which are usually constructed in water-tight iron boxes of various shapes according to the nature of the problem. A glass sheet is often provided on one side to view the flow phenomena with regard to the length of strainer, depression head, diameter of strainer, proper size of the shrouding, flow from a line source into a well, cone of depression etc.

An iron tank representing a section of an aquifer, at the apix of which strainer of different kinds can be installed is shown in Fig. 30. At the side of the tank nipples and monometers are provided to study the pressure variation. A combination of pressure observation combined with observed flow lines is often used to estimate the flow net, discharge of a well, extent of cone of depression etc.

Electrical Analogy Methods

Another method very commonly used to solve subsoil flow problems is the use of current flow through a medium and measurement of electrical potentials. Darcy's law which relates velocity of flow through a medium is expressed as :

$$V = K\frac{dH}{ds}$$

where V=the seepage velocity.

H=piezometric head.

$\frac{dH}{ds}$=is the hydraulic gradient and

K=the hydraulic conductivity.

Now the flow of electric current is given by Ohm's law which is expressed as :

$$I = \sigma\frac{dE}{ds}$$

where I =the electric current per unit area.

E =the pressure of the current or the voltage.

$\frac{dE}{ds}$=the voltage gradient and

σ=the electrical conductivity.

Thus a relation exists between the water-head and the voltage, hydraulic gradient and voltage gradient, permeability and electrical conductivity. It also concludes that a resemblance exists between the equipotential lines of flow and equipotential lines of current, and the flow lines.

This suggested the use of electrical analogy models to study of hydraulic flow problems. Lelavosky[12] (1931) in Russia first suggested the use of this technique to solve hydraulic flow problems. Lane[13] (1932) took up investigation of pressure distribution under dams by electrical potential measurements.

In 1933, a solution of the subsoil flow under weirs was sought by the engineers of the country, so the Irrigation Research Institute actively undertook the investigation of the problem in the laboratory by sand tank models representing weirs on sand foundations and by the use of electrical analogy technique. The Institute solved this problem by the active co-operation of several scientific workers and engineers, and a famous publication Flow under Weirs on Sand Foundations,[14] Vol. 12, was issued by the Central Board of Irrigation, Simla in 1936. This technique has now been perfected into a simple tool to solve complicated problems not only of subsoil flow but many other which can be transformed to the measurement of electrical potentials. The principle in general is to represent a high source of water by an electrode maintained at a high potential. The sink is represented by another electrode kept at a low potential. The medium of flow is some conductor through which the current

flow establishes a fall in potential. Generally an electrolyte or a graphite paper is used as a medium. Representing a true boundary condition in a model is the main precaution.

The potential distribution is easily plotted by comparing the potentials with a potentiometer.

A simple set of the apparatus for a two-dimensional current of flow studies is shown in Fig. 31. An alternating current of low frequency is used and the nul point technique is adopted to compare potentials. The source of current can be a valve oscillator, a buzzer or any other of such devices. A head-phone, a galvanometer or an oscillograph can be used for comparing the potentials.

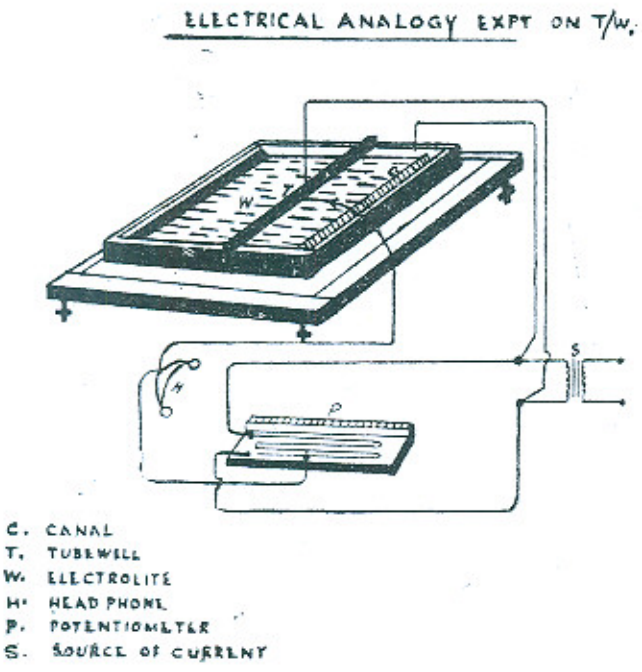


Fig. 31

This technique has been used for study of pressures under weirs, for tubewell discharge and flow pattern located along a line source, and for the determination of interference between group of tubewells etc.

For all the complicated phenomena of multiple wells, and pumping of saline and good quality water, withdrawing from pervious canal, this technique with proper modifications can be used for solving difficult problems.

Other Techniques

There are many devices in use to study complicated cases of subsoil flow. One of the important model analogies used for ground water flow is the rubber membrane which is stretched between boundary and draw-down for single and multiple tubewells is measured.

Very often viscous fluid models, or tracing of flow lines by dyes adopting Heleshaw technique and developed extensively by Mushtaq[15] of the Irrigation Research have been used to solve the subsoil flow problems.

In this connection the last to be mentioned is the use of sodium chloride or copper sulphate adopted to represent medium of different conductivities.

Glycerine is also used to change the density of gelatine models and beta naphthol is used to prevent decay of gelatine solutions.

REFERENCES

1. M. Muskat, *The flow of Homogeneous Fluids* through *Porous Media*, 1937. McGraw-Hill Book Company, New York
2. C. O. Wisler & E. F. Brater, '*Hydrology*', 1959. John Wiley & Son, Inc. Now York.
3. Sir Murdoch Macdonald and Partners, *Methods and Criteria for Tubewell Design*, Hunting Technical Services, WAPDA, Lahore.
4. T. P. Ahrens, *Well Design Criteria*, *Water Well Journal*, Sept-November, 1957.

5. Nazir Ahmad and A. Razzaq, A Study of Velocity limits between Laminar and Turbulent Flow for Punjab Aquifer Sand, *Pak. Journal of Scientific Research*, Vol. 8, No. 1, Jan. 1956.

6. *Groundwater and Wells*, Edward E. Johnson, Inc. Saint Paul, Minnesota, 1966.

7. V. E. Hansen, D. F. Peterson and D. W. Israelson, *Hydraulic of Well. Bulletin* No. 351, Utah State, Agriculture College, Utah. March, 1962.

8. Forchheimer P. H., '*Hydraulik*' Chapter III, 1930.

9. J. Kozeny, *Wasserkraft und Wasserwirtschaft*, 1927.

10. M. Musket and H. G. Botest, *Physics*, 1931.

11. H. J. Fraser and L. C. Graton, *Jour. Geol* 43, 785, 1935.

12. S. Lelavasky, *Percolation under Aprons of Irrigation Works*, Cairo, Egypt.

13. E. W. Lane, Security from Seepage under Masonry Dams on Earth foundation, *Proc. Am. Soc.* C. E. Paper No. 1919, 1935.

14. A. N. Khosla, N. K. Bose. E. Mc. Taylor, *Design of Weirs*, Central Board of Irrigation Publication Simla, Vol. 12, 1936.

15. Mushtaq Ahmad, A new method for demonstrating the flow of water under models of works and the pressures on the floors:—*Water and Water Engineering*, Vol. 5, No. 616, June 1947.

International Conference on Water for Peace

From 23rd to 31st May, 1967, about 5,000 Engineers, Scientists and Diplomats from 91 Nations gathered in Washington, D.C. to exchange ideas on Water Resources Development. The Conference was organized by Johnson Administration, conceived with the idea that International Co-operation in developing water resources can help build better world.

About 700 papers were submitted and only 175 were read in the Conference. Very useful and interesting information is contained in the Proceedings.

In this Volume we reproduce the full text of the Paper read by Mr. B. M. Abbas, Chief Engineering Adviser, Government of Pakistan and a brief extract from Mr. Batisse of Unesco on Research and Training for Water Resources Development and some informative papers on Water Resources Development. The following is the information on these three items beginning with Water Resources Paper.

PLANNING WATER DEVELOPMENT IN PAKISTAN

By **B. M. ABBAS**
Chief Engineering Adviser

The most urgent problem for Pakistan is finding enough food for its large and fast-increasing population besides improving their standard of living. Water which forms one of the basic resources will contribute a major share to this development. The present population of the country is estimated to be 115 million, 87 percent of this population live in rural areas and are almost wholly dependent, either directly or indirectly upon agricultural production for their livelihood. Approximately, half of the Gross National Product is derived from agriculture. However, the growth in population and the limited extent of culturable land has created a situation whereby the greater part of the farmers have to secure their livelihood from a piece of farm land that is too small. Not only is the total production of foodgrains within the country insufficient to meet the needs of the people now dependent upon large imports from abroad every year but nutritional levels are also low. The main objective of water development is to achieve self-sufficiency in

foodgrains, to bring nutritional levels to an acceptable standard, to provide raw materials for industry and to produce surplus of cash crops for export in either primary or processed form.

General Situation

Pakistan consists of two provinces, West Pakistan and East Pakistan, separated by a thousand miles of Indian territory. The two have got different topography, soils and climate and problems of development. Whereas in West Pakistan there is abundance of land which cannot be supplied with enough water, East Pakistan has one of the highest population densities in the world and has too much water during the monsoon period and too little in the other months.

West Pakistan is an arid to semi-arid region served mainly by the river Indus and its tributaries. The rainfall is moderate to negligible. The province has an extensive network of irrigation canals, the largest in the world. The development of Irrigation up to the present time has, however, been almost entirely dependent on the natural flows of the river system without storage. Nearly 60 percent of the combined annual inflow occurs in the months of June, July and August. It means that a considerable proportion of the resources goes waste to the sea. During the winter months, river flows are too low to meet the demands of agriculture. Besides shortage of water, the extensive irrigation has created waterlogging through the rise of subsoil water level. Due to the lack of an adequate natural drainage system and insufficiency of irrigation waters in the hot and arid climate, harmful salts have concentrated in the upper soil, causing salinity. This has thrown large areas of land out of cultivation.

East Pakistan, on the other hand, is a tropical monsoon region located at the extreme northern end of the Bay of Bengal. It contains the confluence of two great international rivers—the Brahmaputra and the Ganges—along with a third big river, the Meghna. The land is criss-crossed by a network of rivers with hundreds of smaller tributaries and spill channels. Floods, droughts and severe tropical storms result from the climatological and geographical conditions of the area. The main crops are grown during the monsoon season and depend on rainfall but the crops are periodically damaged by high floods. Only a part of the cultivated area is sown during the dry months. Organised irrigation has been started only recently.

Limitations to Planning

The major rivers of Pakistan receive perennial supplies from the melting of snow in the Himalayan ranges. During the monsoon season the overflowing of the rivers causes flood problems. During most of the remaining part of the year the river flows are low and inadequate to meet the needs of irrigation. In planning water resources development it is necessary to evaluate the effect of irrigation and other diversions on the stream flows and to determine the availability of water to meet the requirements of all present and future projects. Such evaluation has to cover an entire river basin. Similarly, basin-wise planning is required for flood control. The upper reaches of the major rivers of Pakistan lie in other countries. Planning for an optimum development of the water resources therefore, requires the co-operation of the other countries concerned. Pakistan and India with the assistance of the World Bank


U. S. S. R.
SINKIANG
KASHMIR
INDUS AND
RIVER
JAMMU
AFGHANISTAN
PAKISTAN
INDIA
Kabul
Peshawar
Srinagar
Jammu
Kohat
Bannu
Mianwali
Sargodha
Lyallpur
Sheikhupura
Lahore
Amritsar
Gujrat
Madhopur
Rapar
Ferozepure
Montgomery
Multan
Bahawalpur
Panjnad
Quetta
Sukkur
Jacobabad
Hyderabad
Karachi
Hub Dam (5)
RANN OF KUCH
ARABIAN SEA
JHELUM RIVER
CHENAB RIVER
INDUS RIVER
RAVI RIVER
SUTLEJ RIVER
BEAS RIVER
Tarbela Dam
Khanpur Dam (2)
Rawal Dam (3)
Khajuri Kach Dam (4)
Hub Dam (5)
LEGEND.
International Boundary
Main Cities
Dam
1. Tarbela Dam
2. Khanpur Dam
3. Rawal Dam.
4. Khajuri Kach Dam
5. Hub Dam
50 0 50 100
Scale of Miles
West Pakistan
Water and Power Development Authority
Development Projects
LOCATION MAP

were able to sign a Treaty in 1960 for the sharing and the utilization of the waters of the Indus River System. No such agreement has yet been worked out regarding the use of the waters of the rivers flowing from India into East Pakistan.

Long-term Plans

Within the above limitation, long-term plans have been prepared for the development of the water resources in both the wings of Pakistan. The salient features of these Master plans are set out in the following paragraphs. In the development of water resources, the project planning studies are directed towards providing the optimum single or multiple purpose benefit, that is the project has to provide the greatest net benefit to the area of the river basin. The project size as determined from this consideration is evaluated in greater details for the final feasibility study of the project.

West Pakistan

Situation : West Pakistan has a gross area of about 199 million acres of which about 131 million acres lie in the Indus Basin. The present estimated population of West Pakistan is about 51 million which is expected to increase to about 87 million by 1985. Out of the total cropped area in West Pakistan of about 41 million acres, 70 percent lies within the canal irrigated area of the Indus Plain. The existing canal system covers a culturable area of about 33 million acres of which 25 million acres are actually receiving irrigation supplies.

From time immemorial, land has been irrigated from the spills of the Indus River System and through inundation canals which operated during the flood season without any diversion dams. In the last 100 years most of these canals have been converted into weir-controlled canals by the construction of diversion dams in the rivers. This conversion made it possible to run the canals throughout the year and also to extend irrigation to new areas. The areas on the tributaries of the Indus were developed first. Ten Headworks are located on these rivers: Jhelum, Chenab, Ravi and Sutlej. Those at Rasul, Marala and Khanki are older weirs with shutters. The others are barrages with gates. The weirs at Rasul and Marala are being replaced by new barrages. Thus, the Khanki weir, the oldest headworks in West Pakistan, will remain as a reminder of the 19th century irrigation structures.

Indus Waters Treaty : The inadequacy of surface waters for the canals in the western region gave rise to inter-state dispute as far back as 1934. These were resolved through Commissions set up by the Government. After Independence in 1947 a dispute arose between India and Pakistan regarding the sharing of the water of the Indus River System which was ultimately solved in 1960 through the good offices of the World Bank. The Indus Waters Treaty fixes the rights of each country in relation to the other concerning uses of waters of the Indus River System and contains provision for settlement in a co-operative spirit of all those questions which might arise between the two parties in regard to the interpretation or application of the treaty. The Treaty provides for the construction by Pakistan of a gigantic system of replacement works to make up for the waters of the three eastern rivers, Sutlej, Beas and Ravi allocated to India. The system of works includes two storage reservoirs, five new diversion dams and eight inter-river link canals in addition to the remodelling of certain existing works. Some of the replacement works

have since been completed while some including the storage dam at Mangla on the river Jhelum are nearing completion. Preliminary works of the other dam on the river Indus, *viz.* Tarbela Dam, have been taken up. The work on the diversion dam on the Indus and on link canal has yet to be started.

Waterlogging and Salinity : With the introduction of large-scale artificial irrigation in the Indus Plain the groundwater-table started rising. As natural drainage of the area was inadequate and artificial, drainage was not provided, this caused waterlogging in the low-lying areas and the groundwater-table rose to within five to ten feet of the surface, over most of the areas. The canal system which was designed to serve the largest possible number of people did not provide adequate supplies to meet the full water requirements of the crops and, therefore, the water was spread over the land very thinly. This resulted in bringing the harmful salts already present in the soil structure to the surface. In the high water-table areas this upward movement of the salts was further accelerated due to evaporation of the groundwater moisture to the surface by capillary action. Large areas suffer from sodium damage. Reclamation of saline and alkaline soils is thus one of the most pressing problems for irrigated agriculture in West Pakistan.

As a result of many years of continuous research and investigation it has been concluded that the best way of dealing with the twin menace of waterlogging and salinity is to provide adequate drainage and to increase the water allowance to an extent that, apart from fully meeting the consumptive requirements of the crops, could also leach the salts from the root zone of the crops to the deeper strata of the soil crust. Suitable cropping patterns for the effective reclamation of the damaged land are also to be evolved. In areas where the groundwater is fit for irrigation, the solution lies in the installation of tubewells provided a suitable aquifer is available. These tubewells, apart from providing adequate drainage by pumping, also furnish additional irrigation supplies to meet the water requirements for crop and for leaching of the salts. In areas where usable groundwaters do not exist, the allocation of surface waters will have to be increased and the drainage improved by constructing surface and subsurface drains.

Water requirements : The total culturable area available for development from the Indus River System is 87 million acres. The water requirement for the irrigation of this area will be more than 400 MAF but the surface water available in the rivers is about 130 MAF only, a part of which is lost in the river channels through seepage and evaporation. The maximum river diversion on full development of the surface water resources would be of the order of 116 MAF only. Thus, it is not possible to develop the entire area with the available supplies. At present about 80 MAF of surface waters are being withdrawn for irrigation. By 1975 the surface water diversions are expected to be increased to about 95 MAF. The existing canals have a diversion capacity of about 240,000 cusecs. It is proposed to increase their capacity by about 40 percent.

Storage of Surface waters : The requirement of stored surface water for full development of surface water resources has been estimated at about 26 MAF. At present practically no storage reservoir exists. The

Mangla Dam on the Jhelum which is nearing completion has a gross capacity of 5.55 MAF. The Tarbela Dam on the river Indus will have a gross storage of 11.1 MAF and a live storage of 8.2 MAF. The next largest storage proposed to be taken up is at Kalabagh on the Indus with a live storage of about 6.4 MAF so that there would be a total capacity of at least 20 MAF by the end of 1985.

Groundwater : About 10 MAF of groundwater is now being used annually for irrigation. Of this 6 MAF is pumped by private tubewells, partly electric and partly diesel operated. 2 MAF is pumped by electrified Government tubewells and 1.5 MAF is lifted by means of wells operated by bullocks. It has been estimated that 45 MAF of groundwater could ultimately be pumped for agriculture without lowering the groundwater-table beyond 15 feet from the surface. Some of the pumped water with excessive salts would require mixing with the surface waters before it could be applied to the land. The potential groundwater supply of 45 MAF is expected to be developed by the installation of tubewells of a total installed capacity of 130,000 cusecs. The number of tubewells, so far installed, is over 32,000.

Planned irrigation development: The future development programme aims at removing the constraints on the present irrigation system and realising its full potentials in a phased manner. There would be continued installation of tubewells to provide new irrigation supplies and, simultaneously, to control the water-table. Initially, emphasis would be given to zones with fresh groundwater before the mixing zones where the groundwater requires dilution with canal supplies unless they have to be treated together for project feasibility. Public tubewells within these zones will generally have priority where the water-table is higher and where growth of agricultural production would be much more rapid than with the alternative private tubewells. Thus the early tubewells would serve the combined purpose of water supply and drainage; but later the objective could become essentially that of a water supply alone. Simultaneously, there will be development of surface drainage for storm run-off in the high run-off areas as crop values increase and a less fallow land remains to absorb excess water. The completion of the Mangla Dam on the Jhelum in 1967 will offset through storage the loss of flows from the Ravi and Sutlej when they are diverted to India and will also benefit a number of northern canals commanded by better regulation of the Jhelum flows in Rabi season. The next important stage is the Tarbela which should be brought into operation by 1975. The programme of development will include the integration of tubewells and canal supplies. Canal enlargements will benefit particularly the Lower Indus region and Sutlej and Panjnad left bank region. Construction of further storage reservoirs would take place primarily on the Indus River to meet the rising demand for water and make good the loss of capacity due to siltation in the earlier reservoirs.

Flood protection : With the construction of the proposed storage of the Jhelum and the Indus the problem of flood damage by these two rivers will be considerably reduced. Levees on either bank of the Indus have been constructed for flood protection in the lower 600 miles of the river where it is agrading. In the case of the Ravi and the Sutlej the flood problem is expected to be reduced appreciably when dams on these

rivers in India are completed.

Navigation : Practically no inland navigation system exists in West Pakistan. Only on the Indus river a limited number of country boats ply from Kalabagh up to the Arabian Sea. Some of the bigger canals like Nara in the southern area, are used by country boats.

Hydro-Power : The present hydro-power capacity installed in West Pakistan is 266 MW comprising 160 MW in 4 units at Warsak and the rest from a number of canal falls. Two units of 100 MW each at Mangla will come into operation by June, 1967 and a third in April, 1968. Three other units will come up later on. Tarbela envisages a total power installation of 2.1 million KW in 12 units of 175,000 KW each.

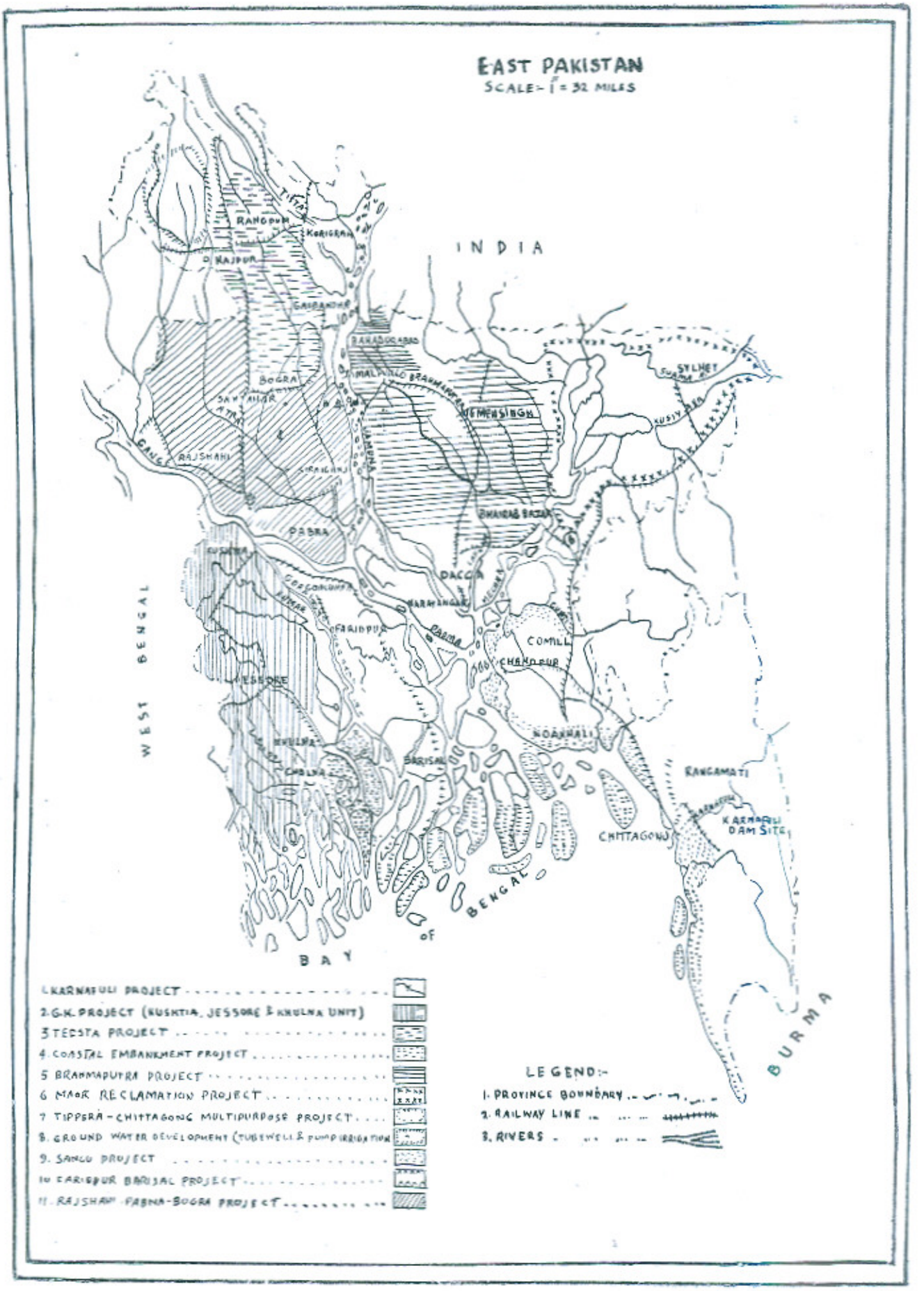
Investment : The Third Plan (1966—70) envisages an expenditure of Rs. 2,962 million on water development in West Pakistan in addition to Rs. 3,265 million on Indus Basin Works. The Fourth Plan (1971—75) expenditure is expected to be of the same order.

Situation : The development of this province is in its early stages, because the area which now comprises East Pakistan had been neglected before Pakistan's Independence in 1947. East Pakistan has an area of about 55,000 square miles and is densely populated. The present estimated population of about 64 million is expected to increase to 105 million by 1985.

By 1985, the agriculture sector would have to (*i*) meet the food and fibre needs of an additional 41 million people, (*ii*) improve the nutrition value of the daily diet and bring it up to an acceptable level, (*iii*) meet the increased demands for agricultural products stemming from the doubling of per capital income, and (*iv*) provide the agricultural raw materials for an expanded industrial sector. To meet these goals, agricultural production on the existing farms covering about 22 million acres will have to be expanded considerably, as there is little scope for the development of additional land.

The 22 million acres of cultivable area in the province are divided into very small holdings, each farm averaging 3.5 acres of which 3.1 acres are cultivated. They are generally fragmented with 29 percent having 10 or more fragments. The present cropping intensity is 127 percent which means that 27.5 million acres of crops are grown on the 21.6 million acres of land under cultivation. The small fragmented farm necessitates the use of primitive agricultural methods. Use of fertilizer, improved seeds, and the other modern techniques which contribute to increased production are yet to be practised on a large scale.

Floods and droughts :—East Pakistan suffers from both over-abundance and scarcity of water. Unfortunately, these conditions recur each year. About one-third of the land area is regularly flooded during the monsoon season. This increases to two-fifths of the land area during years of greater flooding. These annual floods inhabit the adoption of improved farming methods, cause material damage to crops and induce sickness and hardship among the people. Flood damages must be stopped or reduced considerably if the economic development programme of the Province is to succeed. The drought is also a perennial phenomenon. It begins in November and lasts through March. Some year, it lasts even longer. This not only results in large tracts of land lying fallow during the best


EAST PAKISTAN
SCALE:- 1" = 32 MILES
INDIA
RANGPUR
KURIGRAM
DINAJPUR
GAIBANDHA
BOGRA
SARIAKANDI
JAMALPUR
BRAHMANBARIA
MYMENSINGH
SYLHET
SUNAMGANJ
KUSIYARA
RAJSHAHI
PABNA
SIRAJGANJ
DHARAIL BAZAR
KUSHTIA
DACCA
MANIKGANJ
FARIDPUR
PADMA
COMILLA
CHANDPUR
JESSORE
NOAKHALI
KHULNA
BARISAL
RANGAMATI
KARNAFULI DAM SITE
CHITTAGONG
WEST BENGAL
BAY OF BENGAL
BURMA
1. KARNAFULI PROJECT
2. G-K PROJECT (KUSHTIA, JESSORE & KHULNA UNIT)
3. TEESTA PROJECT
4. COASTAL EMBANKMENT PROJECT
5. BRAHMAPUTRA PROJECT
6. MAOR RECLAMATION PROJECT
7. TIPPERA - CHITTAGONG MULTIPURPOSE PROJECT
8. GROUND WATER DEVELOPMENT (TUBEWELL & PUMP IRRIGATION)
9. SANGU PROJECT
10. FARIDPUR BARISAL PROJECT
11. RAJSHAHI PABNA-BOGRA PROJECT
LEGEND:-
1. PROVINCE BOUNDARY
2. RAILWAY LINE
3. RIVERS

growing season but it also delays sowing of the summer crops thereby reducing the full productive potential of the land.

Flood problem : East Pakistan, for the most part, is a delta formed by the three great rivers—the Brahmaputra, Ganges and Meghna which join in East Pakistan and outfall into Bay of Bengal. These rivers have a combined annual flow of about 1,200 million acre-feet which is enough to cover the entire Province to a depth of 34 feet. Almost all of it (93 percent) comes from across the international boundary.

A study carried out in 1927, covering the period 1870—1920, indicated that floods occur on the average every two and one-half years, moderate to severe flood every four years, a severe flood every seven years and a catastrophic flood every thirty-three to fifty years. With progressive economic development since 1927 and 70 percent increase in population, the damage presently caused even by a moderate flood would be much more than that caused by a severe flood in the period of studies referred to above. The problem is unique and complex.

Ganges River : Most of the drainage area of the Ganges, estimated 350,000 square miles above the Hardinge Bridge in East Pakistan, lies in the north-eastern part of India and runs parallel to the Himalayan Ranges. The average annual discharge is 412,000 cubic feet per second or about 300 million acre-feet. High flows are uniform with a difference of less than five feet between the highest and lowest levels. The highest maximum stage was recorded in 1910 and it is estimated that the corresponding discharge may have been of the order of 3 million cubic feet. The river which is about 5,000 feet at Hardinge Bridge widens to over 10,000 feet shortly thereafter and resumes a meandering pattern within bank limits cutting banks severely and building bars and shoals. Banks are 15 to 20 feet high at low water stages. At highflood stages the water surface overstops the banks by five feet or more. The high water slope of the river from Hardinge Bridge to Goalundo is about 0.23 feet per mile.

Brahmaputra River : The Brahmaputra rises in the northern most ranges of the Himalayas in the south-western part of Tibet and drains an area of about 207,000 square miles above Bahadurabad of which about 1,000 square miles only are within East Pakistan. As this river enters East Pakistan, its flood flows rank it as one of the largest rivers in the world. Based upon available limited data, the average annual discharge at Bahadurabad is estimated to be 678,000 cubic feet per second, *i.e.* about 500 million acre-feet representing a unit run-off of approximately three times that of the Ganges river. To this figure should be added the flow into the Old Brahmaputra channel, upstream of Bahadurabad to obtain the figure of total flow entering East Pakistan from Assam. The maximum recorded flood level gives a corresponding discharge of over 2.5 million cubic feet per second. The high stage slope of this river from Bahadurabad to Goalundo is about 0.35 feet per mile. Sections near Bahadurabad show various channels, shoals and islands with no pattern predominating in successive reaches indicating a highly changeable channel of probably low hydraulic efficiency and heavy sediment load. Because of the great width of the river and ample slope, over-bank flooding during the monsoon season is only three to five feet deep.

Meghna River : The Meghna is the smallest of the three big rivers in East Pakistan. Proportionately more of its drainage area lies within the province. The annual discharge of the Meghna at Bhairab Bazar, about 75 miles upstream of its junction with the Ganges-Padma, is 124,000 cubic feet per second, *i.e.*, an annual flow of over 90 million acre-feet. The 75 mile tail end of this river formerly carried most of the Brahmaputra flows and has, therefore, a capacity much large than that required for the present Meghna discharge. The stream exhibits well developed meander patterns and flows on a very flat gradient. At flood stages the slope of the Meghna downstream of Bhairab Bazar, is only about 0.06 feet per mile which undoubtedly reflects the influence of backwater from the Ganges.

Master Plan : The full potentia of the agriculture sector can be realised only through the comprehensive development of the water resources. The Master plan for water development projected up to 1985 has this objective as a major part of the overall development plan for the province. The plan is basically water control by the reduction of adverse flood effects, by drainage and irrigation. The different projects are relatively independent but are integral part of the overall water plan. Each is suitable for development in one or more stages. Embankments will keep out river flood water, regulators will admit or drain water by gravity and pumping stations will drain enclosed areas when drainage by gravity is not possible, or will supply irrigation water. Only a few projects will provide hydro-electric power water supply, recreation facilities, inland fisheries and navigation will also benefit from the projects,

Watershed Management : This does not apply to East Pakistan which contains the lower reaches of the river. However, with further development in the future, it will be necessary to ensure that water pollution from industrial installations is avoided. Algae in water, after irrigation becomes common, may also be a problem.

Storage Reservoirs : There are no potential storage sites on the reaches of the major rivers within East Pakistan. Information concerning sites for possible storage outside the provincial boundary is not available. The area in Assam of India through which the Brahmaputra River flows is known to be a seismic region. Upstream storage as a means of flood control (because of the above factors) is, therefore, precluded to East Pakistan at least for the foreseeable future.

Levees and channel improvement : The only means of controlling floods in the province is to construct levees and improve river channels. An outline of a flood protection plan has been prepared. This envisages the construction of about 3,000 miles of embankments along the rivers and improvement of about 900 miles of river channels for protection against upland floods. These will benefit an area of about 9 million acres. The construction of embankments has been started from upstream, along the Brahmaputra river. Although not much adverse downstream effects are expected, the situation will be watched carefully and the plans modified, if necessary.

Irrigation : Irrigation has long been practised in East Pakistan on a small scale, using indigenous methods. The Ganges-Kobadak Project, the first modern irrigation project, was partially completed in 1962 and at present it provides irrigation supplies

to about 200,000 acres of land. Other projects employing tubewells or low-lift pumps along rivers have been started in different parts of the province. Irrigated agriculture, however, still plays a minor role in this region and much development has to be done.

Proposed Irrigation diversion: In order to meet the requirements of agriculture, it has been estimated that about 7.9 million acres have to be provided with irrigation facilities by 1985. Water will be diverted or pumped from the streams and, where possible, pumped from underground. Based on the studies carried out at experimental farms and allowing for canal losses, field losses, etc., it is estimated that the irrigation efficiency will be about 50 percent. Thus, the water to be diverted would have to be double the quantity actually used by the crops. Apart from small diversions from the minor rivers of the Chittagong area, the annual diversions for irrigation, during a dry year, will be about 80 million acre-feet.

Mode of diversion : While tubewells and low-lift pumps have shorter construction periods than large canal system based on gravity diversions, they are also considerably more expensive. More schemes, providing gravity diversions through the construction of weirs and barrages generally result in other benefits also, such as added recreation facilities and production of hydro-electric power. Gravity diversions are expected to occupy a lesser role in the development of irrigation in the Province and will serve only about one-third of the total irrigated area. Low-lift pumps will serve most of the remaining areas. Only limited information is available on groundwater at present although investigations are being carried out in the field.

Quality of water : Except for those areas which are near the Bay of Bengal and are susceptible to salt water intrusion, all of the surface waters of East Pakistan are of good quality. Water from the Ganges river contains greater amounts of plant nutrients than that of the Brahmaputra river.

Some special problems : Irrigation projects offer marginal opportunities for investment. Farmers ability to pay for them is uncertain. This is especially so in East Pakistan where irrigation is supplemental. The costs of irrigation works have therefore to be subsidised by Government. Further, development of irrigation requires intensive extension services amongst the farmers to educate them in the use of canal irrigation water along with improved farming techniques and use of fertilizers, etc. The difficulty of acquisition of land for constructing the facilities in an area where land-holding is very small, is acute. Solution of all these problems calls for the institution of a strong organization in the field with adequate support from the Government.

Salinity : Due to heavy rainfall (70—100 inches annually over a period of five months) and better natural drainage, the lands of East Pakistan do not face the problem of rise of salts and their concentration in the upper layers of the soil. However, the coastal saline lands occupy an area of about 6,000 square miles bordering the Bay of Bengal. The soils range from sandy soils to clay, but are mostly silty clay loam. The topography is generally flat with occasional coverage with sea-water. The groundwater-table which is mainly sea water is 35—40 inches deep. Fortunately, the surface soils

are alluvium deposits of the Ganges river and generally rich in CaCO3 (4-10%). This high concentration of Ca++ ions offsets the detrimental effect of Na + ions brought in by the tidal waves. Moreover, whatever salts that may accumulate are washed by the considerable rainfall. These areas are being reclaimed for rice cultivation through the construction of embankments which prevent flooding by saline tidal waters. The Coastal Embankment project provides for about 3,000 miles of earthen embankments with automatic flap gates for draining out the accumulated rain water from within the polders during periods of low water in the tidal outfall channels outside the polders. This project, which is considered to be one of the biggest of this nature in the world, is being executed almost entirely through manual labour. About 1250 miles of these embankments have been constructed so far reclaiming about 1.2 million acres of agricultural land from the ingress of saline water. Though the embankments were not designed to withstand cyclonic storm surges, yet these have saved millions of human lives during the recent series of cyclones in the Bay of Bengal. It is proposed to resection these embankments to make them stronger and provide them with forest cover.

Navigation : The waterways of East Pakistan are transport routes ranking in importance ahead of railways and highways. In addition to established steamer and barge routes for freight and passengers. Sail and hand-powered craft in great numbers serve thousands of villages. Although some waterway routes will be lost through siltation and substitute modes of transport, water transport will have an active and prominent role in the projected expansion of commerce. It is estimated that freight moved by water will increase over three times during the next two decades, from 8 million tons in 1960 to about 25 million tons in 1980.

Hydro-Power : The scope of hydro-power in East Pakistan is limited on account of the generally flat terrain of the province. There is, now, only one hydro-station on the Karnaphuli river with installed capacity of 80,000 KW in two units with provision for another unit of 40,000 KW. Two other hill streams in this region, the Sangu and Matamuhuri, have potential for generation of hydro-power. Canal falls can also generate some power. The prospect of tidal power is not so good on account of fluctuations in tidal range being small.

Investment : The total capital cost of the East Pakistan water plan, anticipated at this time, amounts to Rs. 9,960 million ($2,092 million). The Third Plan from 1966 to 1970 provides an expenditure of Rs. 2,100 million.

It would be seen from the above resumé of the water resources development plans in Pakistan that the most pressing needs in West Pakistan are irrigation and control of salinity and waterlogging through the development of surface water and groundwater, and in East Pakistan flood control, irrigation and protection of the coastal belt from tidal water intrusion. The plans will demand large investments and their implementation will require continued financial assistance from friendly countries. It is also clear that the optimum development of the water resources is not possible without an understanding with the co-basin riparians. An International agreement has been concluded on Indus waters. There must be an agreement in respect of the Ganges waters also.