The outlet capacity from distributary and minor canals to watercourses expressed as cusecs per 1,000 acres of CCA, also known as water allowance.
Dispatching load:	The process of assigning generating plants to various positions on a load curve in order to indicate the amount of energy to be generated by each plant in a certain period.
Distributary (irrigation):	A canal of medium size, smaller than a branch canal and larger than a minor canal.
Distribution system (electric):	That portion of an electric system used to deliver electric energy from points on the transmission or bulk supply system to the consumers.
District:	Small territorial unit in West Pakistan for purposes of civil administration (about 50 in the Province).
Diversity:	That quality or characteristic by which individual maximum demands occur at different times. There is hourly, daily, weekly, monthly and annual diversity.
Division:	Large territorial unit for purposes of civil administration (12 in Province).
Doab:	An Urdu term referring to the land between any two adjacent rivers in the Punjab.
Drawdown:	*In tubewells*: the difference between the static water level in a well and the stabilized water level attained after continuous pumping at a constant rate of discharge. *In reservoirs*: the extent to which the water level of a reservoir is lowered when releases for irrigation and/or power exceed the inflow.
Electric system loss:	Total electric energy loss in the electric system. It consists of transmission, transformation, and distribution losses, and unaccounted-for energy losses between sources of supply and points of delivery.

Evapotranspiration: The amount of the water consumed in a given area during a specified time by transpiration from vegetation and evaporation from the soil.

Extra high voltage (EHV): Term applied to voltage levels of transmission lines which are higher than the voltage levels commonly used. Often used in the report as synonymous with either 380 kv or 500 kv.

Firm power: Power intended to have assured availability to the customer to meet all or any agreed-upon portion of his load requirements.

Full delta: The level of irrigation supplies at which crop yields reach the maximum attainable in the light of all the other circumstances of the agricultural regime. In the case of West Pakistan full delta supplies were in addition defined to include an allowance for the control of soil salinity.

Headworks: The works constructed at the off-take of a main canal. It includes the weir or barrage on the river as well as the control structure across the head of the canal.

Horizontal drainage: Tile, pipe or open channel land drainage or a combination of these.

Hydrological year: Year beginning towards the end of kharif, running from October 1 to September 30.

Impounding: Filling a reservoir with water.

Installed capacity: The total of the capacities as shown by the nameplates of apparatus such as generating units, turbines, synchronous condensers, transformers or other equipment in a station or system.

Interconnection: A transmission tie permitting a flow of energy between the facilities of two electric systems.

Interruptible load: Electric power load which may be curtailed at the supplier's discretion, or in accordance with a contractual agreement.

Inundation canal: Canal which is dependent upon the surface level of water in a river for its supplies and is therefore generally filled only at times of flood flow.

Kharif: An Urdu term for the summer growing season, which includes the six months beginning April 15 and ending October 15.

Kharif-Rabi ratio: Ratio of the areas cropped in the two growing seasons.

Leaching: Washing down into the earth of salts in the topsoil.

Leaching requirement:	The amount of water entering the soil that must pass through the root zone in order to prevent soil salinity from exceeding a specified value. It is used primarily under steady state or long-time average conditions.
Live storage capacity:	The reservoir capacity excluding dead storage capacity.
Load:	The amount of electric power required or delivered at a specific point, usually expressed in kilowatts or megawatts. (Also often loosely used all inclusively to designate demand and energy such as in Load Forecast.)
Load curve:	A curve indicating the amounts of energy required at different instantaneous loads over the course of a period.
Load factor:	The ratio in percent between the average load over a specified period and the maximum or peak load occurring during the period.
Lost and unaccounted for (electric energy):	The calculated difference between energy sent out from generating stations and the sum of energy sales and energy accounted for but not sold.
Main canal:	A main irrigation supply canal off-taking from a river.
Maximum demand:	The greatest of all simultaneous demands on an installation or source of power supply within a specified time.
Mean water year:	Average monthly or 10-day river flows over the 41-year period 1922/23 through 1962/63.
Mean-year flow:	See Mean water year.
Median flow:	The values of flows such that half the recorded flows are above and half are below in amount.
Mining:	Extraction of groundwater beyond balanced recharge.
Nameplate rating:	The full-load continuous capability of a generator and its prime mover, in terms of megawatts, under specified conditions, as designated by the manufacturer.
Nonfirm power:	Power supplied (or purchased) under an arrangement which does not have the continuous availability guarantee feature of firm power.

Nonperennial canal:	Canal designed to receive water supplies for a part of the year only, usually April 16 to October 15 (i.e. kharif) and fed from a permanent barrage spanning the source river. Control of river flow is the chief feature differentiating nonperennial and inundation canals.
Off-peak energy:	Energy supplied during periods of relatively low system demands.
On-peak energy:	Electric energy supplied during periods of relatively high system demands.
Overload capability:	The maximum load that a machine or device can carry for a specified period of time under specified conditions when operating beyond its normal rating but within safe limits predetermined.
Overpumping:	See Mining (of groundwater).
Peak demand:	Demand at the instant of greatest load in a period.
Peaking capability:	The maximum output, specified in kilowatts or megawatts, that a generator or system can sustain for short periods of time.
Peak load:	The maximum load in a stated period of time.
Peak-load station:	A generating station which is normally operated only to provide capacity during peak-load periods.
Perennial canal:	Canal designated to receive water supplies all the year round and fed from a permanent barrage spanning the source river.
Persian wheel:	A mechanism powered by bullocks or camels used for lifting water from wells, canals, or streams.
Perspective Plan:	An outline of a plan for the economic development of Pakistan over the period 1965–85, prepared by the Pakistan Planning Commission.
Province:	West Pakistan.
Rabi:	An Urdu term for the winter growing season which includes the six months from October 15 to April 15.
Rated capacity:	See Nameplate rating.
Reactive power:	Power that does no work, measured in voltamperes reactive (Vars of Kvar).
Recharge (groundwater):	The process whereby water, at or near the ground surface, percolates downwards into the store of groundwater thus replenishing water which was removed.

Regulated streamflow:	The controlled rate of flow at a given point resulting from reservoir operation.
Re-regulating dam:	A dam or barrier built in a stream below a main dam to provide supplemental storage in order to smooth water releases from the main dam.
Reserve (electrical):	The difference between generating capability and load on the generators at a specified time, generally loosely used in this report as the difference between peak capability and peak load.
Reservoir capacity:	The gross volume of water which can be stored in the reservoir.
Rim stations:	Stations established on main rivers, near where they enter the Indus plains, at which the flow is gauged.
Riverain area:	The active flood plain lands along main rivers.
Salinity:	A saline condition in soils or water which is detrimental to plant growth.
Scouring:	Removal of silt or other material by flow of water.
Sediment:	Matter carried by rivers which settles at the bottom of the reservoir.
Siltation:	The deposition of silt or sediment on the bottom and sides of a reservoir.
Sluicing:	Passing water through low level outlets or sluices at a dam or barrage, generally in an attempt to remove some of the sediment deposited.
Spillway:	Structure for discharging superfluous water flows at a reservoir or on a river.
Storage capacity (reservoir):	The gross volume of a reservoir available to store water.
Subsurface drainage:	Water table control by either horizontal or vertical drainage facilities.
Superstorage capacity:	Storage capacity available in a reservoir between normal maximum water elevation (FSL) and maximum elevation to which water can safely be raised for short periods.
Surface drainage:	Removal of surface effluent water by use of open channels.
Tailwater level:	Level of water at foot of structure in a river, such as dam or barrage.
Tehsil:	Administrative subdivision of a district comprised of several Union Councils.

Tile drains:	Subsurface horizontal drains lined with tiles.
Transpiration:	The process by which plants draw water into their roots for either building plant tissue or passing through the leaves into the atmosphere.
Tubewell:	A drilled well, cased and screened, usually gravel packed.
Turbine (hydraulic):	An enclosed rotary type of prime mover in which mechanical energy is produced by the force of water directed against blades fastened to a vertical or horizontal shaft.
Turbine (steam or gas):	An enclosed rotary type of prime mover in which heat energy in steam or gas is converted into mechanical energy by the force of a high velocity flow of steam or gases directed against successive rows of radial blades fastened to a central shaft.
Underwatering:	The application of insufficient water to sustain the maximum yields which would be attainable in the light of all the other circumstances of the agricultural regime.
Union Council:	The smallest political subdivision composed of several villages.
Value added:	Output at factor cost, net of purchased inputs.
Vertical drainage:	Drainage by tubewell pumping.
Watercourse:	Farmers' channel, carrying water from a Government canal to the fields. Also used in reference to the area irrigated from such a channel.
Waterlogging:	State of the land with groundwater lying at or near the surface. The use of the term indicates that groundwater is so high that crop growth is precluded or crop yields lessened by it for at least part of the year.
Water table:	The height in the ground to which the earth is saturated with water.
Water year:	See Hydrological year.
Weir:	A structure across a river designed to pond water and thus raise its level for purposes of diversion into irrigation canals.

Names

ADB:	Agricultural Development Bank.
ADC:	Agricultural Development Corporation.

Agriculture Consultant:	International Land Development Consultants N.V., and Hunting Technical Services Ltd.
Study Group:	A group of staff members of the International Bank for Reconstruction and Development assigned to assist Dr. Lieftinck in the execution of the Indus Special Study.
Binnie:	Binnie & Partners, Consultant to WAPDA.
Coode:	Coode & Partners, Consultant to WAPDA.
CTM:	Chas. T. Main International, Inc., Dam Sites Consultant to the Study.
Dam Sites Consultant:	Chas. T. Main International, Inc.
Gibb:	Sir Alexander Gibb & Partners, Irrigation Consultant and coordinator of consultants to the Study.
GOP:	Government of Pakistan.
Harza:	Harza Engineering Company, International, general engineering Consultant to WAPDA.
HTS:	Hunting Technical Services Limited, Agricultural Consultant to the Study.
IACA:	Irrigation and Agriculture Consultants Association.
IBRD:	International Bank for Reconstruction and Development (World Bank).
IGC:	Indus Gas Company, which distributes Sui gas in the Sind (Sukkur, Hyderabad, etc.).
ILACO:	International Land Development Consultants N.V., Agricultural Consultant to the Study.
Irrigation Consultant:	Sir Alexander Gibb & Partners.
KESC:	Karachi Electric Supply Corporation, Ltd.
KGC:	Karachi Gas Company, which distributes Sui gas in the Karachi area.
LIP:	Lower Indus Project: regional study carried out by Hunting Technical Services Limited and Sir Murdoch Macdonald & Partners.
LWDB:	Land and Water Development Board.
MESCO:	The Multan Electric Supply Company, Ltd.
PMS:	Power Market Survey Organization.

Power Consultant:	Stone & Webster Overseas Consultants, Inc., Power Consultant to the Study.
REPC:	The Rawalpindi Electric Power Company, Ltd.
SCARP:	Salinity Control and Reclamation Project.
SGTC:	Sui Gas Transmission Company, responsible for transmitting gas from Sui to the South.
SNGPL:	Sui Northern Gas Pipelines, Ltd., responsible for transmitting Sui gas to the North and distributing it and the gas from Dhulian field there.
S&W:	Stone & Webster Overseas Consultants, Inc.
TAMS:	Tippetts-Abbett-McCarthy-Stratton International Corporation, Consultants to WAPDA on Tarbela Dam.
T&K:	Tipton and Kalmbach, Inc., Consultant to WAPDA.
WAPDA:	Water and Power Development Authority of West Pakistan.
WASID:	Water and Soils Investigation Division (of WAPDA).

Units of Weights, Measures, Currency, etc.

Acre-foot (AF):	A measure of volume of water, corresponding to 43,560 cubic feet, the volumetric equivalent of one acre covered to a depth of one foot.
Ampere:	Unit of measurement of the intensity of electric current, being that produced by one volt acting through a resistance of one ohm.
Animal Unit (AU):	Livestock expressed in terms of units determined by their respective feed requirements compared with the requirements of a standard bullock. The standard bullock is taken to equal one animal unit.
Bale (cotton):	1 bale = 392 pounds.
Btu:	British thermal unit, the standard unit for measuring quantity of heat energy such as heat content of fuel. 1 Btu = 0.29307 watt-hours.
cfs:	Cubic feet per second.
cfs/month:	1 cfs/month = 59.45 AF (30-day month) or 61.43 AF (31-day month).
Cusec (cfs):	One cubic foot per second, used to describe the rate of flow of water.

Cusec-hour:	At one cubic foot per second, the volume of water for one hour would be 3,600 cubic feet or 0.086 acre-foot or 2800 US gallons.
cy:	Cubic yard.
Fps:	Feet per second.
FSL:	Full supply level.
GPV:	Gross production value (output × prices).
Horsepower (hp):	Unit of mechanical power equivalent to 550 foot-pounds of work per second; 33,000 foot-pounds per minute. 1 horsepower-hour = 0.7457 kwh.
Kilovars:	1,000 reactive volt-amperes.
Kilovolt (kv):	1,000 volts.
Kilovolt-ampere (kva):	1,000 volt-amperes.
Kilowatt (kw):	1,000 watts.
Kilowatt-hour (kwh):	Unit of electrical work; work done by one kilowatt of power in one hour. 1 kwh = 1,000 watt-hours.
Mac:	Million acres.
MAF:	Million acre-feet. 1 MAF = 1235 million cubic meters.
MAF/month:	1 MAF/month = 16,850 cfs. = 477.2 m^3/sec.
Maund:	A Pakistani unit of weight equal to 82.28 lbs.
Mcf:	Thousand cubic feet (gas measurement).
Megawatt (mw):	Unit of electric power equivalent to 1,000 kilowatts.
Megawatt-hour (mwh):	Unit of electrical work; work done by 1,000 kilowatts of power in one hour.
MMcf:	Million cubic feet (gas measurement).
NPV:	Net production value (GPV less input costs).
Ohm:	Unit of electrical resistance.
Paisa:	One hundredth of a Rupee.
Pcf:	Pounds per cubic foot.
Ppm:	Parts per million.

Rs:	Pakistani Rupees. Official rate is Rs 4.76 = US$1 or 1 Rupee = $0.21.
SPD:	Standard Pakistan Datum (based on mean sea level at Karachi).
TDN:	Total digestible nutrients which are the sum of all digestible organic nutrients, viz. protein crude fiber, nitrogen-free extract, and fat TDN represents the approximate heat energy value of a feed.
Ton (long):	2,240 pounds.
Trillion:	10^{12}.
Volt:	Unit of electromotive force (or electric pressure analogous to water pressure) being that which when coupled to a conductor with a resistance of one ohm will produce a current of one ampere.
Watt:	Rate of energy transfer equivalent to one ampere flowing under the pressure of one volt at unity power factor.
Watt-hour:	Work done in an hour at the steady rate of one watt.

Volume Two
PROGRAM FOR THE DEVELOPMENT OF IRRIGATION AND AGRICULTURE IN WEST PAKISTAN

Annexes

Volume Three
BACKGROUND AND METHODOLOGY—SUPPLEMENTAL PAPERS

The three volumes together represent the core of the complete report made by the Bank to the Government of Pakistan. They present not only the Study Group's conclusions and recommendations but also an invaluable record of the manner in which the problems encountered were confronted and solved, and how the Bank's consultants went about their work.

Volume I is a condensed, integrated version of the analysis and results of the entire study, including an evaluation of the huge Tarbela project, the problems of agricultural development, the interaction of agriculture with other sectors of the economy, the demand for power and means of meeting the demand, and areas of critical concern, such as the need for electrical interconnection within West Pakistan.

Volume II gives a detailed discussion of irrigation and agriculture, including the use of improved seeds, fertilizers, new cropping patterns, and modern techniques of husbandry, in addition to the development of water resources.

Volume III contains papers on the background and methodology of the study, particularly the macroeconomic framework, a linear program of irrigated agriculture in the Indus Basin, and a computer simulation of the power system.

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