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PROCEEDINGS OF THE REGIONAL SYMPOSIUM ON FLOOD CONTROL, RECLAMATION, UTILIZATION AND DEVELOPMENT OF DELTAIC AREAS

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REPORT OF THE REGIONAL SYMPOSIUM ON FLOOD CONTROL, RECLAMATION, UTILIZATION AND DEVELOPMENT OF DELTAIC AREAS

I. INTRODUCTION

1. Deltaic areas are in general formed of potentially productive land with high soil fertility, abundant water, interlaced inland waterways and close proximity to the sea; they are usually densely populated. Thus their development will enable them to contribute substantially to raising people's standards of living.

2. Most of the countries in the ECAFE region have one or more deltaic areas, some of which are undergoing gradual development while some are still at the early stage of being investigated and studied with a view to formulating development plans.

3. The Fourth Regional Technical Conference on Water Resources Development organized by the secretariat of the Economic Commission for Asia and the Far East at Colombo, Ceylon, in December 1960, expressed the opinion that the subject of flood control in deltaic areas and related problems should be discussed in a special symposium.

4. The Commission at its seventeenth session held at New Delhi, India, in March 1961 approved the holding of this Symposium. The Symposium has been accordingly organized under the name of "Regional Symposium on Flood Control, Reclamation, Utilization and Development of Deltaic Areas", jointly by the United Nations Economic Commission for Asia and the Far East and the United Nations Bureau of Technical Assistance Operations (BTAO).

Attendance

5. Representatives from the following member and associate member countries of the Commission attended the Symposium:

China	Pakistan
Federation of Malaya	Philippines
France	Thailand
India	Union of Soviet Socialist Republics
Indonesia	United Kingdom
Iran	United States of America
Japan	North Borneo
Republic of Korea	Singapore
Netherlands	
New Zealand	

6. In addition, there were observers from the Governments of Nigeria (Africa) and the Federal Republic of Germany. A number of international organizations were also represented. A full list of participants is given in annex 1.

Addresses of welcome

7. On behalf of the Executive Secretary, who was absent from Bangkok on United Nations business, Mr. M. S. Ahmad, Officer-in-Charge, welcomed the participants at the opening session of the Symposium. He conveyed the best wishes of the Executive Secretary for a successful meeting and expressed his appreciation to BTAO for its co-operation as joint sponsor of the Symposium.

8. The voluntary assistance of the Governments of the Republic of China, Japan and the Netherlands in preparing for the Symposium was pointed out as an outstanding example of international co-operation. These countries provided experts (one from China, three from Japan and three from the Netherlands) for the ECAFE Mission on Deltaic Areas which carried out a field inspection and study of some of the deltaic areas of the ECAFE region and prepared a report which formed a basic document for discussion at the Symposium.

9. He explained that the purposes of the Symposium were to pool the knowledge and experience of experts, from countries both inside and outside the ECAFE region, and to exchange views on the complex and diverse problems confronting the development of deltas; to impart to the countries of the region a better understanding of the problems in the deltaic areas and to promote and stimulate their more vigorous development; and to formulate recommendations regarding possibilities of further development.

10. Mr. J. N. Corry, Regional Representative of the United Nations Technical Assistance Board and Director of United Nations Special Fund Programmes in the Far East welcomed the participants on behalf of TAB. He expressed his best wishes that the Symposium might be a successful medium for the dissemination of information concerning deltaic areas and provide valuable guidance to the countries of the region in planning their development programmes.

Vote of thanks

11. Mr. Ricardo L. Calingo of the Philippines proposed a vote of thanks to the Government and people of Thailand, the ECAFE secretariat and BTAO for the excellent arrangements made for the Symposium and the courtesy extended. The vote of thanks was carried unanimously.

Election of Chairman and Vice-Chairmen

12. Mr. P. R. Ahuja (India) was unanimously elected Chairman of the Symposium. Mr. Boonchob Kanchanalak (Thailand) and Mr. Gholizadeh (Iran) were unanimously elected First Vice-Chairman and Second Vice-Chairman, respectively.

Adoption of the agenda

13. The agenda as given in annex 2 was adopted.

Organization of the Symposium

14. The Chairman appointed Mr. A. Volker and Mr. K. Deguchi discussion leaders for items 4, 5 and 6 of the agenda and the following rapporteurs for the substantive items:

Item 4. The natural framework of deltaic areas and the data required: Mr. F. H. Allen (United Kingdom)

Item 5. The present stage of development of Deltaic areas: Mr. Hideo Kikkawa (Japan)

Item 6. Possibilities of and problems involved in furthering the development of deltaic areas: Mr. Ren-Jen Sun (China)

Item 7. Discussion of papers submitted by participating countries: Mr. Anis Ahmad (Pakistan)

Working methods

15. The report of ECAFE Mission on Deltaic Areas was prepared in three parts—Part I contains the subject matter of agenda item 4, Part II contains item 5 and Part III item 6. The procedure of the Symposium on each of three items was for the consultants to introduce the report after which participants give general remarks. Then the items were opened for discussion. To guide discussion, participants were given annotated agenda having from 10 to 15 questions for each of the above items and discussion centred around these annotated agenda. On item 7 participants introduced their own papers or papers presented from their countries after which discussion took place.

Drafting Committee

16. A drafting committee was appointed to prepare the report of the Symposium. The committee comprised representatives from the following countries: China, France, India, Japan, the Netherlands, New Zealand, Pakistan, Thailand, the Union of Soviet Socialist Republics, the United Kingdom, the United States of America and North Borneo.

Field trips

17. Two field observation trips to projects in the vicinity of Bangkok, i.e., Damnern Saduak canal and Chiengrak-Klong Darn project were organized by the Government of Thailand for the benefit of participants. On the first trip, participants observed that, in spite of unfavourable hydraulic conditions (flooding, high groundwater table, threat of salt water intrusion) and unfavourable soil conditions (heavy clay soil), human efforts nevertheless made it possible to use the area successfully for intensified horticulture and fruit orchards. On the second trip, the reclamation of coastal saline land by embankment and sluices as well as drainage and conservation works were observed.

Expression of sympathy to storm victims of East Pakistan

18. At the request of the Chairman, the representative of Pakistan reported briefly on the disastrous cyclone and storm surge which recently struck the Chittagong area of his country, resulting in heavy loss of life and severe property damage. The participants unanimously expressed their deep sympathy to the Government and people of Pakistan who had suffered such great losses in this storm.

II. THE NATURAL FRAMEWORK OF DELTAIC AREAS AND THE DATA REQUIRED

(Agenda item 4)

19. The Symposium had before it document E/CN.11/WRD/DA/L.2 (Report of the ECAFE Mission on Deltaic Areas: Part I) which was introduced by Mr. A. Volker (Consultant), after which the following points were made.

20. New water resources projects on the upper reaches of rivers may have important effects on conditions in the deltas, changing the pattern of flood discharges and sedimentation, and perhaps increasing the intrusion of saline water from the sea. It is desirable that the requirements of the deltaic areas should be taken into account when such major works in the upper reaches are being planned.

21. Navigational and fisheries requirements and water rights should also be considered in planning major projects in the upper reaches of rivers.

22. Problems of sediment transport and deposition are of special importance in deltaic areas. Delta channels may change their courses or tend to silt up; the seaward extension of deltas leads to a rise in bed and water levels; and littoral drift may tend to close the outfalls of the channels. More information should be collected on this subject and further research should be encouraged.

23. Drainage and the control of groundwater may present considerable difficulties in deltaic areas and alluvial fans. In some cases, e.g. deltaic areas in semi-arid regions, the salinity of the groundwater may due to various reasons be excessive.

24. In planning the further development of deltas, the extent of the economic and technical investigations will probably be related to the degree of present utilization and to the extent to which there is government control of land use and tenure. Full investigations are easier to carry out in thinly-populated and less developed areas, but are essential in highly-developed areas in order to increase production.

25. Soil surveys, hydro-geological, ecological surveys and land classification maps are necessary from the outset in planning the development of deltaic areas. Aerial surveys in conjunction with limited ground surveys form a good first basis for this classification. Limited and approximate information can quickly be extracted from the aerial photographs for use in the first stage of planning; and more detailed information

can be obtained for subsequent developments by a closer scrutiny of the same photographs. Various standard methods of land classification were referred to. It was agreed that more and more detailed information was needed to increase production for highly-developed or utilized deltaic areas.

26. It appeared that the question of fertility was really one of potential fertility, particularly in relation to sands, catclays, and acidic or saline soils. It was agreed that the realization of potential fertility depended largely on the progress of technology, and that much could be done with unpromising soils. Nevertheless, some soils presented such difficulty that, if only from the economic point of view, they probably could not be made fertile at present. It was suggested that the point at issue was not fertility, but the aspects of deltaic areas which might be favourable or unfavourable to fertility. A case was cited where drainage had led to the decomposition of organic material in the soil, thus making artificial fertilizers unnecessary for several years. It was pointed out that certain chemical fertilizers applied over long periods could destroy the soil structure. It was also stated that in some areas the fertility of the soil depended on annual inundation. Finally, it was emphasized that, in any investigation of soil fertility problems, the first step should be to consult the local farmers.

27. Little data seemed to be available on the rate of accretion in deltaic areas. It was stated that in the Netherlands 100-1000 years might elapse before the foreshore rose to its maximum elevation. A rate of rise of about 10 feet a century was quoted for an area susceptible to reclamation in the United Kingdom where the sediment load of the river was very small. The delta of the Volga river (USSR) was stated to have extended 20-30 km into the Caspian Sea after the mean level of the Caspian has fallen by 2.5 metres. It was pointed out that, in Malaya, periods of accretion alternated unpredictably with periods of erosion, and this appeared to be a problem in coastal hydraulics. In Taiwan, the foreshores cannot be reclaimed at low levels because of drainage problems and the expense of pumping. It was stated that the reclamation of foreshores at low levels might entail the construction of unduly expensive embankments or dikes which might require substantial protection against wave attack.

28. It was agreed that deltas were, almost by definition, areas of change and potential instability. Injudicious river training works might, by altering the hydraulic regime and the sediment load, reactivate channels which had previously seemed to be more or less in equilibrium or non-active. It was agreed, however, that some parts of deltas were more stable than others, and that it was desirable to delineate such areas and to encourage their reclamation and development.

29. It was most important to collect data on storm-surge water levels, and to continue the process of collection for a long period—or indefinitely. This data was required for (a) the design of coastal embankments or dikes, and (b) the development of surge forecasting and warning systems. A statistical analysis of recorded surge levels should be adequate for the establishment of design criteria for the height of banks. Meteorological data were also essential for the development of storm-surge forecasting and flood-warning arrangements.

30. It was generally agreed that agro-hydrological investigation work could be reduced by the judicious use of genuinely representative sample areas. The areas should be selected to be representative in relation to the particular factor requiring study.

31. Items that can be investigated at moderate costs in sample areas are:

(a) Drainage requirements (optimum depth of phreatic table for dry root crops, capacity of drainage works, required spacing of ditches or tile drains).
(b) Irrigation requirements (type of irrigation, consumptive use).
(c) Soil conditions (physical and chemical composition).
(d) Farm management (crop scheme, bookkeeping account).

32. It was emphasized that a little reliable information on time was more valuable than the result of a complete survey or investigation which arrived too late. Key factors in selecting sample areas are: accessibility, representativeness, physiographic features, and hydrologic delimitation. Selection can be based on reconnaissance surveys.

33. A large body of opinion favoured the establishment of a special agency for the implementation of major improvement schemes. It was clearly advantageous, at least from the administrative and managerial point of view, for countries to place responsibility for research and planning firmly with one organization. Examples given included Pakistan (Water and Power Development Authority), India (Bhakra Control Board and Damodar Valley Corporation) and Nigeria (Niger Delta Development Board). It was the general feeling that comprehensive planning should embrace the whole river basin.

34. The drainage and irrigation requirements of various crops influence projected hydraulic engineering works. The relative quantities of water needed by such crops as rice and groundnuts were quoted in support of this view. It was stressed that the short-term fluctuations in the demand for water must be known by the hydraulic design engineer.

35. On the minimum data requirements for delta development, it was suggested that the discharge of water and sediment should be measured at the apex of the delta, and, if possible, at some secondary stations within the delta. Two or three tide-recording stations should be established, and some measurements of the longitudinal distribution of salinity in the main channels

should be carried out.[1] A resistivity survey of the main areas of the delta was also desirable, supported by information obtained from a few boreholes. It was added that reliable topographic surveys were of course a prerequisite to any development. Of all these data, those on the total discharge of sediment might be the most difficult to obtain. While the data listed above may be regarded as the minimum needed for the initial planning of a deltaic area, it was stressed that deltaic conditions were highly complex and that many of the factors were inter-related. It was, therefore, difficult to do without a comprehensive survey—of which aerial photography, supported by field inspections, should be the basis. Valuable geomorphological maps could easily be prepared from the aerial photographs. Finally, it was suggested that the probable effects of drainage should be considered at an early stage, as the shrinkage of peats and unconsolidated silts could be of major importance.

III. THE PRESENT STAGE OF DEVELOPMENT OF DELTAIC AREAS

(Agenda item 5)

36. The Symposium considered document E/CN.11/WRD/DA/L.3 (Report of the ECAFE Mission on Deltaic Areas: Part II) which was introduced by Mr. A. Volker and Mr. K. Deguchi. In the subsequent discussion the following points were made.

37. Significant encroachment on overbank storage makes flood discharges larger and flood stages higher. Overbank storage depends on the type of flood, on the river channel and the disposition of embankments. For long duration floods the effect of embanking is smaller than for short duration floods.

38. Often the deposition of sediment keeps the river bed rising and embankments have to be raised higher and higher. Due consideration should be given to whether the river is of the aggrading type or not. River basin development should include the protection of deltaic areas from floods and in this respect the sediment problem both in and upstream of the delta should be studied.

39. It was pointed out that embankments along the sea coast had to be high enough to prevent flooding but the problem was sometimes one of economy. Foundation conditions and suitable construction materials sometimes imposed severe limitation on height.

40. The maintenance of embankments must always be adequate. The growing of grass or shrubs may be a help in the maintenance of coastal embankments if indigenous vegetation will not grow. Research should be directed towards the development of suitable plants. Bricks and brick blocks have been used for revetments in West Bengal.

[1] The "PYCNOSONE" is a simple and reasonably reliable instrument for measuring salinity. Further information may be obtained from the Hydraulic Laboratory at Delft (Netherlands).

41. In some localities tidal effects in the freshwater reach are used for irrigation. The limit of saltwater instrusion in the lower reaches of the river depends on the discharge of the river. Increased utilization of water upstream may therefore preclude the use of tidal effects for irrigation in the deltaic area.

42. The system of irrigation by tidal effects is applied in the lower reaches of the Chao Phya river in a limited way. This system is also used in the Mekong river and to a much greater extent in the Shatt-el-Arab river.

43. Sources of salt water intrusion in deltaic areas were:

(a) direct flooding by seawater;
(b) deep seepage or seepage through permeable formations in the subsoil;
(c) shallow seepage through the body of the dike;
(d) leakage through gates in sea sluices and intrusion during the operation of navigation locks; and
(e) drainage from saline areas and return flow.

Suggestions were made to limit this intrusion by enclosing bays or river mouths, thus creating freshwater reservoirs. Typical examples from Japan and the Netherlands were cited.

44. High saline groundwater elevations are harmful, especially to upland crops. Deep drainage systems can be used for lowering the water table. The use of this method in combating the effects of saline groundwater, especially during the non-irrigation period, was stressed.

45. Silt laden water may or may not promote fertility depending on the source and characteristics of the sediment. In India there are localities where flooding causes infertility and others where it adds to fertility.

46. The examination of the chemical composition of silt from some rivers has indicated that the direct fertilizing effect of silt is small. In the cases where a beneficial effect had been observed this was held to be due to:

(a) improvement of soil structure;
(b) the start of a new soil formation;
(c) in infertile soils, to the build up of a new layer in which the plant could root.

47. In semi-arid deltas flooding has the advantage of supplying the moisture required by crops and of washing away some or all of the salt in the soil. In some countries flooding is based to raise the elevation of the land.

48. It is generally considered that the ploughing in of rice straw adds organic matter to the soil and improves soil structure and fertility. This requires a certain amount of labour however and is impracticable for floating rice. It is harmful to plough in straw in permanently waterlogged areas. In some regions the burning of straw is preferred because in this way insect pests and diseases are reduced while the beneficial

minerals in the straw are retained. It was suggested that the relative advantages of ploughing in or burning straw be the subject of investigation on experimental farms.

49. Rice straw is also used for industrial purposes. In Taiwan, straw from the first crop is left on the land; straw from the second crop is used for making paper, bags, etc. Adequate water control is necessary for the successful use of chemical fertilizers in deltaic areas. Chemical fertilizers are usually required for double or multiple cropping. In the Cho Shui Chi area, the application of chemical fertilizers and compost manure has led to higher yields than in any other part of Taiwan.

50. Despite unfavourable conditions such as heavy soil and salinity, successful horticultural and orchard development has taken place in part of the Chao Phya delta area (Damnern Saduak and Phasi Chareon canals) due to:

(a) the economic situation (proximity to Bangkok and the availability of transport facilities);
(b) the location of the gardens on young marine soils with a relatively high gypsum content which compensates for the unfavourable effect of the heaviness of the soil (70 per cent clay fraction);
(c) the liberal use of chemical fertilizers; and
(d) the initiative and industry of the farmers in improving water control.

A somewhat similar development had taken place on the Shatt-el-Arab river.

51. The usefulness of facilities to promote mechanization was recognized. Tractor centres had been established in Burma and India. Mention was also made of the system in Taiwan where a factory had been established for the manufacture of small tractors and where loans are given to farmers on a 3-year return basis to purchase tractors.

52. Farmers are often hesitant in adopting the more efficient farming practices demonstrated on experimental farms. Factors playing a role are:

(a) the preference of farmers for traditional methods;
(b) fragmentation of the land;
(c) charges imposed for the use of water;
(d) complacency;
(e) insufficient and ineffectual government action. (There is a need for the multiplication and distribution of seed and for better marketing facilities).

IV. POSSIBILITIES AND PROBLEMS OF FURTHER DEVELOPMENT OF DELTAIC AREAS

(Agenda item 6)

53. Mr. A. Volker introduced part III of the Report of the ECAFE Mission on Deltaic Areas (Document E/CN.11/WRD/DA/L.4).

54. Deltaic areas offer good opportunities for development because of favourable natural conditions and often on account of density of population in the deltas or in contiguous areas. It was mentioned that both the upstream and the deltaic area should be developed in a co-ordinated manner.

55. The promotion of industry hand in hand with agriculture is important because it stimulates the raising of general prosperity, which gives a market for agricultural products and raw materials for industry and helps to absorb excess labour.

56. In general possibilities for storage, diversion and detention are very limited in the upper reaches and accordingly flood control in deltaic areas should not await the completion of works upstream.

57. The choice between flood reduction by overbank storage and flood protection by embankments depends primarily on (a) the climatologic and hydrologic regime of the river, (b) the reach of the river under consideration, and (c) the stage of economic development of the area considered. In some localities in East Pakistan, sluices are to be constructed in embankments. Part of the flood will be passed through these sluices into depression channels behind them where groins will be built to divert the floodwaters on to the land for the deposition of silt. In other places in East Pakistan, floods will be diverted through sluices with control depths not exceeding two feet.

58. As to the limiting natural ground level needed before diking new areas, it was stated that national economic conditions generally govern. In India, the usual criterion is that no land should be diked for reclamation before it has attained the average level between high spring and high neap tides. On the other hand, in Japan and in the Netherlands, land as low as 6 metres below mean sea level has been reclaimed. From the agro-hydrological point of view seepage, shrinkage and subsidence should be considered in addition to land elevation and soil condition.

59. Hydraulic and agricultural improvement works should be carried out concurrently. It was emphasized that it is even better if agricultural experimentation and demonstration farms can be established earlier, so that when hydraulic works are completed farmers will already have received guidance on how to improve their techniques and methods by making use of the improved hydraulic conditions.

60. It was mentioned that a single farmer who succeeds in increasing his yield and in raising cash crops makes a greater impact on his neighbours than official demonstration farms. In this connexion the case of Damodar Valley (India) was mentioned: there, the most capable and receptive farmers are selected and supported by the Government to act as pilot demonstrators.

61. In planning agricultural improvements the following items amongst others should be considered: variety of rice, fertilizers, prevention of insect pests and diseases, marketing of products, and land consolidation.

62. Subsidence of reclaimed land has occurred in several places in the world. In the Netherlands, land is estimated to have sunk at the rate of 20—25 centimetres a century. In the reclaimed area of the Wash in the United Kingdom, in addition to a general rise of mean sea level in relation to the land of about 10 inches per century, shrinkage and bacterial decomposition of peat soils has led to land subsidence of several feet; embankments have had to be raised several times. In Niigata in Japan also land subsidence has taken place, as a result of which pumping stations have had to be remodelled.

63. Care should be taken in the drainage of catclay soils (acid sulphate soils) to avoid aeration and the oxidation of pyrite and subsequent breakdown of clay, which releases aluminium ions and damages crops. Catclays must be kept under water while draining. Experience in Japan has shown that paddy can be grown successfully in catclay areas when the land is kept wet.

64. It was explained that fisheries development may be adversely affected by: (a) construction of dams and other structures preventing fish from moving into their spawning areas; (b) elimination of water areas by embankments; (c) contamination of water by industrial wastes. It was recognized that, while fisheries development was very important in the planning of deltaic areas, this and other important aspects such as trade and navigation had been excluded from the scope of the Symposium in order to limit discussion and highlight only the important points brought out by the Mission.

65. It was emphasized that drainage systems should not be combined with irrigation canals especially in areas subject to saline intrusion. Nevertheless in the early stage of some developments controlled drainage systems for water conservation had been successfully employed. Separate irrigation and drainage is an absolute necessity when high crop production is planned. However, in areas outside saline reaches and where sprinkler irrigation is adopted, a combined system may be feasible.

66. For irrigation in coastal zones where the importation of fresh water is neither feasible nor desirable, the construction of tanks and larger reservoirs created by enclosing tidal creeks offers a possible solution as a water conservation measure, the potentialities of which should be fully examined. Where loss by evaporation assumes importance, it may be desirable to explore the possibilities of conserving water by spreading mono-molecular films on the water surface. Attention should be paid to the water-salt balance of reservoirs.

67. In some countries a benefit-cost ratio of not less than unity is the decisive factor in determining whether or not agricultural or hydraulic improvement works should proceed, while in other countries the ratio is not decisive. It was pointed out that indirect benefits should be taken into account when making the decision. With respect to project priorities, the view was expressed that socio-economic factors such as population pressure, the economic position of farmers, and national and provincial policies have a great influence on development and should be taken into consideration.

68. It was felt that, although agricultural production could be improved in most ECAFE countries by promoting modern farming methods without improving agricultural and hydraulic conditions, it was preferable to improve agricultural and hydraulic conditions concurrently because of population pressure and the urgent need to produce more food.

69. Where there is a choice between the improvement of existing land and the reclamation of new land, it was generally felt that the intensification of agriculture and industry on existing land is the more promising as the first stage in future development of deltaic areas. It was suggested that the raising of prosperity by development of existing land may tend to limit the rate of increase of population. The reclamation of new land usually means greater investment (and the time-delay in realizing the full benefits on new areas is important in this respect). New reclamation may merely spread subsistence farming to a greater number of people. It was recognized however that pressures may require the development of new areas and that this may take the form of agriculture, urbanization and industry. It was particularly noted that new areas offer unique opportunities for the demonstration of modern cropping systems, crop diversification etc.

70. Master plans were considered to be imperative in guiding actual development by partial schemes. Such plans effectively help in instituting a programme of investigation and avoid the collection of unnecessary data. It is often desirable that master plans be made available for the appraisal of schemes without waiting for publication. Master plans are not final plans: they need constant revision. They are indispensable when starting development and clearly show the necessity for collecting data, the importance of which is often overlooked. The elaboration of a master plan may take some years, but can be done while data is being collected.

71. The feasibility of using models for deltaic areas in evolving master plans was also discussed. Mathematical models and analogue computers have some advantages over physical hydraulic models when very large areas are concerned; but all types of model require large quantities of reliable data for the investigation of a deltaic problem. Problems of erosion and siltation can at present be studied only in mobile-bed hydraulic models of relatively small areas.

V. PAPERS PRESENTED BY COUNTRY REPRESENTATIVES

(Agenda item 7)

72. Eleven papers were presented to the Symposium by participating countries. Each paper

was introduced by the author or the country representative and then discussed. The full texts are published in the proceedings of this Symposium. The list of papers is given in annex 3.

VI. RECOMMENDATIONS

73. Having regard for the urgent need for economic development to be carried out by the countries of the region and the potentialities of deltaic areas for improving the living standard of the peoples of the ECAFE region, the Symposium recommends:

(a) The establishment of panels of experts to assist in developing deltaic areas. Within this broad framework, the fields for assistance may be proposed by the governments concerned. Possible fields include the formulation of investigation programmes, the formulation of master plans, investigation of agro-hydrological conditions, engineering techniques for economic design, and protection against cyclones, etc.

(b) The holding of another symposium dealing with the development of deltaic regions. The following topics are recommended:

(i) Water management in deltaic areas with emphasis on salinity and drainage.

(ii) Planning and design of tidal embankments.

VII. CLOSING SESSION

74. The draft report of the Symposium was discussed and adopted on the afternoon of 9 July 1963.

75. The representative from Iran informally extended an invitation to hold the next symposium at Teheran. This invitation was noted with gratitude and it was left to the Executive Secretary to decide the venue and time.

76. The Symposium unanimously adopted a vote of thanks to the Government of Thailand, ECAFE, BTAO, consultants and the Chairman.

77. The Symposium concluded with the closing remarks of Mr. Koichi Aki, Chief, ECAFE Bureau of Flood Control and Water Resources Development, Mr. M. S. Ahmad, Officer-in-Charge for the Executive Secretary of ECAFE and of Mr. P. R. Ahuja, Chairman of the Symposium.

Post Symposium study tour

78. At the conclusion of the Symposium, there was a study tour of the Kojima Bay and Nobi delta in Japan, where participants observed the works discussed at the Symposium and gathered first-hand information of interest to them. The study tour took place between 11 to 20 July 1963. The programme of the study tour is given in annex 4.

Annex 1

LIST OF PARTICIPANTS

MEMBERS

China

Mr. Ren-Jen Sun, Deputy Director, Planning Department, Tidal Land Development Planning Commission, c/o Chaiyi Tidal Land Development, Meiliao, Yulin Hsien, Taiwan.

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Mr. R. Hussenet, Troisième Secrétaire, Représentant permanent a.i. dela France auprès de la CEAEO, Bangkok.

Mr. Lescaillon, Ingénieur, Adjoint au Chef de la Mission d'Aide Economique et Technique Française au Viet-Nam, Saigon.

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Korea, Republic of

Mr. Chol Chi Jeon, Chief, Flood Control Section, Bureau of Water Resources Development, Ministry of Construction, Seoul.

Netherlands

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Dr. I. S. Zonneveld, Chief of the Department of Ecology of the Netherlands Soil Survey Institute.

New Zealand

Mr. A. D. Benham, Investigating Engineer, Ministry of Works, Wellington.

Pakistan

Mr. Mohammad Anis Ahmad, Assistant Engineering Adviser, Water and Power Department, Karachi.

Philippines

Mr. Ricardo L. Calingo, Chief, Project Development Section, Flood Control and Drainage Division, Bureau of Public Works, Manila.

Thailand

Mr. Boonchob Kanchanalak, Senior Hydrologist, Chief of Hydrology Section, Royal Irrigation Department, Bangkok.

Union of Soviet Socialist Republics

Mr. B. G. Shtepa, Chief Engineer, State South Institute on Designing of Water System and Meliorative Construction Works, Moscow.

Mr. O. A. Yershov, Attaché, Embassy of the USSR, Bangkok.

United Kingdom of Great Britain and Northern Ireland

Mr. F. H. Allen, Director of Hydraulics Research, Department of Scientific and Industrial Research, Hydraulics Research Station, Wallingford, Berkshire.

United States of America

Mr. Hugh F. Tolley, Reclamation Engineer, Chief, Public Work and Engineering, United States Operations Mission, Bangkok.

ASSOCIATE MEMBERS

North Borneo

Mr. W. G. Rodger, Drainage and Irrigation Engineer, Public Works Department, Jesselton.

Singapore

Mr. David Chow Siong Keng, Executive Engineer, Marine and Drainage Branch, Public Works Department.

OTHER STATES[a]

Nigeria

Mr. Johannes Hartough, Agriculture Adviser, The Niger Delta Development Board, P.M. B. 67, Port Harcourt, E. Nigeria.

Mr. P. O. Malone, Civil Engineer, The Niger Delta Development Board, P.M. B. 67, Port Harcourt, E. Nigeria.

Federal Republic of Germany

Dr. Guenther Dillner, First Secretary and Liaison Officer to ECAFE, Embassy of the Federal Republic of Germany, Bangkok.

SPECIALIZED AGENCIES

International Labour Organisation (ILO)	Mr. John S. Fox, Director of the ILO Liaison Office with ECAFE, Bangkok.
Food and Agriculture Organization of United Nations (FAO)	Mr. P. Kung, Irrigation Officer, FAO Regional Office for Asia and the Far East, Bangkok.
United Nations Educational, Scientific and Cultural Organization (UNESCO)	Mr. A. L. Gardner, Deputy Chief, UNESCO Mission, Bangkok.
World Meteorological Organization (WMO)	Lt. Commander Dumrong Chareonsook, Meteorological Department, Bangkapi, Bangkok.

NON-GOVERNMENTAL ORGANIZATION

International Commission for Irrigation and Drainage (ICID)	Mr. John Boonlu, Engineer-in-Charge, Dikes and Ditches Project, Royal Irrigation Department, Bangkok.
International Union of Geodesy and Geophysics (IUGG)	Mr. Boonchob Kanchanalak, Senior Hydrologist, Chief of Hydrology Section, Royal Irrigation Department, Bangkok.

OTHER ORGANIZATION

International Commission on Large Dams (ICOLD)	Mr. M. A. Hamid, Chairman of the Pakistan National Committee on Large Dams, Vice-President of the International Commission on Large Dams, Rawalpindi.

[a] These include
(i) member of the United Nations, participating in a consultative capacity under paragraph 9 of the terms of reference of the Commission;
(ii) the Federal Republic of Germany, participating in a consultative capacity under ECOSOC resolution 617 (XXII) of 27 July 1956.

SECRETARIAT

Mr. M. S. Ahmad	Officer - in - Charge for the Executive Secretary.
Mr. Koichi Aki	Chief, Bureau of Flood Control and Water Resources Development.
Mr. A. R. Khanna	Senior Officer, Bureau of Flood Control and Water Resources Development.
Mr. J. M. Barrett	Senior Officer, Bureau of Flood Control and Water Resources Development.
Mr. Kanok Pranich	Economic Affairs Officer, Bureau of Flood Control and Water Resources Development —Technical Secretary of the Symposium.
Mr. K. Deguchi	Agricultural Land Bureau, Ministry of Agriculture and Forestry, Kasumigaseki, Tokyo, Japan—Consultant.
Mr. A. Volker	Rijkswaterstaat, Directie Waterhuishouding en Waterbeweging, Koninskade 25, S'Gravenhage, Netherlands — Consultant.

Annex 2

AGENDA

1. Opening addresses.
2. Election of Chairman and Vice-Chairmen.
3. Adoption of the agenda.
4. The natural framework of deltaic areas and the data required:

   Natural framework of deltas and data and information required for flood control, reclamation, utilization and development of deltaic areas; geology, geomorphology, pedology, ecology, climatology, hydrology of delta, hydrography of coastal areas, geo-hydrology and agro-hydrology; data available and how to fill up gaps.
5. The present stage of development of deltaic areas:

   Present status of water and land use and tenancy conditions, present methods and policies of flood control, reclamation, irrigation, drainage and other works in deltaic areas and discussion of technical, economic and social factors in the present stage of development.
6. Possibilities of and problems involved in furthering the development of deltaic areas:

   Criteria and factors for the further development of water and land use, such as flood protection, irrigation and drainage, soil conditions, farm management, occupancy and tenancy, etc.; priority of development projects in connexion with desirability and physical, technical, economic and social feasibilities; measures for further development.
7. Discussion of papers received from the participating countries.
8. Adoption of the report of the Symposium.

Annex 3

LIST OF PAPERS PRESENTED AT THE SYMPOSIUM

1. Utilization and development of the deltaic area of East Pakistan (WRD/DA/1)—by B. M. Abbas.
2. Development of the coastal region of East Pakistan by embankment (WRD/DA/2)—by Shafiqul Haq.
3. The present development condition on the Choshui alluvium, fan, Taiwan, Republic of China (WRD/DA/3)—by Ren-Jen Sun.
4. Reclamation of Ansong-Chon tidal area (WRD/DA/4)—by Bureau of Water Resources, Ministry of Construction, Republic of Korea.
5. The Sunderbans of West Bengal (WRD/DA/5) —by V. N. Nagaraja.
6. Tidal irrigation in the delta of the Karun and Shatt-Al-Arab rivers with complications from increased salinity of water (WRD/DA/6)—by M. B. Gholizadeh.
7. Problems in the improvement of deltaic waterlogged paddy field with special reference to irrigation and underground drainage (WRD/DA/7)—by Hikaru Tsutsui.
8. Multipurpose utilization of land and water resources in the Volga-Akhtuba flood plain and Volga delta (WRD/DA/8)—by B. G. Shtepa.
9. Maintenance of a river mouth which is connected with a tidal basin (WRD/DA/9)—by Hideo Kikkawa and Seiichi Sato.
10. Effect of closure of Kojima bay on the tide and flood water levels at the mouth of Asahi river (WRD/DA/10)—by Seiichi Sato and Hideo Kikkawa.
11. Reclamation schemes in the Mekong delta in Vietnam (WRD/DA/11)—by Yuan Hsi Djang.
12. Report of ECAFE Mission on Deltaic Areas, Part I, The natural framework, data and information needed on deltaic areas (E/CN./11/WRD/DA/L/2).
13. Report of ECAFE Mission on Deltaic Areas, Part II, The Present stage of development of deltaic areas (E/CN.11/WRD/DA/L.3).
14. Report of ECAFE Mission on Deltaic Areas, Part III, Possibilities and problems of further development of deltaic areas (E/CN.11/WRD/DA/L.4).

Annex 4

PROGRAMME OF STUDY TOUR IN JAPAN

Thursday, 11 July — *ARRIVE TOKYO*

Late evening—arrive Tokyo International Airport.

Accommodation at *GINZA TOKYU HOTEL.*

Friday, 12 July — *MEETING IN TOKYO*

Morning—meeting on Nobi Delta and Kojima Bay Reclamation Works.

Accommodation at *GINZA TOKYU HOTEL.*

Saturday, 13 July — *TOKYO—OSAKA—KYOTO*

Late morning, depart Tokyo for Osaka by plane.

From Osaka, proceed by chartered bus to Kyoto.

Accommodation at *KYOTO HOTEL*

Sunday, 14 July — *KYOTO — NARA — OSAKA — OKATAMA*

Morning—depart Kyoto by chartered bus to Osaka via Nara.

From Osaka, proceed to Okayama in the afternoon by Japanese National Railways limited express train, arriving in the evening.

Accommodation at *NEW OKAYAMA HOTEL.*

Monday, 15 July — *OKAYAMA — MITZUSHIMA — TOMONOURA*

Morning—field inspection of Kojima Bay reclamation works.

Afternoon — proceed to Tomonoura, en route inspecting Mizushima coastal reclamation for industrial area.

Arrive at Tomonoura and Sansuito islet in the evening.

Accommodation at *KINSUI-BEKKAN.*

Tuesday, 16 July — *TOMONOURA—FUKUYAMA — NAGOYA*

Depart Tomonoura for Fukuyama by chartered bus in the morning.

Inspection of Fukuyama coastal reclamation for industrial area. From Fukuyama, proceed to Nagoya in the late morning by Japanese National Railways limited express train, arriving at Nagoya in the afternoon.

Accommodation at *NAGOYA KANKO HOTEL.*

Wednesday, 17 July — *FIELD INSPECTION OF DEVELOPMENT WORKS IN NOBI DELTA*

Morning—field inspection of Nabeta reclamation works and the sea sluice of the Nikko river.

Afternoon—inspection of Nagoya harbour and its breakwater and Nagoya coastal reclamation for industrial area.

Accommodation at *NAGOYA KANKO HOTEL.*

Thursday, 18 July — *FIELD INSPECTION OF DEVELOPMENT WORKS IN NOBI DELTA*

All day field trip by chartered bus to inspect Kaneyama head works of Iichi Irrigation project, Inuyama head works of Nobi Irrigation project, Kiso river delta and Tsuyama city.

Return to Nagoya for accommodation at *NAGOYA KANKO HOTEL.*

Friday, 19 July — *NAGOYA — KUWANA — GIFU FIELD INSPECTION EN ROUTE*

Morning — leave Nagoya by chartered bus for Kuwana City via Meishi Highway, en route inspect deltaic areas of Nagara and Ibi rivers, outfall of Nagara river and Nagashima town embankment.

Afternoon-continuing on the field inspection of Ibi delta and inspection of the circle levees of Takasu and Ohgaki.

Proceed to Gifu city.

Accommodation at *NAGARA-GAWA HOTEL.*

Saturday, 30 July — *GIFU — TOKYO*

Morning—leave Gifu by Japanese National Railways limited express train for Tokyo.

Accommodation at *GINZA TOKYU HOTEL.*

End of the Study Tour.

DOCUMENTATION

A. REPORT OF ECAFE MISSION ON DELTAIC AREAS

PREFACE

The Fourth Regional Technical Conference on Water Resources Development, organized by the United Nations Economic Commission for Asia and the Far East at Colombo in December 1960, felt that the subject of flood control in deltaic areas and related problems was sufficiently important to be discussed in a special symposium.

The Commission at its seventeenth session held at New Delhi in March 1961 approved the holding of this Symposium and the Netherlands Government offered to provide experts to assist in the preparation and organization of the Symposium. Later the Governments of Japan and the Republic of China made similar offers. An Expert Mission on Deltaic Areas comprising experts offered by these countries was organized to carry out field inspections and studies of several deltaic areas in the ECAFE region from November 1962 to February 1963. These experts and their fields of specialization are:

Hydrology and Flood Control	Mr. A. Volker (Netherlands)
Agricultural Engineering	Mr. Katsumi Deguchi (Japan)
Water and Land Use	Mr. C. P. Lambregts (Netherlands) Mr. C. T. Wang (China)
Agronomy	Mr. Kotaro Nagai (Japan)
Pedology	Mr. I. S. Zonneveld (Netherlands)
Geomorphology	Mr. Masahiko Ohya (Japan)
Technical Secretaries	Mr. Kanok Pranich (ECAFE) Mr. Joseph M. Barrett (ECAFE)

The Mission made field inspections of the Nobi delta in Japan, the Cho Shui delta and tidal land in China: Taiwan, the Sundarbans delta in India and East Pakistan, the Irrawaddy delta in Burma, the Chao Phya delta in Thailand and the Mekong delta in Cambodia. The report of the mission forms a basic document for discussion at the Symposium.

In accordance with the agenda of the Symposium, the Mission's report is divided into 3 parts as follows:

Part I	The natural framework, data and information needed on deltaic areas.
Part II	The present stage of development of deltaic areas.
Part III	Possibilities and problems of further development of deltaic areas.

The views expressed in this report are entirely those of the members of the Mission and not necessarily of the Economic Commission for Asia and the Far East or of the Governments of the countries which so generously provided the valuable services of the experts.

Part I

THE NATURAL FRAMEWORK, DATA AND INFORMATION NEEDED ON DELTAIC AREAS

1.1 SYNOPSIS

To achieve the optimum development and utilization of a deltaic area sound planning and careful execution are essential. Planning must be based on a comprehensive knowledge of all related factors such as the land itself, climatic environment, hydrology and hydrography, agriculture and social conditions and potentialities. In this part of the report these factors are discussed and their influence in several deltaic areas of the ECAFE region illustrated.

Knowledge of the land embraces physical makeup of the soils, land forms and their genesis, and the anticipated effects of flooding or other natural phenomena. A convenient and usable means of presenting the varied land data is in the form of land classification maps compiled for specific purposes. Much of the needed basic information can be obtained from carefully conducted surveys in the field of geomorphology, soils and native vegetation. In the body of this paper brief descriptions of the physical characteristics of several deltaic areas are presented. The deltas discussed are: the Nobi in Japan, the Cho Shui in China: Taiwan, the Irrawaddy in Burma, the Chao Phya in Thailand and the Sundarbans in India and East Pakistan. The wide variation in physical make-up, environment and major problems emphasizes the need for careful study and planning for each delta.

Climate has an important role in the development of deltaic areas in relation to the problems encountered and the extent to which corrective measures should be carried. Information will be needed on temperature ranges and seasonal variations. Precipitation is a critical factor, both in the rhythm of plant growth and frequently in the nature and extent of flooding and the remedial measures which may be undertaken. Data will be needed on the amount and variation of annual precipitation, the geographic and temporal distribution and the nature of occurrence, whether resulting from monsoons or from typhoon or cyclone activity.

The delta of a river is the transition between the upstream area and the sea. From upstream comes the river flow with fresh water and from the sea come the tides with salt water. The deltaic reaches of the river can be divided into zones ranging from upstream where the effects of river flow predominate to downstream where the effect of the sea area is predominant. Most technical difficulties occur in the transition zones where effects of both river and sea are experienced. Accurate hydrologic and hydrographic data and skill and judgment in their interpretation are needed to define adequately the problems which may occur in the deltaic reaches of the streams.

The hydrologic regime of a river determines what works are needed for the protection and utilization of a deltaic area. The important characteristics of the regime are: Frequency and duration of floods, rate of rise and fall in river stage, flood volume, minimum dry period flows and amount of sediments transported. In establishing or maintaining a programme of data collection the following points should be considered:

(a) Continuous records of river stage, stage-discharge relationship and sediment load should be obtained at the apex of the delta.
(b) At selected downstream points on the river and its branches the same data as in (a) should be obtained at intervals of sufficient duration to establish and maintain good correlation with the apex station.
(c) In the case of rivers with considerable over-bank storage, periodic observations should be made of water stage in the flooded areas.
(d) Suitable river maps should be prepared and maintained to show current characteristics of the river bed and banks. Periodic observations and depth charts at critical points are important.

All deltaic areas in the ECAFE region are exposed to the effects of astronomical tides and abnormally high sea level or storm surges. The range of the astronomical tides and their effects on delta development varies widely among the deltas of the region. These characteristics are fairly consistent and predictable at any given location. Storm surges are generated by off-shore differences in barometric pressure and the drag of wind over water associated with typhoon and cyclone activity. The occurrence and magnitude of storm surges have a profound bearing on the protection and utilization of deltaic areas. A programme of data collection on tidal levels and storm surges should include:

(a) Permanent recording tidal gauges at carefully selected locations along the coasts and in the estuaries or river branches. More widely distributed gauges should be maintained for sufficient periods of time to establish satisfactory correlation with the primary stations.
(b) Periodic hydrographic surveys to obtain data on erosion and deposition with detailed attention given to critical areas.

Ground-water movement and its availability in usable quality and quantity is an important factor in the development of deltaic areas.

The successful improvement of the agriculture of a deltaic area involves many interrelated factors. Water supply for plant growth is essential and where not available from precipitation must be supplied by irrigation. Information on the water requirements of the different crops is needed. Careful soil classification is needed to plan proper land utilization. Apart from soil and water, other factors which influence agricultural development are size and shape of farm units, farm practices, availability of farm labour, communications, markets, farm credit, etc. Recognition and understanding of all of these factors is needed for proper planning and development.

1.2 LAND CLASSIFICATION

1.2.1 Introduction

The foundation for planning any measures for land reclamation or improvement is a thorough knowledge of the land itself. Information is needed of the physical make-up of the land, its use under existing conditions and its potential use after the establishment of improvement works.

A convenient and readily usable manner of showing basic land data is by means of land classification maps. Different types of classification maps can be prepared to highlight the information needed for planning improvement projects for different purposes. The land may be so classified as to show suitability for specialized crops or general agriculture, for possible improvement by irrigation or drainage for urban or industrial development, or the classification may show the types of flooding that may be anticipated from rivers or storm surges. Under most conditions land classification data are more useful if separate maps are made for each purpose.

The land classification is derived from basic data provided by research in the fields of geomorphology, soil science and ecology. The classification can best be done by a team of specialists in these three basic sciences, working in close co-operation with the project planners. The compilation of the basic geomorphologic map, soil map and vegetation map would of course be the responsibility of specialists in these fields. In general, the classification map for any one purpose will be more simple than the basic maps from which it is derived.

The cost of careful land classification surveys is low in comparison to the costs of engineering works and other physical improvements required for a development project. On the other hand, insufficient knowledge of land conditions can, as past experience has shown, cause great losses of investment in improvement works.

1.2.2 Geomorphology

Geomorphology is the subject of physical geography which deals with the form of the earth, the general configuration of its surface, the distribution of land and water and the changes that take place in the evolution of land forms.

A well-conceived development plan should be based on detailed knowledge of land conditions and a substantial part of such knowledge may be obtained from geomorphologic study of the land followed by preparation of a geomorphologic map.

(a) *Geomorphologic mapping*

The usual procedure in geomorphologic mapping is to prepare first a provisional map from aerial photographs. This provisional map shows mountainous and hilly land, upland and terrace, valley plain, alluvial fan, natural levee, back swamp, upper and lower deltaic areas, existing and former river course, sand-dune, sand-spit, tidal land, dry river bed, etc. Through field surveys the provisional map can be rectified and put into a final form.

(b) *Geomorphologic map showing classification flood-stricken areas and types of floods*

A geomorphologic map as a base for the classification of flood-striken areas will make it much easier to understand the land conditions as they relate to planning and development, especially in deltaic areas. It will aid the study of past and anticipated floods with respect to area of inundation, length of the period of stagnation, depth of stagnation, direction of flood currents, changes in the course of floods, possibilities of erosion or deposition and other factors. It will also serve the purpose of defining types of floods.

The manner in which a geomorphologic survey gives a better understanding of flood types and land conditions stems from the fact that the relief of the ground surface, however slight, and the deposits of sand, gravel and other sediments have been formed by repeated floods over the area. Geomorphologic elements such as plateau, terrace, valley plain, upper and lower deltaic areas, fan, natural levee, back swamp, coastal area etc. influence the extent and nature of floods. For example, in the case of a fan, erosion and deposition of sands and gravels are common and changes of river channels are frequent, however, flood waters drain off quickly; in a natural levee, channel changes are less frequent, water drains off readily and depositions are mostly sand; in back swamp and lower deltaic areas, stagnation is generally deep and remains over a long period, with depositions of silt and clay.

To prepare such a flood-type classification map, the conditions of floods in the areas observed through field inspections are entered on the provisional geomorphologic map, showing classification of flood-striken areas prepared from aerial photographs. These conditions are: areas never inundated, seldom inundated or, if inundated, draining quickly as the flood recedes and areas usually inundated, with the depth and duration of submergence.

The value of a flood-type classification derived from a study of geomorphologic and topographic features of an area can be seen from the classification map prepared for the basin of the Kiso, Chikugo, Kano and Ishikari rivers in Japan and the close conformity between the map and actual flood experiences in the basin. Especially noteworthy is the flood of the Kiso river following the Ise-wan Typhoon (Typhoon Vera) in 1959. The results of this flood, occurring five years after preparation of the flood-type classification map (figure 1) were found to conform almost exactly to conditions predicted from the map with respect to direction of flood currents, areas of inundation, depth of stagnation and period of stagnation.

There are striking differences in the natural conditions of the deltaic areas of Southeast Asia. To illustrate, these provisional maps showing classification of flood-striken areas have been prepared of the lower Kiso river basin in Japan, the Khulna area in East Pakistan and the Cho Shui river estuary in Taiwan, figs. 1, 2 and 3.

1.2.3 Soil science (pedology)

The principal element of a landscape is the soil, as a foothold for man and animals and their dwellings, a rooting environment for plant life, a storage reservoir and regulator for water and sometimes as the victim of violent rivers, seas and storms. The soil has always been the most important means of food production and will remain so in the foreseeable future.

There are many differences in the soils of different areas, particularly within deltaic areas, which influence or limit the way in which the soils are used. In planning the reclamation, improvement and utilization of deltaic areas, it is very important that a thorough study of the soils be made by qualified soil scientists. This study should be accomplished in the early planning stages as it will indicate which areas are susceptible to reclamation, what measures of improvement should be undertaken and for what uses the areas are best suited.

(a) *Scope and methods of soil classification*

Through the ages farmers all over the world have accumulated a mass of practical knowledge about the

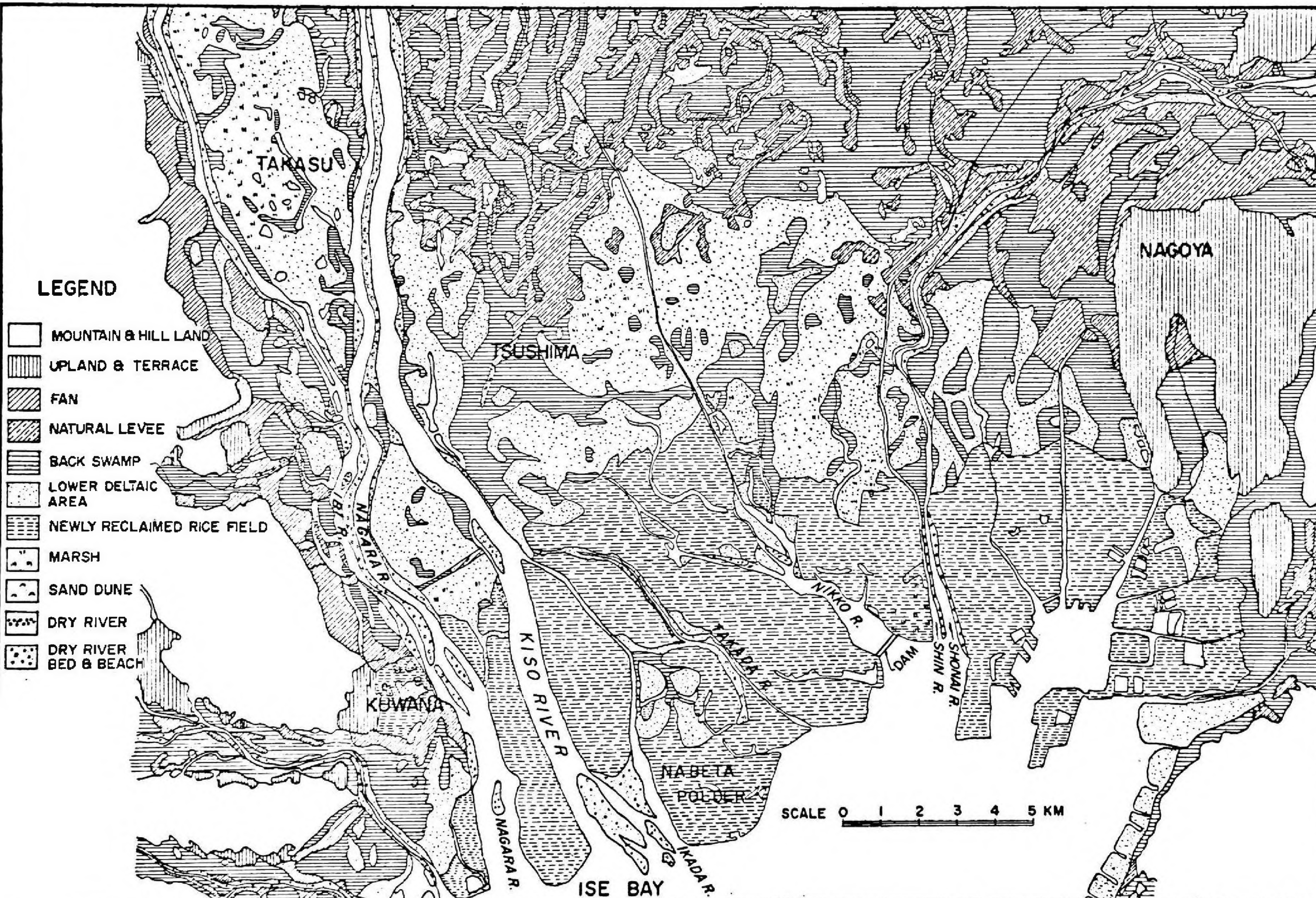


Figure 1. GEOMORPHOLOGIC MAP OF THE LOWER KISO RIVER BASIN FOR CLASSIFICATION OF FLOOD-STRICKEN AREAS

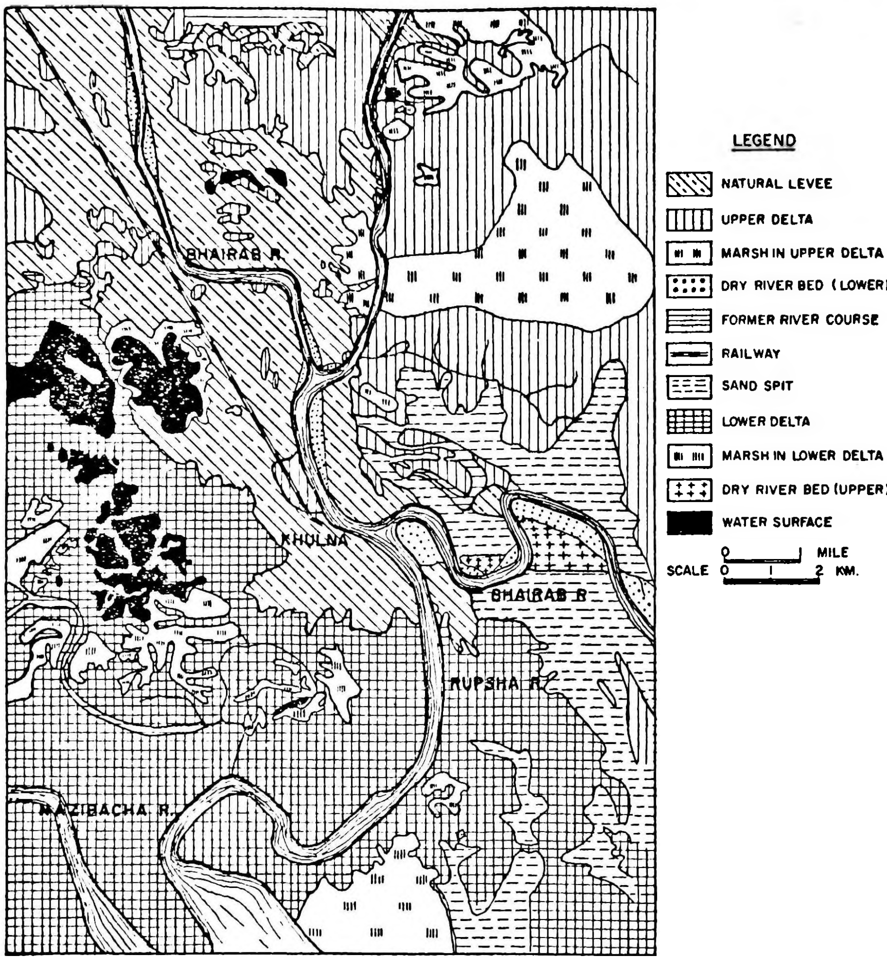


Figure 2. GEOMORPHOLOGIC MAP OF THE CITY OF KHULNA (EAST PAKISTAN) AND ITS VICINITY FOR CLASSIFICATION OF FLOOD-STRICKEN AREAS

soils of their own localities. An important part of practical soil science is collecting and systematizing the farmers' wisdom and expanding and enriching it through the application of modern science, thus making it more useful.

The conduct of soil research has several aspects, which may differ according to the special purpose for which it is undertaken. Soil research embraces the physical, chemical and biological study of the soil itself and the relationship of the soil's properties to the environmental factors of soil formation. Among these factors are parent material, climate, topography, hydrology, vegetative and animal life, time and the activities of man. Study of these relationships is important to give the scientist a better understanding of the soil and guidance on the practical application of scientific data.

In some of the older soil classification systems, there was frequently a tendency to ignore the differences in the relatively young soils of deltaic areas. There are great soil variations between different parts of the delta, which are of great importance in the improvement of these areas.

An essential part of soil research is soil mapping; not only as a means of recording observed data but also as a tool for the research itself. Without a clear picture of the configuration of the soil units in the field; as provided by the mapping, it is difficult to obtain a good understanding of the genesis and qualities of the soil units and their associated land features. It is important that during soil mapping the physiographic features of the land are recognized. This is of great help in properly drawing the boundaries between different soil units. Maps prepared without knowledge of physiographic relations or based on an insufficient number of field observations, borings and test pits may be misleading. The cost of a carefully conducted and comprehensive survey and an accurate, systematic map may not greatly exceed that of a careless or limited survey. The value of the former will be inestimably higher.

The uses to which a soil classification map is to be put may determine the manner in which the surveying and mapping is conducted. For some specific engineering or agricultural purposes a "single value" map may be needed. Such a map would show only

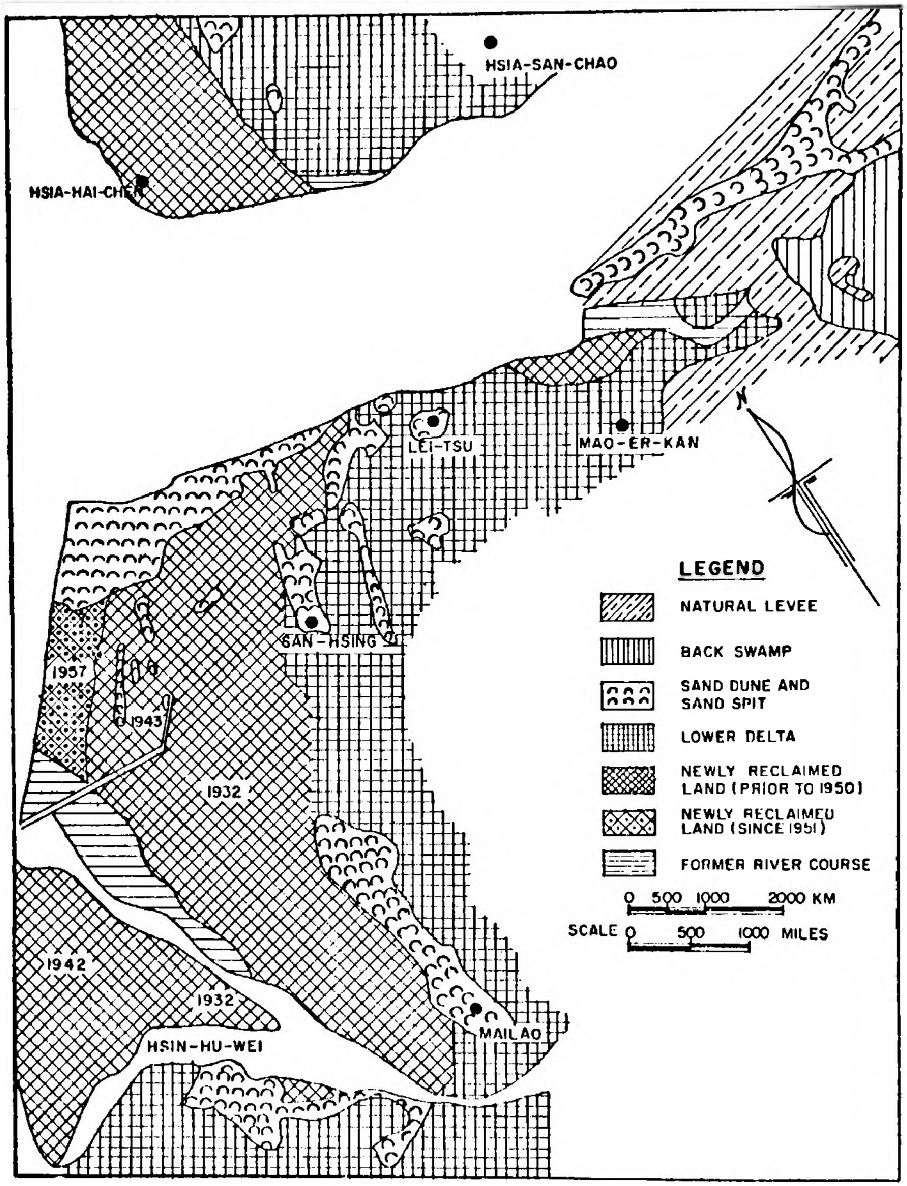


Figure 3. GEOMORPHOLOGIC MAP OF THE ESTUARY OF THE CHO SHIU RIVER AND VICINITY FOR CLASSIFICATION OF FLOOD-STRICKEN AREAS

a few soil properties such as thickness of strata or texture. On the other hand, a comprehensive classification showing all soil properties may be needed for some purposes requiring a knowledge of the inter-relationship of those properties. Also the comprehensive survey may serve a number of purposes. The cost of a comprehensive survey and map may not be significantly greater than the cost of a single-feature survey. The basic costs of qualified soil scientists and technicians, aerial photography and topographic mapping, transportation, subsistence etc. are much the same for both types of survey. Generally, in consideration of all the uses to which a soil survey may be put, it will be more economical to prepare a good comprehensive soil map from which information for any specific use may be readily extracted. Fig 4 shows the reconnaissance soil map of the vicinity of Khulna in East Pakistan.

A comprehensive soil survey must take into consideration all relevant soil characteristics such as texture, mineral content, organic content, biological activity, chemical reduction features and many others. The close inter-relationship of these characteristics and the presence or absence of some define the individual soil units. To classify the soils without consideration of all factors would be as foolish as to claim that a dog and a cat are of the same family simply because they are the same colour and each has four legs.

There is a close relationship between the above-mentioned soil characteristics and general physiographic features. In deltaic areas both are closely

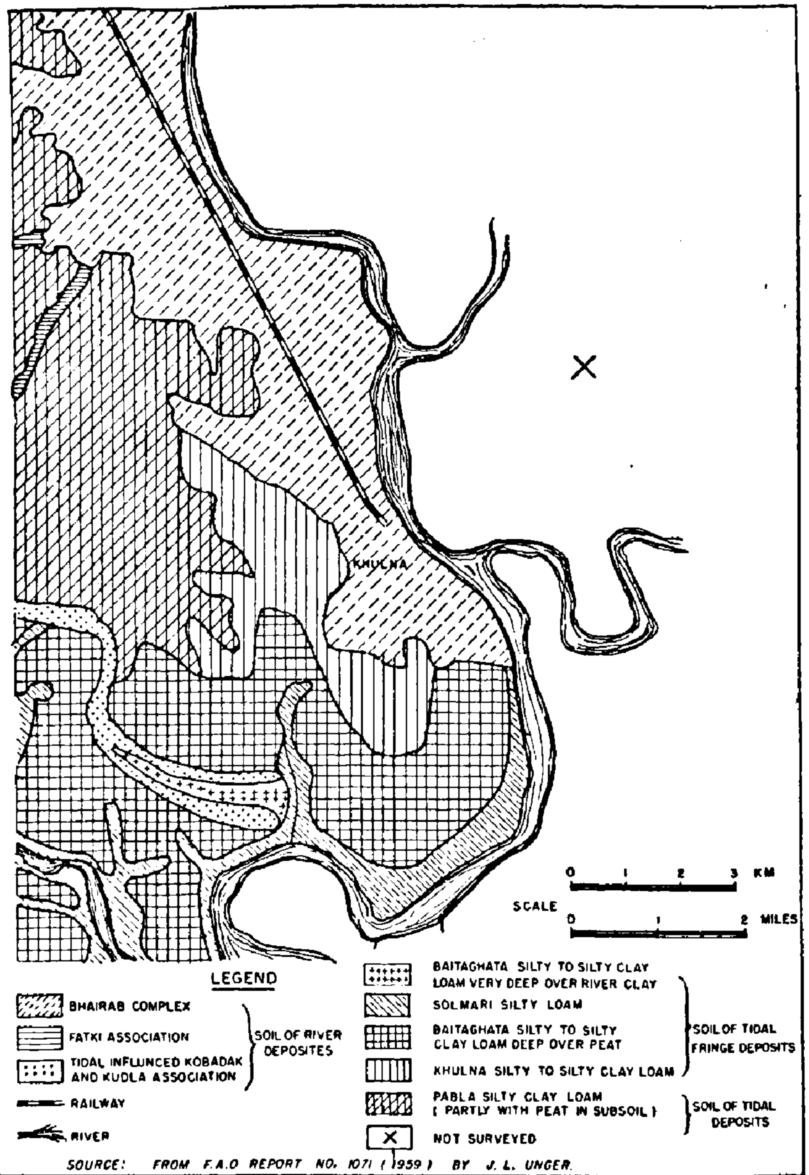


Figure 4. RECONNAISSANCE SOIL MAP OF THE VICINITY OF KHULNA—EAST PAKISTAN

associated with geomorphology. This is partly due to the fact that the soil characteristics are determined to a great extent by their parent materials (sediment).

In deltaic areas which are highly developed for agriculture and other uses the close relationship between geomorphology and soil characteristics has frequently been obscured. However, land use native vegetation and weeds in the cultivated tracts are physiographic features correlated with soil conditions.

Comprehensive soil surveying and mapping requires a thorough knowledge of the related soil sciences, including sedimentology, geology and geomorphology, and also a working knowledge of the relationship between the soils and vegetation and farm practices. Obviously a comprehensive soil survey will require the services of scientists and technicians with thorough academic training and broad field experience.

The relationship between microtopography, geomorphology and soil classification is illustrated by the maps of the Khulna area in East Pakistan. Figs. 2 and 4.

The scale of soil maps should be consistent with the purpose they are to serve. Reconnaissance maps may be of a scale smaller than 1:50,000 and usually show classification by related groups (associations or complexes) of soil units. A detailed soil map should be of a scale larger than 1:50,000 and show individual soil units. Good aerial photography is an essential aid to soil surveying and mapping. Not only does the rectified photograph provide an excellent base on which to sketch field observations, but also, through photo-interpretation by skilled observers, much basic information can be plotted before the field work is started. However, field checking of such plotting should not be neglected.

The following is a brief summary of the personnel and equipment needed for a detailed soil classification:

(1) Well-trained soil scientists with academic qualifications and assistants with wide experience in field work. A willingness to make close personal observations of the soils and some of woodcraft are important.
(2) Aerial photographs or at least good and detailed land use, culture and topographic maps.
(3) Field equipment such as spades, augers and simple equipment for measuring permeability, consistency, etc.
(4) Simple field laboratory such as pH meter and Wheatstone bridge with equipment for preliminary chemical and physical analyses.
(5) Services of a well-equipped laboratory for detailed analysis of soil samples.

(b) *Important soil and ecological features in development of deltaic areas.*

The role of soil in sustaining plant growth is primarily to provide a foothold and support for the plant structure and to supply nutrients and water for plant growth. To perform the latter function it is essential that oxygen be available in the soil for respiration. Even marsh plants, including rice, which have facilities for the passage of air through the stem require oxygen in the soil to prevent the formation of toxic conditions. There are many factors and soil features which influence the ability of plants to take up water and nutrients and influence the penetration of oxygen into the soil. The more important of these factors which are of special significance in the study and development of deltaic areas are listed here:

(1) Subsoil.
(2) Texture (mineral grain size distribution).
(3) Salinity and alkalinity.
(4) Lime-polysulphide ratio and catclay phenomena.
(5) Topography.
(6) Chemical reduction and oxidation in soils.
(7) Physical processes of soil formation from the muds of newly deposited sediments; amongst others, shrinkage.
(8) Organic matter and peat layers.
(9) Differences between marine and alluvial deposits.
(10) Structures, permeability and biological activity.
(11) Clay minerals.
(12) Processes of continuing soil formation.
(13) Chemical compounds in soils.
(14) Mineral and silt content of non-saline waters.

1.2.4 Ecology

Ecology is the science of vegetation, whether in its natural state or as influence by man. Ecological studies are concerned with vegetation as a whole and not with individual plants. The units into which vegetation may be classified are known as communities or associations and are characterized by certain groups or combinations of species. Analogous to the factors of soil formation are the factors of vegetation formation such as climate, parent material (available plant species), soil, hydrology including water quality, topography, living organisms, time and the influence of man. The study of ecology is closely related to soil classification and the correlation between the two can be measured qualitatively and quantitatively.

In conducting a soil survey, a study of the vegetation will help in recognizing and defining the soil units. The ecological survey and map can also form a basis for land classification and provide information about types of flooding, salinity of water, salt water tidal range and occurrence of valuable plants, timber, etc. In cultivated areas, weed growth can be a valuable indicator of water conditions on and in the soil, fertility, salt conditions, methods of cultivation and so forth. Although weeds have not been extensively studied in the tropical regions of Southeast Asia, much information can be obtained using the same methods as employed in Europe and North Africa.

A study of vegetation and mapping of comprehensive communities can be recommended. It should be kept in mind that vegetation maps give a picture of existing conditions, whereas a soil map gives also a picture of potential changes.

In an ecological classification, close observation of vegetation should be made in all parts of the survey area. A list of all species found in a sample plot of about 100 square metres in each part of the area. The frequency of occurrence or abundance of each species should be observed. Data concerning soil, climate, topography, groundwater and other physiographic features should be observed. The area should first be classified into main divisions such as forest, grassland, paddy field, orchard, etc.

1.2.5 Types of land classification map

As mentioned in the introduction to this section, paragraph 1.2.1, good land classification maps are essential tools of planning. From the geomorphologic, the vegetation and the soil map, information is drawn to compile land classification maps for specific uses such as flood control, land and agricultural improvement, urban expansion etc. The basic maps should be consistent with the information needed for the land classification map and the purpose for which it is to be used.

(a) *Classification for a master plan*

Before plans are made for individual improvement project it is very important that an overall "master plan" be made for systematic development of the whole deltaic area. The basic data from which the master plan is prepared may often be of a reconnaissance nature. The reconnaissance land classification map may be of rather small scale, 1:100,000 or 1:200,000 and fine detail is unnecessary. Soil types, vegetation and other data will usually be shown as complexes or mosaics rather than individual types. Some detailed mapping of representative sample areas may prove very useful in interpreting the whole map.

The master plan will generally require information on present conditions, flooding, drainage, land use, state of development and potential possibilities. For potential development, interest is generally centred on soils to determine areas suitable for improvement and areas which should be avoided or which will require special treatment.

If good aerial photographs are available, the work involved in preparing reconnaissance geomorphologic, soil and land classification maps can be greatly reduced and a much less amount of field observation and checking will be needed.

(b) *Classification for detailed planning*

In the preparation of detailed plans for the improvement and development of selected areas detailed information is needed. Large-scale and classification maps at a scale not less than 1:20,000 should be prepared for the various types of improvement to be undertaken. Obviously, the basic soil classification, geomorphologic and other surveys should be conducted in the same detail as is required for the land classification.

For irrigation and drainage improvement, detailed contour maps will be needed. Special attention should be directed to soil texture in relation to permeability. Catclay, saline and alkaline areas require special treatment and detailed information will be needed. The occurrence of peat layers or unconsolidated sediments which might give rise to land subsidence should be determined.

For flood protection and reclamation schemes, knowledge of flood types, etc. is needed.

Land re-allocation or consolidation undertakings will require attention to present and potential soil qualities and productivity.

General agricultural improvement programmes require knowledge of all soil and water factors pretaining to crop production.

1.3 GEOMORPHOLOGICAL FEATURES AND FLOOD TYPES OF DELTAIC AREAS

This chapter gives brief descriptions of several deltaic areas of Southeast Asia which will illustrate the general principles presented in other parts of the paper. Particular attention is given to the geomorphologic features and flood types of the areas. The river reaches above the deltaic areas are discussed only as they contribute to conditions in the delta regions.

1.3.1 Nobi delta

(a) *Upper reaches*

The Kiso river, principal river of the Nobi delta, originates in the Japanese Alps of central Japan. The river basin above the city of Inuyama is characterized by high mountains and steep slopes, which with the abundant rainfall undergo heavy erosion. Great amounts of sand and gravel are carried into the downstream reaches.

(b) *Upper deltaic area or Nobi plain.*

The Kiso river basin lying to the south and west of Inuyama constitutes the Nobi plain. The ground level in the eastern part of the plain is higher than in the western part partly because the load of sand and gravel transported by the Kiso river, which enters the plain from the north-east, is much greater than the contributions of the Nagara and Ibi rivers which enter the western part of the plain. Terraces have been formed in the eastern part of the plain and are 10 to 50 metres (30 to 150 feet) above sea level. They are free from river flood and storm surge. The central part of the city of Nagoya is situated on such a terrace.

The Kiso, Nagara and Ibi rivers have built up fans where they enter the plain. The largest is the fan of the Kiso river, which has a radius of about 12 km (7.5 miles) from its apex at Inuyama.

Changes in the river courses of the plain are evidenced by the many natural levees, the largest of which has a maximum length of 22 km (13.7 mi) a width of about 3.75 km (2.3 mi) maximum height of 10 m (33 ft) above mean sea level and minimum elevation of 0.5 m (1.64 ft) below sea level. These natural levees show the former main course and branches of the Kiso river before the 15th century. Back swamps occupy the spaces between natural levees. These features are shown on figs. 1 and 5.

Because of deposition of the large amounts of heavy sediment carried by the streams entering the Nobi plain the streams are becoming dry rivers. The term "dry river" from a geomorphological point of view is defined as a river where the stream bed is higher than the adjacent alluvial plain.

(c) *Lower deltaic area*

The area situated to the south of a pre-historic or early historic shore line (roughly a line passing through Nagoya, Tsushima and Takasu) constitutes the lower deltaic area. See fig. 5. Extension areas of tidal land along Ise Bay have been reclaimed since the 16th century.

The ground level of the lower deltaic area about 185 sq. km (70.4 sq. mi), is almost all below mean sea level. About 40 per cent of the area is more than 1m (3.3 ft.) below mean sea level. There is evidence that these low areas are the result of land subsidence. During the period 1931 to 1955 measured subsidence amounted to 30 cm in the delta and 14 to 20 cm in the natural levees. The general slope of the delta is gentle, about 0.07 in 1000. A contour map of the delta appears as fig. 6.

In the lower deltaic area, as in the Nobi plain, the bed of the Kiso river has built up higher than the adjacent terrain through deposition of sediments. As a result frequent river floods overtop the banks and inundate the delta and newly-reclaimed paddy fields. Sediment deposited by the flood is building up new natural levees.

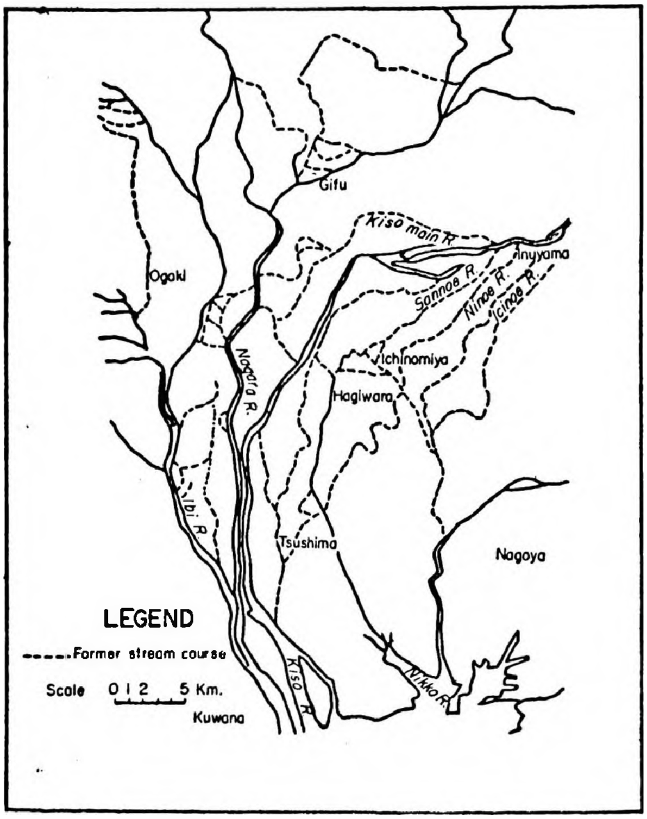


Figure 5. FORMER RIVER COURSES IN THE NOBI DELTA PRIOR TO 15TH CENTURY

1.3.2 Cho Shui delta

(a) *Upper reaches*

The Cho Shui river originates on the steep slopes of the Ho-Huan mountains of Taiwan at an elevation of about 2,900 metres. The upper reach of the river, above the railway crossing near Linnei, has a steep gradient (19 in 1000). The native rock of the area is largely black, brittle and friable shale with some lateritic gravel layers. Because of the topography, nature of the rock, earthquakes and heavy rains, landslides are frequent and contribute considerable sand and gravel to the river. From the heavy sediment load carried by the river it gets its name Cho Shui Chi, meaning "Dirty Water River".

(b) *The upper deltaic area* is a large fan with its apex just below the Linnei railroad bridge and with a radius of about 13 km. The ground surface at the apex is about 100 metres above sea level and the lower periphery about 40 metres. The fan is composed of sands and gravels deposited by the many diverging river channels. Fig. 7 shows the fan and former channels of the Cho Shui.

(c) *The lower deltaic area* of the Cho Shui below Mao Er Kan is small and actually an alluvial fan. The ground elevation is from 1.7 to 10 metres and has a general slope of about 1.25 in 1000. The soil is sandy and river-side sand dunes have formed from the sediments brought down from the upper and middle

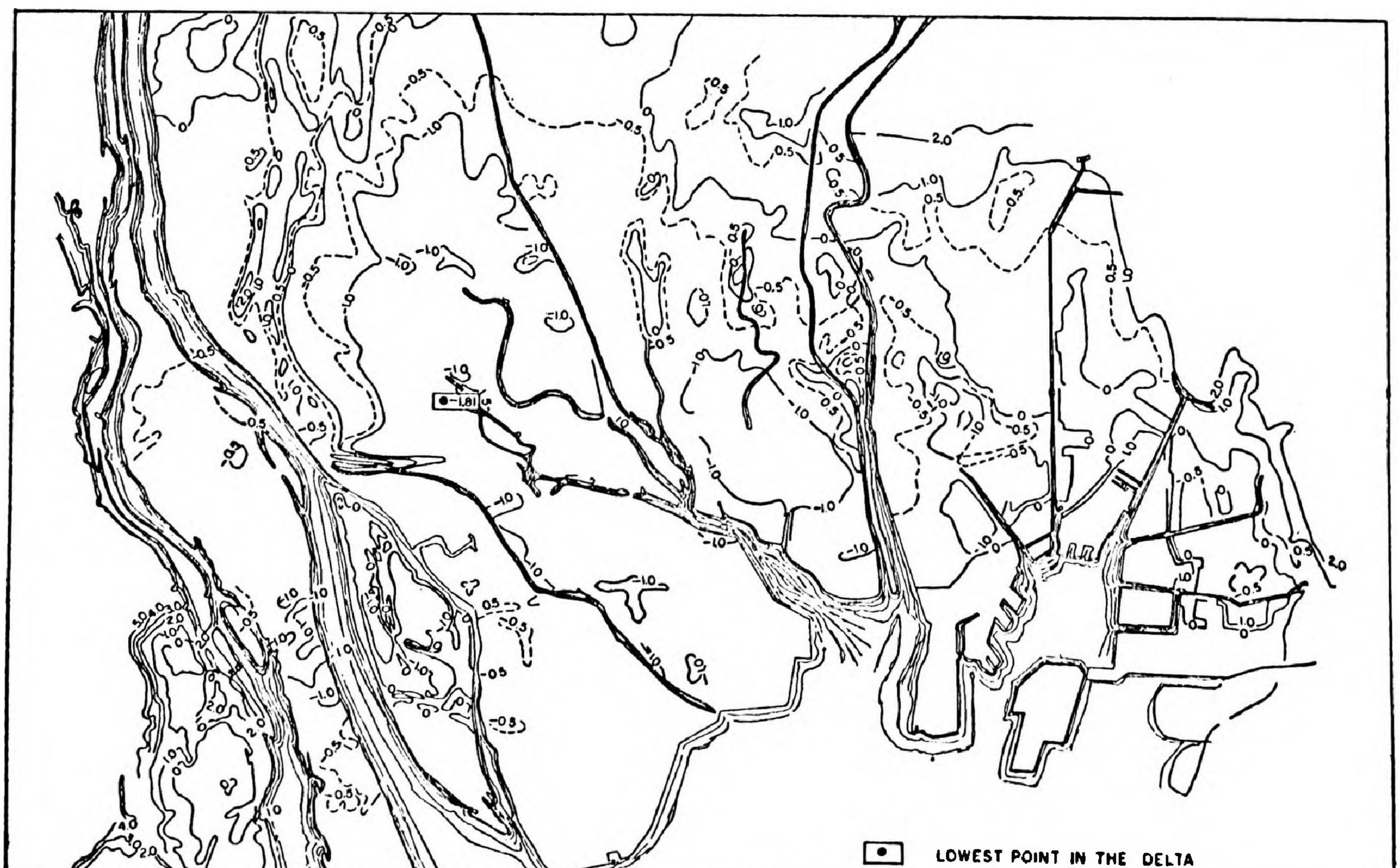


Figure 6. CONTOUR MAP OF THE NOBI DELTA

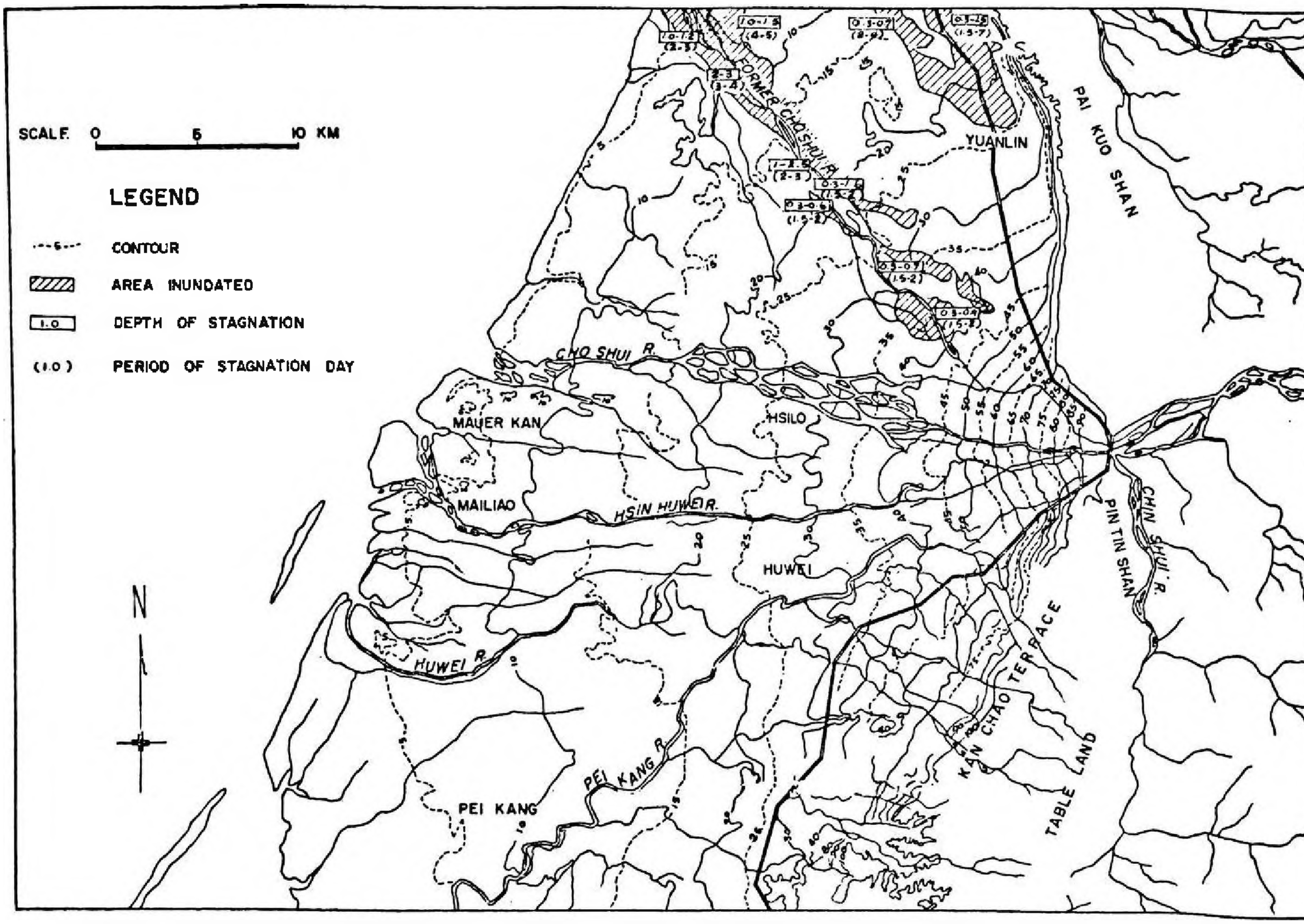


Figure 7. STATE OF FLOODING IN THE CHO SHUI DELTAIC AREA CAUSED BY THE FLOOD OF 1958

reaches of the river. Since 1932 extensive areas have been reclaimed and the shore line pushed out. A geomorphologic land classification of the area is shown in fig. 3. Fig. 7 shows the state of flooding in the delta caused by the flood of 1958.

1.3.3 Irrawaddy delta

(a) *Upper reaches*

The Irrawaddy river has its origin in the mountains of northern Burma. It is joined by its major tributary, the Chindwin, near the city of Pakokhu. The upper watersheds of both streams are mountainous, slopes are steep and total rainfall is high with many localized torrential downpours. Severe surface erosion contributes large amounts of sediment to the streams. The sediment load of the Irrawaddy at Mandalay is about 32 million tons annually and the load of the Chindwin at its mouth is 109 million tons.

(b) *The middle reach* of the Irrawaddy above Myanaung comprises the so-called "dry zone". In this reach, except for the Chindwin river, there are no other large tributaries. The long dry season and the violence of the few rainstorms make this a zone of powerful erosion approaching "Bad Lands" in character. The sediment load of the Irrawaddy is estimated to be 261 million tons annually at Myanaung. Of this amount 109 million tons are contributed by the Chindwin, 32 milion by the Irrawaddy at Mandalay and the remaining 120 million tons by erosion in the dry zone.

(c) *The deltaic area* of the Irrawaddy has its apex at Myanaung. It extends 290 km (180 miles) to the south and has a maximum width of about 240 km (150 miles). There are many distributaries in the area. However, the Rangoon and Bassein rivers which connect with the distributaries are really separate streams.

A noticeable feature of the area is its low altitude. Except for a few scattered hills and terraces the total area of 31,000 km^2 (12,000 sq. mi) is less than 16 metres (50 feet) above mean sea level. About 5,200 km^2 (2,000 sq. mi) are below high spring tide level. The slope of the area is very flat. The ground level at Henzada is about 11.5 m (38 feet) above mean sea level. The slope from Henzada to the estuary of the Irrawaddy is 0.054 in 1,000. The low-lying hills, covered by laterite, are of Pleistocene, Pliocene and Miocene age. The area between Myanuang and Yandoon is the higher part of the plain and here the rivers are incised and have banks 6 to 9 m (20 to 30 feet) high.

This upper part of the area comprises a fine sand or silt layer. The thickness at Henzada is 7 to 8 m. Stratification in the layer indicates successive flood deposits.

Natural levees mark the present and former river channels. The relative height of these levees is lower than was noted in the Kiso and Cho Shui basins. Back swamps occupy between the levees and along the river banks. In the Kiso delta the natural levees were used for upland crops and the back swamps for paddy. In the Irrawaddy delta the lower part of the levees are used for paddy and the back swamps remain marsh.

Flooding in the Irrawaddy delta results partly from upper reach discharge and partly from local rainfall. At Bhamo the flood levels in the river correspond closely to the precipitation, both peaks occurring in July. Because of the time required for flow down the channels — floods from the upper reach arrive at the delta roughly one month after the peak rains to find the area already suffering from floods due to local rains.

Because of heavy rainfall, violent showers and large tidal range erosion is common in the deltaic area. Hence there is little vertical accretion to the land level; however the area is extending seawards at a rate of about 50 m (164 ft) annually. The sandbars formed near the sea shore are fixed by vegetation so that the lagoon behind each bar gradually fills with mangrove and rises above the sea level.

The southern extremities of the Irrawaddy delta are forested with species best suited to the conditions of soil, flooding and degree of salinity of the water.

1.3.4 Cho Phya delta

(a) *Upper reaches*

Four large rivers: Ping, Wang, Yom and Nan, rise in the mountains of northern Thailand and combine to form the Chao Phya river near the city of Nakorn Sawan. A fifth principal tributary, the Pa Sak which drains the hills bordering the central plain and northeast Thailand, enters the Chao Phya near the head of the lower deltaic area at Ayuthaya. For a distance of about 50 km (30 mi) below Nakorn Sawan the Chao Phya is confined to a single stream by the encroaching hills on either side. In the watershed above these "narrows" are several basins in which a large part of the debris furnished by the streams is deposited.

Below the narrows, in the vicinity of Chainat, the river branches into several distributaries, the principal ones being the Suphan, the Noi, the Chainat-Pasak main canal and the Chao Phya. Completion of the Chao Phya dam at Chainat in 1957 has provided considerable regulation of the flow in the several distributaries to meet irrigation and flood control demands.

(b) *The deltaic area* of the Chao Phya comprises the triangular shaped plain of Thailand from Chainat to the Gulf of Thailand. Its base extends from the Mae Klong river to the Bang Pakong river and includes the Chim or Suphan river. The lower deltaic area, in the narrow sense of the term, comprises the area from the town of Ayuthaya southwards to the coast. The elevation of the delta is only 30 cm (1 ft) to 2 m (6.6 ft) above mean sea level and the slope is very flat, about 0.02 in 1,000.

Predominant features in the deltaic area are the four natural levees formed by the Chao Phya and its distributaries. The largest of these levees extends along the Chao Phya from Chainat to Ayuthaya, a distance of about 145 km (90 mi). At its head the levee is about 17 m (56 ft) above mean sea level and at the lower end it is about 2 m (6.6 ft). The relative height of the levee with respect to adjacent terrain is about 2 to 3 m (6.6 to 10 ft). The width ranges from 5 km (3.1 mi) in the upper portion to 8 to 10 km (5 to 6.2 mi) in the lower portion. In addition to these four principal levees are many smaller levees which mark the course of former river channels.

Back swamps occupy the areas between natural levees. Water from rain and floods stagnates in the back swamp areas for several months of the year, hence the areas are mostly used for paddy fields. The depth of stagnation in these areas ranges up to a depth of about 3 m (10 ft). In the deepest areas the cultivation of floating rice is a well-developed practice. Virtually all of the deltaic area is covered by flood water during the rainy season, which makes extensive rice production possible.

The relationship at the natural levees and back swamps to high-water levels is illustrated in fig. 8.

Because of the flat slopes of the deltaic area and the comparatively gentle nature of the floods the sediments entering the area are fine, hence the soils are generally finer and heavier than those found in the Kiso and Cho Shui deltas.

1.3.5 Sundarbans delta

The Sundarbans of India and East Pakistan is formed by three large rivers the Ganges, Brahmaputra and Meghna. The Ganges and Brahmaputra orignate in the perpetual snows of the great Himalaya mountains and drain a large part of both the southern and northern slopes of that range. Thus these streams are fed by snow melt and the monsoon rains of the lower reaches. The Meghna river rises in the Luhai hills in Assam at a much lower elevation but in an area subject to intense monsoon rains. Owing to the rugged topography and abundant rain, erosion is intensive.

b. *The deltaic area* can be roughly considered as the area lying south of the Rajmahal hills and the Shillong plateau and extending to the shore line of the Bay of Bengal. The Sundarbans has an extensive and very complicated system of interconnected distributaries.

The presence of many natural levees indicates many major and minor changes of stream channels in

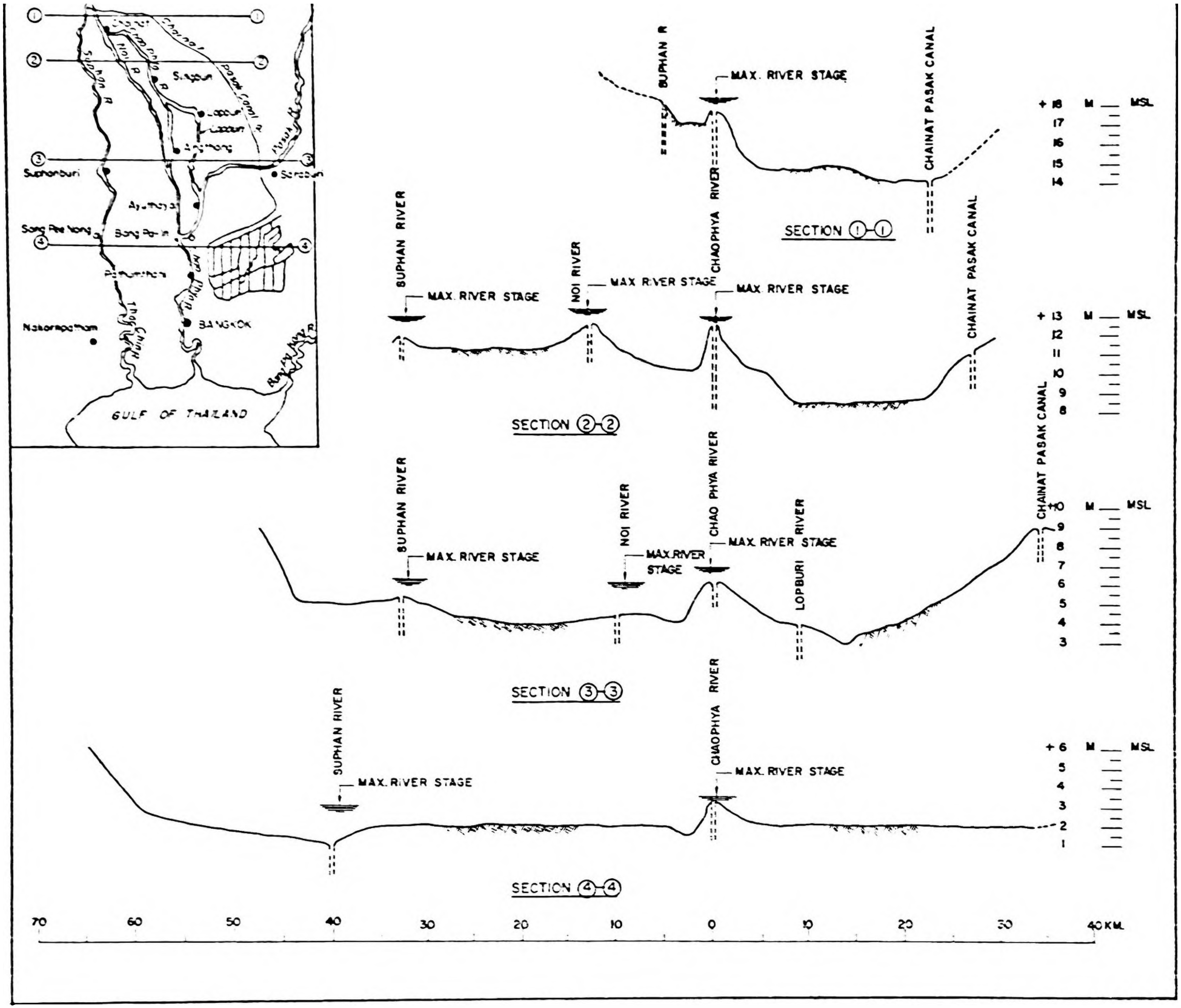


Figure 8. CROSS SECTIONS OF THE CHAO PHYA DELTAIC AREA

the past. Most prominent is the natural levee extending from Calcutta to the southeast which shows a major shift of the Ganges from west to east. This shift was due to a crustal movement with the ground dipping in the eastern part of the Ganges plain. Thus the age of the western part of the delta, in India, appears to be greater than the eastern part, in Pakistan.

Some differences in the topography of the eastern and western parts of the Sundarbans are quite noticeable. The height of the natural levees in the western part is greater than in the eastern. An east-west section through the delta at latitude 22° 50′ N shows the following height of levee, progressing from west to east: Betna river—4.8 m (16 feet), Kobadak river—4.5 m (15 feet), Bhaddra river—3.0 m (10 feet) and Bhairab river—2.4 m (8 feet). In the western part the creek banks are more pronounced. The small side drainages are more deeply incised in the western part than in the eastern. The lower reaches of the estuaries are wider in the western part, while the upper reaches are wider in the eastern part. The natural vegetation and soil conditions in the eastern part show more fresh water influence than in the western part. These differences show an interesting relationship between erosion and deposition that deserves further study.

The close relationship between micro-topography, flooding and land use is quite apparent in some parts of the Sundarbans. Near the village of Kishorimophanpur, India, the difference in ground elevation between former river courses and "dry river" beds is only 50 cm (1.6 ft) yet different varieties of paddy are grown in each area. Near Goshaba, India, the ground level in a former river course is 50 to 70 cm (1.6 to 2.3 ft) lower than the adjacent delta. In the rainy season the depth of stagnation in the former river course is about 1 m (3.3 ft) but only about 15 to 20 cm (0.5 to 0.65 ft) in the adjacent delta areas. Here also, different paddy varieties are planted under each condition. Throughout the delta human activities have for a long time been well adapted to the local natural conditions.

1.3.6 Comparison of deltaic areas

An itemized comparison of the geomorphology, soil conditions and flood types found in each of the deltaic areas visited by the mission is presented in table 1.

1.4 HYDROLOGY AND HYDROGRAPHY

1.4.1 Climatological features

(a) *Climatological classification*

There are distinct differences in the climatic conditions prevailing in each of the deltaic areas. According to the Koppen classification the climatic types in the deltaic areas are as follows:

Nobi delta	Cfa
Cho Shui delta	CW
Chao Phya delta	AW
Irrawaddy delta	Am
Sundarbans delta	Am

(b) *Temperature*

A noticeable difference in the range of seasonal temperatures is seen in the Nobi delta when compared to other areas. This is shown in table 2 and fig. 9. In the Nobi a distinct maximum is reached in July and a minimum in January the difference being 13.9° C. In the Chao Phya, the Irrawaddy and the Sundarbans the temperatures are much more nearly uniform throughout the year. The seasonal difference in Rangoon is only 4.9° C. Except in the case of the Nobi delta the rhythm in the growth of vegetation is not attributable to temperatures.

(c) *Precipitation*

Except in the Nobi delta of Japan, the annual rhythm of plant growth results from temporal variations in precipitation rather than variations in total amount.

In the Nobi delta the monthly distribution of precipitation shows a maximum in summer and a minimum in winter. The summer rains show two peaks, one in June in the "Bai-U"[1] season and the second in September during the typhoon season. August has less rainfall, coming principally from eratic thunder storms. In the delta the number of floods (41 per cent of the total) is greater during the Bai-U season than the number occurring during the typhoon season (21 per cent during the period 1923 to 1952). The Bai-U season corresponds to the rice planting season when much water is needed.

The precipitation in the Cho Shui delta is uneven in distribution. The total rainfall averages 1,390.3 mm (54.7 in) annually (1937 to 1960). The peak precipitation occurs in June and is mostly from typhoons. The dry season extends from November to January.

The Chao Phya delta is enclosed by mountainous terrain on three sides with the result that precipitation occurs principally during the south-west monsoon season when moist air streams come in from the Bay of Bengal and Indian Ocean. A distinct dry season, from November to April is observed at Bangkok. The rainy season shows a minor peak in May and the major peak in September. The average annual rainfall at Bangkok is 1,387 mm (55 in).

The Irrawaddy delta of Burma has the largest precipitation of the deltaic areas of South-east Asia, 2,812 mm (110 in) measured at Rangoon. The distribution shows a dry season from December to March and a rainy season from April to October. The minimum occurs in January and the maximum in August.

[1] Bai-U is the result of the front formed between the wet-cold Okhotsk air mass from the north and the warm moist Ogasawara air mass from the south.

TABLE 1. COMPARISON OF VARIOUS DELTAIC AREAS

Deltaic area	Geomorphology and Soil conditions: Topographical elements	Predominant soil texture	Some other soil features	Height of ground M.S.L.	Slope	Size	Rate of coastal advance	Ground subsidence or upheaval	Flood Type: Meteorological cause	Hydrological cause	Time of occurrence of flood peak	Erosion or deposition	Depth of stagnation of water	Period of stagnation
	Fan	Gravel, sand		10 m — 50 m	3.3/1000	Radius 12 km	44 m/year	Subsidence	—	River flood	June	Violent erosion and deposition	Shallow	Short
	Natural levee	Sand and silt		-0.5 m — 10 m	0.5/1000	Length 22 km	(8.5 km/192 years)	Subsidence 14 — 20 cm)	Typhoon	River flood	July	Deposition (sand)	Shallow	Short
Nobi delta	Back swamp	Silt, clay (less than 40%)						—) 1931- —) 1955	Front	River flood		Deposition (silt)	Deep	Long
	Lower deltaic area	Silt, clay (more than 40%)		Below sea level 185.2 km²	0.07/1000			Subsidence) 30 cm	—	River flood, and storm surge	Sept.	Deposition (silt clay)	Deep	Long
	Newly reclaimed land	Sand, silt, clay	Local salinity and alkalinity	-1.81 m				—	—	Storm surge	—	Deposition (silt clay)	Deep	Long
	Fan	Gravel, sand (large)		40 m — 100 m	4.6/1000	Radius 13 km			—	River flood	—	Violent erosion and deposition	Shallow	Short
	Natural levee	Coarse sand		10 m					Typhoon	River flood	August	Deposition	Shallow	Short
Cho Shui delta	Back swamp	Silt, clay						Upheaval	—	River flood	—	Deposition	Deep	Long
	Lower deltaic area	Sand, silt		1.7 m — 10 m	1.25/1000		150 m		—	River flood	—	Deposition	Deep	Long
	Newly reclaimed land	Sand, silt	Local salinity and alkalinity	2.5 m — 3.0 m			3.75 km (1932-1957)		—	Storm surge	—	Deposition	Deep	Long
	Fan	Gravel (small), silt, sand			Flat	Small		—	—	River flood	—	—	Shallow	Short
	Natural levee	Silt, sand		2 m — 17 m	0.12/1000	Length 145 km		—	—	River flood	—	Deposition	Shallow	Short
Chao Phya delta	Back swamp	Clay	Physical immature subsoil, local catclay			Width 5-10 km		—	—	River flood	August	Deposition	Very deep (3 to 4 m)	Long
	Lower deltaic area	Clay (silt)	Local catclay and physical immature subsoil, local salinity and alkalinity	30 cm — 2 m	0.02/1000			—	—	River flood and High tide		Deposition	Deep	Long
	Fan					Small		—	Cyclone	River flood	—	—	—	—
	Natural levee	Fine sand, silt			0.054/1000	31,000 km²		—	—	River flood	—	Deposition	Shallow	Short
Irrawaddy delta	Back swamp	Clay (silt)	Local physical immature subsoil		From Henzada to estuary			—	—	River flood	August	Deposition	Very deep	Long
	Lower deltaic area	Clay, silt	Local salinity and alkalinity and catclay	Below high spring tide (5,200 km²) 0.3 m (5,200 km²)			50 m/year	—	—	River flood and High tide	—	Deposition	Deep	Long
	Natural levee	Silt, fine sand		Western part is high Eastern part is low	0.04/1000 near Khulna				Cyclone	River flood		Erosion is larger in the western part	Shallow	Short
Sundarbans delta	Back swamp	Clay, silt	Local peatlayer and immature subsoil					Subsidence in eastern part	—	River flood	—	Deposition is larger in the eastern part	Very deep	Long
	Lower deltaic area	Clay (silt)	Salinity and alkalinity, local catclay, peatlayers and local physical immature profiles.	Western part is high Eastern part is low					—	Storm surge			Deep	Long

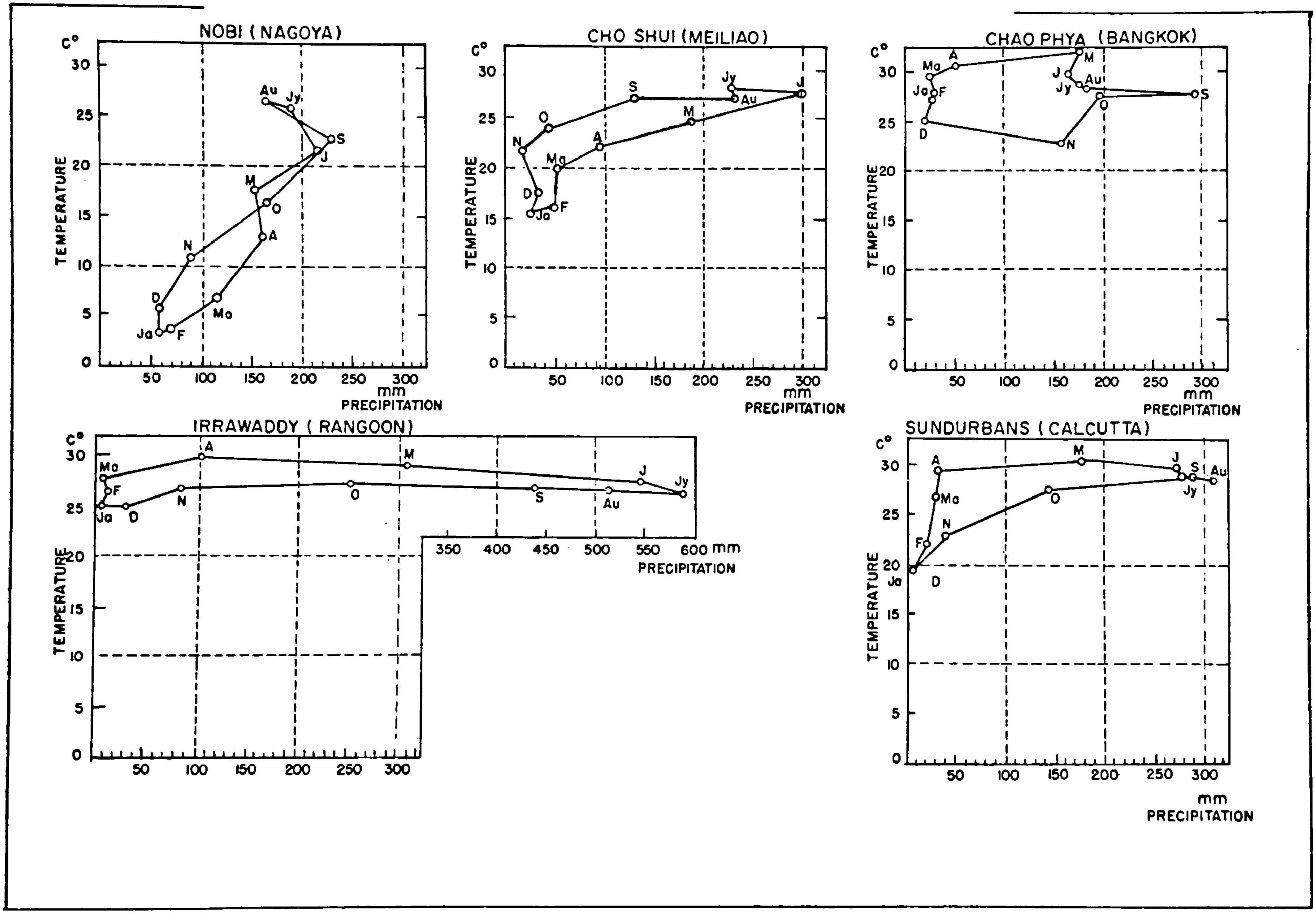


Figure 9. COMPARISON OF THE CLIMATE OF THE VARIOUS DELTAIC AREAS

TABLE 2. COMPARISON OF CLIMATE IN THE VARIOUS DELTAIC AREAS

Delta	Stations		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Nobi delta	Nagoya	Temperature (°C)	2.6	3.2	6.5	12.4	17.3	21.3	25.7	26.5	22.6	16.2	10.5	5.3	14.2
		Precipitation (mm)	51	68	113	151	150	211	181	166	232	166	87	55	1,629
Cho Shui delta	Meiliao	Temperature (°C)	15.4	16.2	19.9	22.1	24.7	27.3	27.9	27.3	27.1	23.9	21.7	17.8	22.6
		Precipitation (mm)	21.7	49.4	52.1	93.6	188.1	298.5	225.8	236.7	129.4	42.9	19.0	33.1	1,390.3
Chao Phya delta	Bangkok	Temperature (°C)	26.8	27.1	29.6	30.9	31.5	29.9	28.7	28.3	27.8	27.5	22.4	24.9	28.0
		Precipitation (mm)	23	25	33	48	173	163	175	185	295	198	53	18	1,387
Irrawaddy delta	Rangoon	Temperature (°C)	25.3	26.4	28.6	30.2	29.1	27.4	26.9	26.9	27.3	27.8	27.2	25.3	27.4
		Precipitation (mm)	1	7	2	102	310	544	591	513	437	200	82	25	2,812
Sundarbans delta	Calcutta	Temperature (°C)	19.4	22.1	27.0	29.9	30.5	29.8	28.9	28.7	28.8	27.5	23.3	19.4	26.3
		Precipitation (mm)	6	42	27	29	175	271	278	309	288	141	39	5	1,610

According to Calcutta records, the Sundarbans delta experiences a dry season from November to April and a rainy season from May to October. The average annual precipitation at Calcutta is around 1,610 mm (63 in).

In addition to seasonal variations, there are also some striking variations in total annual precipitation. In the upper reaches of the Cho Shui at Chi-Chi during the period 1941 to 1952 a difference of over 1,000 mm (39 in) was recorded.

In the Chao Phya delta, the wettest year differed from the dryest year by nearly as much as the average rainfall. At the same time, the duration of the rainy season ranged from 174 to 236 days.

(d) *Geographic distribution of rainfall within the deltas*

In the Nobi and Cho Shui deltas the precipitation increases from the coastal areas towards the mountains. The precipitation at Nagoya is 1,629 mm and at Gifu at the foot of the mountains is 1,943 mm. At Mai-Liao in the Cho Shui delta the average annual rainfall is 1,030 mm (40 inches) and at Chi-Chi in the upper reaches above the delta the average is over 2,500 mm (98 inches).

In the Irrawaddy delta the condition is reversed. Average annual precipitation in the coastal areas is 2,540 mm (100 inches) up to 3,556 mm (140 inches), while at the apex of the delta the precipitation is 1,270 mm (50 inches) to 2,032 mm (80 inches). See fig. 10.

In the Chao Phya delta the average annual precipitation at Ayuthya in the heart of the rice district is about 1,270 mm (50 inches) whereas in Bangkok it is 1,387 mm (55 inches), not much different. The rainfall during the paddy growing season is only about 1,000 mm (43 inches) while the average requirement for rice is around 1,500-1,800 mm (59-71 in). The deficiency in rainfall is made up by inundation from the flood flows in the river which originate in the upper reaches.

As the geographic distribution of precipitation is closely related to small floods and paddy planting, more micro-climatological research is needed both in the deltaic areas and the upper drainage basins.

(e) *Typhoons and cyclones*

The Nobi and Cho Shui deltas are frequently devastated by typhoons. In the case of Nobi the damage resulting from storm surges is more serious than from the overflow of rivers because the land in the southern part of the delta is below sea level. Typhoons affecting the Nobi delta follow two general paths: across Ise bay from WSW to ENE and across the northern part of the delta from SW to NE; in the case of the latter the delta is subject to storm surges. Isewan typhoon (typhoon Vera) which struck the delta in September 1959 followed the SW-NE track. This typhoon resulted in tremendous loss of life (5,200 persons) and property damage (530,000 million yen, about $1,472 million).

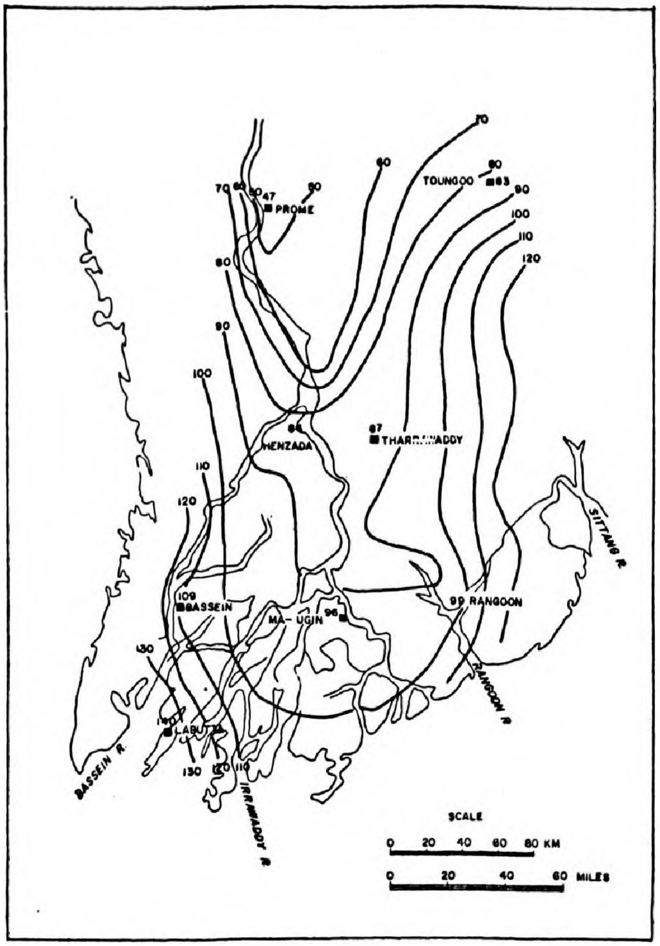


Figure 10. ISOHYETAL MAP OF THE IRRAWADDY DELTAIC AREA

Damaging typhoons which affect the Cho Shui delta usually pass from south to north. The frequency of typhoons which affect the delta is rather high, ten in 1960 and in 1961.

The Chao Phya delta is very rarely attacked by typhoons, but the formation of atmospheric depressions over the South China Sea and the Gulf of Thailand is rather frequent and results in very beneficial rains.

The Sundarbans are at times visited by cyclones, causing storm surges damaging to the areas.

The Irrawaddy delta is mostly free from attack by cyclones.

1.4.2 Subdivision of the deltaic reach of rivers

In this section the subdivision of river reaches in deltaic areas is mainly considered from the hydrologic point of view as an introduction to the observations on flood protection and water control in deltaic areas in the ECAFE region.

The delta of a river forms the transition between the upstream areas and the sea. From upstream comes the river flow with fresh water and from the sea comes the tides with salt water. Many technical problems result from this encounter; flood protection, irrigation and drainage measures differ from zone to zone according to whether the effect of the river or that of the sea predominates. As will be shown later, the technical difficulties in this field may be most pronounced in the transitional zone. This is the case in most of the deltaic areas in the ECAFE region.

Both the vertical astronomical tides (variations in the elevation of the water level) and the horizontal astronomical tides (variations in the velocity and direction of the currents) penetrate from the sea into the estuaries and river branches of the deltaic area. Because of its greater density than fresh water the sea water intrudes into the river mouth over the river bed as a wedge. If there were no tides this salt water wedge would create a more or less distinct interface between the saline water near the bed and the fresh river water in the upper layer. The distance from the coastline over which intrusion takes place is primarily governed by the river discharge. The tides cause intensive turbulent diffusion of the fresh and the salt waters and instead of an interface there is a gradual increase of salt water content with depth. The salinity varies in the tides. For further details reference should be made to the *Proceedings of the ECAFE Fourth Regional Technical Conference on Water Resources Development*[2].

As illustrated in fig. 11, several reaches in the river can be distinguished. The main distinction is between the reach where the water levels are affected by the sea tides (zone A) and that where the levels depend on the river flow alone (zone B). In reach A_1 vertical tides occur with subsequent reversal of the current direction and intrusion of saline water. In reach A_2 the river water is fresh but otherwise the tidal phenomena are similar to those in reach A_1. In zone A_3 the water levels are still affected by the tides but the current direction remains the same and only the velocity of the current changes with the tide.

The boundaries between the various reaches in a given situation are not fixed. They depend on the tidal ranges and on the fresh water flow of the river. Generally speaking, the boundaries shift landward with increasing tidal range and seaward with increasing river flow. This feature is quite pronounced in most deltaic areas of the ECAFE region because of the regime of the rivers with floods during the wet monsoon and minimum flow in the dry season. A typical example is provided by the observations carried out at Ayuthya on the Chao Phya river in Thailand at 136 km. (85 mi) from the sea. With a tidal range at sea of 2.6 m. (8.5 ft), the tidal range at Ayuthya is 0.7 m (2.3 ft) for a river discharge on location of 275 cu.m/sec. (9,700 cfs), whereas the tidal range is practically zero with discharges exceeding some 1,000 cu.m. (35,000 cfs) per sec. With minimum discharge the salt content of the river water near the bed may be as high as 2,000 p.p.m. of total salts per litre, whereas during floods the river water is fresh not only at Ayuthya but even at a few kilometres from the mouth.

[2] United Nations publication, *Flood Control Series No. 19*, Sales No. 62.II.F.2.

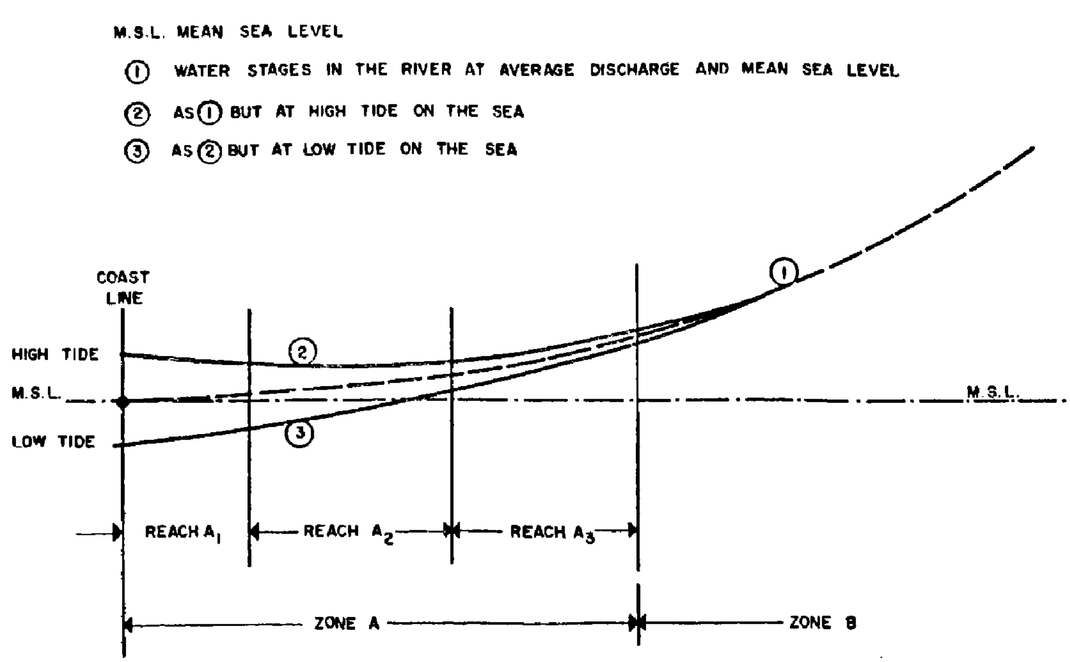


Figure 11. SUBDIVISION OF THE DELTAIC REACH OF A RIVER ACCORDING TO TIDAL PHENOMENA

Another subdivision of the deltaic reach of rivers can be made according to the cause of abnormally high water levels. This subdivision is of primary importance for flood protection. Deltaic areas are affected by floods from two sides: the river floods and the storm surges at sea which are superimposed on the astronomical tides. It is quite important to know whether both phenomena may coincide.

According to the occurrence of the two types of floods, the river can be divided into three reaches (fig. 12).

(1) Reach I, where the effect of the floods from the sea predominates;
(2) Reach II, where the effect of the river predominates;
(3) The intermediate reach III, where a combined effect of both types of flood occurs.

The boundaries between these reaches may be quite different from those of the propagation of the astronomical tides.

In fig. 13 a longitudinal profile is given of the Irrawaddy River during flood conditions. In this case there are no storm surges and the astronomical high tides of the sea determine the maximum levels in reach I.

A further discussion of the river floods and the sea floods is given in paragraphs 1.4.3 and 1.4.4.

The transport of solid material in the river branches and estuaries and subsequent erosion or deposition is as important as the water levels and river discharges. From an engineering point of view, distinction can be made between the "active" zone where important changes in the configuration of the channels take place and the "non-active" zone where a certain equilibrium has been reached and where conditions of beds and alignments of channels are relatively stable. There is no distinct boundary between these zones as a deltaic area is virtually a region of relatively rapid geologic processes.

In the active zone the execution of engineering works may encounter paramount difficulties. In the non-active zone engineering works can be planned in such a way as to gradually change the natural situation without abrupt upset of the equilibrium.

It is essential for the development of the deltaic areas in the ECAFE region that adequate data be available on the conditions in the various reaches of the river branches. Information on the water levels is not only important for the design of flood protection works but also when planning drainage by gravity

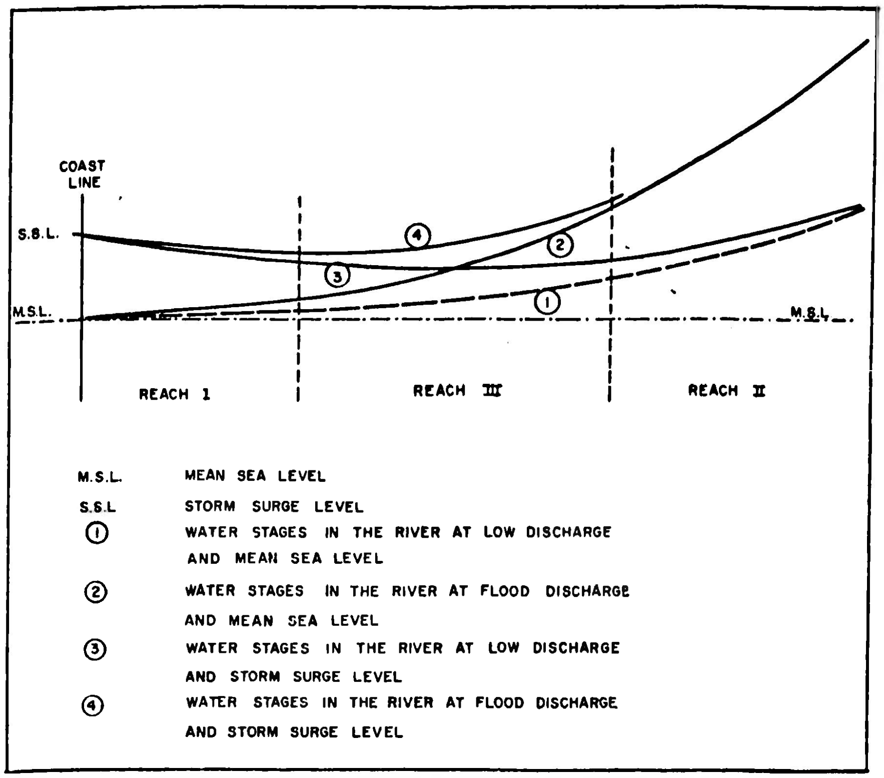


Figure 12. SUBDIVISION OF THE DELTAIC REACH OF A RIVER ACCORDING TO TYPE OF PREDOMINANT FLOOD

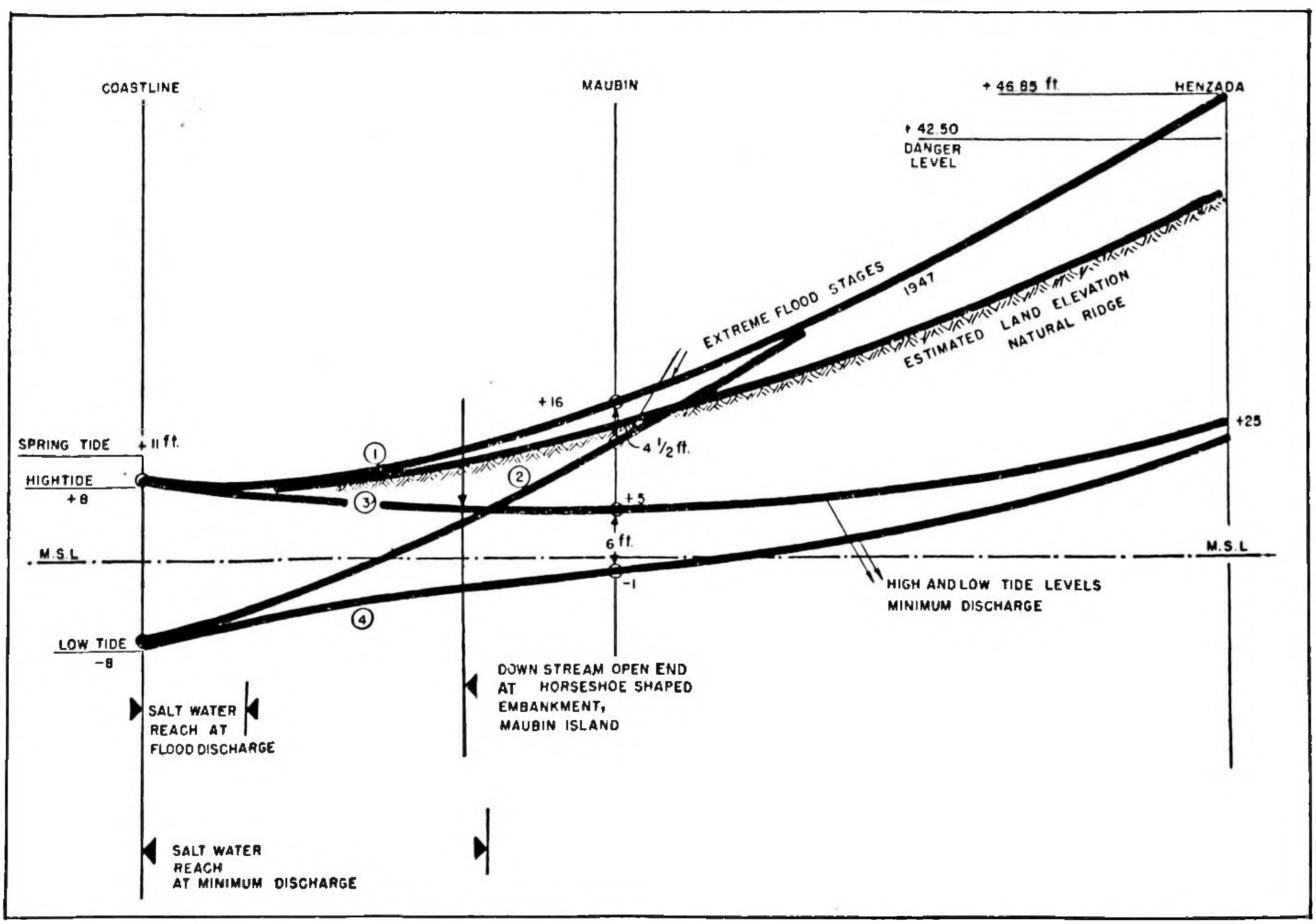


Figure 13. LONGITUDINAL PROFILE OF FLOOD CONDITIONS IN THE IRRAWADDY RIVER

using the low tide levels. In some deltaic areas (Nobi delta in Japan, Chao Phya delta in Thailand and Mekong delta in Viet-Nam) gravity irrigation of low-lying areas is achieved using the high tide in the fresh water reach A_2 (fig. 11) of the river.

The data needed on the regime of the river are discussed in paragraph 1.4.3; those on sea levels in paragraph 1.4.4. The intrusion of sea water in the lower course of the rivers can best be studied by collecting data on the salt content of the river at a number of fixed locations. If these measurements are continued over several years, the relationship between the salt content at a certain point and the discharge of the river and the tidal range can be established. The information can be supplemented by short series of observation at intermediate stations between the fixed stations. General indications can also be obtained from a study of the vegetation along the banks (see paragraph 1.2.4).

Collection of data on zones of deposition or erosion will also be discussed in paragraphs 1.4.3 and 1.4.4.

1.4.3 Regime of the rivers

The hydrologic regime of a river determines what engineering works are needed for the utilization of the deltaic area. Characteristic features of the regime are:

a. Duration of floods
b. Rate of rise and fall of river stages
c. Flood volume
d. Minimum flow in dry periods
e. Transport of solid material

These features depend on the rainfall in the river basin and on the physiographic conditions of the basin. Thus for a given rainfall pattern the characteristics of the river basin (area, shape, infiltration capacity, etc.) have an important bearing on hydrologic conditions in the delta.

In fig. 14 annual hydrographs are given for typical years of the Cho Shui and Chao Phya rivers.

	Catchment area
Cho Shui river (China: Taiwan)	3,150 sq km
Chao Phya river (Thailand)	160,080 sq km

The flood hydrographs show typical differences with respect to duration of floods and rate of rise and fall of the flood peaks. These differences are mainly due to the difference in areas of the river basins. Thus for the small and short river basins the floods are flashy, whereas for the large basins the effect of rainfall on the outflow from the basin is distributed over

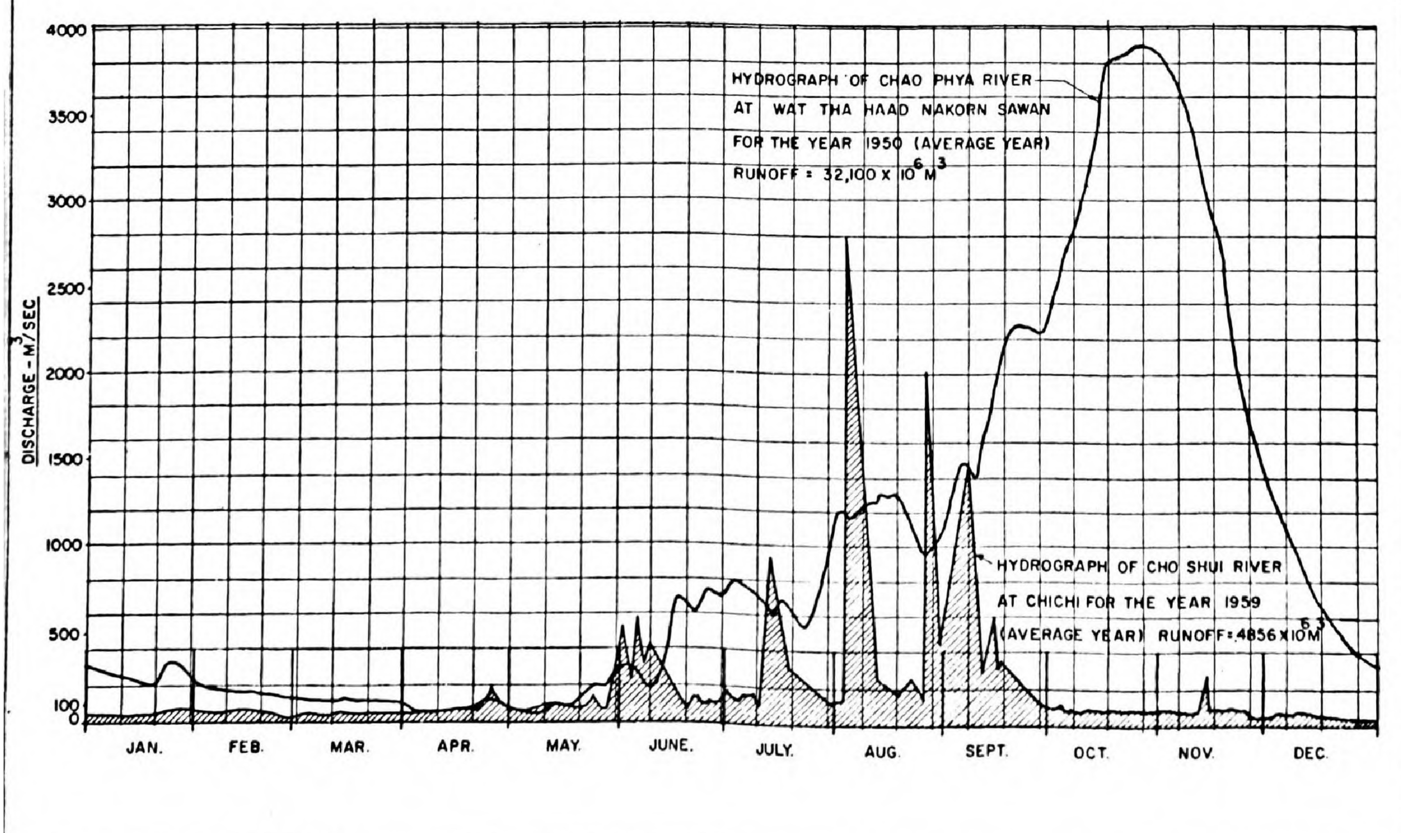


Figure 14. AVERAGE HYDROGRAPHS OF CHO SHUI AND CHAO PHYA RIVERS

longer periods. It should be noted, however, that the hydrographs of the Red river (Northern Viet-Nam) show features similar to those of the Kiso and the Cho Shui, although the river basin (120,000 sq km) is of the same order of magnitude as that of the Chao Phya. In the case of the Red river the variability of the heavy rainfall, the steep slopes and poor infiltration capacities of its river basin are responsible for the flashy nature of the floods.

The type of the flood hydrograph determines whether, in the first stage of development, adequate flood protection by embankments is an absolute necessity or not. The flashy nature of the floods in the Nobi delta (Kiso river) in Japan, in the delta of the Cho Shui river in China: Taiwan and the Red river in northern Viet-Nam is such that without high embankments no utilization of the deltaic areas at all would be possible. In the deltaic areas of the Irrawaddy in Burma, the Chao Phya in Thailand and the Mekong in South Viet-Nam, on the other hand, the relatively gentle rise of the river water and the spreading of the flood volume over several months make it possible to grow paddy over large areas with modest means of flood control.

Data on river stages can be collected easily and are most useful, but when planning flood control by diversion of water or utilization of water for irrigation purposes, information on the discharges must be available. It may be that in the early stage of development of a deltaic area, data on river stages are sufficient, but when planning for the future, the need is immediately felt for data on river discharges extending over a long period.

In all deltaic areas of the ECAFE region data are being collected either on river stages or on stages and discharges. This collection of data could be made more valuable if extended and supplemented by other data.

As for the data needed on the regime of rivers in the deltaic area, the following points should be considered:

(a) At the apex of the delta, continuous records of the river stages together with stage — discharge relationships should be checked periodically. By intermittent measurements the relationship between the river discharge (both for rising and falling river stages) and the transport of solid material (bed-load and suspended load) can be established.

(b) At selected points downstream from the apex and along its branches the same items as mentioned under (a) should be carried out. In selecting gauging stations preference should be given to locations near main intakes of irrigation water or main outfalls of the drainage system. Gauging stations for measuring discharges should be located outside the tidal reach of the river whenever possible.

(c) In the case of rivers with considerable overbank storage (for example the delta of East Pakistan, the Irrawaddy, the Chao Phya and the Mekong) periodic readings of the water levels in the flooded areas would be desirable.

(d) Special river maps on a scale of 1:50,000 and 1:10,000 are necessary. These maps should represent the configuration of the minor and major bed of the river as well as the strip of land along the banks some 2,000 metres wide. Embankments and hydraulic structures can be plotted on this map. The geodetic basis of these maps can be made using a network of secondary triangulation points.

(e) Periodic depth charts at critical points in the river in connexion with the river map mentioned under (d) above are needed. Priority should be given to reaches where bank erosion occurs and where the formation of bars hampers navigation.

(f) Hydraulic model studies. In the case of rivers with considerable overbank storage, much can be learned about the repercussions of flood protection works on the hydrologic regime from a physical or mathematical model comprising the entire deltaic area or large parts of it. For critical sites in the rivers physical models with movable beds of a portion of the river reach can help in planning hydraulic improvement works. For all models it is necessary to collect before hand data of the type mentioned under (a) and (e) in order to adjust the models to the observed conditions.

To facilitate documentation it is advisable to draft hydrologic yearbooks summarizing, in a comprehensive form, the detailed observations.

In implementing the programme of hydrologic investigations priority should be given to the measurements at the apex of the delta. When extending the network to gauging stations downstream, empirical relationships can be established between stages and discharges at the apex and at downstream points, taking into account the travel time of flood waves. In this way the hydrologic conditions in a great number of locations can be ascertained by observations over a short period, so long as continuous data is collected at a number of standard stations.

1.4.4 SEA LEVEL AND TIDAL EFFECTS

All deltaic areas in the ECAFE region are exposed to the effect of astronomical tides and abnormally high sea levels called storm surges.

The ranges of the astronomical tides in the various deltas differ rather widely, for instance in the deltaic area of the Irrawaddy river the mean spring tidal range is about 5.8 m at Elephant Point at the entrance to the port of Rangoon and only about 2.0 m for the Nobi delta at Nagoya (Japan). The tides are generally semi-diurnal, except for the tides along the delta of the Chao Phya river (Thailand), which are diurnal.

The tides propagate into the estuaries and lower portions of the river branches. The tidal range will be modified according to the configuration of the channel system. In the case of deep channels with few ramifications the tidal range may first increase when going upstream and finally diminish. In shallow channels with many ramifications the tidal ranges decrease right from the coastline.

At flood tide a certain volume of water enters the estuary (flood volume) and likewise at ebb a certain volume flows out (ebb volume); the sum of both is called the tidal volume. The flood and ebb currents play an important role in the configuration of the estuaries. Upland water discharge modifies the pattern of the tidal currents in the estuaries and causes the ebb currents to predominate, as shown in fig. 15. This is an important feature for those deltas in the region with prolonged flood periods during the wet monsoon and minimum flow in the dry season.

The tidal currents try to maintain openings in the coastline; their effect is partly checked by the transport of solid material by currents and waves. Thus the tidal currents in the outlets, the currents and waves in the coastal area, the littoral drift and the sediment load and discharge of the river determine the configuration of the outlets. A change in one of these conditions will modify the shape and depths of the channel systems in the outlet. Certain conditions such as channel depths and widths, etc. of the outlet are essential for access of shipping to harbours in the delta and for the drainage of inland areas. The processes involved are quite complex and improvement of existing conditions by engineering works can only be planned by model tests, provided that detailed information on the regime of tides, erosion and deposition is available.

Storm surges are generated off-shore by differences in barometric pressure and drag of the wind over the water in cyclone and typhoon areas. They are super-imposed on the astronomical tides and when coinciding with high water spring tides may lead to very high sea levels affecting the coastal zone of a delta.

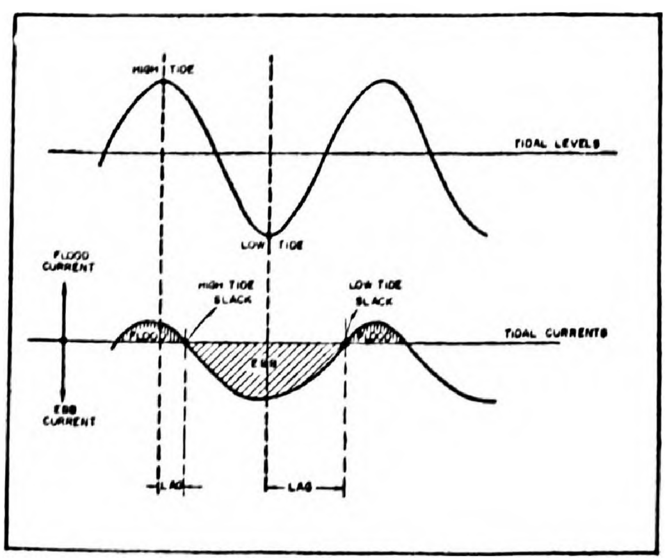


Figure 16. TIDES AND CURRENTS IN AN ESTUARY WITH UPSTREAM DISCHARGE

The considerable differences in height and frequency of occurrence of storm surges in the deltaic areas of the region have an important bearing on the utilization and flood protection works in the coastal zone (paragraph 2.2.2). In Japan and China: Taiwan storm surges caused by typhoons occur frequently. In the last 50 years the highest recorded sea level at Nagoya Port (Nobi delta) was 3.89 m (12.8 ft.) above mean sea level (Ise Bay Typhoon, 26 September 1959). The highest level near Hsin-Chu tidal land (northern part of the west coastal tidal land of China: Taiwan) observed during the period 1957-1960 was 3.20 m (10.5 ft.) above mean sea level (8 August 1960).

There is no reliable data on the storm surge levels along the northern coast of the Bay of Bengal (Sundarbans in India and East Pakistan) but frequent damage by abnormally high sea levels has been recorded. In October 1960 at Chittagong (East Pakistan) a surge elevation in sea level of some 3.5 m (11.5 ft.) above the astronomical tide was reported.

In contradistinction to the storm surges in these localities, the sea levels along the deltaic areas of the Irrawaddy river (Burma) and the Chao Phya river (Thailand) show only small deviations from the astronomical tides. In the last decades sur-elevations of not more than a few decimetres have been reported.

The storm surge levels at sea propagate into the estuaries and open river branches. The effect on the water levels in the channel system of the delta depends on the rate of rise and duration of the storm surge levels at sea, the configuration of the channel system and the presence of zones of flooding. The maximum water levels in the delta will occur when the storm surges coincide with the river floods. As explained in paragraph 1.4.2, the intermediate reach III is exposed to the combined effect of both river and sea floods.

The significance of data on these levels for planning flood protection works is obvious. The coincidence of abnormally high low-water tides with heavy local rainfall may also be an important feature when planning drainage works.

As for other data needed on the tidal levels and related features the following items can be mentioned:

(a) Tidal levels and storm surge levels in the coastline, to be collected by recording tidal gauges. The number of these gauging stations can be limited to 2 or 3, distributed over the entire length of the coastline of the delta. The records of storm surges will be valuable if extending over many years so that the relative frequency of occurrence of abnormally high sea levels can be established.

(b) As under (a) for stations in the estuaries and lower reaches of the river branches. The number of these recording tidal gauges depends on the configuration of the deltaic area, but can still be limited to a few if the data collected in these fixed stations can be supplemented by records described under (c).

(c) Data on the tidal levels and tidal currents over a short period at temporary intermediate stations between the gauging stations mentioned under (a) and (b). During a few days for each of the periods with mean, spring and neap tidal ranges, data should be collected on the tidal levels and the tidal variations in the discharges of the channels. Correlation of simultaneous measurements at the various stations with the long-term observations at the fixed station will give a good conception of the tidal conditions in the delta and provide a base for projects involving closure of tidal channels and indicate their repercussions on conditions elsewhere. A fine example of such a tidal survey of the delta is provided by the investigations carried out by the government of West Bengal in the Sundarbans area (India).

(d) Data on the silt content of the water in the channels. This data can be collected together with the data mentioned under (c).

(e) Data on erosion and deposition in the channels. This requires the implementation of a programme of periodic hydrographic surveying. Conditions in the shallows are as important as the configuration of the deeper channels.

(f) Detailed data on critical areas such as bars in the outlets. The investigations comprise information on the pattern of the tidal currents around the area during the tidal cycle, data on the variation of salt and silt content during the cycle, examination of the nature and origin of the silt, study of the recent development of the situation using historical hydrographic maps, etc. These data become valuable if combined with data of a general nature as mentioned under (a) to (e).

1.4.5 Geo-hydrologic conditions

The subsoil of deltaic areas is characterized by the presence of unconsolidated sediments down to considerable depths. Pervious layers such as sand and gravel alternate with semi-pervious layers of clay, loam or peat. The pore space is saturated with groundwater and the phreatic table is always close to the surface. If the pore water is of good quality, deltaic areas offer good possibilities for the development of groundwater resources.

Groundwater is extensively use for domestic, industrial and agricultural purposes in certain deltaic areas of Japan and China: Taiwan. In other deltaic areas of the ECAFE region the utilization of groundwater is less developed. The main reasons are the availability of fresh water in the rivers, the absence of industries and the absence of a second crop during the dry season. In the Sundarbans delta (India and East Pakistan) groundwater is abstracted for domestic purposes in areas where the salt content of the surface water prohibits its use as drinking water. Wells have been drilled sometimes as deep as 200 m (650 ft) to find groundwater of suitable quality.

In this paper only some of the practical aspects of groundwater in deltaic areas will be mentioned. Reference is made to the proceedings of the Regional Seminar on the Development of Groundwater Resources with Special Reference to Deltaic Areas.[1]

(a) *Occurrence of groundwater*

Groundwater that can be abstracted occurs in layers of gravel or coarse and medium sand of considerable thickness. The salt content of the water in these layers varies considerably with location and depth. In rough outline the salt content increases from the interior in a seaward direction and with depth. There are, however, many exceptions and there is no direct relationship between the salt content of the surface water in the present situation and the salt content of the groundwater. The sediments may have been originally deposited in a fresh water environment or they may have been flushed after deposition by a flow of fresh groundwater originating in adjacent higher areas where rainwater infiltrates into the out-crops of pervious formations. Thus fresh groundwater may occur under those portions of a deltaic area where under present conditions the water in the estuaries and river branches is saline. Artesian groundwater may occur in the vicinity of the adjacent higher areas. Shallow pockets or lenses of fresh groundwater in an otherwise saline environment are found under high ridges of pervious material such as dunes, former beach ridges and old river channels.

(b) *Seepage conditions*

The geo-hydrologic conditions of deltaic areas govern the occurrence of seepage when these areas are used for various purposes.

Seepage flow to areas with an elevation below that of the surrounding terrain or open water occurs both through embankments or dikes of pervious material and through pervious formations in the subsoil. The rate of flow depends on the head, the transmissibilities of the aquifers in the subsoil and the resistance of the semi-pervious layers against the vertical passage of water. Leaks in these layers due to the presence of sand lenses or the cutting of semi-pervious layers when dredging drainage channels or irrigation canals are liable to produce excessive seepage rates. Seepage through the subsoil may occur several kilometres from the partition between areas of different elevation.

In the saline reaches of rivers seepage of water with a high salt content to adjacent low-lying areas will take place. This may lead to a salt intrusion and subsequent contamination of the aquifers. The seepage water oozing into the land areas may be harmful for agriculture.

(c) *Groundwater levels*

A distinction must be made between the piezometric heads in confined aquifers at various depths and

[1] United Nations publication, sales No.:64.II.F.5.

the free groundwater level or phreatic table at shallow depth. The latter is of primary importance for agriculture (paragraph 1.5.1), but there is an intimate relation between the two.

In deltaic areas where until now groundwater has not been intensively used for industrial or agricultural purposes, information on the geo-hydrologic conditions is scarce. The development of groundwater resources however deserves more attention. In the agricultural development of deltaic areas utilization of groundwater may be attractive when the following conditions prevail:

(1) fresh groundwater occurs in aquifers of considerable transmissibility;
(2) artesian groundwater occurs;
(3) surface water cannot be used because of high salt content or pollution,
(4) introduction of a dry season crop is considered. In this case, the execution of development projects can proceed by stages, each involving small capital investments, whereas the use of surface water for irrigation often involves considerable initial outlay.

The programme of investigation of geo-hydrologic conditions comprises the following items:

(i) Reconnaissance bore-holes in a number of locations both in the coastal and upland zones of the deltaic area. The drilling of these holes and sampling of the formations encountered should be combined with geophysical well logging, spontaneous potential, electrical resistivity and neutron logging and with the installation of permanent filter strainers of various depths lengthened with tubes for observation of the groundwater levels. In this way the maximum amount of information can be obtained from the drilling operations.
(ii) Geo-electrical resistivity survey on the land surface.

By this prospecting, it is possible to ascertain the delimitation between the zones with fresh groundwater and zones where, because of the presence of saline groundwater exploitation is not feasible. Since a resistivity survey involves little time and cost, the areas with saline groundwater can be eliminated from further investigations in the first stage of the implementation of the programme.

The geo-electrical resistivity survey is essentially based on determination of the electrical resistivities of formations of various depths by measurements on the land surface using different spacings between the electrodes generating the electric field. The electrical resistivity of formations is highly influenced by the salt content of the water in the pores. The method is most suitable for investigations in deltaic areas where the groundwater table is high and the formations are horizontally superimposed. The reconnaissance holes mentioned under (a) can be used for testing and gauging the method and then, for a great number of intermediate locations, additional information can be obtained using method (b) which is easier and cheaper.

(iii) Test-holes and pumping tests.

After selection of suitable areas, more detailed information especially on transmissibilities, can be obtained with the commonly used method of bore-holes and pumping tests. The investigations can again be made more valuable if combined with geophysical well logging and the installation of permanent filter strainers for deep observation wells.

(iv) Shallow observation wells.

Data on seasonal variations in the elevation of the phreatic table at various locations can easily be collected. This data is of great use both for geo-hydrological and agricultural purposes. The shallow observation wells can preferably be arranged in rows between typical natural or artificial land features such as natural levees, back swamps and drainage and irrigation canals. Observations should be carried out for a long period at a number of fixed points together with observations at temporary intermediate points. If the observations are carried out simultaneously at the fixed and temporary points, a correlation can be established between the groundwater levels at the fixed and temporary points. In this way, the number of observations can be reduced considerably.

(v) Hydrogeological archives and maps.

It is important to have a central office where all collected data are processed and preserved. With growing information the conception of the hydrogeological conditions can best be clarified by drawing up hydrological maps and profiles.

1.5 AGRICULTURE

Before planning an improvement scheme to solve the agricultural problems of an area, full recognition and understanding of those problems is essential. Very seldom is low production caused by only one limiting factor. Mostly, low production is the result of interrelated factors, which are partly due to agro-hydrological deficiencies in the production environment, social and economic factors, marketing and communication and backwardness of the farmers. To ensure successful accomplishment of the purposes of a development scheme, all production factors should be investigated. The following paragraphs outline the most important information needed.

1.5.1 Agrohydrological data

Water is an indispensable element in agricultural production. It is needed for plant growth (evapotranspiration), preparation of the soil, some fertilizing processes, reduction or prevention of excessive salt accumulations in the soil, etc.

Water for all purposes is provided by nature in the form of precipitation. The occurrence of precipitation differs widely both in point of time and geographic distribution. In most of the deltaic areas of Southeast Asia, the total amount of precipitation during the growing season is nearly sufficient for one crop per year. Deficiencies in distribution in a given area may frequently be offset by the natural or artificial importation of water from another area.

For each agricultural crop, there is an optimum water requirement. If there is a deficiency in the water available to the crop, additional water can be supplied (irrigation). If there is excess water it can be removed by drainage. The crop requirement may vary from time to time during the growing season depending on the stage of plant growth, temperatures, humidity, amount of sunlight and other factors. In addition to the water actually consumed by the plant in the process of growth (transpiration) there are certain other unavoidable water losses such as evaporation from the soil or water surface, percolation and sometimes surface waste. The water needed for plant growth plus the unavoidable loss is sometimes called the water requirement of crops or crop requirement.

Extensive data in climatic conditions and water requirements are needed for an agrohydrological improvement programme. From the standpoint of water supply, information will be needed on the total amount and distribution of precipitation in the study area. It is important to know the frequency of drought periods, maximum rainfall in short periods, distribution of maximum and minimum rainfall over longer periods. Data on temperatures, humidity of the air and soil, wind velocities, etc. will have a bearing on the water requirements of crops. Less readily available are good field data on the water requirements of either the primary or second crops. There is a relationship between total water use by the farmers and total supply available, although in practice these may not be related to optimum requirements. For example, in the Nobi delta large quantities of water are used, which may be attributable to the permeable soils and to excess application of water because of the farmers' right to claim large amounts. On the other hand, in Taiwan considerable attention has been given to the water requirements of rice and sugar-cane and irrigation practices, with the result that irrigation water consumptions have been reduced considerably.

It would be very useful to assemble detailed information on water requirements of different crops in selected pilot areas in the region. Several methods for the calculation of crop requirement from its relationship to climatological data have been suggested by such researchers as Blaney-Criddle, Penman and Viehmeyer.

Further insight into the problems of crop requirements, water use and water management can be gained from a study of the respective groundwater levels and surface water levels in the paddy field. Such a study must include determination of salt content in areas where salinity is a problem.

1.5.2 Soil and soil elevation

The importance of a comprehensive soil map and the agricultural land classification map derived from it have already been discussed.

A contour map is necessary for planning irrigation and drainage work. Often such factors as soils, crop patterns, agrohydrology etc. can be explained from a study of the micro-topography of the area. Such a map should be made early in the planning stage. For irrigation or drainage works, a scale of at least 1:20,000 and a contour interval of 20 cm to 30 cm (about 1 ft) is desirable.

1.5.3 Land use and crop pattern

Over the years and to a remarkable extent, farmers have adapted their crops to natural circumstances such as available water, land elevation, soil quality and other associated land features. Often they have succeeded in growing crops under unfavourable conditions, for example the cultivation of floating rice in areas flooded to a depth of 3 to 4 m (10 ft to 13 ft). A study of existing farm practices can provide valuable information on these natural conditions and also on other governing factors such as labour supply, communications, marketing facilities and convenient location of holdings. Before new farm practices and crops patterns are introduced they should be throughly tested on pilot farms.

1.5.4 Size of holdings, size and shape of farm units and fragmentation

A study of size, forms and fragmentation of parcels is important to improvement planning. In some regions, there is a relationship between size of farm holdings, soil productivity and size of farm family. Often productivity can be increased by improved farm practices, however improvement may require additional farm labour. If not available, labour may be a limiting factor. In the Nobi and Cho Shui deltas, holdings are small but unit yields are high. In the Irrawaddy and Chao Phya deltas, the holdings are larger but unit yields are lower. Under some circumstances, shortage of labour can be offset by mechanization, coupled with land consolidation where necessary.

1.5.5 Social and economic factors

When the aim of improved agricultural production is to be achieved either through improved techniques, intensified agriculture or improvements in irrigation and drainage facilities, vital social and economic problems arise. Crop and labour-use patterns have to be changed to adapt to new farming conditions. In addition, more intensive labour input is required for the application of fertilizers, pesticides, etc. and for the multiple cultivation of land. Eventually farmers may have to change even their traditional behaviour and way of thinking. Social and economic problems arising from these improvements may be solved more easily when good credit facilities and extension systems are available and when farmers co-operate in labour, equipment and marketing.

1.5.6 Collection of agricultural data

From a consideration of the above factors, it is evident that many facets of agricultural science and engineering, agricultural economics and rural sociology must be investigated.

The objective of the planning determines the detail and scope of the data needed. This is reflected in the type of personnel, time and funds required. For the development of an overall master plan, less detailed information is needed and greater freedom can be taken in extracting and interpreting data from secondary sources. On the other hand, for detailed planning for specific improvement works and measures, detailed information will be needed.

It should be emphasized that a sound agricultural investigation is equally as important as sound engineering investigation and design, if the return of investment cost is to be realized in increased agricultural production and improved economic and social conditions.

Part II

THE PRESENT STAGE OF DEVELOPMENT OF DELTAIC AREAS

2.1 SYNOPSIS

In the various deltas, flood protection works have reached different stages, depending on natural conditions, land utilization, population, living conditions of the people, etc. This part of the report deals with the present stage of protection works against river floods, sea floods and floods in the intermediate zone in the deltas visited. Comparison of flood control systems in these deltas can be summarized as follows: In the Sundarbans and Irrawaddy deltas flood control by means of embankments is designed to protect the fields from sea water flood as well as from the river flood. In the Chao Phya delta, with its extensive network of irrigation canals, flood water is distributed and diverted into the canals and during large floods is spread over more or less the whole delta. In the Cho Shui and Nobi deltas, control of river flood is dealt with separately from the irrigation system. Flood water is confined in the main rivers and is channelled to flow as fast as possible to the sea.

On water management, the present stage of major drainage and irrigation works in the various deltas is presented delta by delta. In the Indian part of the Sundarbans, closed encircling dykes preventing salt intrusion were originally built by farmers. Recently the Government has taken them over and is now trying to improve the dike system and drainage conditions of these closed areas. In the part in East Pakistan a coastal embankment is now under construction for better flood protection and drainage. In the Irrawaddy delta, there is no major irrigation. In the zone where river floods predominate and in the intermediate zone, open or horse-shoe embankments have been built. Drainage in these protected areas is very poor and improvement is needed.

The Chao Phya delta has an extensive network of canals and regulators for supplementary irrigation and in some areas for conservation and drainage. The completion of a large storage dam upstream will help to reduce peak floods as well as provide more water for dry-season irrigation. There are no major irrigation and drainage works of this type in the Mekong delta nor major flood protection works.

The Cho Shui and Nobi deltas have good major irrigation and drainage facilities with a rather high degree of flood protection. In both deltas, irrigation by ground water is extensive.

The present rural structure comprising farm pattern, fragmentation of farm land, labour structure, communications, domestic water supply and electricity, in the deltas visited by the Mission are also dealt with.

In agriculture, the present system of crops and production, cropping techniques and agricultural institutions are described.

In the Nobi, where the climate is too cold for rice during the winter season, the rice crop follows wheat, barley and rape seed. In recent years, employment in the factories is more attractive than farming and most farmers seek employment in industry and tend their farms only on a part-time basis. Thus agriculture there is declining. On the other hand, the Cho Shui delta in China: Taiwan, has become a major agriculture area. Multiple cropping is practised extensively and the yield of various crops, though already high, is still on an upward trend. In the four tropical deltas, Chao Phya, Irrawaddy, Sundarbans and Mekong, single rice cropping is predominant. Shortage of water during the dry season makes multiple cropping difficult. The deep-rooted traditional methods of agriculture, coupled with a lack of government guidance and incentives make it difficult for farmers to adopt modern improvements and thus the yields are low.

Details are given of cropping techniques involving plant selection, use of fertilizers and mechanization, which are three of the main factors conducive to high rice yields. In the Nobi and Cho Shui deltas where the cropping technique has reached a relatively high level, much attention has been paid to plant breeding to obtain good rice varieties suited to the soil-climate complex of the areas. Fertilizers are also heavily applied and mechanization is progressing. In the Sundarbans, Irrawaddy and Chao Phya deltas, there is no notable difference in rice cropping technique, which is still primitive. Winter rice, which has a long growing period is common. Application of fertilizers is negligible and mostly only simple farm implements are used.

Agricultural institutions concerned with credit, co-operatives, marketing and extension services in the various deltas are briefly discussed.

2.2 FLOOD CONTROL

2.2.1 Protection against river floods

In the deltas visited varying degrees of river protection have been undertaken depending on natural conditions, population, land utilization, living condition of the people, etc.

Where there is no protecting facility against floods in the portion of the river below and near the apex, the river can find its course quite freely and erratically, changing its course occasionally in the process of meandering. However it should not be forgotten that any river in a delta which keeps a steady and regular course in the present age was in a similar state for a long continuous period before any human attempts were made at river training.

The present landscape of the upper and middle portion of the Ganges and Irrawaddy deltas shows traces of former river courses, marked by the belt of woods and the pattern of land parcels. Erosion of river banks or silting up of the river are progressing at many points in the river courses. In cases where the flood discharge is considerable and the velocity is high, the embankment on the eroded bank may survive only until erosion reaches the foot of the embankment. Such unstable and short-lived embankments are seen in the Sundarbans delta. There the embankment was built of clay dug from immediately adjacent areas in front of or behind the embankment. The crest height is about 1 m above the normal high-water level and the slopes, both front and back, are around 1:2 to 1:3. A comprehensive development plan for part of the Sundarbans delta is now being executed by the Pakistan Government. The plan comprises embankment of more than 60 units of islands, closure of the channels for use as inland canals and construction of sluices for drainage of the areas.

In the upper reach of the Irrawaddy river, embankments were built to a height about 1 m above the 100-year flood level, with grass facing and gentle back slope of about 1:3 to as low as 1:10. These have never been over-topped. The sole function of the embankments of both the Sundarbans and Irrawaddy deltas is to protect the land behind them from flooding. River training to maintain the river course, limit the width of meandering or prevent bank erosion is not done. The changes in the course of the Ganges can be traced through the disappearance of lands and villages and the recurrence of islands and sand bars during the last 20 years.

In the Irrawaddy delta the flood discharges are tremendous but in general the river floods have not seriously threatened or destroyed the value of human habitation in the areas. Agriculture, especially rice production, is carried out in the manner best suited to the natural condition of floods. No densely populated towns are situated in the flooded areas.

In the Chao Phya delta of Thailand, river floods have been moderated or partially controlled by a modern system of diversion dams, regulators, irrigation and drainage canals in addition to the natural detention basins. A multi-purpose dam (Bhumipol dam, Yanhee project) on the upstream reach will contribute to flood control. The river seems to have been rather stable in its course and its flows are more or less gentle; floods do not generally cause much damage.

The Cho Shui river (Taiwan) is smaller than those mentioned above, but is steep and torrential in the upper reach and has caused immense silting up of its course in the delta. Formerly the river had four main channels from the apex to the sea through the delta plain causing flood damage and complicating the diversion of water for irrigation. After great damage in 1911, three of the channels were closed at the take-off points and the flood was confined in the Cho Shui river by levees on both banks of the river (see figure 7).

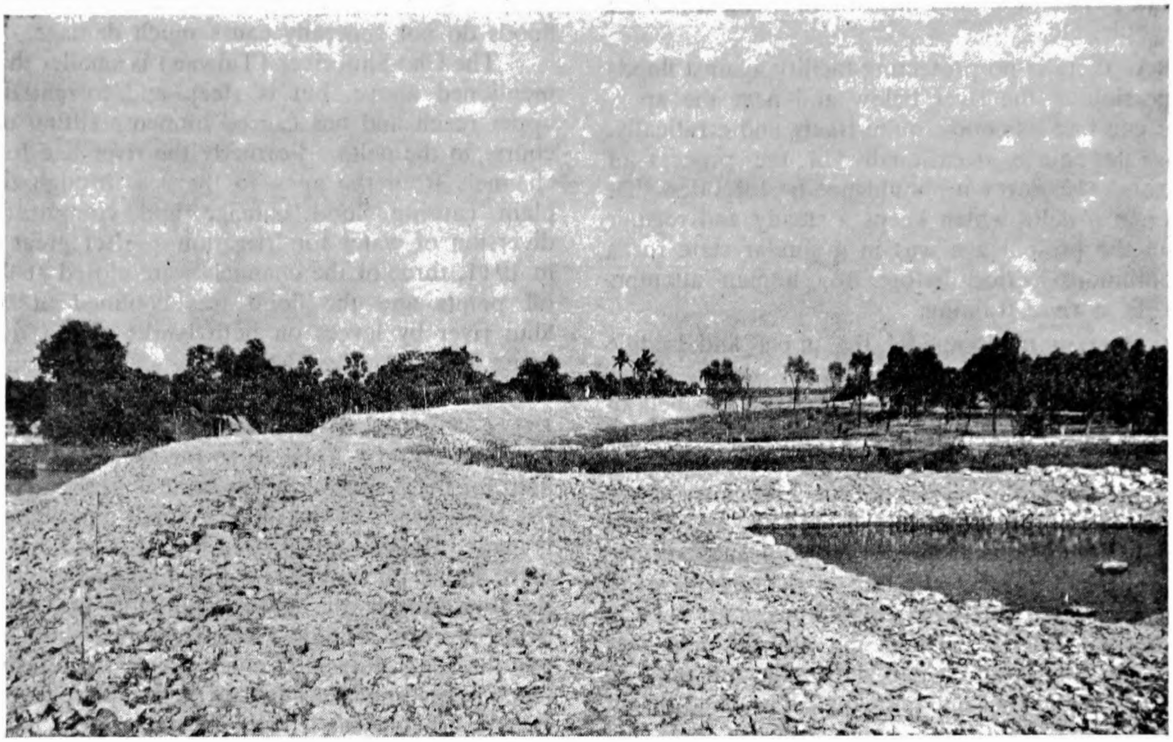
The training work on this river commenced in 1911. Levees, cross dykes and spur dykes are the main structures. There is so far no reservoir specially built for flood control in this basin. In the upper reach the levee has a comparatively small cross section and is made of gravel taken from the river bed. It is faced with stone pitching or wire-sausage protection. In the lower reach, the levee is built of earth and has a a larger cross section. The river bed there is sandy and the water current is much slower than in the upper reach. Investigations for further improvement of the river are being carried out in the context of regional multi-purpose planning.

The Nobi delta of Japan, though small, has three not so small rivers. These rivers used to be very torrential and wild. In some places the swift current eroded the river bed and banks while in others the current was slower and sediments were deposited. Due to the heavy rain in the hilly upper reaches the river level could rise sharply within a short time. Apart from the danger from river floods the Nobi coastal area is subject to high storm surge from the sea caused by typhoons. Thus the Nobi experiences worse natural conditions than most other deltas. Yet because of the great effort invested in the flood control works over a long period of struggle, the Nobi has now become one of the most highly developed districts of Japan both in agriculture and industry. The flood control works there comprise a levee, bank revetment, groin or spur dykes, widening of river channels in places, dredging, storage reservoirs in the upper reach, sea dykes and sea sluices. However, because of the financial factor, the levee was designed to withstand upto a 100-year frequency flood only.

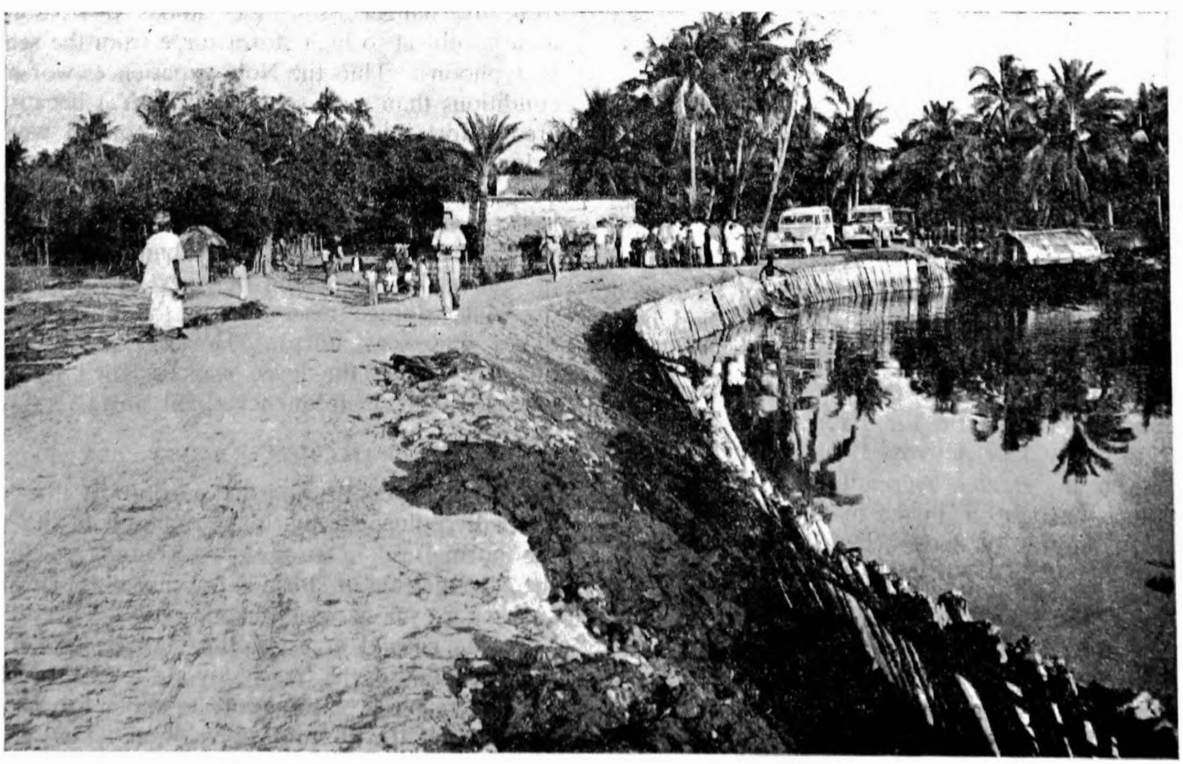
2.2.2 Protection against sea floods

The lower or coastal portion of the delta is generally influenced by tidal conditions of the sea, viz., the normal tide caused by astronomical effects and the extreme tide or storm surge caused by strong winds such as a cyclone or typhoon.

The coastal areas of the Ganges facing the Bay of Bengal and of the Irrawaddy at the Gulf of Martaban are covered with natural forests and scrub mangroves. Thus there are no provisions of any kind to protect these areas against sea floods. There are, however, embankment protecting low land from sea floods in



Reconstruction of embankment under the Coastal Embankment Project in the Sundarbans in East Pakistan



One of the embankments in the Sundarbans in East Pakistan before reconstruction the areas behind the forest zone and on the lower reaches of the rivers. These embankments are provided with openings to drain off surplus water; the openings are often simple cuts, but in some places may be equipped with sluice gates. The lowest patches in these cases which are 1 or 2 metres below high-water level, is used exclusively for paddy. The embarkments are generally designed with only 1 or at most 2 m of freeboard above ordinary high-water level in the tidal reaches of the rivers. Thus whenever there is a storm surge, the embankments are overtopped and the paddy fields flooded. It is felt that studies should be made to strengthen the embankments both in height and thickness.

The coastal area of the Nobi delta has long been protected against sea flood and the area has been well developed for industrial, agricultural and urbanization purposes. In 1959 a storm surge (Isy Bay Typhoon) of greater than design intensity hit the area and overtopped the sea dyke. Altogether there were 3,300 m of breaches in 220 places along the dyke; 39,000 hectares of highly developed land were flooded for as long as 30 days and more than 5,300 persons were drowned. Since then the sea dyke has been reconstructed and made higher and stronger. Economic limitations were no longer discussed as human lives could not be weighed in terms of economy.

Because of favourable meteorological conditions, the coastal area of the Chao Phya delta along the Gulf of Thailand has never been subject to strong storm surge. There are no embankments against sea tide and storm surge along the western and central coastal areas. Along the eastern coastline, there is a very low embankment behind the mangrove belt to protect the high sea tide from intruding into the southern part of the Chiengrak-Klong Darn project. A highway has been built on this embankment. Although the highway surface is only about one metre above the high tide or present ground level (the level of the foreland has been raised considerably during the past 30-40 years due to sedimentation), the embankment serves its purpose quite satisfactorily. Because of the combination of several factors, viz., no storm surge, a large mangrove belt along the coastline, high elevation of the foreland (close to the high water level) and the long long distance from the shore line to the embankment (about 500-1,000 m), the embankment could be made quite low.

2.2.3 Protection in the intermediate zone

The "intermediate zone" considered in this paragraph is that portion in the middle reach of the deltaic area where the river flood mentioned in para. 2.2.1 and the sea flood in para. 2.2.2 meet each other. In a large delta, this zone moves and varies seasonally according to the conditions of river flow and sea tide, from probably near to the river mouth during flood time up to the middle reach, where only a slight tidal movement is recorded in the dry season. Thus in such a delta the zone covers a longer reach than in a small delta (see paragraph 1.4.2).

A few observations regarding the intermediate zones of the deltas visited by the Mission are given below:—

a. In the intermediate zone of the Irrawaddy and Chao Phya deltas, the rise of water levels due to river flood as well as sea flood is small when compared with the other deltas.

b. Rise of water level due to the synchronization of river flood and sea flood is comparatively large in the intermediate zone of deltas like the Sundarbans and the Nobi.

c. In the Cho Shui delta, the slope of the river is rather steep and thus the intermediate zone is not too far from the river's mouth and the reach is rather short.

d. In the Sundarbans and Irrawaddy deltas, there are many cross channels connecting the branches of the rivers, thus making the protection against flood in this zone more difficult and complicated.

e. Erosion and silting up of the rivers in this zone are complex phenomena as they are caused by both river flow and tidal flow.

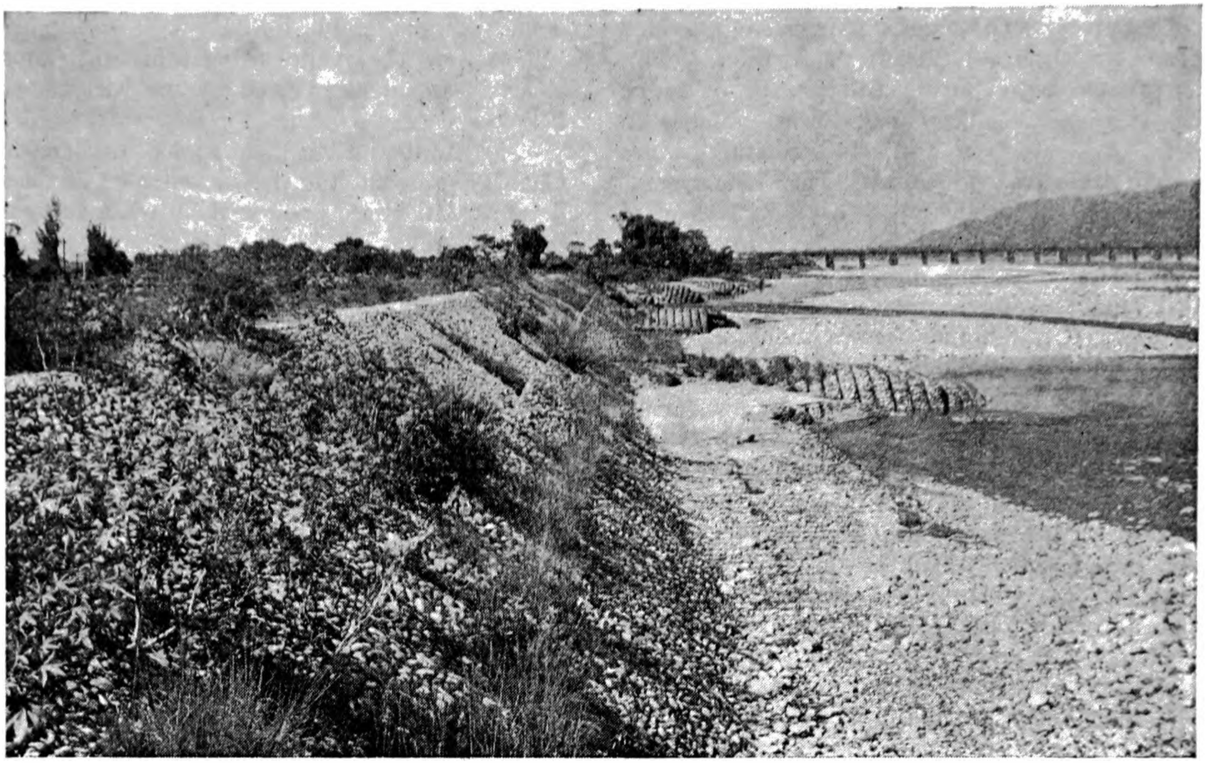
In the deltas of the Irrawaddy and Chao Phya, river floods begin to spread over the plain from the upper part of the delta. By the time the floods reach the intermediate zone they have already spread over a vast plain and the water level on the fields is not too high. In fact such floods give quite useful inundation and bring fertile silt to the paddy fields. Moreover, because of the favourable geographic locations of the deltas, outside the typhoon belt, the storm surges are rather small. There is therefore, a vast plain of paddy fields in the intermediate zone without protecting facilities against floods. Also there is no serious erosion or silting up of the rivers in this zone.

In the Sundarbans, many deltaic islands protected against floods by embankments have often been damaged because of breaches caused by overtopping or scouring at the toe by tidal current. At many points spur dykes have been built to protect the embankment toe. However, there is no protection of the river banks and scouring of the banks will continue so long as no river training work is executed.

At the middle reach of the Kiso river in the Nobi delta during the typhoon of 1959 (Iswan typhoon or typhoon "Vera") the sea flood combined with river floods, caused the river to exceed the highest water level ever recorded in the previous 100 years by more than 1 m and the embankments were breached in many places. One solution there may be to increase the height of the river embankments. However, this has to be studied most carefully before being implemented.

When river improvement is executed, many problems may arise and planning should be done very carefully, taking them into consideration:

(a) The river bed has a tendency to deepen owing to the construction of dams in the upper reaches. Also



Bank rivetment and spur dikes on the Cho Shui river by wire sausages

Temporary training wall in the Cho Shui river channel to guide the flow of the river, made of bamboo and packed with river gravels the dredging of the downstream stretches will increase the penetration of sea floods through the deepened channel (Kiso river).

(b) Because of the decrease in flood discharge and sediment after the construction of a dam in the upper reaches, the existing sand and gravel deposits generally move downstream, thus changing the regime of the river (Kiso river).

(c) Embanking or increasing the height of embankments in the middle reach of a river, resulting in significant encroachment on overbank storage, may cause a rise in the water level in the upper and lower reaches—as is seen in the records of the Irrawaddy river.

(d) The low elevation and flatness of the land in the lower reaches make flood protection more difficult. Also drainage by gravity will be very difficult or even impossible and pumps may have to be used.

2.2.4 Comparison of flood control systems in the various deltas

Owing to the different social, economic and natural conditions in the deltas, flood control systems differ greatly. These differences are mainly in the adaptation to specific natural and agricultural conditions rather than in techniques. The systems are described briefly as follows:—

(a) In most parts of large deltas in the ECAFE region, except in the coastal areas, besides rainfall, inundation by river flood is an important source of water for paddy fields. Flood control is therefore designed primarily for protecting the field from surplus flood water. Embankments are built on the natural bank to augment the height of the bank. Where the land is very low, it is totally or partially surrounded by embankments (in the Irrawaddy delta, a horseshoe-shaped embankment has been built) to exclude surplus water. In extremely high floods the embankments are liable to be overtopped.

(b) In the Chao Phya delta, flood water is distributed and diverted into the river branches, numerous irrigation and drainage canals and natural depressions (for instance into the floating rice areas north and west of Ayutthaya). In the case of a high flood, the flood water would spread over more or less the whole width of the delta in a thin layer. An extensive network of canals and regulators makes such moderation possible.

(c) In the Cho Shui and Nobi deltas, control of river floods is separate from the irrigation system. There, flood water from the upper reaches is confined in the main rivers and is channelled to flow as quickly as possible to the sea. Rainwater in the deltas flows down to the sea through the many small rivulets and streams. In the portions near the coast where the land is lower than the sea or river level, the surplus water has to be pumped out from the embanked areas.

(d) In the coastal areas of any delta, sea dykes or embankments are necessary to protect the land against salt water. It is observed that the embankments along the rivers in the coastal area of the Sundarbans delta may not be strong enough to withstand extreme storm surges. The possibility of providing stronger dykes, of course, depends very much upon the socio-economic importance of the area and the stage of development reached. Embankments along some parts of the coasts in the Irrawaddy and Chao Phya deltas are free from the danger of high storm surges. In all these deltas, the foreland covered with mangroves and other vegetation offers a good protection for the embankments against sea floods and waves.

In the Nobi delta, a record meteorological tide of 3.55 m occurred four years ago in the Ise-bay and damaged the sea dykes, which have since been reconstructed and are believed to be capable of withstanding typhoons.

2.3 WATER MANAGEMENT

2.3.1 Major drainage and irrigation

The systems of major drainage and irrigation in the various deltaic areas of the ECAFE region differ widely according to natural conditions and the stage of agricultural and industrial development. But even in well-developed areas such as those in Japan and China: Taiwan there are still many possibilities for further improvement.

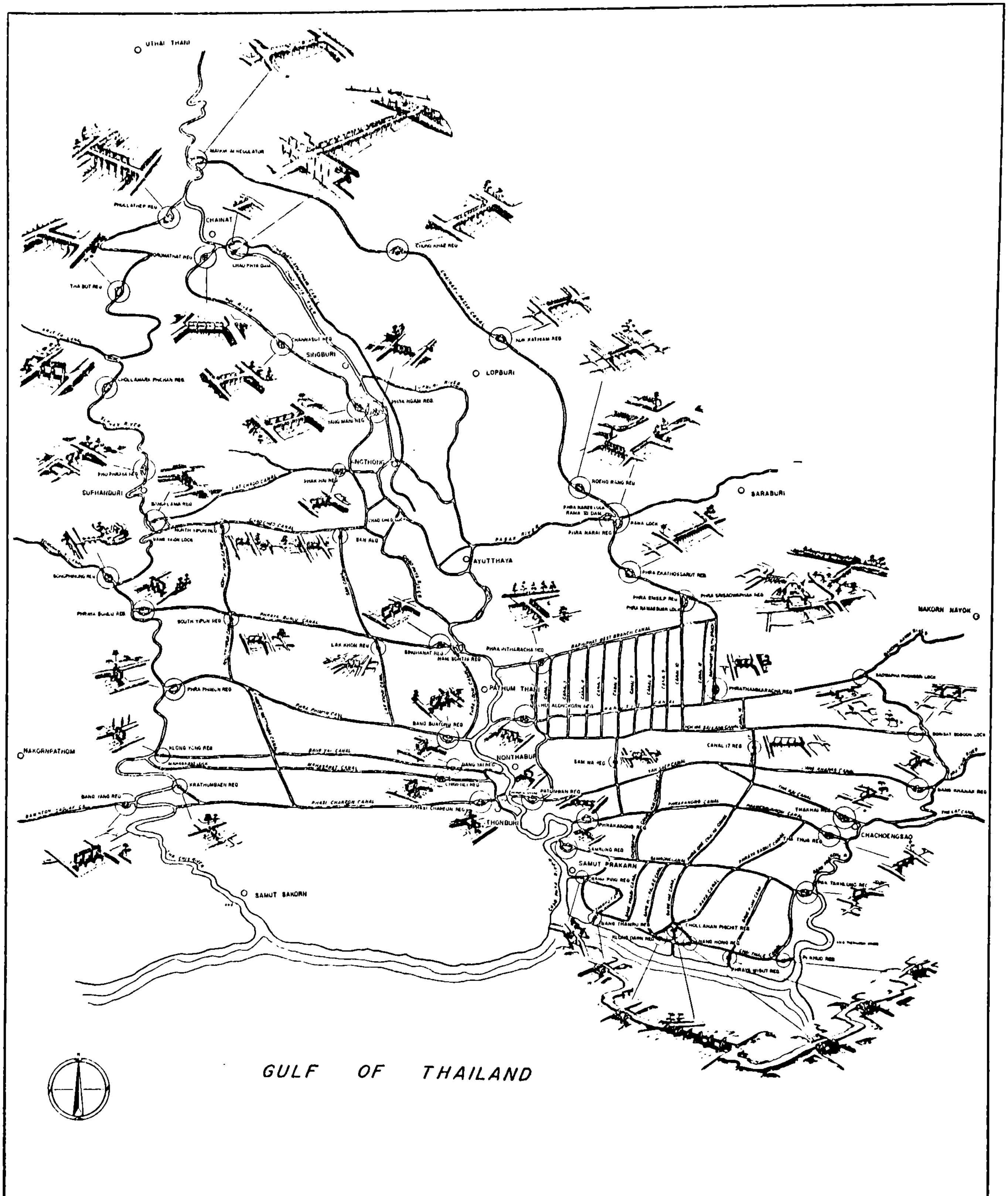
(a) *The Sundarbans* (India)

Conditions of major drainage and irrigation in this area are governed by (i) the salt water intrusion into the estuaries and creeks and the necessity of protecting the relatively low-lying land (at about the level of ordinary high tide or even below) against this intrusion and against storm surge by closed encircling dykes or "bunds", and (ii) the policy of water conservation both in the fields and in the bunded units as a whole. The water supply for the wet monsoon rice crop depends on rainfall alone, which is generally adequate in amount but irregular in distribution. Major drainage is governed by this policy.

Originally the dykes were built and maintained by farmers ("village bunds"). No adequate provision was made for the outfalls of the natural drainage channels and many channels had been dammed off. In other locations wooden box sluices were provided but with insufficient hydraulic capacity. To get rid of the excess water after a heavy rainfall, farmers used to cut the bunds thus endangering the flood protection.

Recently the dykes were taken over by the Government. Permanent concrete or stone sluices are now being constructd at the main outfalls. A major problem is the silting up in certain localities of the external drainage channels outside the sluices. The system of internal drainage channels also requires further improvement.

A master scheme now being investigated aims at the enclosure of some of the estuaries and major



Major and Medium Structures for Irrigation and Drainage in the Chao Phya Delta.

creeks. Execution of this scheme will lead to a substantial improvement of flood protection, major drainage and some irrigation facilities.

(b) *Coastal area of Khulna district (East Pakistan)*

In many respects the conditions of major water control in this area are similar to those in the Sundarbans in India. The "Coastal Embankment Project", now being carried out by the East Pakistan Water and Power Development Authority (EWAPDA) aims at better flood protection and drainage. For the design of sluices, a drainage standard of 25 mm (1 in) per day for localities where the annual rainfall amounts to 1,750 mm (70 in) and for other localities in proportion to this depth has been adopted. This is based on the assumption that the crop on land flooded to a depth of less than 15 cm is not damaged.

Mention should be made of improvements in the poor drainage conditions in the lowest depressions at the northern border of the coastal area and in the deltaic flood plain north of this area. A typical example is the "Bil Dakatia" near Khulna to which reference is made in paragraph 3.3.3.

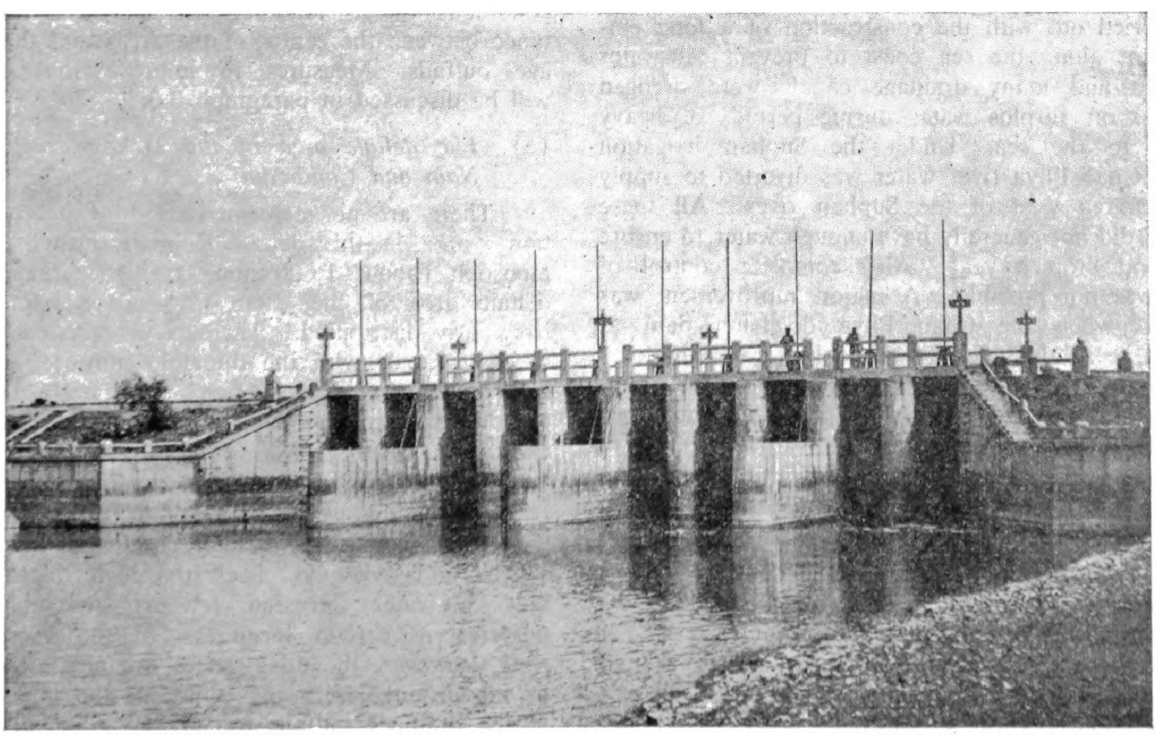
(c) *Deltaic area of the Irrawaddy river (Burma)*

There is no major irrigation in this area. Water for the wet-season rice crop is supplied by rainfall, which is more than adequate in amount but may be irregular in distribution. The facilities for major drainage depend on the various types of flood protection works.

In the zone where river floods predominate and in the intermediate zone, embankments have been built encircling the areas between the river branches at the upstream end but leaving the downstream end open to the floods (open or horseshoe embankments). Since the annual rainfall is of the order of 2,500 mm drainage conditions of the areas in the open embankments are poor, especially in the southern part and in the depressions. Only after the recession of floods can the water drain off gradually through the existing channels at the southern end. In the depressions, however, water remains stagnant even during the dry season.

In the intermediate zone, which is exposed to high tidal levels, drainage conditions may be quite poor. The elevation of the land in this zone is lower than in the former and the high tides penetrate through the open southern end of the embankment, thus hampering drainage. A typical example exists at Yandoon Island, for which projects are now being prepared to improve the present poor drainage conditions (paragraph 3.3.3).

In the intermediate and coastal zones of the Irrawaddy delta, many areas have no flood protection at all. Land in the salt-water tidal reach suffers from salt-water intrusion in August and September, when the combination of high astronomical tide, river discharge and southerly wind creates a high sea tide and thus floods the lands with saline water. Projects are under way (e.g. Labutta project in the south-western part of the delta) to project these areas by encircling dykes. The drainage problems of these areas are similar to those described for the embanked areas in the Sundarbans in India and Pakistan.



Bajola drainage sluice in the Sundarbans in India

(d) *Deltaic area of the Chao Phya river (Thailand)*

This area, where the wet monsoon rainfall (1,000 mm) is not adequate to meet the requirement of the rice crop and is irregular, provides a unique example of a system of major water control facilities for supplementary irrigation and the spread of flood waters into a natural depression and over the plain. The Chao Phya river has a gentle rise and fall in water level and moderate flood peaks. The objective of engineering works has therefore been mainly supplementary irrigation and water conservation rather than exclusion of flood waters from the depressions and plains. Originally the rice crop during the wet monsoon season depended entirely on precipitation and river water which spilled over the banks. During the past 100 years, records show that damage to rice crops occurred because of inadequate rainfall and too low river levels rather than severe floods.

Earlier development in this delta consisted in the construction of inland waterways to open up new land and provided many areas with a means of transporting agricultural products to the market (West Bank project and part of Chiengrak Klong Darn project). Later these canals were also used for conserving water during the latter part of the growing season when rain was sometime inadequate and the river was not high enough to over-spill its banks. Regulators and navigation locks were built at both ends of the canals for the purpose. This was followed by the construction of the south Pasak irrigation project, whereby irrigation canals brought water from the Pasak river to feed the large Rangsit area. A project to reclaim the eastern coastal areas was carried out with the construction of a long embankment along the sea coast to prevent salt-water intrusion and many drainage canals were dredged to drain off surplus water during periods of heavy rainfall to the sea. Under the Suphan irrigation project Chao Phya river water was diverted to supply a large area west of the Suphan river. All these projects did not generally have enough water to ensure one good crop a year. Also complete control of water was not possible. A major improvement was obtained when the Chao Phya diversion dam at Chainat, near the apex of the delta, was completed in 1957. Along with this undertaking, many irrigation canals were dug to enlarge the commanded area along both banks of the Chao Phya river down to the sea. Thus an area of about 1 million hectares of delta land is now under the drainage and irrigation control of the Chao Phya irrigation scheme.

In this scheme the depressions continue to act as natural flood detention reservoirs to reduce the amount of flood water that would spill over the flat plain north of Ayutthaya to the sea. There are no major embankments since it was found that the cost of protection against a 100-year flood would not be justified by the benefits.

A further step in the development of this deltaic area will be achieved when the Yanhee multi-purpose project is completed in 1964. This project comprises a large storage dam on the Ping, the largest of the four tributaries of the Chao Phya river. Although this project is primarily designed to produce hydro-electric power, the operation of the dam will help to reduce the peak flood discharges substantially. At the same time more water will become available in the dry season to raise a second crop in parts the Chao Phya project area. A further reduction of the peak flows will be obtained with the construction of the Sounhee dam on the Nan river, now being planned. Then a 100-year frequency flood would be controlled and accommodated by the many diversion canals and the main river between the embankments. After that a further and final stage could aim to provide adequate flood protection and dry season irrigation.

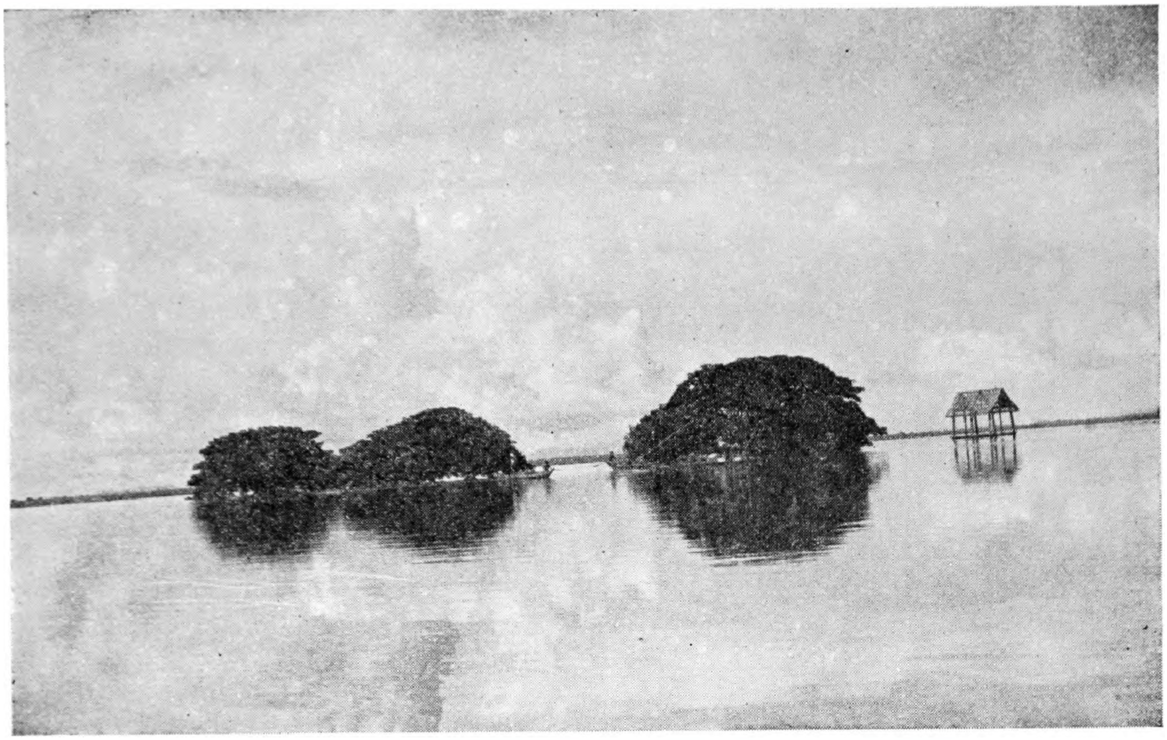
In the upper portion of the deltaic area where the land between the river branches is basin-shaped and where there is a general gentle slope southward, it is observed that the irrigation canals and the drainage channels are built separately. In the flat west bank plain from below Ayutthaya to the sea, the canals serve both irrigation and drainage purpose. The main exception is the Rangsit area to the east of the Chao Phya river from Ayutthaya to Bangkok. Conditions in this area are referred to in paragraph 1.3.2.

The absence of separate drainage and irrigation canals in the coastal areas and the policy of water conservancy towards the end of the flood season are the primary causes of the unsatisfactory drainage conditions there. Another reason is the long distance between the centre of the areas and the drainage outfalls. Measures to improve this situation will be discussed in paragraph 3.3.3.

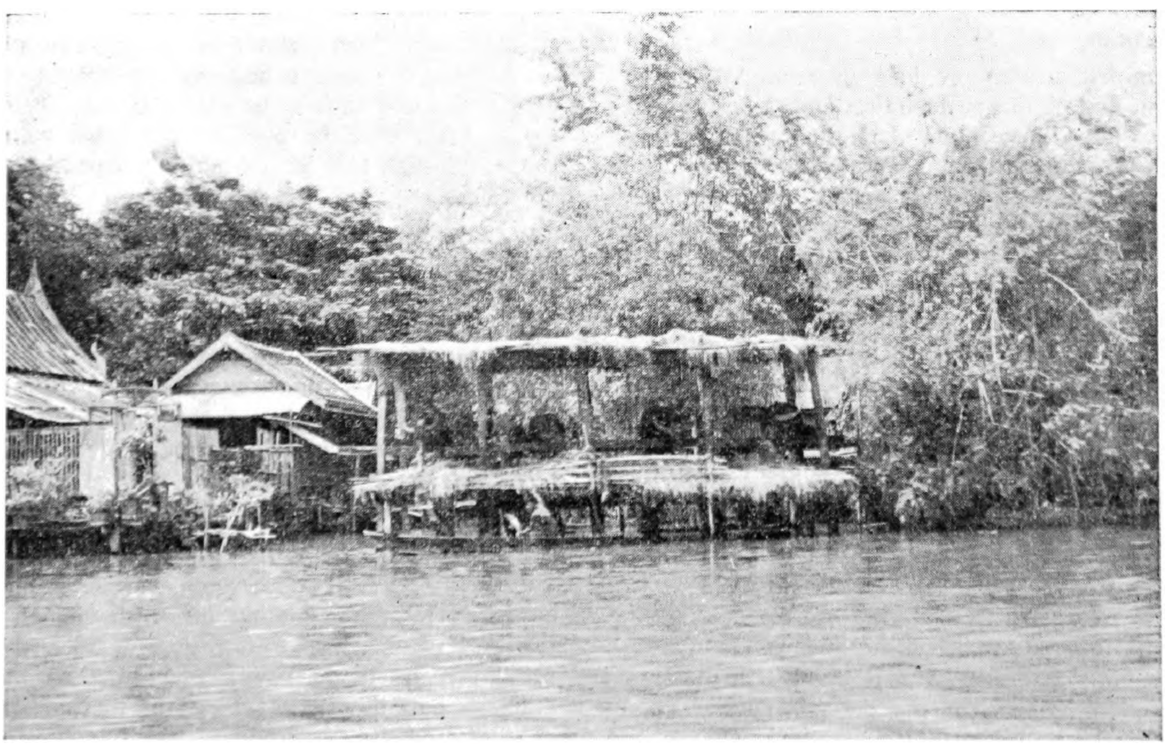
(e) *The deltaic area of the Mekong river (Viet-Nam and Cambodia)*

There are no major irrigation or flood protection works in this delta. Rainfall during the wet monsoon (about 1,600 mm) is higher than in the deltaic area of the Chao Phya river but is also irregularly distributed. There is a dense network of dredged canals with the threefold purpose of drainage, irrigation and navigation. This leads, however, to conflicting requirements as explained below.

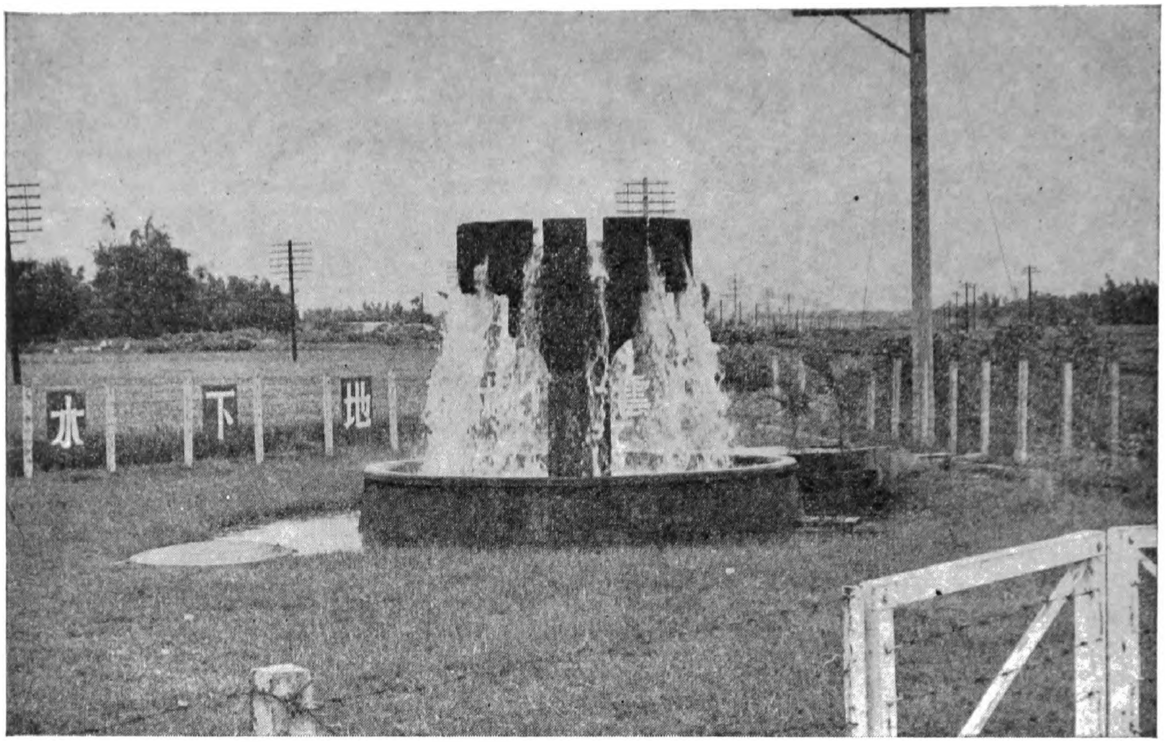
In September, during the wet monsoon, the delta is generally flooded when the river is in spate. Drainage conditions are poor except in the strip along the coast where tides facilitate drainage. There are sluices and dykes to check the high tides and to halt salt-water intrusion (casiers hydrauliques or polders) in certain localities. In the intermediate zone, however, the tidal ranges are either too small or the distance from the centre of the inland areas to the drainage outfalls too great. A small portion of this zone can be irrigated with fresh water at high



Flood in the depression area, north of Ayutthaya, Chao Phya delta



People in the depression area of Chao Phya delta adapt themselves to live with floods. Houses are built on high stilts and buffaloes live on a raised platform during flood



One of the numerous groundwater wells in the Cho Shui delta

tide. In general the drainage and irrigation conditions there present a certain similarity to those in the non-embanked zone in the deltaic area of the Irrawaddy river.

(f) *The deltaic area of the Cho Shui river (China: Taiwan)*

This deltaic area provides an example of major irrigation and drainage facilities and a rather high degree of flood protection. Irrigation water is taken from the river by means of temporary diversion dams, some of which are located at Linnei, near the apex of the delta. Erection of a permanent diversion structure at Chi-Chi, upstream from the apex, is under consideration. This structure would provide some storage so that more water could be supplied in dry periods. In this area irrigation by pumping of ground water is applied on a large scale.

The rather high elevation and steep slope of the land permit effective drainage by gravity. Former river branches and newly-constructed canals are used for this purpose.

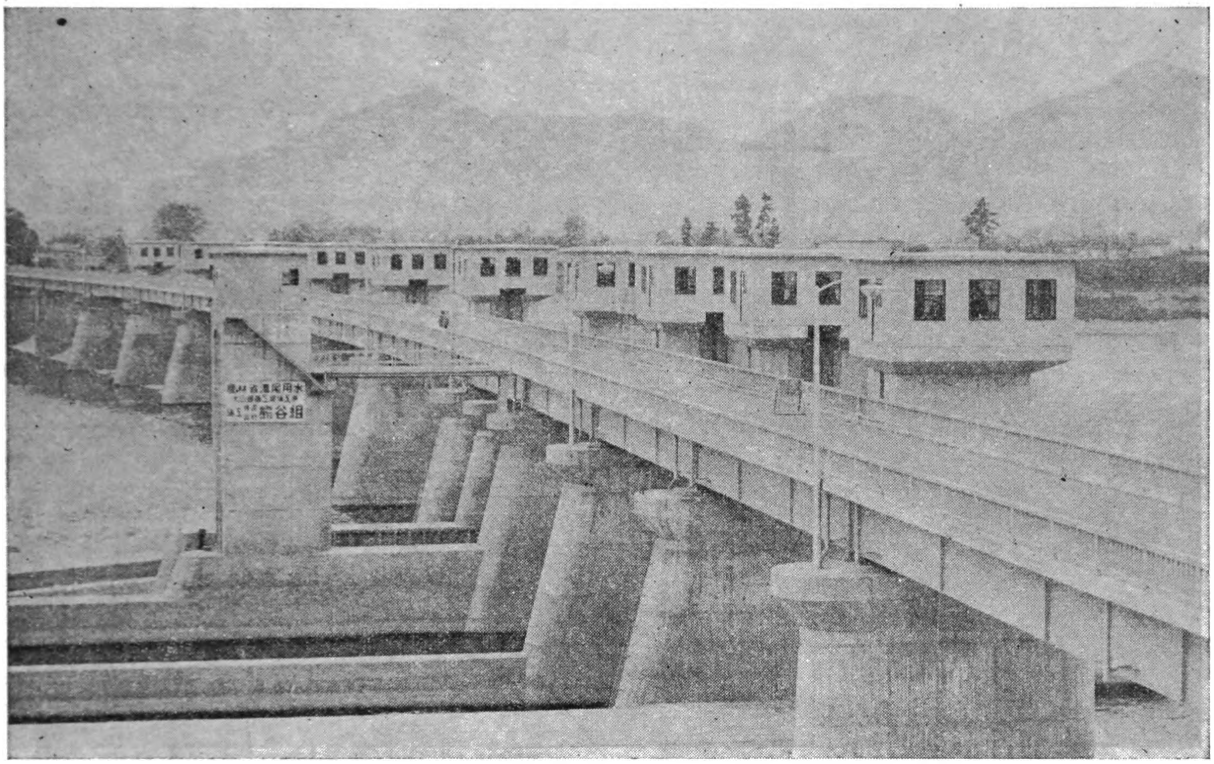
(g) *The deltaic area of the Kiso river (Nobi delta —Japan)*

In this area flood control and major drainage and irrigation facilities have reached a high degree of perfection in spite of the difficult natural conditions: low elevation of the coastal zone, heavy typhoon rainfall and torrential current of the rivers. Further improvement of drainage and irrigation, however, is an absolute necessity in order to keep pace with the fast development of the country in general and in particular of the Nobi delta.

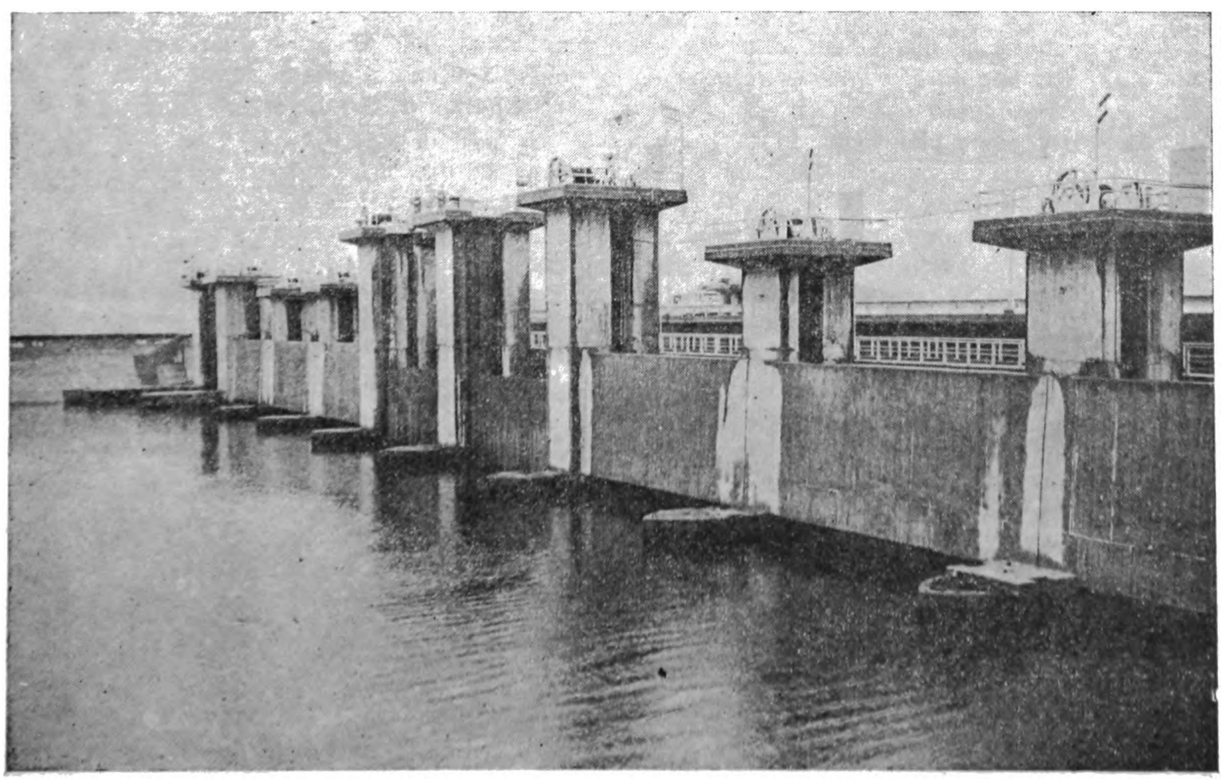
Irrigation water is taken off directly from the river to supply the upland parts of the area. Because of the high elevation of groundwater and heavy soil, drainage conditions for upland crops is poor and crops have to be grown on high beds made in the form of a furrow. In the fresh water tidal reach, the high tide level could conveniently be used.

In the low-lying portions of the area, drainage has to be done by pumping. Owing to the lowering of the Kiso's bed, which made the irrigation intake facilities built along the river banks ineffective, a headwork had to be built a few years ago on the river at Inuyama, the apex of the delta, to head up the water level. Canals branching off upstream of this headwork to irrigate the higher portion of the area have also been constructed. The Government plans to build a second headwork further downstream to improve irrigation facilities for the downstream areas.

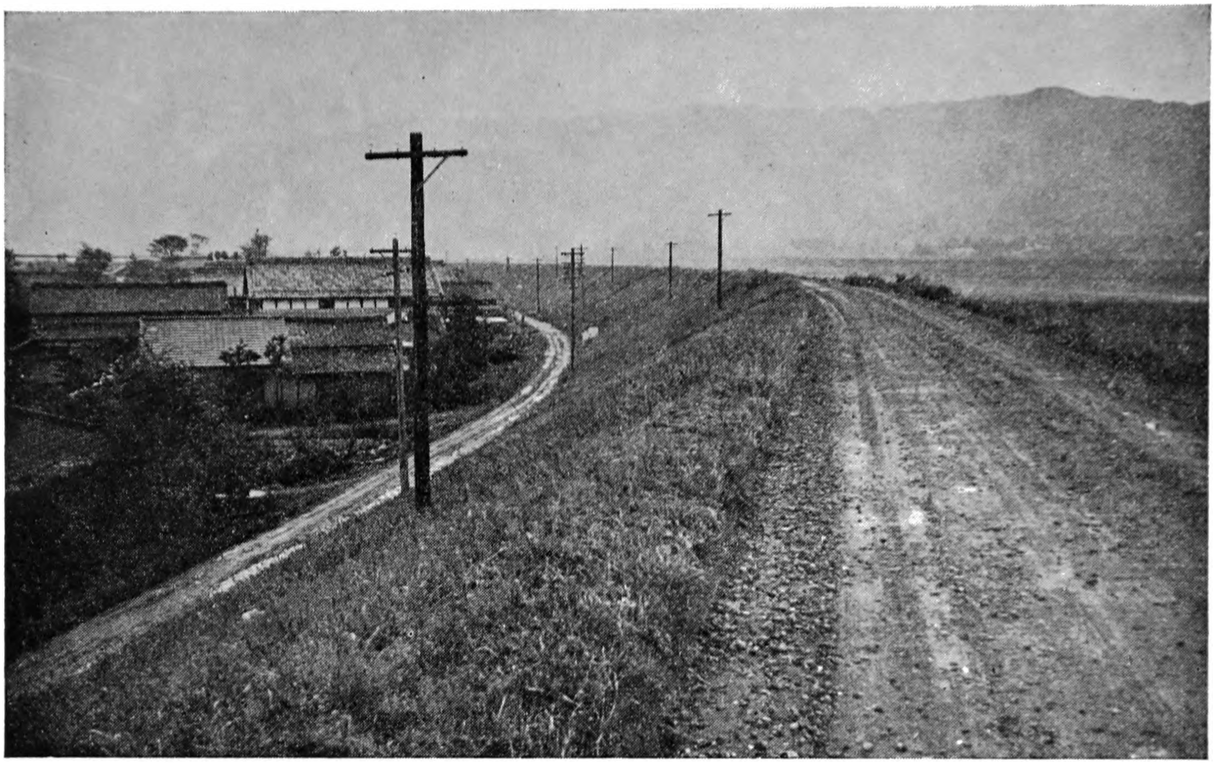
In the coastal area, drainage has been greatly improved by the damming off, with sluices, of the estuaries of the former branches of the Kiso river (Nikko river, Ikada river) which act as the main drainage outfalls. The benefits of these works have so impressed the Government that it is now planning to close the estuary of the Kiso river with a sluice. Irrigation by groundwater is extensive in this delta.



Inuyama headwork of Nobi irrigation project



Sluice in the enclosing dike at the estuary of Nikko river, Nobi delta



River levee of "Waju" area in the Nobi delta (Waju is Japanese word for the inland area enclosed by levee.)

Reclamation by filling up of creeks in the Nobi delta

(d) *Deltaic area of the Chao Phya river (Thailand)*

This area, where the wet monsoon rainfall (1,000 mm) is not adequate to meet the requirement of the rice crop and is irregular, provides a unique example of a system of major water control facilities for supplementary irrigation and the spread of flood waters into a natural depression and over the plain. The Chao Phya river has a gentle rise and fall in water level and moderate flood peaks. The objective of engineering works has therefore been mainly supplementary irrigation and water conservation rather than exclusion of flood waters from the depressions and plains. Originally the rice crop during the wet monsoon season depended entirely on precipitation and river water which spilled over the banks. During the past 100 years, records show that damage to rice crops occurred because of inadequate rainfall and too low river levels rather than severe floods.

Earlier development in this delta consisted in the construction of inland waterways to open up new land and provided many areas with a means of transporting agricultural products to the market (West Bank project and part of Chiengrak Klong Darn project). Later these canals were also used for conserving water during the latter part of the growing season when rain was sometime inadequate and the river was not high enough to over-spill its banks. Regulators and navigation locks were built at both ends of the canals for the purpose. This was followed by the construction of the south Pasak irrigation project, whereby irrigation canals brought water from the Pasak river to feed the large Rangsit area. A project to reclaim the eastern coastal areas was carried out with the construction of a long embankment along the sea coast to prevent salt-water intrusion and many drainage canals were dredged to drain off surplus water during periods of heavy rainfall to the sea. Under the Suphan irrigation project Chao Phya river water was diverted to supply a large area west of the Suphan river. All these projects did not generally have enough water to ensure one good crop a year. Also complete control of water was not possible. A major improvement was obtained when the Chao Phya diversion dam at Chainat, near the apex of the delta, was completed in 1957. Along with this undertaking, many irrigation canals were dug to enlarge the commanded area along both banks of the Chao Phya river down to the sea. Thus an area of about 1 million hectares of delta land is now under the drainage and irrigation control of the Chao Phya irrigation scheme.

In this scheme the depressions continue to act as natural flood detention reservoirs to reduce the amount of flood water that would spill over the flat plain north of Ayutthaya to the sea. There are no major embankments since it was found that the cost of protection against a 100-year flood would not be justified by the benefits.

A further step in the development of this deltaic area will be achieved when the Yanhee multi-purpose project is completed in 1964. This project comprises a large storage dam on the Ping, the largest of the four tributaries of the Chao Phya river. Although this project is primarily designed to produce hydro-electric power, the operation of the dam will help to reduce the peak flood discharges substantially. At the same time more water will become available in the dry season to raise a second crop in parts the Chao Phya project area. A further reduction of the peak flows will be obtained with the construction of the Sounhee dam on the Nan river, now being planned. Then a 100-year frequency flood would be controlled and accommodated by the many diversion canals and the main river between the embankments. After that a further and final stage could aim to provide adequate flood protection and dry season irrigation.

In the upper portion of the deltaic area where the land between the river branches is basin-shaped and where there is a general gentle slope southward, it is observed that the irrigation canals and the drainage channels are built separately. In the flat west bank plain from below Ayutthaya to the sea, the canals serve both irrigation and drainage purpose. The main exception is the Rangsit area to the east of the Chao Phya river from Ayutthaya to Bangkok. Conditions in this area are referred to in paragraph 1.3.2.

The absence of separate drainage and irrigation canals in the coastal areas and the policy of water conservancy towards the end of the flood season are the primary causes of the unsatisfactory drainage conditions there. Another reason is the long distance between the centre of the areas and the drainage outfalls. Measures to improve this situation will be discussed in paragraph 3.3.3.

(e) *The deltaic area of the Mekong river (Viet-Nam and Cambodia)*

There are no major irrigation or flood protection works in this delta. Rainfall during the wet monsoon (about 1,600 mm) is higher than in the deltaic area of the Chao Phya river but is also irregularly distributed. There is a dense network of dredged canals with the threefold purpose of drainage, irrigation and navigation. This leads, however, to conflicting requirements as explained below.

In September, during the wet monsoon, the delta is generally flooded when the river is in spate. Drainage conditions are poor except in the strip along the coast where tides facilitate drainage. There are sluices and dykes to check the high tides and to halt salt-water intrusion (casiers hydrauliques or polders) in certain localities. In the intermediate zone, however, the tidal ranges are either too small or the distance from the centre of the inland areas to the drainage outfalls too great. A small portion of this zone can be irrigated with fresh water at high

Drainage and irrigation are solely for the purpose of raising rice crops. The extension of horticulture in this industrialized region would require further improvement of the drainage system. Subsidence of the land and reclamation by filling up of ponds and creeks would also lead to higher drainage requirements. A system of separate drainage and irrigation canals would then be necessary.

2.3.2 WATER CONTROL IN THE FIELD

Water control in the field includes all those measures and activities which, under given hydrologic conditions, directly influence the water level or groundwater table in the fields in such a way as to control these levels so as to ensure better conditions for agricultural production.

The systems of water control in the field in the various deltaic areas show different degrees of development; in many cases the original natural conditions have hardly been altered, whereas in some other cases an almost perfect control system has been installed. The extent to which control has been established is closely related to climatological conditions, the extension of the major drainage and irrigation systems and the agricultural development. The different systems adopted in the various deltaic areas are discussed below.

(a) *The coastal area of the Sundarbans in India and East Pakistan*

Although there are some differences with respect to the flood protection systems within the area, the water control in the field is about the same. The islands used for agriculture are protected against sea water intrusion by encircling embankments or "bunds". The former natural creeks incorporated in the embanked areas, act as major drainage outfalls; however their effectiveness is limited by insufficient hydraulic capacity.

The water supply for plant growth depends entirely on rainfall; but, owing to the irregular distribution of rainfall during the growing season, cultivation would hardly be possible without special measures of water control, however modest they may be. Water control is primarily focussed on conserving water. The land has been divided by the farmers into units or plots enclosed by field dikes varying in height from some 30 to 70 cm. Thus rain water falling on the unit can be stored. It should be mentioned that the field dikes also serve as pathways for inspection of the fields, control of uniform depth of flooding and control of flushing, items which become more important as more perfect water control is sought. In most cases, the actual degree of water control achieved in the paddy fields is a compromise between the requirements for water storage and the permissible depth of flooding for the rice crop.

To remove excess water from the field, the farmers make cuts in the field dikes. The effectiveness of this measure depends entirely on the water levels in the adjacent plots. In basin-shaped areas which are characteristic of deltaic regions, excess water removed from higher areas can accumulate to harmful depths in the plots at lower elevations. This is especially true if the capacity of the major drainage system is inadequate.

In the polders of the Sundarbans no drainage ditches have been provided. Water control in the field is left to the individual responsibility of the farmer, however water levels in the adjacent plots leave little latitude for control.

The "Coastal Embankment Project" in Khulna district (East Pakistan) aims at better flood protection and at increasing the capacity of the major drainage system. This can be considered a first step towards better drainage which is prerequisite to use of the full potentialities of the soil.

Irrigation is practised on a very modest scale. For this purpose small tanks have been built to supply water during the dry season for the irrigation of small vegetable gardens and for domestic use. The tanks in which rain water is stored have no greater size than some 500 sq m and are built partially by excavation and partially by diking.

(b) *The deltaic area of the Irrawaddy river (Burma)*

In the coastal region of this area there are few flood protection works and major irrigation facilities are entirely lacking. Major drainage is provided by the natural creeks. Nevertheless, successful growing of wet season rice is practised on an extensive scale. This can be explained by the relatively high elevation of the land above adjacent water surfaces and the more than adequate depth of rainfall during the growing season. In Burma the same method of water conservation has been applied as in the Sundarbans. The small field dikes have about the same height, but the enclosed units are somewhat larger on the whole. In the non-embanked coastal areas, the field dikes also provide a modest protection against salt water intrusion during the growing season.

Rainfall is such that equilibrium between storage and depth of flooding can more easily be achieved than in the deltaic area of the Ganges. However the absence of adequate major and minor drainage facilities causes considerable damage which precludes cultivation in the lowest parts of the area.

In this deltaic region salt water intrusion and excess water adversely affect the production of rice. Embanking of the areas would be most beneficial. Thus the construction of the Labutta Polder in the coastal area south of Bassein will double both the total acreage of arable land and the rice yield per unit of area.

In the zone where river floods predominate, dikes have been constructed. These embankments are horse-shoe-shaped, leaving the areas open on the schemes every parcel is connected on one side with the irrigation system and on the other side with the drainage system. Sufficient quantities of water with sufficient head can now be supplied by an up-to-date system of major and minor irrigation and drainage works.

The state, the prefecture, the communities and the farmers share in the costs of the improvement works. The maintenance of the irrigation and drainage ditches is largely done by the farmers.

(c) *The deltaic area of the Cho Shui river (China: Taiwan)*

The system of water control in this area is being developed to a high degree, because limited water is available. Extension and intensification of agriculture have required reconstruction of the irrigation and drainage systems and redistribution of the available amounts of water. Where suitable ground water can be abstracted with tubewells, an additional supply of irrigation water is at hand. New schemes are being implemented comprising separate irrigation and drainage systems.

Irrigation here emphasizes the economical use of water, and both rotation irrigation and crop rotation are practised. For the former, water is given once every 5 to 14 days depending on the crops (for rice about 5 to 7 days). For crop rotation the so-called three year crop rotation is widely employed in the delta. Under this method, the first crop is sugar cane (15 to 18 month growing period) where several applications of irrigation water are given during the first 6 to 6½ months of the growing period, from November to mid-May. The second crop is green manure which is given no irrigation water (from February of the second year to June = 5 months). The third crop is rice grown during June to October with irrigation every 5 to 7 days. After rice comes sweet potatoes and wheat (fourth crop) grown from November of the second year to April of the third year. Irrigation water is not given to these crops. The fifth crop is green manure again, or peanuts, upland rice or soy-beans, for which irrigation water is again not supplied. Then sugar cane is repeated with intermittent irrigation in the early growing period (see figure 16). In this system drainage and irrigation canals are separated.

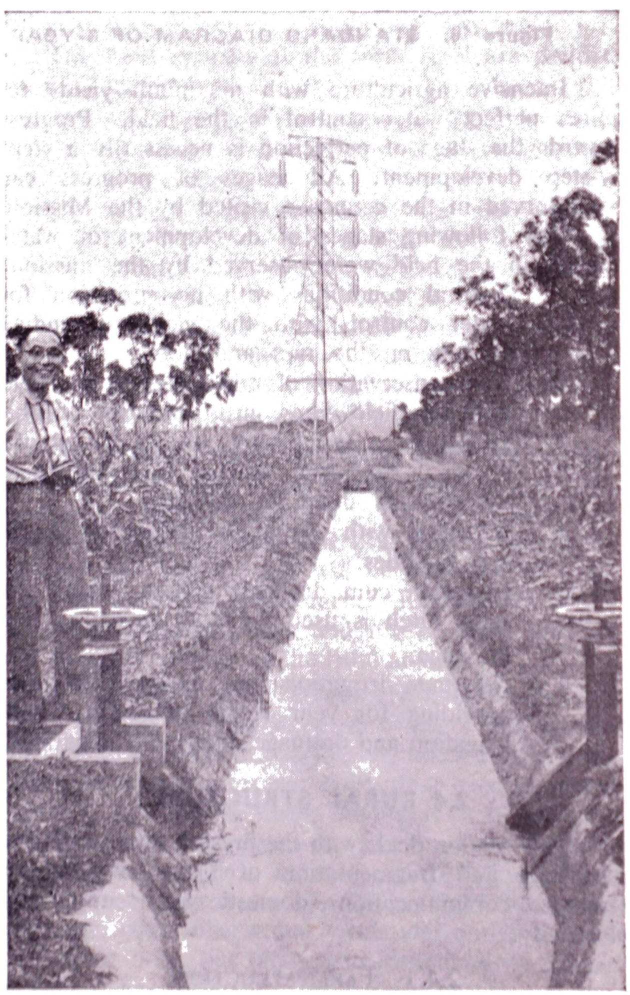
The whole water control, nearly all improvement works and the maintenance of the irrigation and drainage system is directed by the "Irrigation Associations". Farmers and landowners are members of these associations which are governed by a committee elected by the members. The members pay for the use of water and share in the costs of improvement works. Measuring devices to control the quantities of water are used throughout the projects.

Reclamation of tidal land, as being practised in China: Taiwan, requires special water control measures. To acquire experience, a pilot polder has been constructed. The main point of concern is the successful drainage of the reclaimed land because of the high elevation of the groundwater table and the high salinity of the water at shallow depths. Thus adequate drainage is an absolute necessity for the land to be productive.

The system of open drainage ditches as applied in the pilot polder has not proved satisfactory owing to the sandy nature of the soil which causes sliding of the slopes of the drainage channels. Loss of arable land and high costs of maintenance are associated with this system.

(d) *Comparison of the various deltaic areas*

A comparison of the systems of water control in the field in the various deltaic areas shows the widespread influence of rice production. Water management is dictated by the requirements of rice cropping. It should be recognized that the techniques of cropping have been well adapted to the specific natural conditions of each deltaic area. The development of water management is in harmony with the development of agricultural techniques, crop patterns and yields.



An irrigation distributary canal with farm turnouts in the Cho Shui delta downstream side. Here the floods can enter slowly but the inundated area and the depth of flooding are smaller than without these "open dikes". The system of water control in the field is similar to that in the coastal region.

The lower patches of the partially embanked areas are not cultivated because of the long period of deep flooding. This results from insufficient capacity of the major drainage system and lack of minor drainage facilities. There are no drainage provisions in the cultivated areas of higher elevation, but here the natural drainage possibilities are better, moreover the soils are of better quality. As a result, the yields are high, amounting to as much as about 3,000 kg per hectare.

(c) *The deltaic area of the Chao Phya river (Thailand)*

The major water control system in this area where local rainfall is not adequate for rice growing, is primarily focussed on supplementary irrigation and the control and spreading of flood water. This has two advantages for agriculture:

(a) The flood water is distributed over a considerable area thus reducing that portion which is deeply flooded.

(b) Shortage of water caused by insufficient or irrigular rainfall can be alleviated by supplementary irrigation. Damage by drought occurs frequently in this deltaic area, either during the time of land preparation or toward the end of the growing season.

In the Chao Phya delta, four methods of water control in the field are practised:

(a) Water control in the floating rice areas. In the so-called Central Plain of Thailand there are two depressions which are flooded each year, normally to a depth of 3 to 4 metres. In these areas floating rice is grown without any field water control. Hydrologic conditions especially during the early flood season are controlled by diverting water into different channels as well as flood spreading.

(b) Most of the existing irrigation projects do not have farm ditches; irrigation is done by flooding. Water flows from plots adjacent to irrigation canals to the other plots located away from the canals.

(c) The horticultural centre along the Damnern Saduak Canal. In this area, heavy soils occur and hydrologic conditions are unfavourable. In spite of the natural difficulties the farmers, through careful management, succeed in controlling supply and drainage as required by horticultural crops.

Every family holding is a small polder protected by an encircling dike. The internal water level is controlled by a sluice or pump. In the polders an intensive system of ditches with a depth of about 1.5 to 2 m serves both drainage and irrigation. The water level in the ditches is kept about 1 m below the land surface. Irrigation is effected by manual labour or by boat mounted motor driven pumps moving through the ditches and sprinkling irrigation water on the adjacent plots. The maintenance of the whole system, including the encircling dike is done by the individual farmers. This entails considerable use of labour and land, but the degree of water control meets the requirements of horticulture.

A more or less similar system can be seen in the orchard area in Dhonburi opposite Bangkok.

(d) The area of the "dike and ditches scheme" near Chainat. This scheme aims at adequate water supply for rice and second crops. For this purpose the major irrigation system is supplemented with laterals and with irrigation ditches spaced at regular intervals of 400 m. These ditches are partly excavated and partly raised above ground elevation so that irrigation water can be supplied with the required head.

If combined with adequate drainage facilities, the implementation of this scheme will make nearly perfect water control in the field possible. The whole system is constructed, supervised and maintained by the state with the exception of the farm irrigation ditches which are the farmers' concern.

(d) *The deltaic area of the Kiso river (Nobi Plain; Japan)*

In this area conditions of water control in the field are adequate for rice production. This is the result of a major irrigation and drainage system providing facilities for almost the entire area.

Since the land is divided into numerous scattered small and irregular parcels, the system of water control is extensive and complicated. There are several parcels in between the irrigation and drainage ditches through which the water had to flow from one parcel to another. This is done by cutting the field dikes. The height of these low dikes is 20 to 40 cm. Because irrigation water is readily available, no measuring devices in the field have been installed.

In general the irrigation facilities have been developed to a much greater extent than the drainage facilities. The latter are so poor that only rice can be grown unless the farmers provide their own additional drainage facilities.

Many improvement schemes based on modern concepts of water control are now being implemented in connection with land consolidation. In these

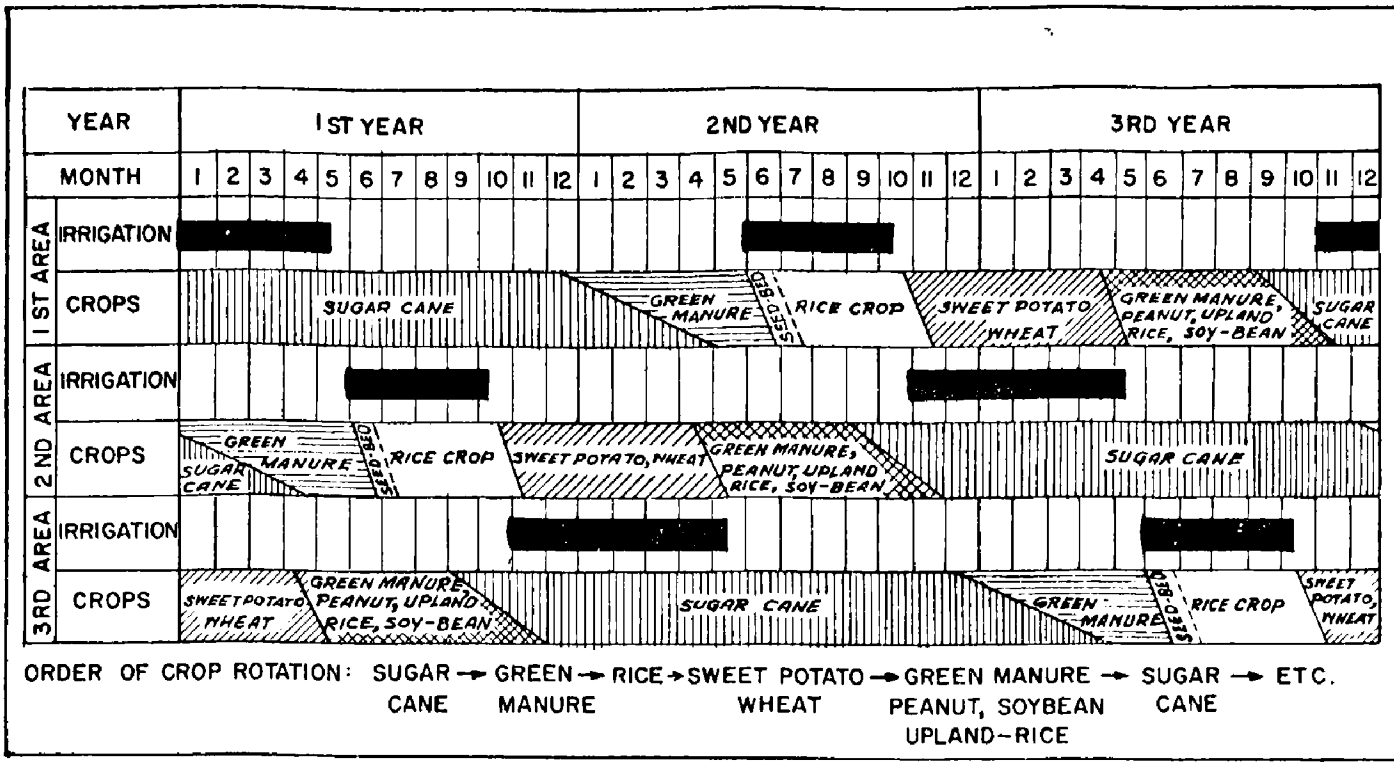


Figure 16. STANDARD DIAGRAM OF 3-YEAR CROP ROTATION AND IRRIGATION SEQUENCE

Intensive agriculture with maximum yields requires perfect water control in the field. Progress towards the stage of perfection is necessarily a step-by-step development. All stages of progress can be observed in the countries visited by the Mission.

The following stages of development of water control in the field were observed by the mission:

1. Natural conditions with no provision for water control, with the yields depending entirely on the rain and flood.
2. The conservation of rain water in the field with low field dikes, ensuring some storage.
3. Irrigation to supplement rainfall during wet season. No farm ditches are provided, irrigation is done by flooding.
4. Irrigation with partial or inadequate drainage facilities.
5. Irrigation cum drainage system, where the same ditch is used for both irrigation and drainage.
6. Adequate irrigation and drainage facilities providing for year round irrigation where irrigation and drainage ditches are separated.

2.4 RURAL STRUCTURE

This section deals with the present farm structure, parcelling and fragmentation of farm land, labour structure, communications, domestic water supply and electricity.

2.4.1 Farm structure

In all the countries visited, the agrarian structure is characterized by family farms. Each family runs a small holding. In general, the more favourable soil conditions are, the smaller is the relative size of the holding. With the increase of rural population, the size of the farm becomes smaller and smaller with fragmentation. In the lower part of the Nobi delta, about 70 per cent of the holdings are smaller than 1 ha. and of this, 40 per cent are smaller than 0.5 ha. In the upper part, where the farmers have "dry" farm land, the average size of holding is about 1.3 ha. In the Cho Shui delta, the average size of the holdings is about the same as in the Nobi, but agriculture is practised more intensively. In the Sundarbans delta, the average size is about 1.5 ha. and in the Chao Phya and Irrawaddy 3-5 ha.

The farm buildings are mostly situated in and around the villages on the natural levees. In the Sundarbans, they are grouped in small clusters on the islands. In the Chao Phya, farm houses are mostly along the rivers or canals close to the parcels.

2.4.2 Parcelling and fragmentation of farm land

In general it is felt that parcels in the various deltas visited are small and scattered and are adequate or economical agriculture. The disadvantages of bad parcelling are greater as agriculture becomes more mechanized and less labour is available. Especially in the non-consolidated parts of the Nobi delta, the parcels are very small and have very irregular shape. Also many farmers have about 10 to 15 parcels scattered over the field. In the Cho Shui delta the situation is about the same but the parcels are not as irregularly shaped. Parcels with the most regular form and of larger size are found in the Chao Phya delta. There the percentage of farmers having scattered parcels is also low. It was difficult to obtain data on fragmentation. However, the bad situation is demonstrated by the result of an inquiry conducted in Burma: in the Pegu village 37 per cent of the farmers interviewed have more than 30 scattered parcels and only 5 per cent have less than 5 parcels.

2.4.3 Labour structure

In the Nobi delta, about 37 per cent of the available labour is engaged in agriculture, 60 per cent of which practise part-time farming. The situation is attributable to the following:

(1) The size of holdings is too small for full-time farming.
(2) In spite of high rice prices, farmers' incomes from agriculture are insufficient to maintain a good living standard because of the small size of holdings.
(3) There are good opportunities for other employment as the area is situated in the vicinity of highly industrialized zones.

The result of this part-time farming practice is that agriculture does not get the attention which is needed for intensive production.

In the Cho Shui delta, about 70 per cent of the available labour is engaged in agriculture. This is because in this delta, with 2-5 crops a year and little mechanization, much labour is required throughout the year.

In the Sundarbans, most of the population are engaged in agriculture and their incomes are very low. Except during the transplanting and harvest periods, there is excess of labour. Possibilities for additional work do not exist except in the vicinity of towns and big villages or in the fishing industry. This unemployed labour is sometimes utilized for the reconstruction of embankments in the area.

In the Irrawaddy and Chao Phya deltas, where holdings are bigger, there are more opportunities for work during the year, especially during transplanting and harvest periods. Yet because only one crop is grown during the year, farmers still have about 4 months of leisure time after servicing their implements and repairing their homes. In some parts of the Irrawaddy delta it is sometimes difficult to get the labour needed for transplanting and harvesting, especially in the vicinity of villages where small-scale industries exist.

In this connexion, mention should also be made of the density of population in the deltas. It is regretted that due to limited time the Mission was not able to collect up-to-date population records for the deltas visited. However, the records of 8 or 9 years ago show very clearly that the population density in each delta was much higher than the average for the whole country. In the Chao Phya delta the density was about 1.3 to 1.5 times that of the whole country, in the Irrawaddy about 1.8 times, the Sundarbans about 2.5 times and in the Nobi as high as 6.7 times.

2.4.4 Communications

Communications between farms and between farm and village are a very important factor in agricultural production because they make possible the transport of farm products to the market and vice-versa, facilitate the movement of labour, equipment and goods between farm house and field, open up rural areas and enable farmers to learn and see more of modern farming methods and practice at other farms.

Communications at the farm level vary greatly in the deltas. In the Nobi and Cho Shui deltas communications are based on roads whereas in the other deltas the greater part of transportation is by canal.

In the Nobi and Cho Shui deltas good road systems connect the agricultural areas with villages and towns. Although internal communications within the farm units are still insufficient and in some places have to be supplemented by boats, under current improvement schemes, farm roads are receiving full attention and many completed schemes average about 100 to 200 m of road length per hectare of land.

The road systems at the farm level are divided into three categories:

(1) First category roads leading from the fields to villages. Most of these roads are metalled or gravelled.
(2) Second category roads are farm roads between fields with a width at the crest of about 3-5 m. and are metalled, gravelled or constructed of local materials.
(3) Third category roads, or farmers paths are within the fields connecting the farmers' parcels, usually with a local soil surface and a width at the crest of 1 to 2 m.

The highways connecting towns and cities and the feeder roads between villages and connecting villages to towns are equally important for the development of rural areas. In the Nobi and Cho Shui deltas, more highways and feeder roads will be necessary to keep pace with the rapid development. In the other deltas the few existing highways and feeder roads are far from adequate to open up the rural areas.

In the Chao Phya, Irrawaddy and Sundarbans deltas, the land is interlaced with rivers and canals which provide almost the only communication facilities. Where the farm houses are built along rivers, creeks or canals, the farmers reach their parcels of land by walking on the field dykes or directly over the field when this is possible. In areas where more canals exist, like the lower part of the Chao Phya delta, communication with villages and towns and outlying areas is by motor boat, but internal communications follow the field dykes. Farmers bring their produce to the markets or towns in large sampans or barges drawn by tugs.

2.4.5 DOMESTIC WATER SUPPLY AND ELECTRICITY

In the Nobi delta, most of the farm houses are connected to a public water supply system. The majority of those not served by public water supply systems use groundwater.

In the other deltas, common sources of water supply are:

(1) rainwater stored in tanks.
(2) groundwater from open wells lifted by buckets or small hand pumps (public or private).
(3) central water supply stations from which water is distributed by vehicles to the houses.
(4) river and canal water.
(5) pond water.

Except in the Nobi and Cho Shui deltas the farm houses do not have electricity. They are lit by kerosene lamps and agricultural work is generally performed manually or by draught animals. After the Second World War gasoline engines have come to play a greater role in the farmers' lives, mainly in driving pumps, threshing and husking machines.

2.5 AGRICULTURE

2.5.1 CROPS AND PRODUCTION

Throughout the six deltas visited the main crop is rice. In the Nobi and Cho Shui deltas, because of population pressure, double or multiple cropping has become a necessity. In the Nobi, where the climate is too cold for rice during the winter season, the rice crop follows wheat, barley or rape seed. In the Cho Shui, double cropping of rice is possible and in the northern half double cropping is further followed by short duration crops or vegetables. With the development of the water resources, in the southern half, where the three-year rotation irrigation system is practised, rice is fast taking the place of sugar cane.

The Nobi delta used to be one of the most advanced agricultural areas in Japan, where most of the farmers were graduates of agricultural schools. This is no longer so as industry in the delta (principally at Nagoya) is growing at a rapid pace and employment in factories is more attractive than farming. Farmers increasingly seek employment in industry and tend their farms only part-time or leave them entirely to the care of their wives. Land cultivation and harvesting by contractors is appearing. Farmers are also laying more stress on vegetables, which are cash crops. The contribution of rice from the Nobi delta to total national production has declined sharply during the last 15 years.

On the other hand, in China: Taiwan, the Cho Shui delta has now become the major agricultural area, accounting for about 24 per cent of the total rice production in Taiwan, with a yield per hectare some 13 per cent higher than the average for the island. Table 3 gives the areas sown to rice, total production and yield in the Cho Shui delta compared with figures for the whole island. Although rice yield per crop is not very attractive (brown rice=2.5 to 3.2 tons per hectare or paddy 3.2 tons to 4 tons), if the total production by double cropping is divided by actual land area sown to rice, the yield is close to 5 tons of brown rice or 6.5 tons of paddy per hectare.

TABLE 3. RICE AREA, PRODUCTION AND YIELD IN THE CHO SHUI DELTA DURING 1961

Division	Rice season	Area hectares	% of* total	Production ton	% of* total	Average yield (husked or brown rice) kg/ha	Index*
Changhua	1st crop	51,847	15.3	168,446	17.2	3,249	112.2
Prefecture	2nd crop	53,170	12.0	134,728	13.0	2,534	108.7
(Northern half	Total	105,017	13.4	303,174	15.0	2,887	112.0
of the delta)		(105,503)	(14.0)[1]	(290,704)[1]	(15.6)	(2,770)	(111.8)
Yunlin	1st crop	18,155	5.4	57,122	5.8	3,146	108.6
Prefecture	2nd crop	44,540	10.0	128,945	12.5	2,895	124.1
(Southern	Total	62,695	8.0	186,067	9.2	2,968	115.2
half of the delta)		(56,449)	(7.5)	(157,188)	(8.4)	(2,790)	(112.6)
Whole of Cho	1st crop	70,002	19.7	225,568	23.0	3,222	111.2
Sui Delta	2nd crop	97,710	22.0	263,673	25.5	2,698	115.7
	Total	167,712	21.4	489,241	24.2	2,917	113.2
		(161,952)	(21.5)	(447,892)	(24.0)	(2,765)	(111.6)
Whole of	1st crop	339,047	100	981,966	100	2,896	100
Taiwan	2nd crop	443,463	100	1,034,310	100	2,332	100
	Total	782,510	100	2,016,275	100	2,577	100
		(752,133)	100	1,863,520	100	2,478	100

Note:
* Percentage or index for the whole of Taiwan during the respective crop seasons.
[1] Figures in brackets show 3-year average between 1958-1960. (Source: JCRR, Rice Review, No. 41; Oct. 1962).

Owing to the race between population and food production, the rate of increase of crop production in Taiwan is rising very sharply. With 1950 as 100, the production of various crops in 1960 were as follows:

Population	142.9
Rice	134.6
Sweet potatoes	134.0
Peanuts	180.7
Soybeans	430.8
Wheat	242.1
Vegetables	135.9
Bananas	91.5
Pineapples	350.0
Citrus	178.6

The above figures are for the whole of Taiwan. In the Cho Shui delta, which is an important agricultural area, the figures would be higher and crop production is still on an upward trend.

In the four tropical deltas, namely, Chao Phya, Irrawaddy, Sundarbans and Mekong, single rice cropping is still predominant. Shortage of water during the dry season makes multiple cropping difficult. The deep-rooted traditional methods of agriculture coupled with a lack of government guidance and incentives make it difficult for farmers to adopt modern improvements.

The Chao Phya and Irrawaddy deltas, well known as the rice bowl of their respective countries, each produces about 40 per cent of the national total. While the rice yield per hectare in the Irrawaddy delta is showing a slight increase, the yield in the Chao Phya stagnates at a low level. Taking the pre-war high-yield period of 1920 to 1926 as 100, the average yield during 1947-1955 was 84 for the central plain of Thailand, which includes the delta. This figure is still higher than those obtaining in the other parts of the country (national average 75). It is felt that this decrease was probably brought about by the rapid expansion of cultivated area. After 1920, the acreage brought under cultivation in the central plain increased about 1.7 times. Rice cultivation was introduced in areas where water supply conditions were not satisfactory, resulting in very low yields. It is expected that with the completion of irrigation facilities now under construction, a substantial increase in both yields and production may be achieved. Apart from rice, some vegetables, pulses, groundnuts, etc., are grown along the river banks during the dry season but the total production is rather insignificant. The large vegetable area along the Damnern Saduak canal and the citrus orchards along the Bhasi Chareon canal are two areas in the delta worth mentioning.

In the Irrawaddy delta, though the yield per hectare is increasing, total production is still below the pre-war level. This is because the cultivated area has diminished due to shortage of labour. One of the reasons for increased yield may be the concentration of cultivation in areas with better soil and the abandonment of areas with poor soil. During the dry season only farmers living along the river banks grow maize and vegetables on the river bed.

Table 4 below gives the yields per hectare of paddy (not white rice) in different countries. These are only country averages and not the yields in the deltas, which are usually higher.

TABLE 4. AVERAGE YIELD OF PADDY PER HECTARE IN DIFFERENT COUNTRIES

Country	Yield Kg/ha. (1959-60)
Spain	6,104
Italy	5,238
Japan	4,767
China: Taiwan	4,607[a]
Burma	1,681
Pakistan	1,478
India	1,362
Thailand	1,354
World	1,899

Note [a] is derived from:

$$\frac{\text{Total production 2,436,100 tons}}{\text{Total area of registered paddy land 528,762 ha.}} = 4,607 \text{ Kg/ha.}$$

528,762 comes from 332,382 ha. (double cropping fields) + 16,054 ha. (spring single crop fields) + 180,326 ha. (fall single crop fields)

Since some registered rice land was used in growing other crops, the areas sown to rice in 1959 were less than 528,762 ha. and thus the paddy yield should be higher than 4,607 kg/ha (H. T. Chang, JCRR, September 1962).

2.5.2 CROPPING TECHNIQUES

Agricultural productivity depends essentially on the harmonious application of farming techniques adapted to the soil and climate of the area. The technical level is in turn governed by many factors such as the cultural standard of the farmers, government action, stage of development of other industries, communications system, price of products, etc. The following paragraphs consider the application of farming techniques in the existing institutional context, taking rice as the main commodity as it is economically the most important product of the deltas visited.

Nobi delta

In the Nobi delta, three factors contribute to the high yield of rice, namely, plant breeding, heavy application of fertilizers and mechanization.

(i) *Plant breeding*. The present varieties of rice are the result of breeding in conjunction with the use of different chemical fertilizers. They are quite different from those of other countries but are still far from being the ideal type. In general, heavy application of fertilizers has induced the outbreak of plant diseases and pests, in addition to lodging. Varieties resistant to diseases, especially rice-blast and straw stiffness, are much sought after by the farmers. To prevent lodging, limitation of the culm length to some 80-90 cm is generally necessary, with consequent shortening of the panicle length to about 20 cm. In order to obtain and small garden tractors have rapidly taken the place of animal drawn ploughs. These machines are also used for transporting farm products to the market. After application of irrigation water and basic dressing of fertilizers, puddling is also carried out by the same tillers by changing the attachments. Weeding is usually done 3 to 4 times by rotary push-weeders in the early stages of growth and once later by hand. After 1950 it became possible to do all necessary weeding, including the control of barn-yard millet (Echinochloa crusgalli) the principal weed, with a single use of the rotary weeder and one application of 2.4D (2.4 — dichloro-phenoxy-acetic acid) at 400-500 grammes per ha, 30 days after transplanting, resulting in considerable saving in labour. Rcently, p.c.p. (pentachlorphenol) and other chemicals have proved effective in controlling barn-yard millet, but as it is very harmful to fish its use is somewhat limited.

The major diseases in the Nobi delta are rice blast (piricularia oryzae), helminthosporium leaf spot (ophiobolus miyabeanus) bacterial leaf blight (bacterium oryzae) and sheath spot (hypochnus sasakii). The major harmful insects are rice stem borer (chilo simplex and Schoenobius incertellus) and brown plant hopper (delphacodes striatellus). For disease and pest control, shoulder-type power dusters are widely used. For effective control of disease and pests, systematic operation on a large scale is, of course, necessary. This includes fore-casting outbreaks of contagious diseases and pests, provision of power-operated sprayers and dusters with an adequate supply of chemicals.

Harvesting time in the delta is around 40-50 days after heading. Reaping is mostly done by hand-sickles. Bundles of the reaped rice are stacked on the ground in dry fields for drying; where the field is wet, these are stacked on bamboo racks. Power threshers and power huskers are generally used and these are operated by family members.

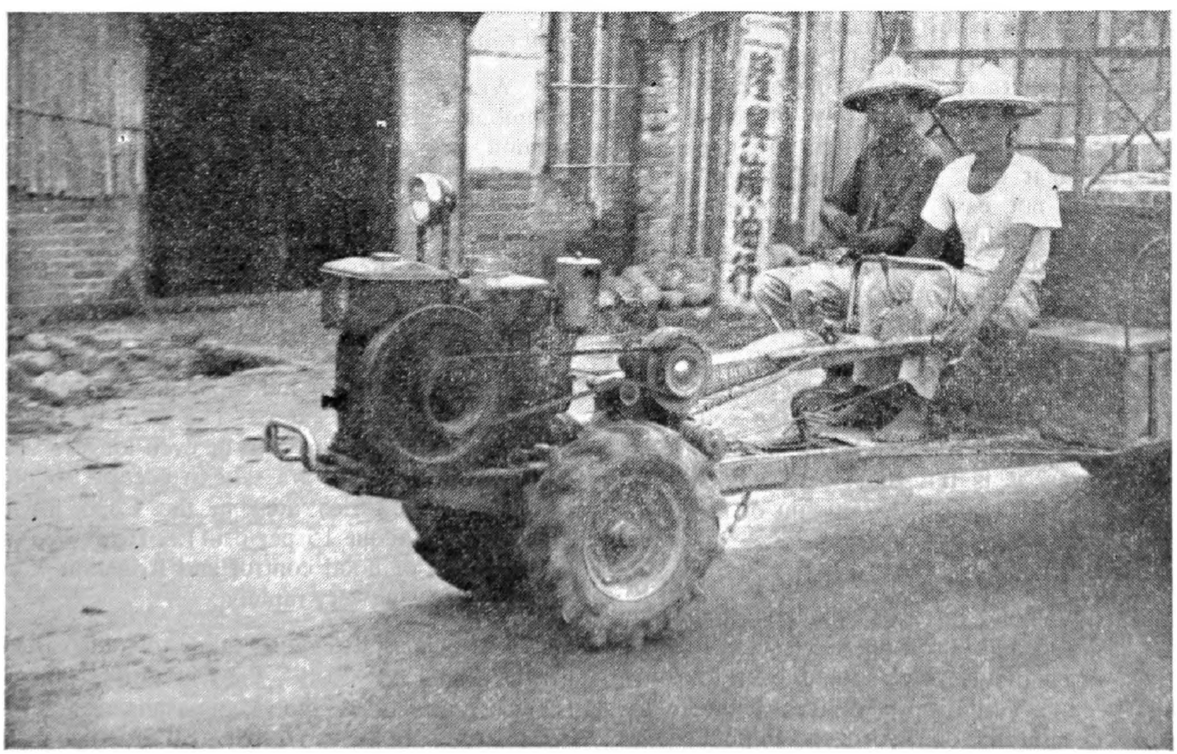
With the various technical improvements mentioned above, 130-140 man-days per ha are now adequate for rice cultivation as against 250 man-days in the period just after the war. Moreover, the margin between bumper and failure of crops has been narrowed down considerably, except in the case of natural catastrophes like typhoons and floods. Since 1955, the country as a whole has had 7 bumper crops in succession.

Cho Shui delta

(i) *Plant breeding*

Rice-growing techniques as practised in the Cho Shui delta (or in Taiwan as a whole) offer a good example for other tropical countries to follow, especially from the point of view of rice varieties used and methods of multiple-cropping.

Rice varieties grown in Taiwan are "Ponlai" rice which is sub-tropical Japonica, and "Chailai" rice which is indigenous Indica (see Appendix I—Brief report on rice). These two varieties are grown at a ratio of 65:35. Selection work has



A power tiller as shown in this picture is commonly used in Japan and China (Taiwan). It can be used to pull a trailer carrying farm products to the market. With attachments, it can also be used for ploughing, harrowing, ground levelling, pumping, etc.

high yields, therefore, tillering (branching) is aimed at. Chemical fertilizers, mainly nitrogenous types, are used to increase the number of effective tillers. The group of varieties with a high response to fertilizers is known as the "panicle-number" type. Where soil-climate conditions are not adequate to produce a large number of tillers through the use of fertilizers, a "panicle weight" type, which has a rather longer culm with compact heavy panicles, is grown. Though this type is rather out-moded, it is still grown in some areas. Most of the glutinous rice and rice used for fermentation purposes belongs to this type.

In the Nobi delta, the "panicle-number" type predominates; this also includes the "Senbon" (thousand tillers) variety, the best of this type originating in Aichi Prefecture, which covers the south-eastern part of the delta.

(ii) *Fertilizers.* Farmers in Japan pay great attention to the application of fertilizers to paddy fields. Three nutrient elements (N, P, K) are applied without exception. The amount of fertilizers used has increased rapidly since the second World War, as can be seen from table 5 below.

TABLE 5. AMOUNT OF FERTILIZERS APPLIED TO PADDY FIELDS IN JAPAN IN KILOGRAMMES PER HECTARE

	N		P_2O_5		K_2O	
	1954	1957	1954	1957	1954	1957
Nutrient element	57	68	38	50	44	59
Fertilizer[a]	278	317	255	333	89	119

[a] Converted from nutrient element into fertilizing materials, e.g. ammonium sulphate for N, calcium superphosphate for P_2O_6 and potassium chloride for K_2O_6.

Though rice does not show a high response in yield to phosphorus and potassium, as seen in table 6 below, application of these two elements is practised to keep the soil balance and for the crops that follow rice.

TABLE 6. TESTING RECORDS SHOWING THE RESPONSE OF DIFFERENT CROPS TO THREE NUTRIENT ELEMENTS (N, P, K) IN JAPAN

Crop	No Fertilizer	Three elements	No Nitrogen	No Phosphate	No Potassium
Paddy rice	70	100	75	97	93
Wheat & barley	35	100	47	68	71
Sweet potato	67	100	93	84	63
White potato	37	100	47	68	70

Notes: Results of field tests as national average.

Nitrogenous fertilizers, which have a great effect on the growth and yield of rice, represent the most important type. The absorption rate of rice plants for this type of fertilizer is generally from 40 to 50 per cent. In the delta, application of fertilizers is generally divided into two stages, basic and top dressing, the latter being further divided into two timings — during the effective tillering stage and during the formation of young panicles. The ratio of basic to top dressing is roughly 6.5 to 3.5. In this connexion, experience recommends that the basic dressing should be mixed well with the soil in the full tillage layer to prevent loss of nitrogen through denitrification. In sandy soils, split doses of nitrogen fertilizer are especially necessary. It should be mentioned also that "Hogoe" (panicle fertilizer) is usually applied during the panicle formation stage, about 25 days before heading, to promote the growth of panicles and increase carbon assimilation. The amount of this fertilizer used is normally under 75 kg of ammonium sulphate equivalent per hectare. The other two elements are used as a basic dressing only. Lately, synthetic fertilizers with the three elements in varying proportions are replacing fertilizers with a single element, like ammonium sulphate. In the Nobi delta there is a fairly large area of so-called "Akiochi" or degraded paddy fields in which the soils are deficient in active iron and manganese. In these fields, the roots of the rice plants are damaged due to the generation of hydrogen sulphide in the reduction layer, especially during the summer when the soil temperature is high. Such fields can be rejuvenated by a top dressing of iron-bearing clay (red clay) or the application of other ferriferous substances. It is also apparent that the use of fertilizers with SO_4 radicals, which aid the generation of H_2S, should be avoided. Thus, after the Second World War there has been a substantial increase in the production of fertilizers without the SO_4 radical, such as urea, calcium cyanamide, ammonium chloride, potassium chloride and fused phosphatic fertilizers. The use of these fertilizers on "Akiochi" fields has given remarkable results. To increase the efficiency of the nitrogen, lime silicate is used, also with good results. Organic and farm manure, which at one time were the principal fertilizers and the use of which was encouraged in order to save foreign exchange and reduce farm costs, have been neglected lately. This is partly due to mechanization, which means a decrease in farm animals, and partly because the high price of rice enables farmers to buy chemical fertilizers.

To reduce the "Akiochi" areas, limit typhoon damage to the crop, diversify the cropping scheme and overcome the labour shortage, early seasonal cultivation was recommended after the war. Under this method, transplanting of seedlings comes 40 to 50 days ahead of the usual planting time. The seedlings are raised from the nursery bed under the protective cover of oiled paper or vinyl (or polyethylene) sheets. Harvesting can be in August or early September. The development of vinyl and polyethylene sheets has resulted in a change in cultivation techniques both for horticulture and rice-growing.

(iii) *Mechanization:* Complete mechanization of rice growing has not yet been attained in Japan. With the exception of transplanting and harvesting, however, operations such as ploughing, harrowing, weeding, spraying or dusting, threshing and husking are mostly mechanized. Power-driven cultivators been done only on the former variety, which has a better response to the application of fertilizers. Hybridization work between the Chailai varieties was started in 1950 and the first result, "Taichung Chailai No. 1", was released in 1956. Formerly the difference in yield between these two types was 300-500 kg/ha in brown rice or 20-30 per cent per ha. Since the Second World War, the yield of Chailai rice has become higher and the difference has been narrowed down considerably. In 1960, the difference in yield by the island average is only 243 kg for the first season and 157 kg for the second season, i.e. the yield of Chailai is 91 per cent and 94 per cent of ponlai for the first and second growing seasons respectively. It must be noted here, however, that double rice cropping is not always on the same field. In Changhwa Prefecture in the northern half of the delta, where 99 per cent of the paddy field is devoted to double cropping as against 22 per cent in the southern half, the acreage given to Chailai is almost twice that for Ponlai in the first season and slightly greater in the second season. The ratio of yield between both types of rice is no longer significant here, showing 94% and 99% in respective seasons. The recent behaviour of Chailai rice has been quite encouraging for the improvement of tropical rice varieties.

(ii) *Application of fertilizers*

Maintenance of soil fertility poses one of the most difficult problems in multiple cropping. The area south of the Shiro river, the present mainstream of the Cho Shui, was at one time the most important sugar cane centre of Taiwan. Besides land rotation between rice and sugar cane, relay interplanting of pulses and vegetables simultaneously between rows of young cane is recommended by sugar cane planters to compensate for decreasing sugar cane acreage. However, under this system it is not easy to select long-term crop programming in relation to soil fertility. In the application of fertilizers, the quantity per ha per year may outstrip that in the Nobi delta because multiple cropping is practised, and the proportion of organic fertilizers is larger than in Japan. Rice straw, which is used as cattle feed and the raw-material in paper manufacture, has started to return to the soil more than before owing to the recent boom in mushroom culture. However, it is felt that there will still be some exhaustion of the soil if the amount of fertilizers is not increased.

Note should be taken of the recent outbreak of "burnt root" or "choke disease" which is similar to "Akagare" in Japan and "bronzing" in Ceylon. In the previous year, this disease had spread over to some 8,000 ha in the Yunlin prefecture. Though no evidence of generation of hydrogen sulphide was reported anywhere, serious damage was caused to the roots in the fields near Huwei, where almost total crop failure was reported. In Japan, this disease is observed usually in water-logged fields with an abundance of humus. The fundamental cause of the disease is considered to be the low potassium/nitrogen ratio in the plant (potassium deficiency). This, however, cannot be taken as a sure indication of soil deterioration. Further study of this disease will be very important, not only for direct controlling but also for proper cropping scheme.

(iii) *Mechanization*

Despite multiple cropping, mechanization of farming operations is not carried out to the same extent as in the Nobi delta. Though small ploughing machines are used increasingly, some threshing is still manual.

Other deltaic areas

No notable difference is observed in rice cropping techniques between the Chao Phya, Irrawaddy and Sundarbans deltas. Despite the very primitive method of culture, direct sowing by broadcasting, which is widely seen in the hilly areas, is practised on a limited acreage in the deltas. The possibility of direct sowing is limited to the period between the pre-monsoon shower, which brings enough moisture for germination, and the starting point of deep flooding which destroys young seedlings. To avoid the possibility of damage to young seedlings caused by a sudden increase in flood water depth, the transplanting method is generally adopted. Usually nursery beds are prepared on a plot with comparatively high elevation and close to watering facilities. After transplanting, weeding is done once or twice before the harvest or not at all. Application of fertilizers is negligible.

Winter rice, having a long growing period, is commonly grown in these deltas. Short duration autumn rice does not generally lend itself to local adaptation because the harvest season comes before the end of the rainy season which renders reaping inconvenient. Spring rice is grown on a very limited acreage. The present variety has been adopted after centuries of natural selection. A good example of adaptability (natural selection) is the floating rice, which is one kind of winter rice capable of elongating inter-node by 5 cm or more per day according to the rate of rising flood water. The stem of this variety grows up to a length of 5 m or even longer. Floating and deep water rices are said to occupy about 35-40 per cent of the rice area in the Chao Phya delta (floating rice about 15 per cent). However, with the development of flood control and irrigation work, this area is decreasing very rapidly.

In the coastal regions, saline-tolerant varieties are grown, thus, "SR-26-B", bred in Orissa State, India, is being grown at the Manmasanagore seed farm (southernmost part of West Bengal) for rice cultivation in the Sundarbans. As it is difficult to diffuse pure seeds for vast areas, many off-types including red-rice are found in many fields in the areas visited.

Some power cultivators are seen in the outskirts of Bangkok in the Chao Phya delta. Small portable motor pumps mounted on a little boat are used in some areas in the delta for spraying water from the ditches to the vegetable beds on both sides. Mechanization and also fertilization seem to be extending to rice culture from these intensive vegetable growing areas.

In the Irrawaddy delta, government tractor centres have been established recently in some regions. The tractors are used mainly for winter crops. Near Henzada, for example, they are used in the river bed after the retreat of floods, for maize, pulses, vegetables, etc. They are time-saving for land preparation and for seeding in places where there is enough soil moisture for germination and promotion of plant growth. It is expected that the same trend will develop in the near future in Chao Phya delta.

In the tropical deltas, simple implements are generally used, such as cattle-drawn plough, hoe, hand sickle and some other bamboo mats and containers etc. Land is tilled at shallow depth by draught animals. As a step towards improvement of rice culture in these areas, use of power cultivators, improved seeds and fertilizers should come simultaneously with the provision of irrigation and drainage facilities.

Pedal threshers are seen at the experimental station in Myaungmya in Burma and some other places in the Chao Phya delta, but for the deltas as a whole threshing is done mostly by trampling by cattle feet. The beating method is also adopted in some areas. Since rice is marketed as paddy (unhusked rice) growers have not as much opportunity to observe the quality of their grain (husked rice) before selling, unlike the farmers in the Nobi delta. This is one of the reasons why they are not too keen on the rice quality.

Ingenious devices or techniques used in some of the deltas invented by the farmers through long experience are worth mentioning (no matter how minor they are). In Taiwan, paddy is stored in vessels made of a bamboo frame plastered with mud in the form of a big jar; the curved surface serves to prevent rats from climbing in. In Burma, farmers pile a high bamboo turret for effective winnowing of threshed paddy. In Thailand and some other deltas, rice bundles are spread out on a threshing bed to be trampled by buffaloes; after levelling, the bed is covered with a dilute paste of cattle dung to prevent cracking. This treatment is said to make it better than a concrete bed for keeping the quality of the rice grains. In Japan, where the climate is not warm enough for the growth of young seedlings, farmers make use of the high specific heat of the standing water layer to protect seedlings from the cold air. For some two weeks, water depth in the nursery is kept at a high level at night and low level during the day. The modern nursery with oiled paper covering for protection, expanded by the governmental extension service had been developed by a local experienced farmer.

2.5.3 Agricultural institutions

Most of the farmers in the Chao Phya, Irrawaddy and Sundarbans deltas lack funds not only for purposes of rice cultivation but also for subsistence between harvests. Government measures are inadequate to solve this problem and most cultivators are dependent on money-lenders, with all the malpractices associated with this sort of credit system. The result is that debts once contracted become difficult to liquidate and the cultivators are held in the tight grip of poverty, usury and debt. This calls for the establishment of a proper agricultural credit institution. Co-operatives, which provide a most suitable agency for channelling funds to agriculture, may with some modifications to suit local conditions provide the best solution to present credit and marketing problems. For example, credit may be dispensed on the basis of the repaying capacity of the borrower rather than on the security that his immovable property may provide.

The basic problem of co-operative credit is, of course, that of securing adequate operating funds. In these deltas, funds, so vitally necessary, can be secured only from government-sponsored institutions in the initial stages. Thus, the State Bank and Reserve Bank in India, the State Agricultural Bank in Burma, and the Agriculture Bank and Co-operative Bank in Thailand were the government institutions which started to support the co-operative credit system in these countries. In Burma, the government has supplied annually some 64.5 million Kyats in loans to agriculturists, which is equal to one-fifth of the estimated total seasonal requirements of the farmers in the country. The State Agriculture Board (SAB) supervised the loans made directly by the government under the Agricultural Loan Act (20 million Kyats in 1956/57) and through co-operative societies (15 million Kyats), in addition to granting loans to village banks and co-operative societies in the villages (8.5 and 10.5 million Kyats respectively). While the record of repayment of direct government loans has been poor, repayments of SAB loans have generally been prompt. This can largely be attributed to the principle of collective responsibility of the village banks and co-operative societies for the loans made through them. Table 7 below shows the sources of loan in a survey of 1,470 households in 16 villages in three districts of the Irrawaddy delta in 1960/61.

Table 7. Sources of loan in three districts in the Irrawaddy delta in 1960/61

Source	*Rate of interest*	*Percentage*
Government loans	6.25% per annum	24.3%
SAB and village banks	12.5% per annum	8.4%
Money-lender	36% per annum (3% per Mensem)	20.4
Money-lender	72%	45.8
Money-lender	above 100%	1.1

The activities of co-operatives in marketing products in Burma seem to be more progressive than those observed in Thailand and other countries visited. In Burma, the first rural co-operative societies were established as early as 1905. After the initiation of the five-year co-operative plan in 1951, the number of societies, now known as Agricultural Producers Co-operatives (Procos) rose rapidly and reached 6,334 in mid-1955. Despite the shortage of trained personnel and local difficulties of various kinds, Procos now have 12 rice mills and a few other enterprises in operation. However, processing of agricultural products has so far been relatively limited.

In Thailand, some 114 paddy marketing societies have been established under the sponsorship of the Ministry of Co-operatives. Most of them have rice mills, but their operations have not always been satisfactory and the volume of business is limited due to the difficulty of competing with private millers. There are a few marketing societies for other agricultural products, but their total membership is not impressive.

In these three deltas as a whole, despite the recent progress made in this direction, the co-operative movement can hardly be said to have made any significant impact on the credit situation. In most cases, the co-operatives cover only a minor part of the rural population and meet only a small proportion of the credit needs of cultivators. Moreover, their reliance on ownership rather than the repaying capacity of the borrower as the criterion of credit-worthiness, has tended to keep co-operative credit beyond the reach of the majority of cultivators due to the small holding guarantee they are able to provide. Apart from dispensing credit, other activities normally dealt with by co-operatives such as farm production, purchasing, welfare, guidance, reclamation and livestock, which are common in Japan and to a certain extent in China: Taiwan, can hardly be expected to get a start in these deltas in the near future.

No agricultural insurance system has yet been developed in any of the deltas except the Nobi. Livestock insurance, however, is available in the Cho Shui delta.

Land reform is one of the major incentives to farmers. In Thailand as a whole, the percentage of land-owning cultivators was fairly high, at 87.2 per cent by the 1953 census, but in the Chao Phya delta, it was less than 40 per cent. The Land Act of 1936 and 1955 fixed ownership of land for agriculture to 8 ha and provided ownership after three years of cultivation. The Act, together with the low rate of taxation on land, has promoted the expansion of cultivated acreage considerably in the country.

The Land Nationalization Act of Burma, passed in 1948 and modified in 1953, nationalized all lands owned by non-farmers, which were then divided into plots and rented out to cultivators. According to the Constitution of the Union, the State is the ultimate owner of all land in the country. Farmer-owners are allowed to retain up to 20 ha. of paddy land, or a lesser acreage of other categories of land. Up to the end of June 1957, about 468,000 ha. of the total 2.5 million ha. affected were nationalized and redistributed to a total of 143,000 cultivators. The average area of the redistributed plots is about 3.3 ha. The institutional agricultural credit referred to above was made available to the farmers at the same time to complement the land nationalization measures.

On the Indian side of the Sundarbans, most of the land (24 parganas)[1] used to belong to land-owners (zamindars). Lately these lands have been placed under the ownership of the State and the land tenure system is undergoing a radical change. However, the remoteness of some locations from the government office prevents the smooth operation of the policy and share-croppers suffering from high rates of tenure are still found in the Sundarbans.

Of the many problems facing the Governments of Burma, India, East Pakistan and Thailand three deserve special mention: ensuring that loans are properly used, that they are recovered and that the farmers obtain reasonable prices for agricultural products. In seeking a solution to these and other similar problems, the governments are showing keen interest in the co-ordination of credit facilities with marketing and agricultural extension services. However, this requiries a sufficient number of extension staff and the existence of a large number of co-operatives or other institutional arrangements to channel the necessary supplies to the cultivators and undertake marketing operations. Trained workers in the agricultural extension service, credit and marketing fields are still in short supply; co-operatives are financially weak and too few in number and their coverage of area and membership are limited.

The facilities for agricultural research in these deltas (Sundarbans, Irrawaddy, Chao Phya) have recently been improved to some extent. In Thailand, there are 8 rice experimental stations in the delta under the Rice Department, including one specially for floating rice. The establishment of a central research institute, the Bangkhen Experimental Station, is under discussion and research work is at present co-ordinated by the Rice Department, which has an engineering division in Bangkhen and a technical division in Bangkok. In Burma, a national agricultural institute has recently been established in Gyogon on the outskirts of Rangoon. This institute also supplements the work of the Hmawbi and Myaungmya rice stations in conjunction with fundamental studies on the Irrawaddy delta. The Agricultural Research Institute in Dacca, which was the central institute for the whole of Bengal State before the partition, is now being expanded. An institute under construction at Haringhata 60 km north of Calcutta will serve as a research centre for the Indian side of the delta. Facilities for animal husbandry and research work in this field are nearing completion at the same place. For the lower portion of the Ganges delta, the Chinsurah branch

[1] "Pargana" means district in west Bengal.

station has existed since before the partition. Practical trials are being carried out on seed multiplication farms in all the three deltas. Training of rural youth is also undertaken at some of the experimental stations.

Selection of rice varieties, culture improvement (trials with different fertilizers, timing and spacing of transplanting, pest and diseases control etc.), introduction of second crops and mechanization are the major fields being studied at most of the existing experimental stations. Though the staff and facilities available are not adequate for the vast areas which these stations are serving at present, the data accumulated, if applied by the farmers, could lead to much higher production in each of the deltas. It is a regrettable fact that because of the absence of adequate extension services and demonstration stations as well as the lack of incentives on the farmers' side, the new techniques and knowledge gained do not reach the farmers as they should.

In Thailand, a well-appointed service was started in 1950 with the establishment of the Extension Division in the Department of Agriculture through the assistance of FAO. Subsequently a four-year (1952-55) development plan was drawn up, including a proposal for the establishment of eight regional centres (later established with United States aid). These centres were intended for demonstration as well as training, although the extension activities relating to rice, animal husbandry and fisheries are being undertaken separately by the extension service divisions of the respective Departments. The number of officers is still relatively small, being 1 to every 13,000 farmers as against 1 to 1,500 in China: Taiwan and 1 to 650 in Japan. Most of these officers belong to the Departments of Agriculture and Rice. Their activities are severely handicapped by lack of transport and the imposition of other duties. Although extension services in inland fisheries are as yet not fully developed, demonstrations and instruction in fish-weeding in farm ponds and paddy fields to supplement farm income and provide an additional source of protein are yielding promising results, especially in the coastal areas of the delta. Since all six main departments of the Ministry of Agriculture operate field programmes of an extension nature more or less independently, a sectional approach with some duplication is inevitable. The field services are on a small scale and few of the field personnel are well trained in extension techniques or in agricultural subjects. As a measure to promoting a higher standard of extension work, a college-level Extension Training Department has recently been established at Kasetsart University. The rural community development programme, which is expected to have an important impact on agriculture, is directed by the Ministry of the Interior.

In Burma, extension services are provided by the Land and Rural Development Corporation under the Ministry of Agriculture, but the number of extension officers is very small. At present, each worker has to cover some two to three thousand acres of farm land. Development along the lines taken in Thailand is being promoted.

In China: Taiwan and Japan, the problems in the sphere of agricultural institutions are quite different. As regards to agricultural credit, institutions meet a far higher proportion of the credit needs of borrowers than in any other countries in the ECAFE region, and the difference between the interest rates charged by institutions and money-lenders etc. is not as large as in other countries. In both cases, especially in Japan, the most important problem is to provide sufficient medium and long-term loans at reasonable rates to encourage the undertaking of such projects as land consolidation, farm mechanization and land improvement. Furthermore, in both countries there is close co-ordination between agricultural credit and marketing. The major part of marketable agricultural surplus is collected through the farmers' associations, which are multiple-purpose co-operatives. These co-operatives also act as "agents" for the purchase of agricultural products from farmers. Agricultural extension services are well developed and organized to meet the farmers' needs. In short, it can be said that in both countries, the agricultural credit and marketing systems are well developed and adequately supported by well-organized extension services.

Part III

POSSIBILITIES AND PROBLEMS OF FURTHER DEVELOPMENT OF DELTAIC AREAS

3.1 SYNOPSIS

In planning flood control in deltaic areas, distinction should be made between the zones where either sea floods or river floods, or both, govern the extreme levels of water.

This part of the report discusses guiding principles and criteria for flood protection in the zones of deltaic areas where river or sea floods predominate and in the intermediate zone. It describes important points to which attention should be paid in case further development is undertaken and touches upon the controversy as to whether river embankment should be constructed or not. The principles of design and planning of river embankments and sea dikes are also explained, with regard to the alignment, desired outer and inner slopes, crest elevations, free board, strip of foreland in front of the embankments, etc.

Though many countries in the ECAFE region have tried to adapt themselves to "live with the floods", sooner or later the introduction or improvement of irrigation and drainage in their deltaic areas, as well as the development of infrastructure for industrialization and intensive agriculture, will take place and necessitate the development of flood control systems.

The implementation or improvement of a flood control system is limited by both the technical and economic aspects. Embankments should not be built so high that an extremely dangerous situation will occur in case of breaching. Also there must be harmony between the degree of flood protection and the stage of economic development of the deltaic areas. The paper recommends the drawing up of a master plan aiming at a perfect flood control scheme and the division of this plan into several stage of gradual development so as to provide adequate flood protection in harmony with the economic development of the areas at each stage. Where some hydraulic works in the deltas have already been carried out, the master scheme should retain the existing works and further step-by-step improvement should be a logical continuation of the system so far adopted. As an example, the paper chooses the Irrawaddy delta and proposes the outline for its further step by step development.

Turning from flood control to the planning of water utilization and soil improvement, the paper describes the guiding principles and criteria of water control (irrigation and drainage) in the fields, at the distributary end, for the creation of the most favourable conditions for plant growth. It explains that, from the agricultural point of view and for the better functioning of the system, a separate system of irrigation and drainage channels is preferred to a combined one, though it is more costly. In deltaic areas where the soil is mainly clay which is impervious when wet, deep drainage may be required. Especially for upland crops and horticulture, underground tile drains may be very useful. The paper goes on to discuss the problems of supply and control of water in the field and the possibilities for further development in the various deltas.

The discussion of major drainage and irrigation systems is also included. For drainage by gravity, it recommends that drainage sluices be located at or near a large water surface (pond), so as to minimize the loss of available head, and demonstrates that many smaller sluices distributed over a number of locations are preferable to only one large sluice. Drainage by pumping is considered feasible and advantageous for low-lying areas in the deltas. For a large area it is advisable not to concentrate the pumping capacity in one location but to subdivide the area into smaller units, each unit to be drained separately by pumping into the embanked channel connected to the river or drainage outfall. The use of reversible pumps would enable the same pumping station to serve dual purposes, namely to drain off the drainage water as well as to supply irrigation water.

Irrigation by gravity of the upper portions of a deltaic area can be accomplished by constructing head-works on the river from which irrigation canals take off. From the upper portions, the irrigation water may be conveyed to the lower portions. However difficulties are encountered when reaching the coastal areas where the ground slope is too small and the crisscrossing of river branches and numerous creeks poses a difficult and costly problem. Therefore the major irrigation facilities of the lower deltaic areas may have to be planned and designed independently of the upper deltaic areas, by pumping water from rivers or creeks into embanked canals. The intake of the system, however, must be located above the saline reach in the dry season. For cases where no suitable locations for the intake in the fresh water reach can be found, three solutions have been suggested: The first is to build tanks to collect rain water; the second is to create a fresh water basin by closing the river's mouth with sluice; and the third aims at pushing back the brackish water by diverting the discharges of the various river branches into a single channel during the dry season. Outlines for further development of the lower deltaic areas of the Chao Phya river (Thailand) are discussed here with a view to encouraging further investigations.

On soil improvement, the various measures are described, viz., fertilizing, management of catclay, desalinization, improvement of soil structure and combatment of soil reduction. What kind of soils and under what conditions should or should not rice straw be ploughed into them is also touched upon.

Promotion of formation of land (by raising the ground elevation) and improvement of land by sedimentation (spreading of fertile river silts on the land) as a means of soil improvement are also considered. Methods employed for fulfilling these purposes are discussed for the sedimentation of both inside land or backswamp and coastal tidal land.

When planning the hydraulic development of deltaic areas an economic feasibility study involving evaluation of benefits and costs often comes into play. Here, a word of caution is expressed, a reminder that considerations should also be given to the indirect benefits for the national economic as a whole. Most major hydraulic development works in deltaic areas have repurcussions in the various fields of human activity; apart from increasing agricultural production, they stimulate industry especially the establishment of processing plants, make possible the development of infrastructure and encourage the development of urbanization and the opening up of hinterlands.

Regarding rural development, four items, viz., infrastructure, land consolidation, farm management and agricultural institutions are discussed.

In the deltaic areas, farm produce is largely transported to the markets through small waterways or canals. Except in the Nobi and Cho Shui deltas, roads and railways are not well developed. Further development by constructing roads on flood and canal embankments should be urged. As regards electric power, it is shown that major industries in the countries are often located in the deltaic areas as these provide big cities, harbours and consumers' markets. Accordingly the provision of adequate electric power supply to the deltaic areas will play a very important role in the economic development of the country.

Dimensions of parcels in land consolidation projects greatly influence the lengths of roads, irrigation and drainage canals and thus have great bearing on the project cost. Where land consolidation is being implemented, it is advisable to combine with it irrigation, drainage, agricultural and land improvements as far as possible. It would be more difficult to carry out land consolidation after the improvements have been made and the farmers have already invested in their lands.

Crop schemes, mechanized farming and crop protection are discussed and highlighted under the main heading of farm management. Regarding agricultural institutions, the paper indicates that agricultural improvement and development will result from the combined efforts of both the government and the farmers. The government should be able to solve basic problems and provide essential services so that the farmers will find it to their advantages to accept advice, work harder and invest more (of their own or borrowed money) to increase production and efficiency. Most Asian farmers have suffered from a vicious cycle of low production, poverty, rack renting, usury debt resulting from high farm rents, exploitation by intermediaries and loss of initiative to increase production. Measures to counter-attack these evils are discussed.

Finally emphasis has been placed on intensifying agriculture. It is urged that the governments focus their attention on increasing agricultural production through improving agricultural techniques, diversification of crops, strengthening agricultural institutions, multicropping and crop rotation, land consolidation, mechanization, etc. It is pointed out, however, that the last three items will require further execution or extension of hydraulic development works; and, though these works should be developed in stages, the partial schemes should fit into a comprehensive master plan, which should be drawn prior to their execution.

3.2 PLANNING OF FLOOD CONTROL

3.2.1 Guiding principles and criteria of flood control

There exist various degrees of flood protection in the deltaic areas of the ECAFE region; while in some deltas arable lands have no flood protection at all, in other deltas, lands are being protected against floods with an average frequency of occurrence of once in 100 years (Chapter 2.2). Further industrial and agricultural development of the deltaic areas requires a higher degree of flood protection than at present and the question is how to achieve it. For many areas, the historical development of flood protection characterized by the construction of embankments or levees wherever this was found to be useful, without any planning for the area as a whole. Rise of water stages in other locations, hampering of drainage and excessive maintenance costs inevitably result from this practice.

This chapter deals with the planning of flood control in the deltaic areas of the region. First the guiding principles and criteria will be discussed, then the technical systems and finally the limitations when applying the various methods to the areas in the region. Distinction will be made between the zones where either the sea floods or the river floods or both types of floods govern the extreme levels. Keeping in view the need for basin-wise planning, attention will also be paid to the relationship between the flood control measures in all the various reaches of river in the basin.

a. *Flood protection where the river floods predominate*

In those deltaic areas where major embankments exist, further development of the flood control system leaves little room for alternative solutions. Typical examples are the deltaic areas of the Irrawaddy, the Cho Shui and the Nobi. A higher degree of flood protection can be obtained by the construction of flood detention reservoirs in the higher portions of the catchment area and by strengthening and increasing the height of the existing embankments. Reservoirs upstream are seldom planned for flood relief alone; but, when deciding on their purpose, allowance must be made among other things for flood protection benefit to the deltaic areas, such as the reduction of costs for increasing the height of the existing dikes, which would otherwise be necessary, and reduced costs of maintenance.

The necessity of river training comes to fore in the further development of the region when agriculture and industry have expanded and considerable capital investments have been made. This point has not yet received full attention but can no longer be overlooked. In those areas where embankments have already existed for many decades, the effect of the embanking on the flood stages and the elevation of the river bed is known by experience. In a long-term programming of flood protection works, these repercussions have to be taken into account, as also the costs of repair and maintenance resulting from the meandering of river course and subsequent bank erosion. This may lead to the necessity of river training when the flood protection reaches a certain degree of perfection. River training can be carried out by stages and steps, but the partial schemes must fit into an overall plan which can only be drawn up when the data mentioned in paragraph 1.4.3 becomes available.

The design frequencies for ascertaining the elevation of the crest of the dikes must be based on a comparison between the costs of increasing the heights and the resulting reduction of flood frequency and of destruction of houses, loss of crops, etc. Generally the design frequencies for the flood protection of agricultural areas should not exceed once in 10 to 50 years depending on the flood type. However, for densely populated areas with diversified and intensive agriculture and horticulture, design frequencies for 100 up to 500 year floods should be considered.

Various means of flood control and flood relief can be considered in those deltaic areas which are still at early stages of development and where no major embankments have yet been erected. In this case especially comprehensive planning and execution in judiciously selected stages is required to avoid the drawbacks experienced in deltaic areas where protection began many years ago. This is the case for the deltaic areas of the Mekong, Chao Phya and certain regions of the Irrawaddy. In the present stage, flood conditions in these areas are characterized by overbank storage, diversion of the flood waters into the various branches, use of the depressions as spill reservoirs, etc.

The first question to be decided upon is whether adequate flood protection can be achieved by measures in the deltaic area alone or whether the only feasible or a more economical solution is to be found in a combination of flood and erosion control works in the upper portion of the river basin and flood protection works in the deltaic area. This requires a study of the flood control possibilities in the entire river basin.

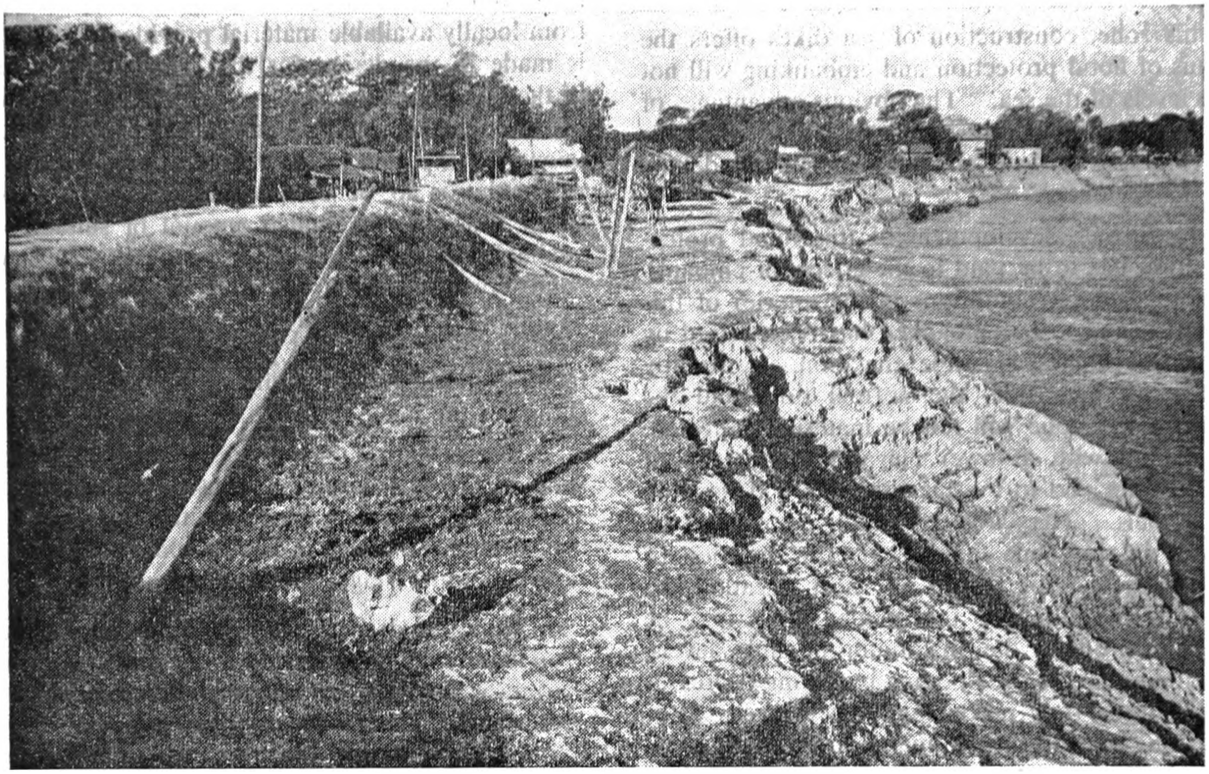
In this study, an important item is the prediction of the effects of embankments in the deltaic area on the flood stages and the position of the river bed. By eliminating the overbank storage and by confining the flow of the river between the embankments, the river regime is considerably modified. The history of the embanking of the Irrawaddy river provides an example of the long controversy that existed on these items and of the many contradictory recommendations either to remove the embankments or to strengthen and extend the existing system. Experience has shown that, at least in that area, no adverse effects have resulted from the diking of both banks of Irrawaddy river downstream of Henzada.

Today the repercussions of eliminating the flooding of deltaic areas can be predicted with sufficient accuracy, provided the basic data mentioned in paragraph 1.4.3 is available.

The rise of flood stages by eliminating the overbank storage can be estimated by means of hydraulic model tests. For floods of long duration, such as occur in the large deltaic areas in the region, this effect will be smaller than for floods of short duration.

It is not a general rule that embanking a river will necessarily entail an additional rise of the river bed. It depends on the hydrologic regime of the river (variation in discharges, duration of the flood flows, etc.) and on the sediment load whether the river bed will deepen or silt up. Channel capacity can be increased by river training; hence embanking has had two quite opposite effects on the position of the river bed in various deltaic areas all over the world.

The well-known principles of flood plain zoning can be applied in the gradual extension of the protected areas. This is one of the items of the master plan aiming at adequate flood protection of the entire area. Setting back the embankments some distance from the main channel will reduce the flood peaks and avoid the necessity of expensive river training in an early stage of the works.



Bank erosion of Irrawaddy river near Henzada

The alignment of the embankments is as important as the cross-section. Even for the so-called non-active rivers, the embankments should be in a position sufficiently retired from the main river channel. The objections raised by the people living near these channels against building embankments in a set back position behind the occupied areas need not to be discussed here. It is considered that the interests of the large areas to be protected should prevail and that an incorrect design of alignments cannot be corrected later by *ad hoc* measures.

When the river is very active and bank erosion by meandering occurs, the choice remains between building a new embankment in a retired position, thus abandoning some land outside the embankment, as against setting the embankment closer to the river and trying to safeguard the dike from sliding as a result of the under-mining action of the current. The former system, which can be seen along the banks of the Irrawaddy river, is justified if the value of the land is small and meandering remains within certain limits. If however intensively used land or towns or villages are being threatened, the embankments have to be protected. This can be done by a revetment or armouring of the submerged slope down to the river bed consisting of flexible elements such as fascine or bamboo mattresses with stones, woven wire baskets with stones (sausages) etc.

Usually, however, by the time that counter-measures are contemplated, the bank slopes have become so steep by erosion that such armouring would be difficult. Then measures to divert the current from the affected bank should be applied, such as spurs and groyns and closure of dangerous channels. These measures may provide temporary relief but they are seldom entirely successful, unless applied over a certain reach upstream of the attacked point. This is the beginning of river training. River training is often an essential measure when adequate flood protection by means of embankments is required. The costs of training a stream, however, are much higher than those for constructing the embankments. The water tightness of earthern embankments is often endangered by rodents such as crabs, rats and white ants. Several counter-measures are being applied or have been proposed, but none of them is entirely satisfactory either because of high costs or inefficiency. It is therefore necessary that major embankments are constantly watched during the flood period. This involves:

(a) The assignment to technicians of local offices for periodic inspection of designated reaches of the embankments during the floods;

(b) The establishment of a flood forecasting and a flood warning system;

(c) The availability of groups of labourers for each reach who can be mobilized at short notice;

(d) The availability of repair material for emergencies at regular intervals along the embankments, as well as means of transport.

These measures call for small costs but require the establishment of a disciplined organization.

b. *Flood protection where sea floods predominate*

In this zone, construction of sea dikes offers the only means of flood protection and embanking will not affect the levels of the sea. The obvious advantages of eliminating salt water intrusion have led to the construction of many coastal embankments in all deltaic areas of the region.

In the further development of this flood protection, attention has to be paid to the effects of embanking on the hydrologic conditions in the interior of this zone. If the land to be embanked has been raised by siltation to the highest possible elevation, i.e. slightly above ordinary high tide, the normal tides and the silt regime in this zone will not be materially affected. Diking of land with a lower elevation may lead to higher high tides and to the increase in silt deposition in the channels. The effect of diking on the storm surge levels in this zone depends on the duration of the storm surges. For storms of short duration the time required for filling up the flooded areas may be too short to produce the maximum possible levels, whereas elimination of the flooding by diking decreases the flood storage thus producing higher levels. For storms of long duration the elimination of storage will not affect the maximum levels.

Closure of estuaries, as applied in the Nobi delta in Japan and as being investigated for the Sundarbans in India, reduces the total length of dikes to withstand the storm surges. By maintaining the existing sea-dikes as a second line of defence, more safety in emergency cases is obtained. Further advantages of this flood protection system will be discussed when dealing with development of major drainage and irrigation systems (paragraph 3.3.3)

c. *Flood protection in the intermediate zone*

In the intermediate zone, the tidal levels and storm surge levels are often lower than at sea. Embanking of this zone may lead to an increase of the storm surge levels within the zone. Any increase of the river flood stages due to embanking of the upstream areas will especially have repercussions on the maximum levels in the intermediate zone.

3.2.2 Systems of flood control

Commonly used systems of flood control in the deltaic areas of the ECAFE region are embankments and sea-dikes, flood detention reservoirs in natural depressions, spillways and diversion works. In addition to this, great benefits have been obtained from flood and erosion control systems in the upper portions of the river basins.

In the further development of flood control, the combination of adequate flood protection of the deltaic area by embankments and flood control works upstream will come more and more to the fore. Discussions of the various systems are given hereunder.

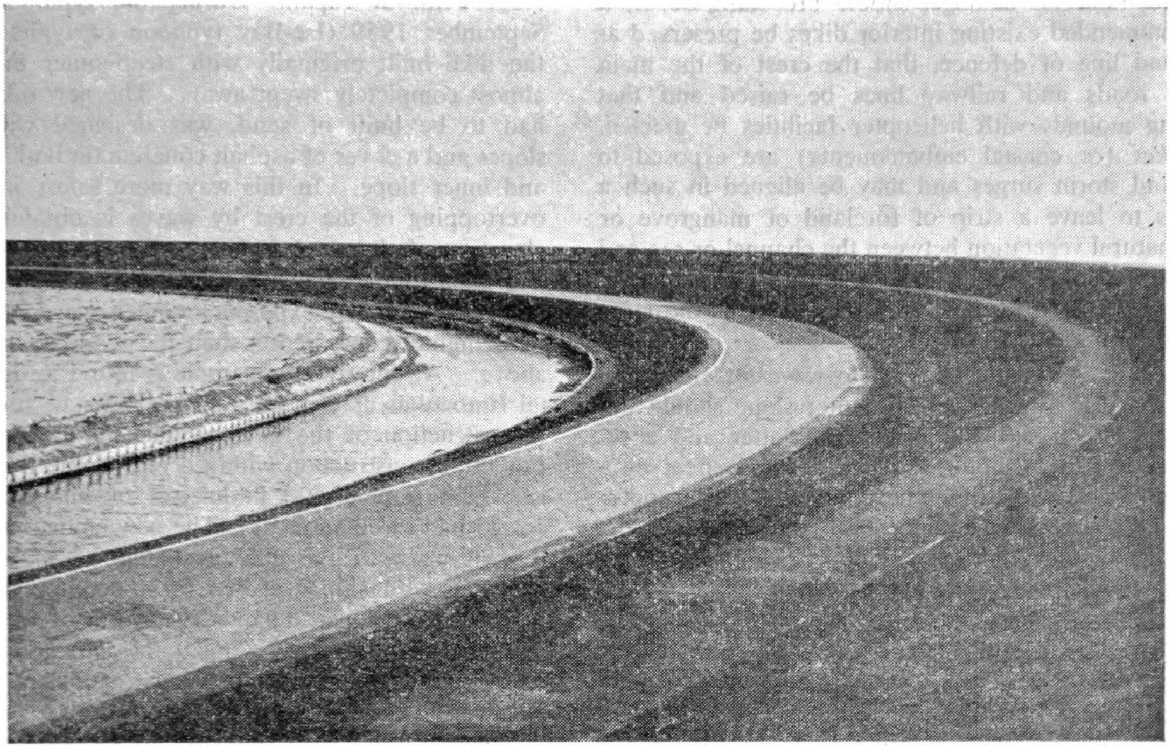
Embankments (or levees or river dikes) can be made from locally available material provided that allowance is made in the design for the geotechnical properties of the building material. In some areas, the suitability of the material and related design requirements is known by experience; for new locations, the use of soil mechanics is to be recommended. In areas with a sandy soil where a limited amount of suitable clay is available, the body of the embankment can consist of sand borrowed from the river and transported by hydraulic filling. A clay cover with a minimum thickness of 0.5 m has to be provided as well as drainage facilities at the toe of the dike at the landside to prevent sliding of the inner slope by seepage.

The elevation of the crest of the embankment should be fixed according to considerations of economy, as explained in paragraph 3.2.1; this approach is more logical than the common one in which the highest ever recorded water stage is taken into account.

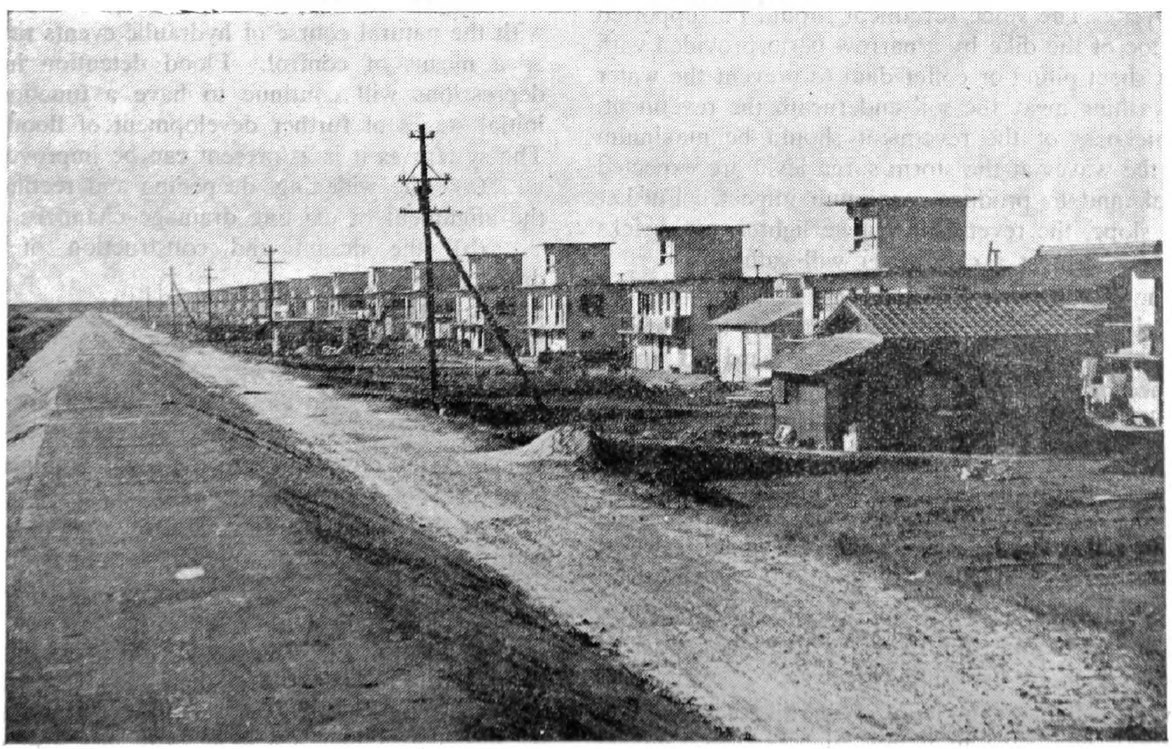
When the design level is fixed, a certain freeboard is added to make allowance for the effect of subsidence, the interval between periodic maintenance works, wave action, etc. This freeboard should never be less than 0.5 m and preferably 1.0 m or even more. In China: Taiwan a freeboard of 1.2 to 2.0 m is adopted. This is larger than in other countries to make allowance for the effects of a possible rise of the river bed and bank erosion by meandering of the river.

The slopes of major embankments at the river side should not be steeper than 1:2 (horizontally 2) and at the land side preferably flatter, 1:3 or 1:4. Good examples of river dikes are found in the deltaic area of the Irrawaddy river. Where the soil in this areas is sandy, the slope on the land side of the embankments is flattened to as much as 1:10. Flat slopes on the land side are most useful for minimizing damage and for preventing breaching in case of some brief overflow of the dikes. For prevention of breaching in localities where this is undesirable, special low spillway or overflow sections may be designed which can resist considerable overflow. A good example is provided by the spillway upstream of the Chao Phya diversion dam near Chainat (Thailand).

Roads on the embankments prove to be most useful for inspection, maintenance and repair works in emergency cases. In areas where the road system has not yet been developed and where periodic flooding still occurs, the embankments offer the most suitable and economic alignments to build roads. If, for reasons of stability or convenience of construction, a shoulder or berm is made on the inner slope of the dike, this platform can also be used for road construction. In this case, however, the road cannot be used if flooding of the protected area occurs. A road on the embankment increases the total width of the earth body, which may be very desirable to reduce the gradient of the seepage line.



Inner side of sea dike of Nabeta polder. The whole face is covered with asphalt concrete. Drainage channel can be seen adjacent to the dike



Farmers' houses in Nabeta polder with a secondary protection dike in front of them

To minimize damage, should breaching occur, it is recommended existing interior dikes be preserved as a second line of defence, that the crest of the main inland roads and railway lines be raised and that dwelling mounds with helicopter facilities be erected. *Sea-dikes* (or coastal embankments) are exposed to tides and storm surges and may be aligned in such a way as to leave a strip of foreland of mangrove or other natural vegetation between the channel or sea and the dike. The resulting loss of a strip of arableland must be accepted in view of the interests of the large area to be protected.

Sea-dikes directly exposed to wave attack should be designed accordingly. The outer slope should not be steeper than 1:3 and preferably flatter and a revetment has to be applied. The adverse effect of a steeper outer slope cannot be compensated by applying a heavy revetment, since both the height of the wave uprush and the impacting effect of the waves will be greater when encountering a steeper slope.

The revetment of the outer slope should not consist of large rigid elements such as large concrete slabs or large pieces of masonry. The revetment must be flexible so that it still holds to the slope even when shrinkage occurs. Large elements are liable to fail during storm attack when the underlying soil has been washed away. The revetment can conveniently be made of stone pitching consisting of blocks of natural stone or concrete or bricks. These elements should not be applied directly on the earthern slope but with an intermediate layer of smaller stones or gravel. To protect the earthern slope during construction and to facilitate the work, a straw cover can be applied as a first cover. The stone revetment should be supported at the toe of the dike by a narrow berm provided with a short sheet piling or coffer dam to prevent the water from washing away the soil underneath the revetment. The thickness of the revetment should be maximum where the waves at the storm surge level are expected to break and to produce maximum impact. Further up the slope, the revetment can be lighter, e.g. bricks and near the crest a clay cover will suffice.

The elevation of the crest is to be ascertained by considering the design storm surge level, the vertical height of wave-uprush and a freeboard to make allowance for subsidence, etc. For a given outer slope, the wave-uprush can be computed when the wind velocity, the fetch and the water depth in front of the dike are known.

For sea-dikes with considerable wave-uprush, the design of a berm or horizontal platform in the seaward slope of the dike will help in reducing the wave-uprush.

The inner slope of the dike should not be steeper than 1:2 and should be provided with a clay cover to prevent erosion by overtopping waves.

An excellent example of a sea-dike designed to withstand severe wave attack and high sea-levels during typhoons is provided by the new dike of Nabeta Polder, Nobi delta in Japan. During the typhoons of 26 September 1959 (Ise-Bay typhoon or typhoon Vera) the dike built originally with steep outer facing was almost completely swept away. The new dike, which had to be built of sand, was designed with gentle slopes and a cover of asphalt concrete on both the outer and inner slope. In this way more safety in case of overtopping of the crest by waves is obtained. The elevation of the crest is 6.3 m above mean sea level.

Dikes in a zone where sea floods still predominate but which are not exposed to much wave attack can be of lighter construction than the seadikes mentioned above. An interesting example is found in the "Coastal Embankment Project" in East-Pakistan aiming at a reconstruction of the village bunds in the tidal zone. For the reconstruction within a reasonable time of not less than some 4,500 kilometres of dikes, a simple design had to be adopted. The new embankments are thrown up with the clay available on location and provided with slopes of 1:3 for the outer slope and 1:1½ for the inner slope. The width of the crest is about 4 metres so as to make the embankments accessible for traffic and providing sufficient seepage length. The elevation of the crest is fixed according the highest tidal level observed in 1958 with a freeboard of 0.9 to 1.5 metres. Although these dikes do not provide protection against high storm surges, they are about the best that can be designed in the present circumstances. At the same time a re-alignment is applied keeping the new dikes away from the channels.

Flood detention in natural depressions

In most cases this system is adopted in compliance with the natural course of hydraulic events rather than as a means of control. Flood detention in natural depressions will continue to have a function in the initial stages of further development of flood control. The system as it is at present can be improved by:

(a) the widening, deepening and rectification of the alignment of existing drainage channels;

(b) the design and construction of artificial drainage canals;

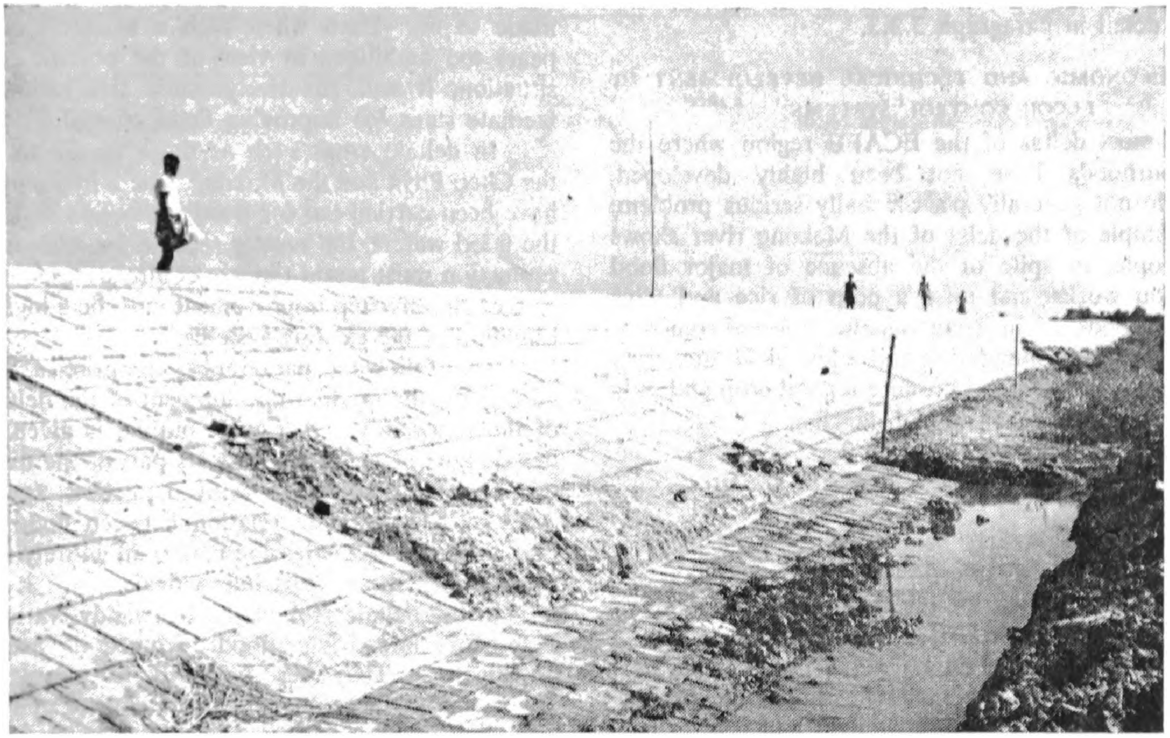
(c) the design and construction of sluices or regulators both at the upstream and downstream ends to control in-and outflow;

(d) the design and construction of low submersible dikes around and inside the areas provided with sluices at the crossings with the main drainage canals;

(e) good maintenance of the system.

In this way, a certain control of the water level in the depressions in the initial stages of floods can be obtained and a better draining off towards the end of the floods. An example of this type of work can be seen in the low-lying depression areas to the west of Ayuthaya in the Chao Phya delta (Thailand).

The flood control works discussed above should be designed in such a way as to fit into a plan aiming at adequate flood protection and water control of



Rivetment of outer slope of embankment with brick blocks, Sundarbans delta in India

An Embankment in the Sundarbans delta in India, with borrow pits in front of it the areas concerned. This item will be dealt with in greater detail in paragraph 3.3.3.

3.2.3. Economic and technical development of flood control systems

In most deltas of the ECAFE region where the neighbourhoods have not been highly developed, floods do not generally pose a really serious problem. The example of the delta of the Mekong river shows how people, in spite of the absence of major flood protection works, can raise a crop of rice and "live with the floods". In Thailand, the non-occurrence of a flood means no inundation and a low yield, moderate floods are welcomed and promise a good crop and only severe floods cause substantial damage.

Improvement of the existing flood control systems in the deltaic areas of the ECAFE region is only justified when:—

(a) the estimated benefits of reduced damage exceed estimated costs;

(b) it is the basic condition for introducing or improving drainage, irrigation or infrastructure.

Benefits should be estimated on a basis of national economy and allowance made for intangible benefits such as reduction in the loss of lives and private property and loss due to interruption of communications, etc. The introduction of drainage and irrigation leading to a more diversified agriculture and to the planting of varieties of rice which give a higher yield necessitates improved flood protection. A good infrastructure, which is the backbone of industrial development, also calls for adequate flood protection.

Thus the implementation or improvement of flood control systems is limited by considerations of economics and, in addition, there must be harmony between the degree of flood protection and the stage of economic development of the deltaic area as a whole.

A technical limitation when improving major embankments is found in the height of the dike above ground elevation. If the dikes are higher than some 8 or 10 metres, an extremely dangerous situation will occur in case of incidence of floods beyond the design flood. The devastations in case of failure will exceed those which occur where the embankments are of moderate height. Even when raising the embankment is found to be the most economical solution, the use of flood stage reducing works, such as reservoirs upstream, diversion works and spillway systems in such a case should be preferred.

The ultimate stage of flood control in deltaic areas is formed by a system of adequate flood protection by means of closed embankments in the deltaic area and flood control measures in the upstream portions of the river basin. This stage of perfection, however, can only be attained gradually and the policy must aim at drawing up partial schemes that do not abruptly upset the existing hydrologic conditions and yet constitute the first stages of a scheme aiming at adequate flood protection. This means that a master plan has to be drawn up in which the step-by-step schemes are made to fit. Even when such a master scheme appears too ambitious in view of the present economic situation, it will effectively guide the various intermediate steps for improving flood control.

In deltaic areas such as those of the Irrawaddy, the Chao Phya and the Makong, where hydraulic works have been carried out for flood protection or to spread the flood waters, the master scheme for adequate flood protection must retain the works already executed, and further step-by-step improvement must be a logical continuation of the existing systems.

The following paragraphs comprise a tentative outline for the gradual development of the deltaic area of the Irrawaddy. A similar outline is given for the deltaic area of the Chao Phya as part of the discussion on improving drainage and irrigation (paragraph 3.3.3.). The intimate relation between flood protection, drainage and irrigation makes an entirely separate treatment of these items impractical.

In the deltaic area of the Irrawaddy, various projects for improving flood protection are being investigated. They aim primarily at improving the drainage conditions, for which the closure of the open embankments is a pre-requisite. The first step will be the closure of the open embankments around Yandoon and Thongwa islands. Some aspects of the improvement of the drainage conditions in these area are discussed in paragraph 3.3.3.

It is also planned to continue diking in the salt water tidal reach, just as in the schemes for Labutta Island and for the Pyapon coastal embankment.

During the further development, the present policy of preserving the mangrove forests in the central coastal zone of this area may be continued. It seems advisable, for the planning of the step-by-step execution of the coastal embankments, to draw up a master scheme aiming at closing the tidal creeks to the north of this forest belt with dams and sluices. This would be attractive, as little water passes down the river branches and creeks in the central part of the delta, which is therefore exposed to salt water intrusion. If the sluices were to remain closed during the dry season, fresh water would be available there and the outflow of water through the main river would be increased, thus reducing the salt water intrusion in the eastern part of the delta. During the flood period, excess water could be discharged through sluices at ebb tide.

In improving the drainage and flood protection of the large area between Bassein river and Irrawaddy river, which is now partly protected by an open horseshoe-shaped embankment (the Ngawun and Irrawaddy embankments) along both rivers, provision could be made for diverting as much drainage water as possible to the west, thus increasing the outflow of Bassein river. This would be of benefit both for maintaining sufficient depths for navigation in the entrance to the Port of Bassein and for combating salt water intrusion in the salt water tidal reach of this river. See figure 17.

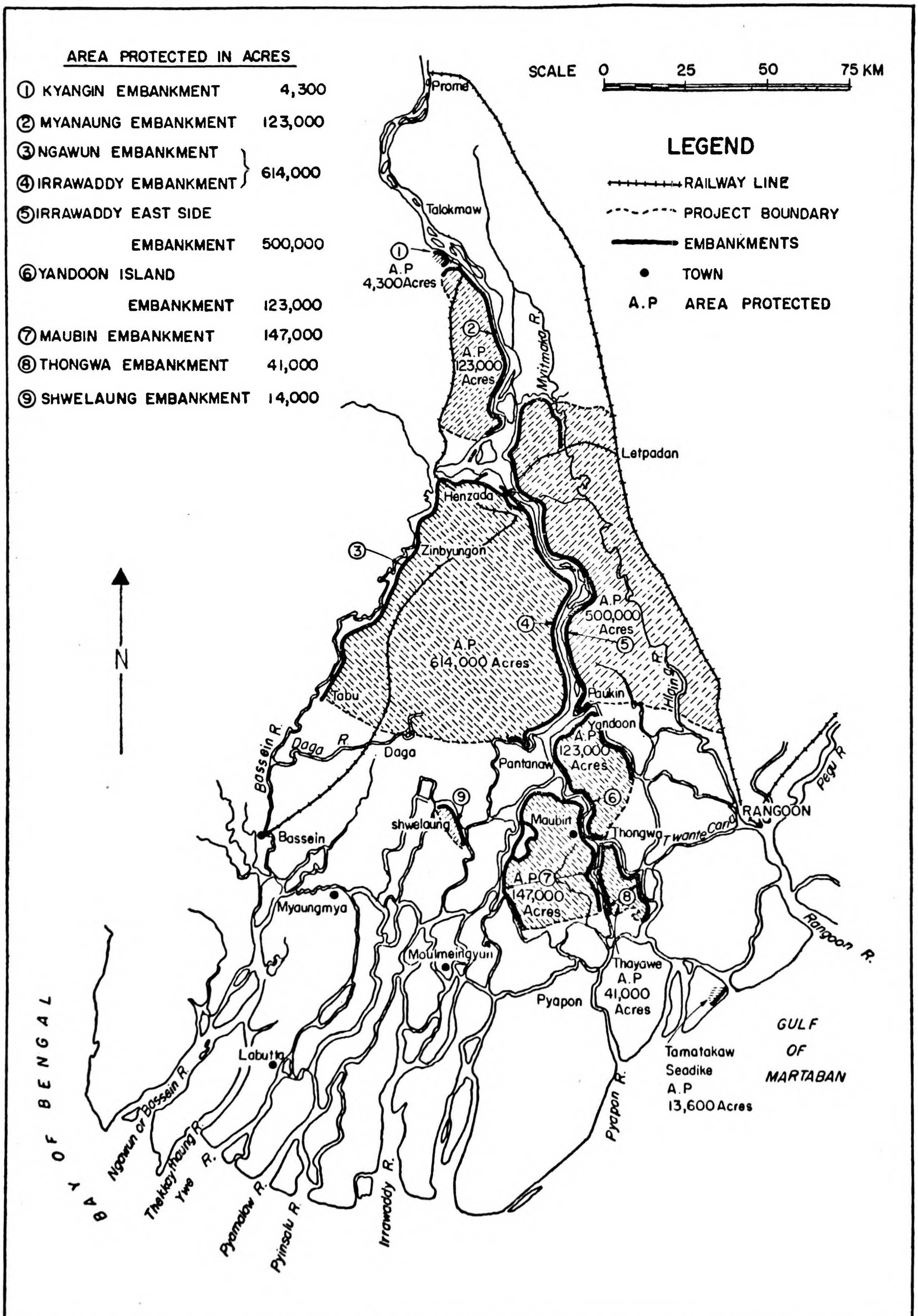
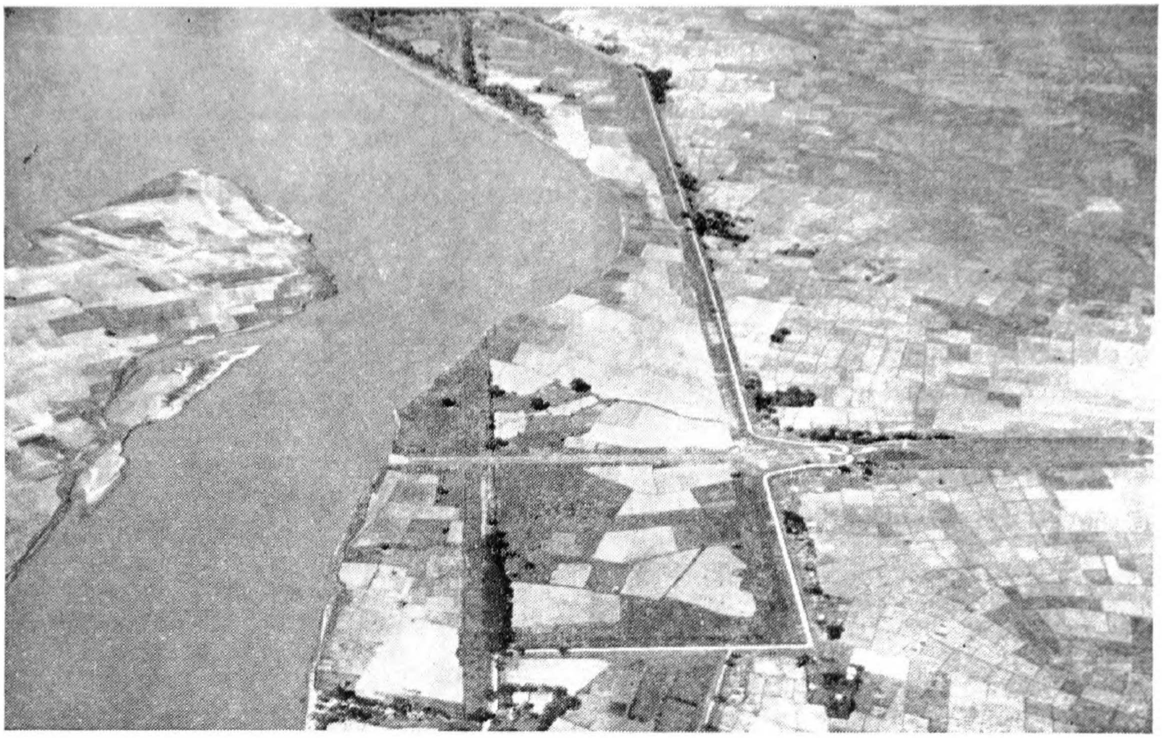
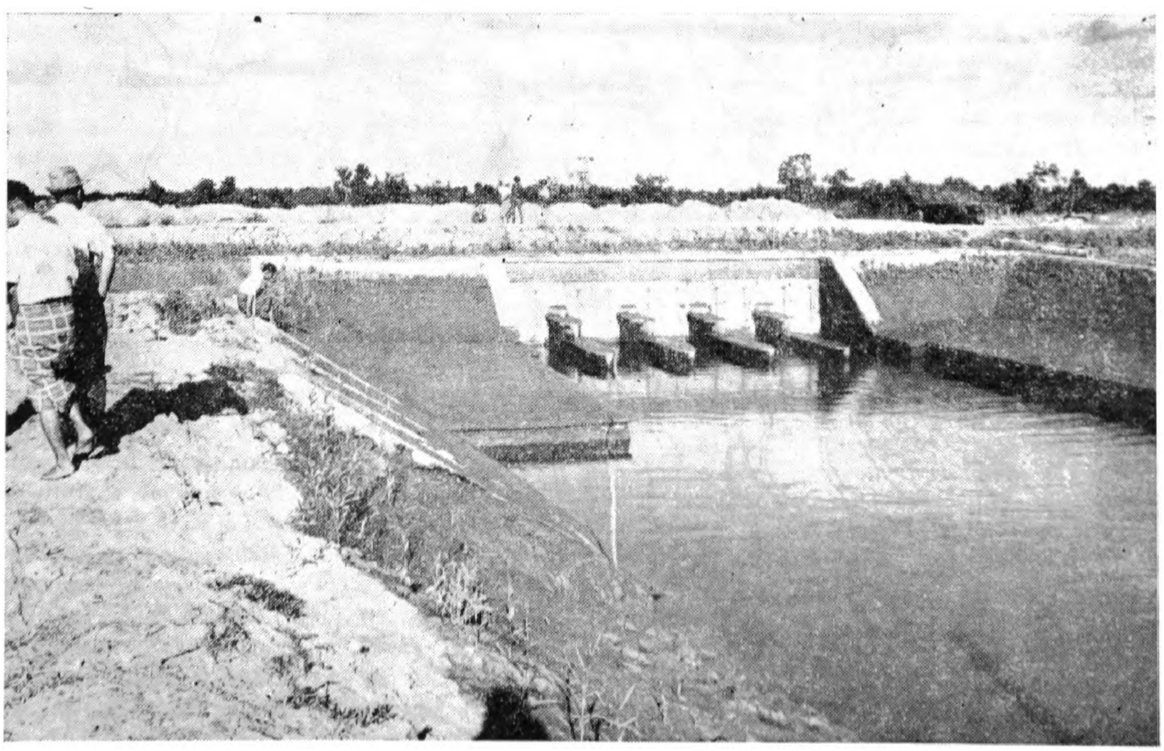


Figure 17. FLOOD PROTECTION WORKS IN THE IRRAWADDY DELTA



Aerial view of the flood embankment and a sluice at Mithwechaung in Yandoon island, Irrawaddy delta. The sluice is for the admission of silt laden water



A discharging sluice of Labutta polder, Irrawaddy delta.

The scheme for closing the tidal creeks aims at reducing salt water instrusion in the central part of the delta, improving drainage conditions and diverting the freshets from upstream. It comprises the enclosure of the creeks north of the forest belt, where they are narrower than in the estuaries and have smaller tidal volumes. It includes damming off the Pyapon river somewhere near this town, but does not extend to the Bassein river to the west or the To river and the Rangoon river to the east. It is considered that closing these wide estuaries with considerable tidal volumes would be beyond the present economic and technical feasibilities. To protect the intermediate area between the Bassein and To rivers against salt water from these rivers, some dams and sluices will have to be built in the connecting channels between their southern reaches and the creeks in the intermediate area.

In the long-term programming, a further item of the master plan that seems worth examining is the construction of a headwork and diversion dam in the Irrawaddy river upstream of Henzada. This structure may offer the following possibilities:

(a) Provision of facilities for supplementary irrigation and dry season irrigation of the upstream portions of the deltaic area down to the line Bassein-Rangoon. As pointed out above, irrigation of the southern central area is ensured by the fresh water reservoirs in the former tidal creeks.

(b) Distribution of the flood water over the Bassein, Irrawaddy and Myitmaka-Hlaing-Rangoon rivers. This will have the advantage of reducing the peak flows in the Irrawaddy river and increasing the ebb currents in the entrances to the ports of Rangoon and Bassein. Further embanking of the Bassein and Rangoon rivers will, however, be necessary.

(c) Diversion of the minimum flow of the main river to the Bassein, Irrawaddy and Rangoon branches for distribution of irrigation water to the down-stream areas.

The tentative outline given above should be considered only as a suggestion which may be of help when implementing a programme of investigation. As more data becomes available, there may be some other alternative solutions.

3.3 PLANNING OF WATER UTILIZATION AND SOIL IMPROVEMENT

3.3.1. GUIDING PRINCIPLES AND CRITERIA OF WATER CONTROL IN THE FIELD

The main principles of water control in the field are based on the creation of favourable conditions for plant growth; this chiefly entails the provision of adequate supplies of two essential elements, namely, water and oxygen. From the physiological point of view, water is essentially used in transpiration, in dissolving and transporting plant nutriments and discharging compounds harmful to plant growth. Water and oxygen are taken up from the soil by the roots. The relation between water content, air content and solid materials in the soil depends on the structure of the soil itself. In this relationship, because of the ease with which water is transported to or from the soil, a certain water control technique has been developed whereby sufficient water contents is provided while at the same time oxygen content is kept at a sufficiently high level. This water-air relationship is particularly critical in soils of bad structure.

Rice is a peculiar plant in that it has a rather shallow (15-20 cm) root zone compared with the length of the stem, and grows in water-saturated soil with a low oxygen content. It flourishes under this condition because it is able to take oxygen from air transported through the stem to the root zone. This does not, however, mean that the oxygen content in the soil and in the irrigation water can be disregarded. The water supply depends on the permeability of the soil, and this varies with different soils to such an extent that, even in water-saturated soils, there can be a shortage of water around the roots because of very poor permeability. In rice cultivation, the most important water control measures to improve water and oxygen supply to the root zone are:—

(a) preparation of the soil for which irrigation water is to be provided;
(b) refreshment of the water;
(c) oxidation of the soil by proper drainage (drying up of soil);
(d) percolation of the irrigation water, which is necessary both for oxygen supply, and for leaching toxic compounds into the subsoil;
(e) maintaining a proper depth of water on the field.

Upland crops and fruit trees, as compared with rice, have a deep root system and are generally unable to channel oxygen from the air to the root system. Hence both water and oxygen have to be taken up mainly from the roots in the soil, so they must be made available there. The deeper the root system, the greater the area available for absorbing water. Fruit trees generally have deep and extensive root systems which enable them to absorb a lot of water from the soil.

From the agricultural point of view, water control is complex, especially when dealing with bad soils. The following paragraphs discuss the criteria for water control in relation to distributing water at the distribution end, namely, the distributaries and farm ditches.

The criteria for water control in the field, in so far as they concern irrigation and drainage, are based on the following:

Irrigation

(1) The water level in the distributaries and farm ditches must be high enough to irrigate the highest ground in the parcel (and, in the case of rice, without drowning the plants grown in the lowest spot).

(2) Water requirements per day or per period must be provided all through the growing season according to plant needs.

The total amount of irrigation water needed for a certain crop is the sum of transpiration plus losses by evaporation, seepage and wastage, minus that part of precipitation which can be used effectively. The total amount of irrigation water needed differs from place to place. For 120 day rice the total irrigation water supplied is about 900 mm. (rotation irrigation) for China: Taiwan, 900 to 1,050 mm. for West Pakistan and Burma and 1,200 to 1,300 for Thailand, South Viet-Nam and Cambodia.

In Taiwan field experiments to find the irrigation requirement have been carried out extensively. It is urged that such experiments be carried out also by other countries as the results will be most useful for designing irrigation works.

In all the deltas visited, priority of irrigation water is given to the rice crop, while upland crops are left to suffer from the lack of water and therefore generally give low yields. Even in the Nobi and Cho Shui deltas where horticulture is practised extensively, irrigation is concentrated on the rice crop.

Drainage

(1) The water level in the drains must be low enough to keep the groundwater table at the depth required.
(2) The drainage system must be able to drain off the excess water (rain and irrigation water) at any time and permit some percolation water for refreshment.

Drainage circumstances should be so developed that the groundwater table is kept at a depth conducive to the full development of the root systems. This means that, on soils with high groundwater table, deep drainage is necessary, especially for upland crops. Experiments in Taiwan on the effect of the groundwater table's depth on sugar cane production demonstrated that the deepest level at 1.56 metre below the surface season. There may be occasions when the water level in the drainage ditches should be lower than 1 metre from the surface. However, this does not mean that the water must be kept at this level throughout the season. There may be occasions when the water level in the drainage ditches has temporarily to be raised higher than the normal required level. The intensity and depth of a farm drainage system depends on the permeability of soil, the volume of excess water during a certain period in relation to the groundwater table, depth of the permeable layer, etc. Heavy soils with low permeability, therefore, need a more intensive drainage system. In good permeable soils with a deep groundwater table, drainage ditches can be further apart. In soils with saline groundwater, deep and intensive drainage ditches will prevent salinization of the top soil and will help in the desalinization operation.

Generally the quantity of excess water caused by rainfall covering wide area is very large. In order to lessen the cost of a drainage system, if the areas are sown to rice crop, the paddy fields are often temporarily used to store excess water in addition to that stored in the drainage system itself. The Hachirogata polder in the Akita prefecture of Japan is an example. This area has been reclaimed from the sea and the ground elevation is about 5 metres below mean sea level. In order to reduce the capacity of pumping stations from 150 m^3/sec. down to 80 m^3/sec. it is designed to store excessive rainwater equivalent to 75 mm. of rain on the paddy fields temporarily. This amount is about one-third of the designed successive rainstorms of 220 mm. in 3 days.

Separate or combined irrigation/drainage system

From an agricultural point of view, a separate system is desirable. It gives better water control in the field. Irrigating or draining one parcel can be accomplished at any time without conflicting with the other parcels. This provides more possibilities for the development of other crops as well. Also a separate drainage system makes it possible to correct mistakes in the water control mentioned above (see also paragraphs 3.3.3.).

Naturally a separate system costs more to construct. In flat area where agriculture is not yet highly developed and only a single crop is grown, a combined system is sometimes used.

3.3.2. SYSTEMS OF WATER CONTROL IN THE FIELDS

From the previous paragraph it can be concluded that the ideal conditions for water control in the fields are as follows:—

(a) Water is supplied in correct quantities and with proper timing in accordance with plant needs.
(b) Irrigation and drainage is controlled effectively, preferrably with individual control for each farm unit.
(c) In the case of paddy, proper depth and circulation of water are maintained in the field. Toward the end of the growing season, the water is drained off to make way for harvesting and to lower the groundwater table.

At the present stage of development these ideal conditions are rarely found in the deltaic area visited. However, in order to increase crop production, it is desirable that water control in the fields be improved. Modern agriculture demands good water control facilities and an efficient size of farm units. In order to obtain adequate control, distributaries and facilities such as sluices, pumps, irrigation and drainage ditches and measuring devices are needed in addition to the major irrigation and drainage systems. For better functioning of the system, it is preferable to have separate irrigation and drainage systems (paragraphs 3.3.1 and 3.3.3.). The fields should be divided into sections by channels and field dikes as needed to fit the different ground elevations.

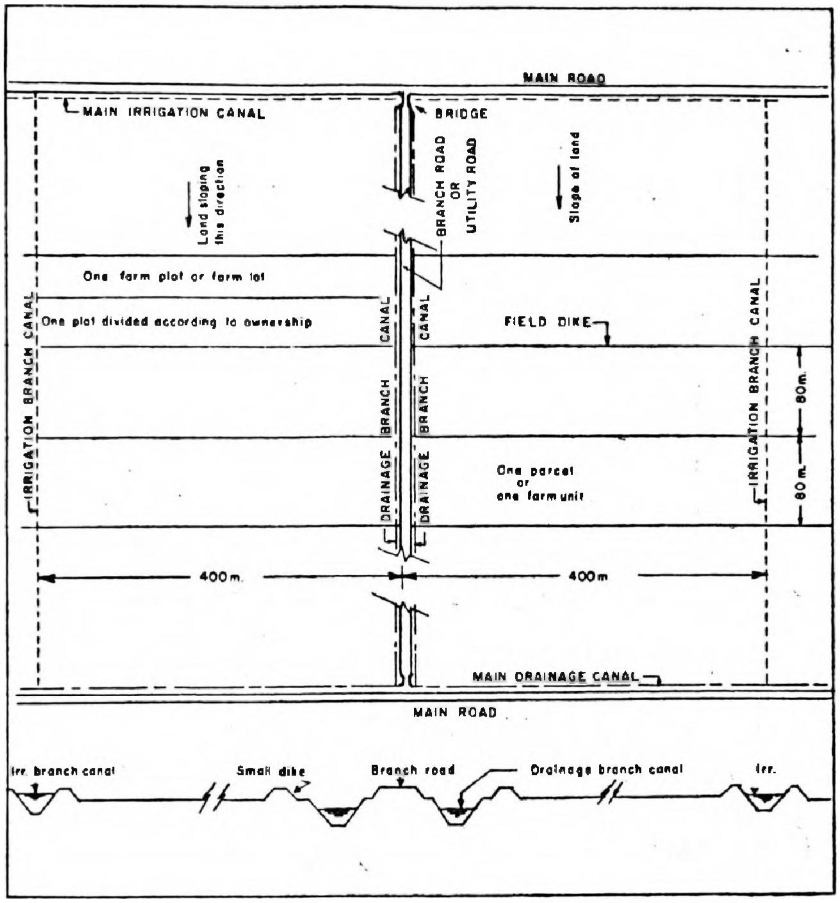


Figure 18. AN EXAMPLE OF A LAYOUT OF FARM PARCELS

Deltaic areas are generally characterized by clay soils which are more or less impervious under wet conditions. To let water permeate through it and to keep the table at a required depth, deep drainage channels may be needed. For horticulture or upland crops, underground drains may sometimes be very useful and effective.

Soil improvement, fertilizing and the introduction of improved farming techniques and methods should be planned and implemented concurrently with the field water control system, so that a reasonable increase in crop production is assured.

Observations made of the various deltaic areas are as follows:

In the coastal areas of the deltas of the Sundarbans and the Irrawaddy, where it is difficult or even impossible to bring water continuously from the river or other sources and where rainfall is the main supply of irrigation water, the possibility of developing large tanks should be explored. They should be developed in such a way that the natural depressions or natural deep channels or creeks are used as storage basins with connexions through canal systems to the higher portions of the area and irrigation has to be accomplished by pumping. In order to make economical use of water when water resources are extremely limited, the water depth on the paddy fields should be kept as shallow as possible by dividing the fields into many parcels by field dikes with connecting canals and canal structures for regulating water distribution.

Most of the paddy fields in the deltaic areas of the Sundarbans and the Irrawaddy, excluding the coastal areas, are inundated naturally by the rivers. Water supplied from natural streams inundates the fields at different depths. Here, water control is necessary to keep the water at suitable depth, to distribute or drain it from the parcels at any required time and to secure proper effects from the fertilizer. To achieve these purposes, every parcel should be connected directly with the irrigation and drainage ditches and bordered by field dikes.

In the Chao Phya delta, where nearly all the areas are sown to rice, irrigation is done more or less by flooding, thus perfect and timely control of water is impossible. Also lots of water runs to waste. The government is now constructing a "ditch and dike project" in the upper part of the delta near Chainat. This project will set an example of good water control in the field and will enable second crops other than rice to be grown. In this delta, lack of irrigation water during the dry season is the main factor prohibiting the growing of second crops in most areas. The possibility of intensifying agriculture there depends mainly on the availability of more irrigation water.

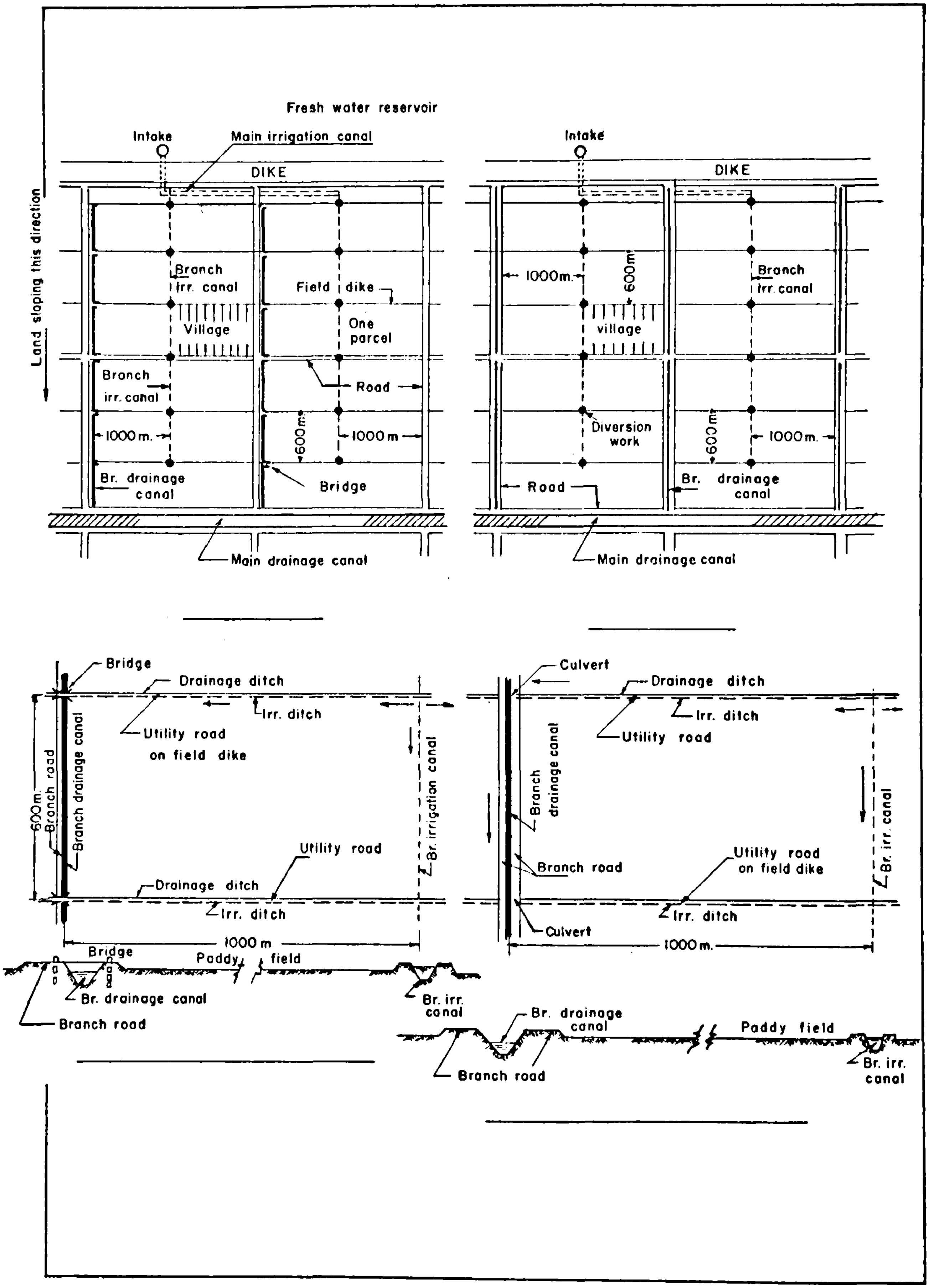


Figure 19. PLANNED FARM PARCEL LAYOUT OF HACHIROGATA PROJECT IN JAPAN

In the Cho Shui and Nobi deltas, where there are good systems of water control in the fields, the drainage is generally not adequate and irrigation is concentrated on rice production even at places where the soil is not very suitable for rice. Hence, it is felt that other crops better suited to the soil and agrohydrological circumstances could be substituted with advantage. Also more irrigation and drainage facilities should be allowed for the upland crops and horticulture. The demand for horticulture will definitely rise with the increased development of industry and urbanization. Improved horticulture requires very good irrigation and drainage facilities in the fields. Irrigation should be made available throughout the whole year and the drainage should be made more adequate especially for the upland crops.

The ideal condition for water control in the field is that every farm plot or lot can be irrigated or drained at any time needed. This means that each farm plot must be directly connected to irrigation and drainage ditches. Figure 18 gives an example of such water control. In this figure, each farm parcel has an area of about 3 hectares and the ratio between width and length of the parcel is 1:5. The distance between irrigation ditches is 800 m and between irrigation and drainage ditches 400 m a utility road of say 2.5 to 3 m crest width (not including shoulders) is provided in between the two drainage ditches. To economize the cost of construction and to save the land area, in some cases one large drainage ditch may be provided only on one side of the road with a smaller ditch on the other side connecting with the larger ditch by pipes embedded under the road. For each farm parcel there are field dikes all around to check the water level. In case there is a slope in the ground elevation within the parcel, or if the farm holding (plot or lot) is smaller than the parcel, intermediate field dikes may be required for every 10 or 15 cm of difference in ground elevation or to mark the boundaries of each plot. However, for small farm holdings, co-operation among farmers or arrangement for farm consolidation is advisable.

It is to be noted that the above explanations and figures serve only as examples. The area of the farm parcels, the ratio of width to length of the parcels, the location of road (some prefer placing the road along side the irrigation canal), etc., are flexible and should be designed to suit each phyical condition as well as economic requirements. However, one should bear in mind that the smaller the farm parcel, the larger will be the construction cost of the system.

In some of the deltas in the ECAFE region, it is expected that mechanization with heavy machineries will sooner or later be introduced. In such cases, field water control facilities should be planned to fit in with mechanized cultivation and harvesting in the future. For mechanization with heavy machinery, a much larger farm parcel than 3 hectares, for instance, say, 30 hectares, is advisable. In the Hachiro-gata reclamation project of Japan, farm parcels of 60 ha have been planned on the area where the ground elevation is flat. Where the land has slope, a subdivision to smaller areas of 30 ha has been anticipated, in order to come within the limit of 10 to 15 cm difference in ground elevation. Figure 19 shows two plans of farm parcel layout of the Hachiro-gata project.

3.3.3. Major drainage and irrigation

a. *Drainage*

The agricultural requirements with respect to the depth of flooding and the permissible variation in the depth of water level in the ditches should be the starting point of the design of a drainage system. Drainage systems should not disturb the proper balance between water supply and drainage by uncontrolled removal of water. Even when irrigation facilities are available, allowance in the design should be made for conserving water.

Since embankments hamper the natural outflow of water, the improvement of drainage facilities should be considered when constructing dikes.

Drainage by gravity

Drainage can be effected by gravity taking advantages of tides in the tidal zone and low stages in the river reach. For the control of the internal water levels, a sluice is made between the outfall and the system of canals, natural channels or creeks and ponds forming the internal drainage network. The hydraulic capacity of the entire system to discharge water does not depend on the capacity of the sluice alone but also on the dimensions (cross-sectional area and length) of the canals and channels.

Drainage by gravity is limited by the available head and by the duration of the periods that head is available. Especially in the case of drainage by gravity of flat areas in the tidal zone, the hydraulic design of the drainage system requires special attention. Usually the period during which the water can gravitate through the sluice is limited to a few hours during ebb tide. When opening the gates as the outer level drops below the inner level, water is withdrawn from the canal in the immediate vincinity of the sluice thus decreasing the available head. Only gradually will the drawdown of the water level spread to more distant points, its speed depending on the cross-sectional areas of the water courses. Since the sluicing operation lasts only a few hours, no appreciable lowering of the water level may occur in the remote points on the area to be drained. The whole process is essentially one of non-steady flow and the design should be based on the pertinent hydraulic laws. In most cases, tidal drainage of patches situated at a long distance of say 5 to 7 kilometres from the outfalls is scarcely satisfactory. If the sluices are located at large ponds or at enclosed mouths of creeks, the drawdown near the sluice is small and the hydraulic capacity of the system is improved by the storage effect of the pond. Thus the capacity of the internal drainage channels and the location of the drainage outfalls are important items in the design of a gravity drainage system.

Distribution over a number of locations of the total sluice capacity required facilitates the layout of the internal system of drainage canals. If, however, the channels outside the sluices are subject to heavy silting, it seems advisable to concentrate the required capacity in one or two locations. In this way, maximum benefit will be obtained from the scouring action of the outflowing water and maintenance by dredging can be concentrated. By enclosing the mouths of tidal creeks with dams and sluices and connecting the water channels and ponds in the drainage system, larger units of drainage areas can be formed. This also improves flood protection and the irrigation facilities.

These principles may be of use when improving the drainage conditions in the Sundarbans delta in India and East Pakistan. They may also be applied in drawing up a master plan for embanking coastal areas in the delta of the Irrawaddy river.

Maximum hydraulic capacity of sluices can be obtained by placing the gate sills as much below the outside water level as the foundation conditions and the depths of the connecting canals permit. There are no hydraulic reasons to limit the depth of the sill to the elevation of the lowest water level outside. Since the whole submerged cross-sectional area of the sluices participates in the flow, the discharge increases with increasing depth of the sill. The limit is formed by the depth of the channels on either side of the sluice placed there to avoid deposition of silt or sand in the sluice. If lowering the sluice gate would necessitate a foundation pit with well points during construction, in some cases it may be more economical to apply a wider sluice which can be built in an excavation drained by pumping off the surface water.

Sluices in tidal areas can conveniently be equipped with flaps which operate automatically whenever the outer water level drops below the level on the inner side of the sluice. Provision of special gates to control the inner water levels is then necessary so as to avoid an outflow of water in dry period when its conservation is desired. Stop logs do not serve the purpose since they cannot be easily placed and removed.

For major drainage sluices adjoining saline waters, flaps cannot be used since they allow some salt water to intrude, especially towards the end of the sluicing period.

Drainage by pumping

Drainage by pumping becomes necessary when, because of the low elevation of the land and high outer water levels the available head is insufficient to ensure proper drainage. Drainage by pumping is often considered as being too expensive, but cost estimation proves that the costs per unit area to be drained are low compared wtth the costs of reclamation. Japan provides examples which show that, in well-developed areas, the costs of drainage by pumping are not at all prohibitive.

Drainage by pumping is considered advantageous for low-lying areas in the deltaic region of the Irrawaddy river, such as Yandoon Island (50,000 ha) and Thongwa Island (16,000 ha), and in the deltaic area of the Chao Phya river such as the Chiengrak—Klong Darn area (107,000 ha). For such large patches, it seems advisable not to concentrate the pumping capacity in a single location but to subdivide the total area into smaller units, each unit to be drained separately by pumping into embanked channels through which the water gravitates to the river or to the main drainage channel.

An illustration of this principle is given in figure 20. The main water course inside the area is embanked and provided with a sluice at the outfall to the river. The area has been subdivided into sections draining into the embanked water course. If the pumping stations are equippd with two or more pumps the structures for two sections can effectively be combined. This arrangement is preferable to the one with a single pumping station for the following reasons:

(a) It allows a better adaptation of the drainage facilities to the topography and drainage requirements in each section.

(b) It allows a step-wise execution, so that experience can be gained and the financial strain is not too great.

(c) It ensures greater safety in operation.

The remarks made under drainage by gravity with respect to the capacity of the internal system of drainage canals and channels also apply to drainage by pumping.

The water level in the drainage canal leading to a pumping station is governed by the lowest area within each drainage section and by the agricultural requirements. Isolated patches with still lower elevation can be drained separately into the surrounding higher section area. This avoids having to deepen the canals and having to lift the water from the entire section with maximum head.

The capacity of the pumping station depends, for a given agricultural requirement, on the design rainfall, the layout of the system of drainage canals and the availability of storage within each section. This is an argument for leaving low-lying patches which are difficult to drain under water. On the other hand, when reclaiming swamps and other depressions by filling them up, consideration has to be given to increasing the pumping capacity.

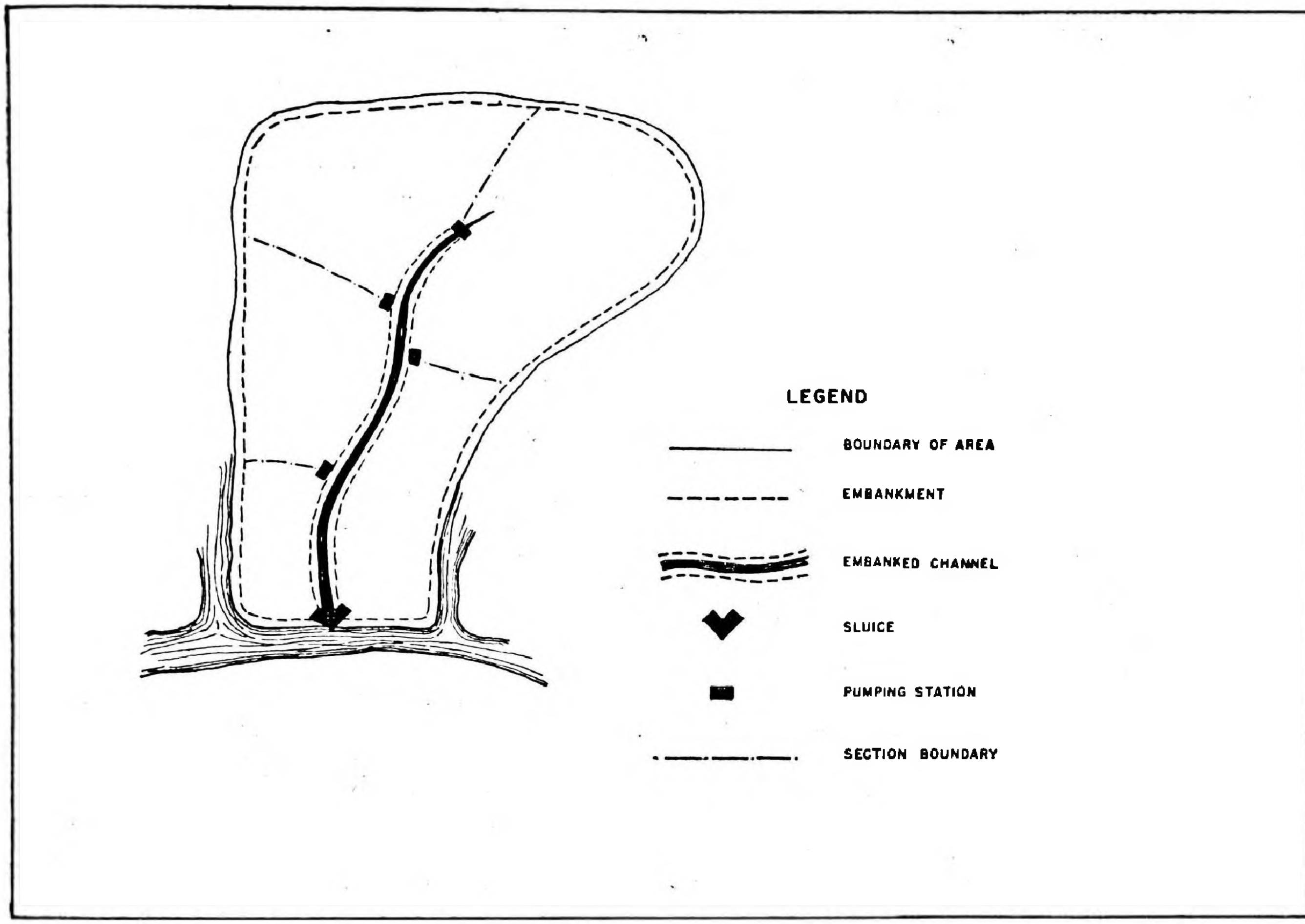


Figure 20. DRAINAGE BY PUMPING

During rainfall, a certain portion of the rain water is retained either on the surface (paddy fields) or in the subsoil (dry crops). In the case of saucer-shaped areas with paddy fields, provision can be made to retard the outflow from the fields to the depression. This will effectively reduce the required capacity of the pumping station. In an area with dry crops, the permissible rise of the groundwater table is often limited by the agricultural requirements. Deep drainage increases storage capacity. Transformation of an area growing paddy into an area with dry crops, therefore, necessitates increasing the capacity of the drainage facilities.

The hydrologic conditions are often such that, during the flood periods, drainage can only be effected by pumping; whereas, after the floods or even during their recession, drainage by gravity becomes possible. By introducing a culvert in the design of the pumping station allowance can be made for both conditions. The use of reversible pumps or devices to reverse the direction of the flow makes it possible to use the same pumping station for the supply of irrigation water.

b. *Irrigation*

Irrigation by gravity of the upper portions of a deltaic area can be accomplished by constructing headworks on the river from where irrigation canals branch off. As mentioned earlier, the irrigation of major portions of the deltaic areas of the Chao Phya, the Cho Shui and the Nobi is based on this system.

From the upper portions, the irrigation water can be conveyed to the lower areas. Difficulties are encountered when reaching the coastal area. The slope in the seaward direction may be too small or even nil and the crossing of river branches poses a difficult problem. Thus the major irrigation facilities of the lower deltaic areas may have to be designed independently of the upper deltaic area. This may be true for the Sundarbans, the Irrawaddy, the Mekong and to a certain extent the Chao Phya.

Irrigation of the coastal area can be effected by pumping the water from the rivers or the creeks to a sufficient elevation at which it enters embanked canals and gravitates further seaward. The intake of this system must be located at a point above the saline reach in the dry season. Its application has been suggested for irrigating the coastal region of the deltaic areas of the Mekong river. When the importation of fresh water is neither feasible nor desirable, there are three alternative solutions:

The first is the construction of tanks to collect rain water from the fields as discussed in paragraph 3.3.2.

The second is to transform the river estuaries into fresh water basins by closing off the rivers near the mouth with enclosing dams equipped with gates.

The third solution aims at pushing back the saline water by diverting the outflow of the various river branches during the dry season into a single channel. This solution has been suggested in paragraph 3.2.3 for the deltaic area of the Irrawaddy river. A similar solution is discussed below for the Chao Phya river.

Major irrigation and drainage canals can be separated or combined. The merits of separate systems have been discussed in paragraph 3.3.1. Separation of the major systems should be applied in areas exposed to salt water intrusion or in areas with saline soils where flushing with fresh water is needed. Moreover, separate major systems have advantages for the irrigation and drainage of upland and horticultural crops which require a perfect water control.

In the deltaic area of the Chao Phya, irrigation and drainage facilities have been extended gradually without upsetting the natural system of draining off the flood waters. It seems advisable to pursue this policy, by adopting as a guide for further development a master plan aiming at complete water control and embodying the full benefits of the existing extended irrigation system.

An essential element in the present water control system of the Chao Phya delta is the utilization of natural depressions as detention reservoirs. Water is kept in temporary storage almost throughout the entire deltaic area; the bulk of the flood water, however, is retained in the large depressions to the west and north of Ayuthya. Elimination of the natural flood detention reservoirs by high embankments would have adverse effects on the flood conditions in the entire deltaic area. The works executed in the depressions comprise drainage canals, regulators and low dams aiming at controlling the in-and outflow in those areas rather than at preventing the flood waters from entering.

Keeping in mind the principle of gradual interference in the existing conditions, the next step should be an improvement of the drainage conditions in the coastal areas to the south of these depressions (the Chiengrak-Klong Darn and West Bank areas). The flood waters in these coastal areas back up the drainage water in the flat plains in the vicinity of Ayuthya. Better drainage facilities in the coastal areas will allow better water control in the detention areas without substantially increasing the flood stages in other reaches of the deltaic area.

Improvement of the drainage facilities in the coastal areas should comprise:—

(a) improvement of the drainage conditions in the zones between the various canals and channels as discussed previously;
(b) improvement of the outfalls of these canals to the main rivers and to the sea.

An important item in this scheme which needs consideration is the necessity of halting the salt water intrusion in the coastal areas. Because of the proximity of Bangkok and the existence of communication facilities by canals, vegetable gardening and fruit orchards have been developed giving these areas a

A fruit orchard in the area west of Bangkok (near Bhasi Chareon canal) high economic value. This holds especially true for the environs of Bangkok and the so-called Lower West Bank Area between Rajburi and Bangkok along the Damnern Saduak and Bhasi Chareon Canals.

The horticultural and fruit orchards areas, however, are exposed to salt water intrusion during the dry season. Sea water penetrates into the rivers Meklong, Thachin, Chao Phya and Bang Pakong which traverse these areas; in the Thachin and Chao Phya rivers especially, the penetration extends beyond the intake of the Damnern Saduak and the Bhasi Chareon canals so that brackish water intrudes into these highly developed areas.

The salt water intrusion in the Chao Phya river will increase with the deepening of the entrance to the Port of Bangkok in the interest of navigation. Also as time goes on, more and more water will be used during the dry season for the irrigation of upstream portions of the deltaic areas. So it can be expected that, even after the completion of the Bhumipol dam (Yanhee project), it will be necessary to make the most effective use of the comparatively small amount of available water during the dry season.

The traditional method of combating salt water intrusion in a river mouth by increasing its fresh water discharge requires an excessive amount of fresh water, most of which is needed for flushing the canals in the interior of the herticultural and fruit orchards areas. If the large amount of water required for these purposes is not available, the only solution will be to close the river's mouths. However, since damming of the Chao Phya river does not seem feasible, increasing the fresh water discharge of the river in the dry season is perhaps inevitable. This can be accomplished by diverting the outflow of water required for flushing the coastal areas towards the Chao Phya river. By damming off the Thachin river near its mouth, south of Damnern Saduak canal, the flow can be diverted through canals running from west to east in eastward direction to increase the discharge of the Chao Phya river near Bangkok. Similarly the enclosure of the Bang Pakong river near its mouth will divert the discharge of that river into the Chao Phya river. By this concentration of outflows through the Chao Phya river, the most effective use will be made of the small amount of water available during the dry season for combating salt water intrusion in its estuary.

The dams on the Thachin and the Bang Pakong rivers would be equipped with gates which could be opened during the flood season and would remain closed during the dry season, thus preventing the sea water from entering.

At a further stage of development, a similar scheme could be considered for the mouth of the Meklong river with the object of diverting the river discharge to the east.

After improving the drainage conditions in the coastal areas as explained above, it would be possible to arrive at better water control in the detention areas to the west of Ayuthya, by retaining smaller areas as detention reservoirs without increasing the flood stages and by improved control of the drainage from those areas after the floods. The drained off water could be used during the dry season to flush and halt salt water intrusion in the coastal areas.

The outline discussed above should be considered as a suggestion intended to incite further investigations, the result of which may lead to a better alternative solution.

3.3.4 Soil improvement

Besides improving flood control, irrigation and drainage, which can also be considered as measures for soil improvement in a broad sense and which have been discussed in earlier paragraphs, there are measures for soil improvement in a more specific sense of the term.

The more intensive agriculture is, the greater the need for changing the soil conditions to suit particular agricultural or horticultural purposes. Since a large part of the deltaic areas in southeast Asia will long continue to be the main rice bowl of the world and since rice culture in its most intensive form has relatively low requirements insofar as soil conditions are concerned, soil improvement in the specific sense, except for the use of fertilizers, is less important than making provision for better drainage and irrigation.

However, the more intensively the land is used for other crops, including horticulture, the more necessary it is to have better soil and to study measures for its improvement.

The following measures for soil improvement are discussed:—

(a) Fertilization
(b) Management of catclay
(c) Desalinization
(d) Improvement of soil structure
(e) Combatment of soil reduction (H_2S formation).

a. *Fertilization*

Raising agricultural yield without fertilizers in deltaic areas is almost impossible. This is especially true where, by flood control and/or irrigation measures, the annual supply of fresh sediment is decreased or halted and the supply of dissolved minerals by the river water is correspondingly decreased. Rice can adapt itself to many soil conditions, such as bad soil structure or water logging and also to poor chemical fertility, but it gives response to some phosphorus and nitrogen compounds. Use of fertilizers tends to increase the requirements for other minerals especially the trace elements. Improvement in irrigation also tends to increase the demands of crops for minerals. In general, river clays have less fertility than marine deposits and old soils less than young soils. Application of green manure with nitrogen giving plants (leguminosae) is highly recommended. Over supply of certain chemical fertilizers can cause serious damage, as has been found in the more developed deltas. Notorious in this respect is ammonium sulphate, especially where it is applied on sandy soils. A better nitrogen fertilizer is calcium cyanamide (CaCN) which also has weed killing properties. This fertilizer, being harmful to the human skin, is not attractive in tropical areas where farmers do not generally cover themselves with many clothes. Urea and ammonium chloride are more highly recommended, the choice between them depending on the crops.

b. *Management of catclay*

The harmful characteristic of catclay is a high concentration of aluminium (Al) ions (preventing phosphorus uptake of plants) and, in serious cases, high acidity. Therefore, means must be found to remove toxic ions. Leaching might seem to be a suitable remedy for, viewed from this point, there is some analogy with the process of desalinization. However, desaliniation is almost entirely a question of deep drainage and freshwater supply. Applying this principle to catclay has proved in many cases to be fatal, for it has been brought out that aeration of potential catclay promotes pyrite oxidation resulting in the formation of new acids and thus causing the liberation of huge masses of the toxic "Al" ions, which have then to be removed. Lowering the pH below 3, promotes the oxidation even if rather inert pyrites which in less acid circumstances would not be oxidized.

Only very moderate catclays with a small surplus of pyrite can be cured by leaching and flushing if enough water is available.

In Japan, where experience in rice cultivation on catclay has been gained, following methods are practised. The land is kept wet most of the time and two rice crops are grown. After shallow plowing, lime is applied and mixed with soil through harrowing and puddling. A few days after, the field is flushed and new fresh water brought in before rice seedlings are planted. With this practice it is claimed that the yield increases after the first of second cultivations and that the amount of lime applied can be reduced. However, a large quantity of irrigation water is needed to flush the field and keep it under water always.

In Sierra Leone (Africa) and Viet-Nam some experience has been gained in leaching and flushing catclay first with salt water to save the limited available fresh water supply. Final leaching is with fresh water.

On heavy clay soils with a high pyrite content, the measures taken have to be focussed on maintaining the pyrite (of which only a very small amount can safely be oxidized in a year) and keeping the "Al" concentration just below the toxic level (less than 250 ppm). The permeability of the soil is, moreover, too low to permit oxidization of pyrite in a short time. The amount of toxic compound to be flushed and leached may give rise to serious damage to adjacent areas with which the drainage water is brought into contact. In most cases, not enough water will be available for flushing and leaching.

To prevent pyrite oxidating, only one measure is feasible, i.e. prevention of aeration of the soil, not only during the dry season but throughout the year. This means keeping the soil under water or under irrigation the whole year. Drainage measures must be limited to those conducive to refreshment of the water for carrying away the toxic compounds. Under these circumstances, air can only penetrate where the topsoil has been neutralized. Some supply of lime would be useful. However, experiments have shown that, in neutralizing catclay which is in a very serious condition, the application of lime in combination with drainage alone never gives good results. Many tons of lime per hectare are required to neutralize a shallow soil layer of a few centimetres. Only in cases where the subsoil is rich in lime can good results be obtained through deep plowing. In the ECAFE region, however, such subsoil has not been found.

The best way of cultivating catclay is to grow two rice crops a year. This will keep the soil under water nearly the whole year and thus prevent pyrite oxidation. Moreover, rice is rather tolerant in respect to the toxic compounds. Another crop, pineapple, may be recommended, as it has high tolerability against catclay toxidity. This has been planted successfully in the catclay area of south Viet-Nam in the Mekong delta.

Bad catclay can never be turned into a good soil. The advisability of using irrigation water on catclay areas should be examined under the benefit-cost ratio and other considerations. In many cases, it is more economical to invest money and labour in better soils than in cultivation on bad catclays.

c. *Desalinization*

The possibilities of effective desalinization depend primarily on the availability of fresh water and on drainage for flushing away the salts. It is well known that the rate and quantity of capillary rise depends on the size of soil capillars, which in turn depends on the texture and structure of the soil and on differences in vapour pressure between the top and the subsoil. The latter plays an important role during dry periods. Silty soils show a strong capillary moisture transporting capacity and therefore are more difficult to drain and desalinize than soils with sandy or clayey subsoil. Clayey soils crack after drying and thus become more permeable. The capillary rise is also low in heavy clay. In areas with abundant and well distributed rainfall over the year, desalinization is reduced to, more or less, a simple question of drainage. In areas with a distinct dry season, salt water may move upwards during dry periods and thus resalinize the top soil. Here the requirements for drainage are much larger and the groundwater table must be kept at such a depth, especially during the dry period, that no capillary rising of water can reach the top soil. In areas short of fresh water, deep drainage, although contradictory to the measures for water conservancy, should be made so as to combat the danger of resalinization.

Rice is one of the most suitable crops for areas where perfect desalinization is impossible because of lack of fresh water. This is due to the following reasons: (1) the tolerability of certain rice varieties towards moderate salt concentrations, (2) the rooting zone is very shallow and therefore relatively easy to keep fresh by a thin layer of fresh water and (3) damage to the soil structure caused by alternating salinization and desalinization does not have much unfavourable effect on the rice plant.

d. *Improvement of soil structure*

Little is known about the soil structures in the deltaic areas in southeast Asia. This probably is due to the fact that soil structure does not play an important role for the cultivation of rice, which is the main crop. For rice cultivation, even on the light textured soils, a "negative" structure (impermeable layer) is aimed at by the well-known method of puddling, which aims to prevent water losses by seepage. On the heavy clay soils of the large deltas of the Ganges, Irrawaddy, Chao Phya and Mekong, puddling is not practised extensively. In Japan, farmers use sheep foot rollers to compact the subsoil on extremely permeable soils (outside the deltaic areas).

Development of deltaic areas includes the introduction of other crops, whether as a second crop after rice or for a rotation scheme without rice cultivation. For the more intensively used parts of the delta, the improvement of soil structure may be profitable, especially in the long run. According to experience in deltaic areas in Surinam, for mechanized rice farming, some soil structure features are important for preventing extreme chemical soil reduction.

Soil structure is governed by two main processes, namely, physio-chemical condition of the clay particles (flocculation-deflocculation phenomena) and on biological reaction (actively producing suitable organic matter compounds and remaniation of the soil). Moreover, the methods of tillage in combination with these processes play a distinct role in the shaping of the structure of the soil. The result of deflocculation is that the soil dries up and forms extremely hard and large lumps and after wetting collapses to a sticky, structureless, almost fluid mass. Deflocculation of clay appears when the Na and/or Mg ions in the absorption complex of clay colloids are high, in relation to the concentration of these ions in the soil moisture and the soil has no important biological activity. Newly desalinized soils can show these features in a temporary or permanent form. The latter is the case when no Ca ions are available to neutralize and coagulate (flocculate) the deflocculated soil particles. Also old non-saline clay soils can have deflocculated structures probably due to relatively high Mg content. Curing these soils is done by supplying soluble Ca ions to replace the Na and Mg ions in the absorption complex. The most suitable method is the application of gypsum which is explained in the paragraph that follows:—

(1) *Promoting flocculation of clay*

In Europe, some experience has been gained in improving the structure of saline soils with the application of gypsum ($CaSO_4$). The gypsum must remain at the surface and the quantities applied should not be larger than can be dissolved in one season. The total amount of gypsum required to react with the Na content in the upper 20 cm of the soil to a value lower than 5 milliequivalent per 100 grammes active (clay plus humus) material is given in the following formula:—

$$R = 0.046 \times (L \div 3H) \times (Na_a - 5) - 5.6$$ [1]

where: R = required gypsum in tons per hectare

L = clay content (particles of less than 2 microns)

H = organic matter content

Na_a = amount of exchangeable Na in the upper 20 cm in millier equivalent per 100 grammes active material.

This means that for a soil comprising 40 per cent clay and some humus saturated with sea water, about 15 ton/ha of gypsum is required. For soils already partly desalinized, and for soils with lower clay content, requirements are much less.

The common problem of the soils in the vast tropical deltas of the ECAFE region which were visited by the mission is that they have a rather high clay content and are subject to a severe dry season. Even in flocculated condition, these heavy soils are already rather impermeable. It will, therefore, be very difficult to bring Ca ions into the subsoil. Consequently, dressing with gypsum ($CaSO_4$) before desalinization or deflocculation will have the best result.

In paddy fields, it is even more important to apply gypsum only on the surface and not to plow it under. Mixing gypsum with soil under the waterlogged condition of the paddy fields may give rise to sulphate reduction and consequently to the formation of an excess of H_2S which is harmful for the crop. Experiments in the Sundarbans have proved that this is not only a theoretical possibility. It is recommended that the application of gypsum should be done during the period when the soil is moist but not in a constantly waterlogged condition. Moreover, the quantity of each application should not exceed the amount that can be dissolved during one season. Sufficient drainage facilities must be made available to carry away the Na (and Mg) ions.

Instead of gypsum, CaCl can be used with success. In general this compound is more difficult to manage (relative hydroscopic characteristics) and rather expensive.

[1] W. H. Van der Molen 1957 — The exchangeable Ca — ions in soil flooded with sea water — Verslagen Lamdbouwkudige Onderzoekingen — 63.17 — S'Gravenhage.

In the formula given above, no Mg is taken into account. Moreover, for the other conditions in tropical areas, other formulae may be more suitable. Investigations are, in any case, necessary.

(2) *Improvement of biological activity*

As mentioned above, structure formation results not only from the physio-chemical process of deflocculation, for biological activity can give a rather stable structure even to clay with Mg and Na content. Inherently saline grassland and grassland flooded by seawater are never seriously damaged by the salt content in the soil.

To promote biological activity, the main guiding principle is to make the environment (soil milieu) as far from extreme as possible, i.e. strong and abrupt changes in moisture content, salinity, etc., should be avoided as far as possible. The opposite of this ideal condition is very common in the large deltas of India, East Pakistan, Burma and Thailand. There, only one paddy crop is grown and the fields are more or less water logged for a long period; then, during the rest of the year, the soil dries out intensively; this results in capillary rise of salt in several locations and in damage to the structure directly through physio-chemical activity and indirectly through deteriorating effects on biological activity.

It is clear that, to fulfill approximately the requirement stipulated in the guiding principle, proper irrigation and drainage should be undertaken. This recommendation lines up perfectly well with all other measures recommended for raising crop production, especially through the introduction of a second crop other than rice.

Other means of improving the soil structure by improving biological activity is through supplying food and building materials to the soil organisms. Application of green manures, cow dung and plowing under of rice straw instead of burning it are useful. The only exception is where the area is more or less permanently waterlogged or where the oxide content of the soil is very poor. Heavy application of masses of organic matter (such as rice straw) promotes reduction resulting in the H_2S formation, which is harmful to plant roots.

Last but not least is the prevention of mechanical damage to the soil structure when reworking the soil under waterlogged conditions. However, for transplanted rice culture, it will not be possible to follow this.

Fish ponds and salt pans require an impervious bottom. Silty soils are particularly suitable for salt pans, as there will be no cracks when the pans dry out. The alternate salty conditions and flushing or leaching by rain water will render the soil deflocculated and hence impervious.

e. *Combatment of soil reduction (H_2S formation)*

A too low oxygen content of the soil which gives rise to H_2S production can be combated by drainage in combination with improvement of structure (flocculation of clay). If, as with paddy, the culture requires periodical waterlogging, sufficient oxygen should be stored in the form of oxides beforehand during the dry period. In soil, as in human blood, iron acts as the medium for the exchange of oxygen. In most young alluvial clay soils, iron is available in suitable quantities. The application of iron oxide, which is done for example in the old paddy soils on the Nobi delta in Japan to promote oxygen exchange in soils poor in iron, will not in general be necessary in other deltaic areas. It may be useful only when, owing to the excessive use of fertilizers or for some other cause, much iron is leached, especially in sandy soils. Too high concentration, however, many, in extreme cases of soils undergoing reduction conditions, be harmful because soluble Fe ions in high concentration (10,000 ppm) are toxic. In permanently more or less waterlogged conditions, no large quantity of organic matter should be added to the soil, as this will promote reduction. Thus, rice straw should not be plowed under in such areas. In areas without a distinct dry period, soil reduction even for rice can be harmful under certain conditions, so periodical drying out of the soil should be promoted.

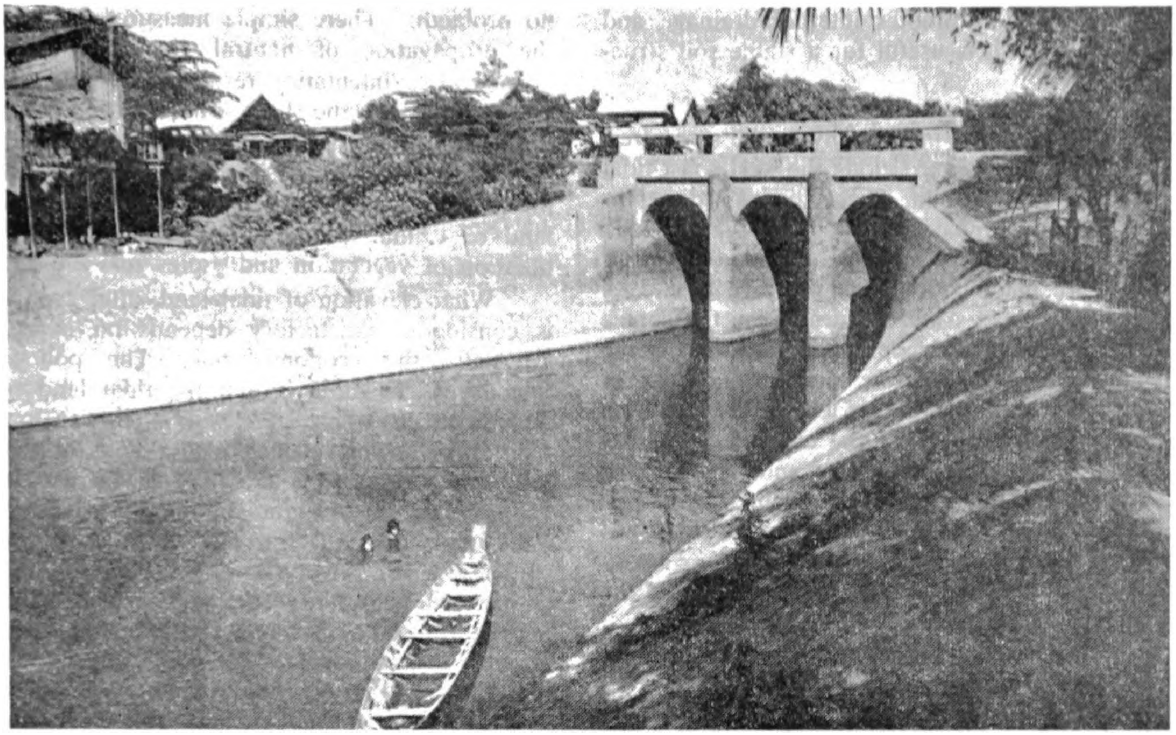
3.3.5 PROMOTION OF FORMATION AND IMPROVEMENT OF LAND BY SEDIMENTATION

In many cases where the ground elevation in the lower part of deltaic areas has not yet been built up to the maximum height and is lower than the normal high tide, sedimentation to raise the ground level is carried out. In order cases, the fertile silt carried by river water is used to improve the land for better crop production. In some countries in the ECAFE region where land shortage is acute, such as China: Taiwan and Japan, efforts are also made to promote sedimentation of the coastal tidal land. In some instances, sedimentation work is also done for raising a protective foreland belt for the sea dikes. This paragraph describes the various methods of promoting sedimentation to serve the various purposes described above:—

(a) *Sedimentation of inside land or back swamp in the deltaic areas*

For promoting sedimentation in this case either for raising the ground elevation or improving the land, the silt laden river water is let into the embanked polders or the back swamps. An example of this is in the Ariake polder in Japan. In Burma at Yandoon Island in the Irrawaddy delta, river water is led by means of a canal with a sluice through the natural levee and embankment into the back swamp. The same is done also in the areas southeast of Phnom-Penh in Cambodia (Mekong delta). There, a highway hampers the natural sedimentation. At many locations along the highway, "Colmatage"[1] sluices have been

[1] Colmatage is the process of raising land elevation and adding fertility to the land by sedimentation.



A sluice at the highway along the Mekong river near Phnom-Penh, Cambodia, for admission of silt laden river water

built and canals lead the silt laden river water into the land behind the highway dike. The aims are both for raising the land elevation and bringing in fertile fresh sediment.

In all these cases, the main problem is to get the sediment further away from the intake sluices into the lower parts of the back swamps. To achieve this aim, frequent extension and deepening of the channels is necessary. It is, however, doubtful whether it is possible to obtain a uniform distribution of sediments.

(b) Promoting sedimentation in tidal land

The following are guiding principles for sedimentation of tidal land:—

(a) The quiet period preceding and following slack water after high tide is the main period of sedimentation. Extending the duration of this period by diminishing water velocities before and after slack water will promote sedimentation, provided the currents that supply the sediments are not hampered too much.

(b) Frequently, part of the freshly deposited sediments is again carried away by the ebb current or the following flood current, particularly in periods of strong wave action. In such cases, measures which consolidate the sediment and decrease wave action will increase the ultimate amount of captured sediment.

To lengthen the slack period as well as to decrease wave action, two measures can be employed, preferably in combination. The first method is quite close to natural conditions and consists of promoting vegetation. Vegetation brakes the water velocity during the whole flooding period and thus lengthens the quiet period. Some kinds of mangrove which are strong and tall, can also decrease the wave action. An optimum condition for sedimentation exists between the density of vegetation and the velocity of the current. If the braking action is too strong in relation to the current velocity, then, in the centre part of the vegetation, the supply of sediment will decrease due to the current's low capacity for carrying sediments. On the other hand, scattered obstacles such as isolated vegetation boundaries in the water tend to increase turbulance and produce erosion effects. Theoretically, the most suitable conditions are vegetation with increasing density backwards from the borders.

To consolidate sediment and prevent fresh sediment from being carried away (eroded) in the case mentioned in the sub-paragraph (b), the most suitable vegetation is a dense, short permanent grass and weed vegetation such as is found along the northwestern coastal low land of Europe. The dense root system gives good mechanical protection against erosion. This vegetation does not hamper the intruding flood water that carries the sediment. Immediately after deposition, the silt particles are protected in the shallow quiet water zone between the short plants.

Another way of preventing erosion is to increase the cohesion between sediment particles. This can be done by withdrawing water from the soil by ditching. Whenever optimum sedimentation occurs in the ditches, cleaning them regularly and spreading the soil over the land promotes soil building. Vegetation also withdraws water from the soil, promotes internal drainage and supplies humus which is useful for a stable soil structure.

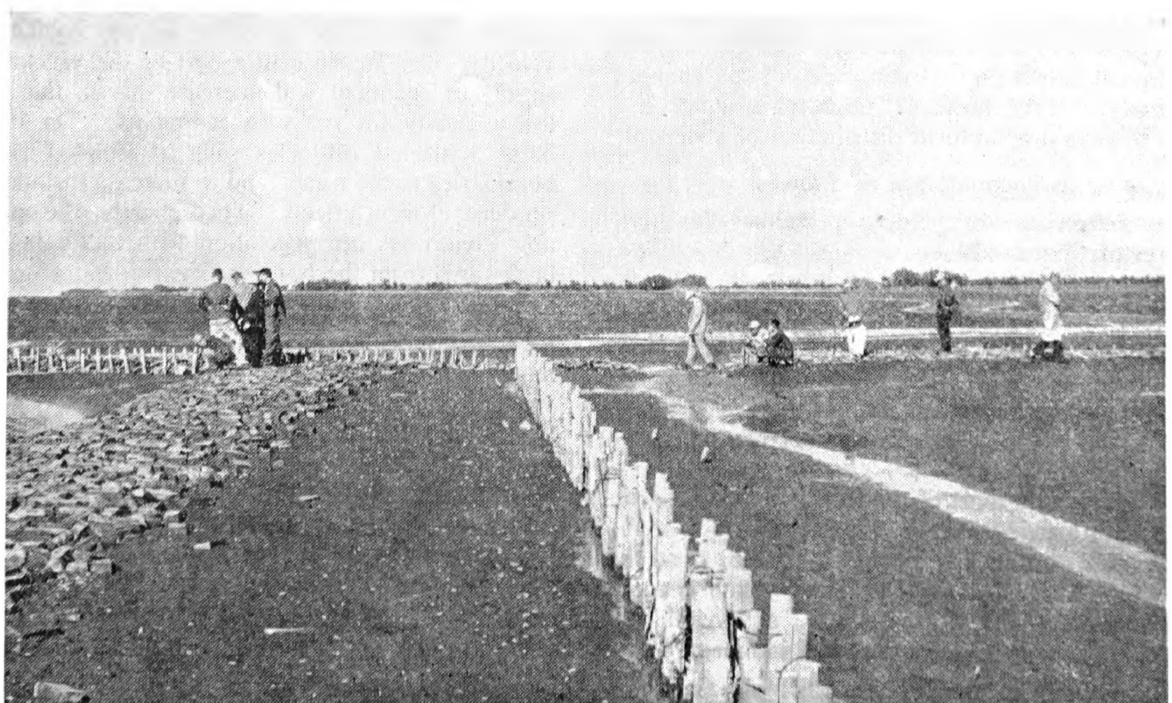
The second method involves hydraulic structures. Examples are the groins used along the west coast tidal land of Taiwan near Yunlin. These square sedimentation pans are made by constructing low dams made with bamboo poles; every pan has a narrow opening. These dams are made lower than the high tide. As soon as the tide recedes and the water level becomes lower than the dams, water coming out of the pans has to pass through these narrow openings. This, of course, take time and the quiet period is thus extended. The bamboo dams also retard the current as well as wave action; thus both aims (a) and (b) of the guiding principles are achieved. Again, with this method, an optimum sedimentation condition depends on the size of the sedimentation plan, the size of opening in relation to the type of tide, the velocity of the current, the kinds and size of sediment, etc.

Building low dikes with openings equipped with gates on the same principle as the pans, but with the land separated into larger sedimentation compartments, has also been suggested.

Comparing the two methods above, if a self-supporting vegetation is available, it is by far the cheapest method and yet very effective. The choice of vegetation to be used is a delicate problem. As far as possible, vegetation from the vicinity should be used. Along the coast where a dense natural vegetation exists, as is the case in Thailand, this is no problem. There simple measures for accelerating the propagation of natural vegetation can already give good sedimentation results. However, in coastal areas with extreme high tides, strong considerable wave action, high salt content and high sand deposition, the environmental conditions are very unsuitable for plant life, as for example in the west coast tidal land of China: Taiwan. In such localities, a combination of vegetation and groins may be necessary.

What elevation of tidal land, after sedimentation, is considered satisfactory depends on many factors, especially the economic one. The policy in the Sundarbans in India is that the tidal land may only be embanked when its elevation is not lower than 1 to 2 feet below normal high tide. In East Pakistan, this elevation is fixed at mean sea level. In China: Taiwan, the aim is to let the land rise to a level of mean high tide. There, the silt and clay content, which is very low under natural conditions, is also an important criterion. The occurrence of high storm surges is another reason for not embanking very low lying land. However, in the highly developed Nobi delta of Japan, where high storm surges also occur, there was no hesitation to embank tidal land with a ground elevation as low as mean neap tide level.

As regards texture (clay content) of sediments, a clay-loam texture is the most suitable for agricultural purposes. Besides elevation and clay content, the availability of fresh water for desalinization and crop requirements is another criterion for deciding upon the suitability of tidal land for embankment.



An experimental siltation pan, made of bamboo, at Yunlin tidal land in Taiwan

3.3.6 Economic feasibility

Sound project formulation and evaluation of benefits and costs are basic factors for a decision on the implementation of any large or small reclamation, flood control, irrigation and drainage project. Even when the necessity for certain works is evident, a more satisfactory decision on alternative solutions can be achieved by comparing benefits and costs.

Whereas the significance of the economic appraisal of development projects has been generally recognized, little attention has so far been paid to the special features of the problem of the economic feasibility of major hydraulic works in deltaic areas.

In many respects this problem is similar to that of major hydraulic works in other areas. The assessment of an investment project is essentially based on a comparison of the expected annual profit with the annual costs of investment.

In private enterprise, investments are confined to projects that promise a relatively high yield on a short term. Priority in this case entirely depends on the current economic situation. Indirect and intangible benefits resulting from the project cannot be taken into account.

Major hydraulic works in deltaic areas can only be planned after consideration of the conditions in the entire deltaic area concerned. Their effect touches the interests of the community as a whole and has repercussions in various fields of human activity. The economic useful life of most of the works for flood protection, drainage and irrigation is practically unlimited. Consideration should be given to long term development rather than to the current situation. Thus, there are ample reasons for central or local governments to carry out or strongly support the execution of major works and to consider their economic feasibility from the point of view of the national economy.

In this case, the method of evaluation differs in some respects from that used for assessing investment projects from the private economic viewpoint. The latter returns are generally calculated with only direct benefits being taken into account: whereas, from the national economic viewpoint, indirect benefits and returns should also be considered (effects on the supply industries and processing plants). The employment situation and the foreign exchange position may also have bearings on this viewpoint.

The assessment of investment projects from the national economic viewpoint is a specialized matter and there may be considerable latitude in fixing costs and returns. However, when applying the same figures to various investment projects or to alternative solutions for the same project, the relative priority of various projects can be better ascertained.

Major hydraulic works in deltaic areas present, besides the commonly considered returns, benefits that do not only refer to the agricultural potential of the area; yet they are of primary importance for a sound development of the deltaic area and the adjacent regions. This is especially true for works aiming at flood protection and at providing drainage and irrigation facilities.

The additional benefits are related to:

(a) The development of infrastructure

Infrastructure consists among other things of a system of facilities for communication by road and water, and for supplying energy and potable water. A good infrastructure is a prerequisite for a more intensified agriculture and for the development of industry. In deltaic areas, adequate flood protection and drainage facilities allow a good infrastructure to be established. As explained in paragraph 3.4.1, the system of road communication can be integrated into the system of embankments.

(b) The development of urbanization

In almost all deltaic areas of the ECAFE region, large cities and ports have been built. Well-known examples are the cities and ports of Calcutta, Rangoon, Bangkok, Saigon, Phnom Penh, Tokyo, Nagoya, etc. In the Sundarbans area in East Pakistan, the City of Khulna is rapidly expanding.

The further development of these cities will be largely promoted by developing flood protection, drainage and irrigation in the adjacent parts of the deltaic areas.

(c) The development of the hinterland

Deltaic areas are the natural outfalls of the river basins and their development has a favourable repercussion on the development of the hinterland.

These indirect benefits of flood protection and water control may be the reason why all works carried out so far in the deltaic areas all over the world are considered justified from the long-term economic point of view. There are no examples of judiciously planned major hydraulic works, the implementation of which was regretted at a later stage of development.

3.4 RURAL DEVELOPMENT

3.4.1 Infrastructure

It is evident that efficient transportation facilities have favourable effects on the prices received by the producer and consequently on increased production and incomes in agriculture. The deltaic areas visited, except the Nobi Delta in Japan and Cho Shui in Taiwan, have not been provided with adequate and efficient transportation facilities. The many difficulties faced by producers in the area come partly from the lack of transportation facilities.

In the deltaic areas, the farmer's produce is largely transported to the markets through small waterways or canals and thus takes a long time to reach the wholesale markets; and often the products deteriorate during transportation. Moreover, transport through waterways is sometimes less efficient, mainly because of difficulty in loading and unloading.

In this connexion, it should be noted that in the deltaic areas transporting produce to the market depends largely on the dealer's boat. The producer is not able to sell the produce at the time when he wants to sell, but only when the dealer offers to buy. Of course the producer is not informed of the share of transportation costs in the prices realized in the wholesale markets. Moreover, the dealer is mostly a money lender as well as a miller; thus the bargaining position of the producer is adversely affected by certain unreasonable pressure put upon him by the dealer. It is important to create healthy competition among dealers and thereby ensure higher returns for the producer.

In Burma and India, the government purchases rice from the producer at guaranteed minimum prices so as to stabilize the prices received by the producer and to stimulate rice production. However, the producer finds difficulty in reaching the official buying stations which purchase paddy from him at guaranteed minimum prices, because of lack of adequate transportation facilities. The value of the government's guarantee to him and its effect on rice production is thus sometimes limited.

In the Chao Phya delta, transportation of farmer's produce is made mainly through the rivers and numerous canals; that by road and railway is very limited. There are good prospects, however, of building roads on top of the irrigation canal embankment, which would certainly help a great deal in extending transportation facilities in the delta. The same holds true for the deltas of the Sundarbans and the Irrawaddy. Further development by constructing roads on both the flood and canal embankments should be urged.

In the Nobi Delta of Japan, railways are already well developed and efficient highways are under construction; but there are still urgent needs to improve the infrastructure. The difficulties arise from the fact that the construction of highways, harbour facilities and water supply for industrial use is not catching up with the tempo of industrial development. The Nobi Delta is historically one of the top four industrial zones in Japan and has undergone remarkable development during the past decade. With the rapid growth of industrial production, cars on the roads and ships in Nagoya Harbour have considerably increased in numbers, and thus the efficiency of transporting and unloading cargoes has dropped. Such difficulties result in increased production costs for industrial goods, without sufficient improvement in productivity to compensate for the increased transportation cost. The large scale highway construction now being carried out will make a considerable contribution to easing the difficulties, but is not likely to solve them if industrial development continues at the same rapid pace. Thus, thoughtful planning of factory locations will be indispensable for the efficient use of roads, railways, water, electric power and labour.

In view of the rapidly increasing demand for electric power supply due to the progress of agricultural, industrial and social development in the countries visited, a number of power development projects are being undertaken. However, in all the deltas visited except the Nobi and Cho Shui only limited areas and people have so far been provided with electric power supply, mostly the urban areas. Almost all rural areas have no electric power supply. The fact should be particularly noted that major industrial zones in the countries are often located in the deltaic areas because of the presence of big cities, such as Rangoon in Burma, Calcutta in India and Bangkok in Thailand. Harbours and consumer markets are mostly concentrated in these areas. Accordingly, the provision of adequate electric power supply to the deltaic areas will play a very important role in the economic development of the countries.

3.4.2 Land consolidation

At several places in the deltaic areas visited, hydraulic development has not produced the expected results. This is due partly to the reluctance of the farmers to change from their age old methods of agriculture to modern farming methods and techniques and partly to such factors as the very small, irregular and scattered farm plots, many of which are not directly connected with irrigation and drainage channels or with roads, etc. Under these circumstances, the following disadvantages are evident:

(a) Poor and complicated water control.
(b) The parcels which are remote or difficult to reach get less attention and are usually cultivated less intensively.
(c) More labour is required in farming.
(d) Mechanized farming is made difficult, etc.

These disadvantages can be overcome by a comprehensive land consolidation scheme. In the Nobi delta and also on a smaller scale in the Cho Shui delta, consolidation works are being carried out, most of them in combination with measures aimed at improving the irrigation, drainage and road systems. This combination has the advantages that the irrigation, drainage and road systems can be made more effective and functional at less cost. Figures 21 to 24 show a part of the Hsilo land consolidation scheme in Yun Lin prefecture in the Cho Shui delta. Comparison of the maps before and after consolidation shows clearly the creation of more efficient farm units as well as improvements in the drainage, irrigation and road systems. The layout (shown in figure 24) of an irrigation and drainage scheme in this area would not have been possible without land consolidation. An important additional advantage is that, under these totally changed circumstances, the farmers are more receptive to guidance. Table 8 gives the results for the whole consolidated area. An estimate of the benefits achieved proved beyond any doubt the profitability of the improvement works and

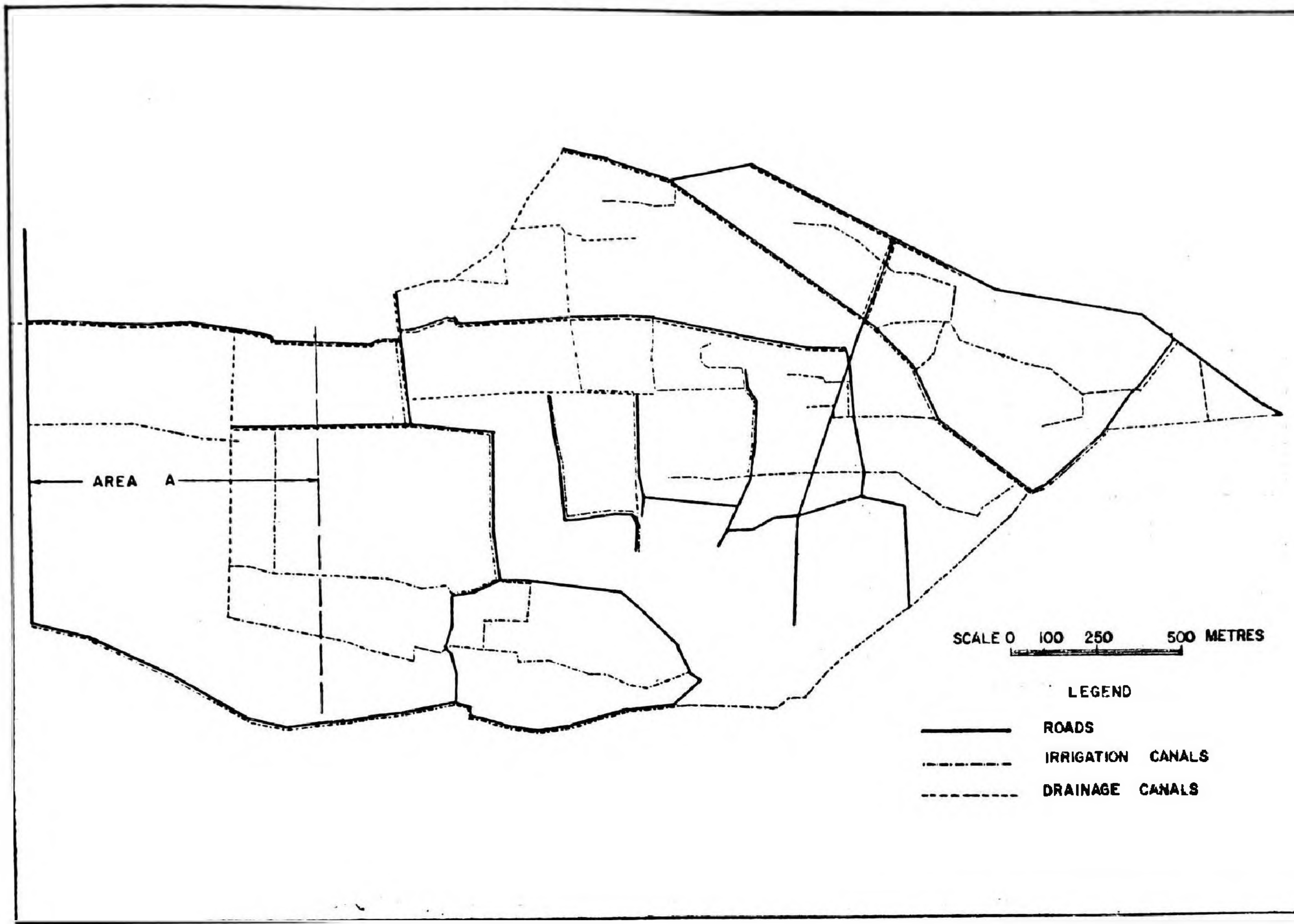


Figure 21. ORIGINAL LAYOUT OF A PART OF HSILO AREA BEFORE LAND CONSOLIDATION

Figure 22. ENLARGEMENT OF AREA "A" IN FIGURE 21

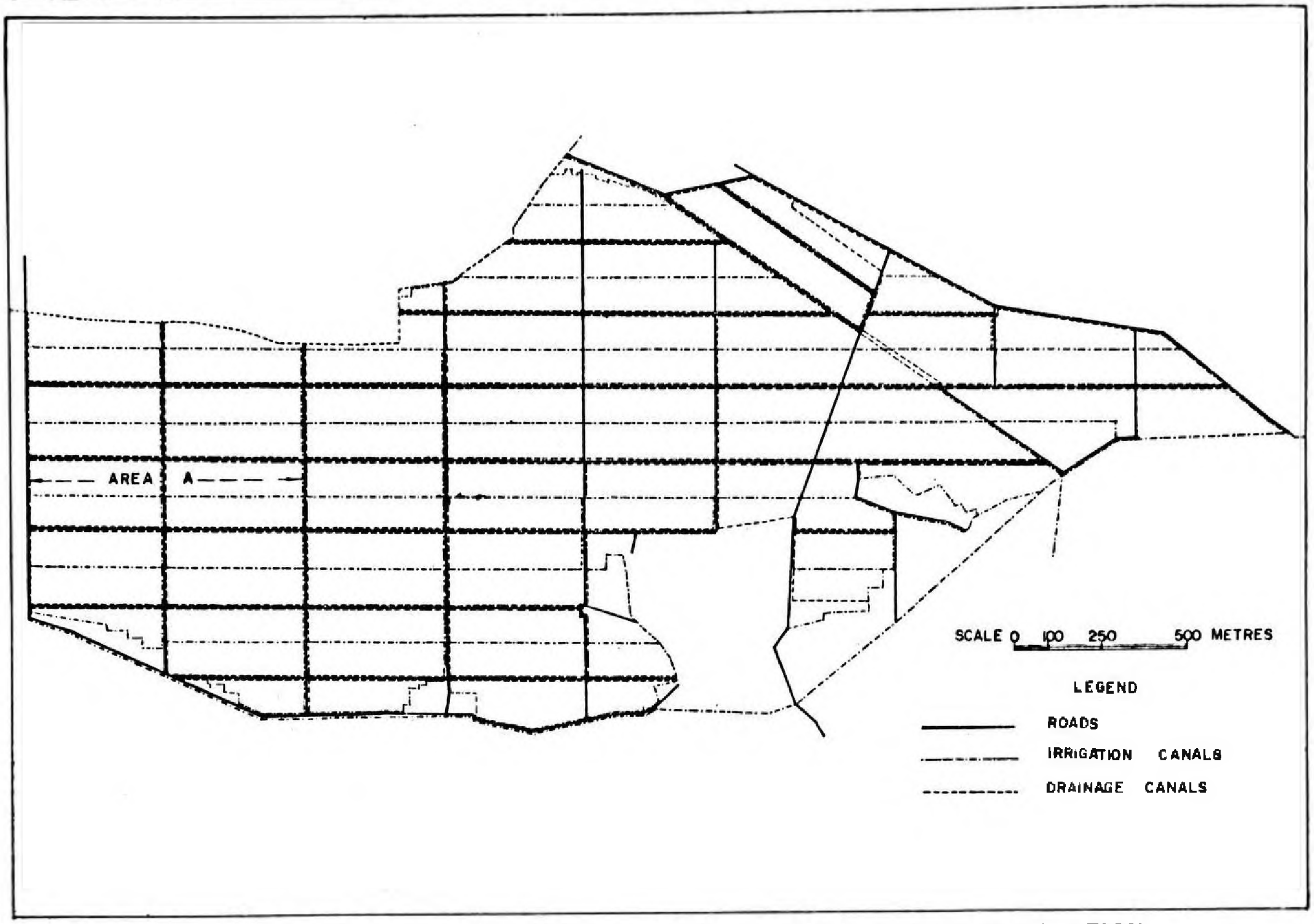


Figure 23. LAYOUT OF A PART OF HSILO AREA AFTER LAND CONSOLIDATION

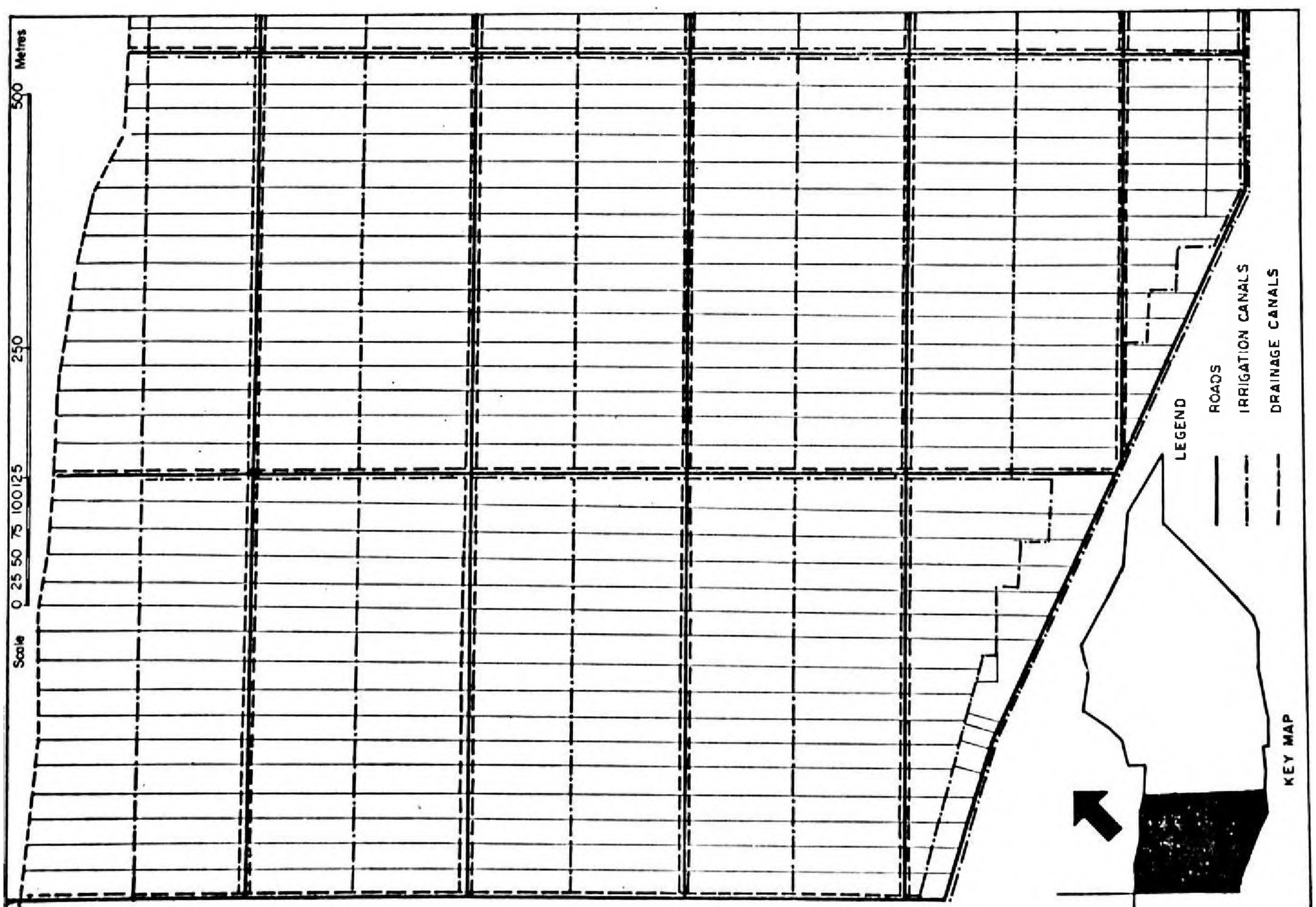


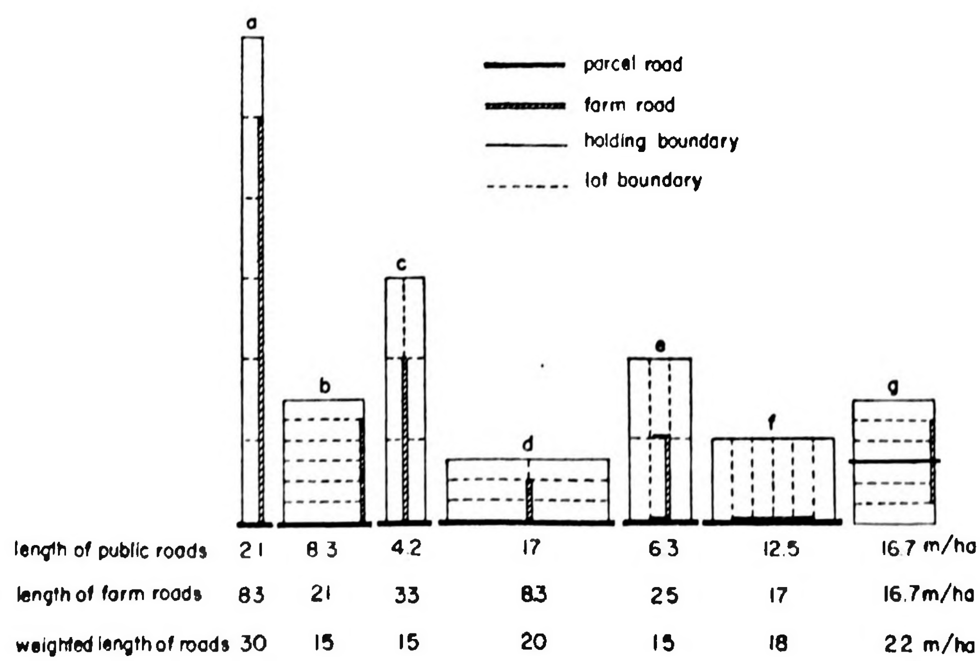
Figure 24. ENLARGEMENT OF AREA "A" AFTER LAND CONSOLIDATION

arrived at the convincing conclusion that a more intensive use of land for the whole area is possible. Not only had the work of the farmers been rendered easier but, at the same time, that of the extension service has become more effective.

In the Netherlands, where land consolidation is an important measure for improving agricultural production, work was started about 40 years ago on a small-scale, consisting mostly of exchanges of parcels. Nowadays, it has developed into a comprehensive measure dealing with the improvement of the whole rural structure in areas ranging from 3,000 ha. to 20,000 ha. The scheme embraces not only the arrangement of parcels, the improvement of water management and soil structure, and the opening up of rural areas, but also the resettlement of farm buildings in order to shorten the average distance between farm buildings and parcels, slum clearance, the installation of water supply and electricity and the enlargement of under-sized holdings through purchases of land and resettlement of farmers in newly reclaimed areas on a voluntary basis. Tree planting along the farmsteads and roads which forms a part of the entire landscape project is also included in the scheme.

The dimensions of parcels greatly influence the lengths of roads, irrigation and drainage canals. Figure 25 shows the effect of the form of parcels on the total length of public and farm roads. The cost of the public road per unit length is, in this example, fixed at three times that of the farm road. Because the total cost of the land consolidation scheme is greatly affected by the total length of the road and of the irrigation and drainage systems, the matter of the size and form of each individual parcel should be given careful consideration. There are, of course, limitations; but, from the engineering and agricultural point of view, this is a very interesting technical-economic problem, especially when the construction and maintenance costs are considered. With very low cost for roads, this does not seem so important, but experience has shown that the maintenance cost for public roads is usually high, especially when the development of the area leads to a desire for metalling or gravelling them.

In the Netherlands, for the reclaimed polders and land consolidation and schemes, many studies of the design are devoted to land parceling working out the layout of the farm units.



Examples of joining 6 lots with definite dimensions to one parcel, and the then required length of public and farm roads; the weighted length is obtained by adding to the length of public roads one third of the length of farm roads (Cost of public roads is 3 times that of farm roads)

Figure 25. INFLUENCE OF PARCELLATION ON ROAD LENGTHS

TABLE 8. IMPROVEMENT RESULTS OF THE HSILO LAND CONSOLIDATION SCHEME IN YUN-LIN PREFECTURE — CHINA: TAIWAN

	Before	*After*
Land area in land consolidation scheme	554 ha	554 ha
Participating farm families	1,136	1,136
Number of farm plots	6,142	2,895
Average size of each farm plot	0.08 ha	0.2 ha
Percentage of farm plots directly connected with roads	31%	98%
Percentage of farm plots directly connected with irrigation channels	26%	99%
Percentage of farm plots directly connected with drainage channels	23%	99%
Percentage of farm families with holdings scattered in more than two places	43%	1%

SOME IMPORTANT BENEFITS

1. Estimated increase in paddy production per hectare = 25%
2. Estimated savings of farm labour = 25%
3. Increase of areas for interplanting due to direct drainage and irrigation facilities of each farm plot = 300%
4. Increased use of compost due to direct accessibility to farm road = 75%
5. Increase in fertilizer effectiveness due to direct irrigation = 30%
6. Elimination of impounding due to improvement of drainage.
7. Elimination of rice blast due to better ventilation between rice plants.
8. Reduction of damage to farm products during transportation due to better road system.
9. Extension and uniformity of farm plots facilities through mechanized farming.

It will be more beneficial if land consolidation is given due consideration when preparing an agricultural master plan which deals with the physical planning of major irrigation and drainage systems, road systems for opening up rural areas, location and extension of horticulture, and areas for future urban expansion and locations for public roads.

Where land consolidation is necessary, it is always advisable to combine improvement works (irrigation and drainage, agriculture and land improvements) as much as possible with land consolidation. It would be more difficult to carry out the land consolidation scheme after completion of the improvement works and after farmers have already invested heavily in their farms.

In the Chao Phya delta, a combination of the scheme for intensifying the irrigation system with land consolidation would render more benefits. In the Cho Shui delta, a rapid execution of land consolidation as part of a master scheme which also provides irrigation facilities for upland crops offers good possibilities for increasing production. For the Nobi delta, where in the near future enlargement of the size of holdings can be expected, the shortest possible road system in the land consolidation scheme is desired from the economic point of view. In the Sundarbans delta, when the construction of tanks is being undertaken, it is also advisable to start land consolidation. As for reclaiming cultivable areas in the Irrawaddy delta, a combination of land consolidation with resettlement of farms offers good prospects.

After the land consolidation has been completed, in order to gain full benefits from it, the following is recommended:

(a) Education and after care. In order to assist the farmers to adapt themselves to the improved conditions, and to make full use of the facilities provided, adequate dissemination of information together with training and demonstrations of modern farming methods are essential. It will be best if this programme is carried out before, during and after the execution of the scheme.

(b) Maintenance. Maintenance is necessary for the good functioning of the system. It is always a good policy in maintaining a water control and road system to give farmers certain responsibilities under the close supervision of a public body. In this connexion, the irrigation associations of China: Taiwan (see paragraph 2.3.2) are good examples. Farmers must be made to understand and feel that proper maintenance for the smooth running of the system is to their own benefit. Hence, requiring farmers to contribute towards the construction cost, operation and maintenance of the works, either in labour or in money, is recommended.

3.4.3 FARM MANAGEMENT

a. *Cropping scheme*

Throughout the deltas visited, crop rotation is not practised in the true sense of the word, except in some parts of the Cho Shui delta, and in the rather limited areas devoted to growing vegetables in each delta, because rice is greatly predominant and occupies the fields during the favourable season each year. Since livestock industry is not developed, the cultivation of perennial pasture grasses or legumes such as clover is not seen anywhere in the deltas. However, following the development of water control project or for other socio-economic reasons, multi-cropping or diversification of agriculture has been started in every delta. For this purpose, the possible measures may be divided into two; one is to shorten and shift rice season to permit the introduction of second or third crops, and the other is true crop rotation by which rice would be replaced by other crops, usually forage crops, for some years. Since the latter may not be feasible for the time being, studies are being concentrated on the former possibility in most of the countries. The breeding of short duration rice varieties has been one of the major objectives. Some of the present improved varieties, which are fruits of the experimentation, mature earlier than the indigenous ones. The work can be developed along the same lines. However the climate at the ripening stage may affect the quality as well as yield of rice. In general, the growth duration s easily shortened when the rice is planted later, but the yield is apt to decrease, whereas early planting ncreases the yield but usually lengthens the growth duration. Since different varieties often behave differently when planted earlier or later, special varieties must be used for this kind of cultivation. As mentioned in paragraph 2.4.2, in the early seasonal method in Japan, rice is planted about 40 days ahead and harvested some 20 days earlier. This means lengthening the growth duration by 20 days. One of reasons for the stabilized high yield obtained by this method, apart from the longer duration, is that the slow vegetative growth in the earlier stage takes place in comparatively cool weather. This method may be adopted in the case of first rice cropping in the Cho Shui delta. In the deltas further south than Japan, when the rice season is shortened or shifted, attention must be paid to shedding, lodging, premature germination and rice quality, aside from the yield. Non-shedding varieties are desirable, especially in the case of autumn rice which is harvested before the end of rainy season. The problem of threshing will be mentioned later. Although the inter-planting seen in the Cho Shui delta is not feasible further south, lodging may increase premature germination, as humidity is the cause of this only in some cases. Further study of dormancy is required for rice breeding, in this respect. In the case of spring rice, the quality is apt to decline due to high temperature. This disadvantage could be overcome to some extent by selection (breeding). Enough study of this principal crop should precede the adoption of multiple cropping programmes by shifting or shortening the rice season.

As for the crop preceding the main rice crop, autumn rice or jute could be tried. Green manure, (Sesbania acculcata or S. speciaa) is also recommended for this season. For the dry season (after the main rice crop), many kinds of pulses, rape horse gram and peas, ground nut, mustard, vegetables and green manure for seed purpose etc., may be introduced. Apart from spring rice, maize and tobacco and, under certain conditions, also wheat and barley would be possible. When short duration varieties are used in the dry season, three croppings a year may not be difficult. Some kind of trial should be made with each crop. Fertilizing and care-taking are essential to make multi-cropping possible without sacrificing the yield of the principal crop; hence green manures as a substitute for or supplement to chemical fertilizers must not be neglected. A suitable technique and system of seed correcting on green manure is also required. For introducing commercial crops, such as jute, tobacco and vegetables, enough consideration should be paid to processing and marketing these products. Calculation of the farmer's actual income and expenses must be followed by that of the water requirements for each crop.

Some result was obtained in Japan from experimental rotation of paddy and upland crops in fields hitherto used only for paddy; each was grown for some years in succession. Higher yields of rice are observed after some years of upland crops and there is less growth of weeds. Particularly in the case of deteriorated fields subjected to "Akiochi"[1], a period of growing upland crops produces a remarkable improvement of the soil. However, farmers have not shown much interest in such rationalized farm management, except in the vegetable growing areas, because it involves sacrificing the rice culture in some parcels for several years.

b. *Use of fertilizers*

To increase yield per unit area, fertilizing is an important and indispensable factor. However for most of the countries in ECAFE region except Japan and China: Taiwan, the price of chemical fertilizers is high as compared with that of rice. Thus the amount of application will naturally remain limited, unless some measures of supplying cheap fertilizers are established. Nitrogen is most effective almost everywhere, but there are places covering a fairly large total area where the effect of phosphorous is distinct, for example, the cat-clay area in the Chao Phya delta, and in Myaungmya and Bassein districts of the Irrawaddy delta. The effect of potassium is comparatively low in general. in Thailand fertilizer trials on farmers' fields have been carried out since 1958 on a nation-wide scale, and the economical dose of fertilizers in the Chao Phya delta has been found to be 25.0 to 37.5 kg/ha for N as well as for P_2O_5. Also the effect of rock phosphate, which is cheaper, has been found to be almost the same as that of superphosphate. The standard of 100 lbs/acre of ammonium sulphate adopted in India agrees with the results of experiments made in Thailand. The results of trials in Thailand show 30 to 40 per cent increase in yield when nitrogenous and phosphorous elements are used together in the above amount.

Wherever rock phosphate or bone meal is available, the use of green manure is quite desirable. With some of the quick growing avenue trees or canal or field bunds shrubs, much as Glyricidia maculata or Tephrosia candida, which produce a good quality of leaves, as much as 13.5 to 18.0 kg (30 to 40 lbs) of green matter from a tree may be utilized as bulk green manure. Further study should be to find what is the best result obtainable from utilizing these limited amounts of fertilizer. Consideration should also be paid to the breeding of rice variety which will then give best response to the light dressing of chemical fertilizers or local fertilizing materials. Prevention of lodging is one of the key factors and the culm length could be shortened in the future when water control

[1] "Akiochi" is the deterioration of paddy soil one of the causes of which is the lack of iron, manganese and other elements. The deficiency results in the generation of hydrogen sulphide (H_2S) which damages the roots of rice plants and reduces their power of absorption.

projects have been completed. A good example is seen in the Chailai variety in Taiwan.

After the completion of water control projects, not much supply of fertilizing elements from natural inundation can be expected and the potential soil fertility may be reduced rapidly by drainage; hence fertilizer application must be considered as a routine farm operation. Without any fertilizing plan, multi-cropping should not be undertaken. A fertilizing scheme for a long term is required in Cho Shui delta where multi-cropping is intensive.

c. *Mechanization*

There are two approaches to the mechanization of field operations, namely: (a) partial mechanization by small or middle sized equipment as is being done in Japan at present, and (b) mechanization by large machinery, which prevails in the United States and a few other countries. Starting from type (a) and approaching type (b) gradually is one way, and starting from type (b) directly is another. Type (a) was started in the Cho Shui delta and a shift from type (a) to type (b) is likely in the Nobi delta. While both types are possible in the other deltas visited, a selection must be made by the governments concerned according to the socio-economic situation.

In this case, government sponsorship or the formation of co-operative farming societies would be indispensable. However, co-operative farming is the most difficult among the activities of co-operative societies. Therefore it might be necessary to provide an incentive such as the completion of irrigation or reclamation schemes, because water control and road systems should in any case precede farm mechanization.

Due to the heavy soil and to the poor drafting ability of cattle, mechanization of work on land preparation is quite desirable in most of the deltas visited, especially where multi-cropping is to be practised. Land preparation for upland crops is most difficult in the dry seasons. Hard soil may be softened by inundation for a day or two and, when the soil moisture is adequate, the various operations of soil preparation such as plowing, harrowing and seeding should be done in quick succession, for otherwise tilled soil may become hard again and proper soil moisture for operation and for germination may be lost by rapid evaporation. Various cultivator or tractor attachments widely adaptable to different places are recommended and workshops for simple repairs should be provided at the co-operative or government tractor centres. Where water control has been completed, drill seeding should be tried by a method similar to that used for upland crops. Small and medium-sized power cultivators have been improved and well developed in Japan and to some extent in China: Taiwan. However, equipment used should be adapted to the different types of soils in the indigenous lands. In the Nobi delta, power tillers are mostly owned by individual farmers despite their small holdings. Even for double cropping, from the economic point of view their machines cannot be considered as fully utilized, though they are also used for transporting farm products. This is the direct result of the subsidized high price of rice.

Loss of rice grains through shedding before and during harvesting is generally much higher than estimated by farmers, especially when reapping is delayed. It is estimated that the adoption of non-shedding varieties would result in gains more or less equivalent to the increase in yield achieved through using fertilizers. However, non-shedding varieties are usually not welcome by farmers unless proper threshers are available. This anomaly well illustrates the reluctance on the part of the farmers to change the rice varieties in Japan. Old fashioned methods of threshing are prevalent in the deltas of Sundarbans, Irrawaddy, Chao Phya, Mekong and to a much lesser extent also in Cho Shui.

Mechanization is also desirable in disease and pest control work. This subject is dealt with in a later paragraph.

Lately, Japan's Ministry of Agriculture and Forestry decided on a policy aimed at improving the general agricultural conditions, such as by widening farm roads in the process of land consolidation and introducing big-sized combines for mechanization. In carrying out this policy, some difficulty was experienced in threshing, because most of the improved varieties of rice have non-shedding characteristics and the climate at the harvesting season is not as dry as in the other deltas. Rice straw cannot be utilized for making rice bales or for other uses when harvested by combines; but paper sacks are beginning to replace straw ones. Transportation on a bulk cargo system and bulk storage in bins with driers are being studied. The sowing of rice seeds from the air was started recently in northern Japan. Newly reclaimed polders such as Nabeta in the Nobi delta or Hachiro-gata (still under construction) in northern Japan offer the best fields for trying out this method. This should also be tested in some places in the Irrawaddy delta, where the farmers' holdings are comparatively large and labour supply is short.

d. *Crop protection*

Damage caused by insects, including several species of stem borers and leaf-hoppers, is more serious in all the deltas visited than damage due to plant diseases. Rice blast is said to be found in districts where the disease never existed before. In the Sundarbans and Irrawaddy deltas, symptoms similar to bacterial leaf blight or seasame leaf blight are found frequently in the fields and these symptoms usually become apparent at the same time as damage by salinity. A comprehensive survey of these maladies should be undertaken before a programme for control is planned, especially after the introduction of double cropping for fertilization. Since early detection of the diseases is important for effective control, proper training of personnel, such as members of farmers' associations, farm advisers or even school children, should be undertaken. For this purpose, the reinforcement of existing research stations with both personnel facilities should be made. The target should be the establishment of a network of forecasting and control units manned by responsible officials and provided with enough stock of chemicals and equipment. A good example of this is found in the Nobi delta. To make the control measures more effective, power sprayers or dusters are desirable. The use of helicopters or planes is also becoming popular in the Nobi delta.

e. *Close relationship between the various aspects of agricultural technique improvement*

There is a close relation between the various aspects of agricultural technique improvement. For instance, after the completion of a water control project, an increase in yields becomes necessary to pay for the project works. Soil fertility may be decreased because of rapid decomposition of organic matters in the soil, due to drainage and decreasing of silt carried by flood water. Fertilizing the land, on the other hand, is thus made possible and is indeed desirable. To promote the effect of fertilizers, equipment for deeper tillage is required and the rice variety should also be changed to suit the new conditions. It may be anticipated that the outbreak of diseases and insect pests will be promoted by fertilizing. Experience also tells us that shifting of crop season and/or introduction of new crops for diversification are liable to induce diseases and pests or damage by birds. Controlling these, which is necessary for securing a high yield, can be effectively practised after providing proper utility roads around the fields. For the cultivation of second crops by water supplied during the dry season, marketing and transportation facilities must be provided beforehand. Consequently, the technical improvement should not be undertaken without taking all these and related problems into consideration.

It is considered, however, that the arrangement of new farming circumstances is the most effective motive for the introduction of new techniques.

3.4.4 Agricultural institution (Incentive to farmers)

The improvement and development of agriculture will result from the combined efforts of both the government and the farmers. Basically, it is through the decisions of a multitude of individual farmers, each assessing his own resources and prospects, that national production targets are achieved or frustrated. If the targets are to be achieved, the government must be successful in its role of solving basic problems and providing essential services so that the farmers will find it to their advantages to accept advice, work harder and invest their own or borrowed capital to increase production and efficiency.

Certain types of investment, for example, large scale irrigation projects, flood control and reclamation, must fall to the government. On the other hand, agricultural production is an industry entrusted to millions of people, including wives and children at the labour level, in vast area of land. Most farmers in the deltas visited have suffered from the vicious cycle illustrated in figure 26, namely low production ⟶ poverty ⟶ rack-renting ⟶ usury ⟶ debt. These result from high farm rents of tenancy for the limited area, marketing handicaps (exploitation by intermediaries, price fluctuations and inadequate margins between farm prices and the cost of new inputs, such as fertilizers) and lack of initiative to make extra efforts to increase production. It is a most difficult thing for any government to decide on a balanced policy in order of need so as to break this vicious cycle. However, the principal policy or measures may be land rent control, land reform, improvement of the marketing system, provision of cheap credit for technically sound development expenditure, subsidies on the cost of fertilizers or farm machinery and programmes for guaranteeing minimum prices, or in limited cases, incentive prices. A government sponsored agricultural bank with a network of country branches should be established to make credit more readily available to farmers so as to enable them to adopt improved practices and obtain production requisites. To achieve the maximum success, attention will have to be paid to the supply of adequate funds for lending, the supervision of production loans and the establishment of simple and flexible operating procedures. Though satisfactory and stable prices are the most effective incentives to farmers, price subsidies should not be recommended for important export crops. Thus government policy should aim at improving the efficiency of marketing. The producers could be helped most by the provision of a wide network of warehousing facilities with inexpensive short-term credit and market outlets, which would strengthen their bargaining power by enabling them to withhold their produce from sale at harvest time in order to await a better price. Facilities like those offered by the Public Warehouse Organization in Thailand should be expanded through the provision of larger funds. A special committee composed of the representatives or producers, consumers, experts on agricultural problems, and the ministries concerned should be established in order to fix prices that are fair to producers and consumers alike. In general the emphasis should be on guaranteed minimum floor prices rather than support prices, but in some instances an incentive price might be necessary to promote diversification or the adoption of improved production techniques such as fertilization. Among related measures, consideration should be given to the advisability of offering a subsidy for the purchase of new requisites so as to encourage their adoption by cultivators. A

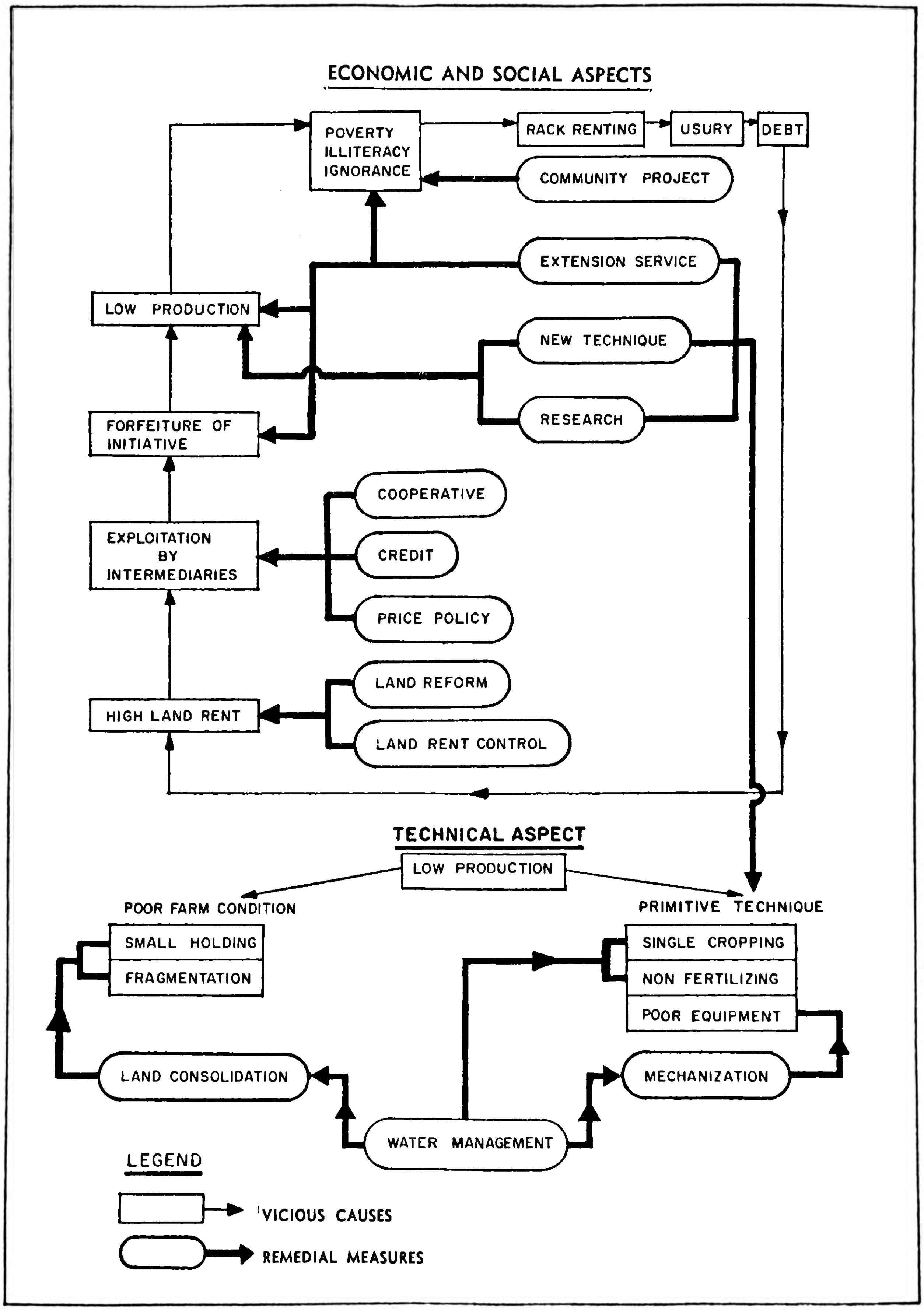


Figure 26. VICIOUS CYCLE AND PROPOSED COUNTERMEASURES

subsidy on transport costs might be more appropriate in some areas. All measures must be focused on eliminating the farmers' age-old state of indebtedness.

Research, basic and applied, on farm production problems, the promotion of self-help through rural community development programmes based on surveys, the extension of available technical knowledge to farmers and the training of agricultural specialists and farm leaders in adequate numbers are also essential services to be expected from the government. Though some of these services, for instance rice breeding, seem to be provided wholly from the government side (by national capital), the farmers' favourable reaction or co-operation is quite indispensable, as stated in paragraph 2.4.3. For the dissemination of new techniques and knowledge, it is very important, however difficult it may be, to station the right personnel at the terminal points of the system, as is usually the case with co-operative activities. If the personnel do not make an effort to win the confidence of the farmers, the system may not produce the desired results. Officials who neglect this are often met with. For carrying out the activities of co-operative and extension services, the personnel need not always be government officials. Apart from orthodox ways of expanding and developing the system, consideration should be paid to utilizing traditional social gatherings such as the socio-religious meetings held in temples which take place frequently and which are more deeply rooted in the farmers' life than government services as a countermeasure against the present shortage of qualified personnel. Existing intermediaries such as the terminal personnel or officials of co-operative societies or extension services may be utilized, after they have been re-educated and trained suitably. In the process, the importance of the human factors should not be overlooked. Thus, it may be useful to educate the village leaders or heads of villages who will then be able to help in inducing the farmers to accept new techniques and ideas.

Another vicious circle in the farmers' life may be illustrated thus: undeveloped communication ——→ isolated society ——→ resigned self-sufficient livelihood ——→ expectation of reward beyond rather than in this present life.

It would be difficult for any government to promote all these measures simultaneously for the whole country and yet remain within the limited national budget and manpower. Therefore, the potential of the government in rendering services in every aspect such as improved farming techniques and methods, credit, marketing etc., should be focussed on the newly improved or reclaimed areas.

In some cases, research and demonstration services are provided by the government departments concerned, such as the Satkhira farm in the Khulna district which belongs to the Water and Power Development Authority in East Pakistan and the Chainat farm for the introduction of second crops which belongs to the Royal Irrigation Department of Thailand. This sort of facility will be most effective if co-operation and co-ordination of the services of specialists from the other organizations concerned with agriculture improvement are also obtained.

3.5 DEVELOPMENT PROJECTS

3.5.1 Agricultural development

The development of agriculture should form a part of the overall government plan for economic development. This is especially important in most of the countries visited, where the economy is predominantly agricultural, with from 40 to 85 per cent of the population engaged in agriculture. The deltaic areas, though forming only a small part of most countries, are of great importance from the agricultural point of view because of their good soil, abundant water, interlaced navigable waterways and comparatively dense population. However, in these deltas, except the Nobi and Cho Shui, the production per unit area is rather low (see paragraph 2.4.2) and offers a large margin for improvement. It is felt that improved agricultural techniques, such as the application of green manure compost and fertilizer, weed control, pesticides, selection of seeds, etc., even if unaccompanied by the extension of the existing water control works, would result in substantial increase in production.

However, the goal should be further development aiming at diversification and larger increases in agricultural production, through intensified agricultural activities in all these countries and through the enlargement of family holdings in some of them. This further step of intensifying agriculture requires a good water control system necessitating execution or extension of major hydraulic works in the deltaic areas.

a. *Intensifying agriculture*

To achieve intensive agriculture, the following measures are required:—

(a) Improved agricultural techniques, such as use of green manure, compost and fertilizers, selection of seeds, weed control, pesticides, etc., as mentioned above.

(b) Diversification of crops and introduction of new crops. In the deltaic areas of southeast Asia, the main crop is rice. There is ample room for diversifying crops and for introducing new crops which have been grown successfully in other deltas. On the natural levees and the young soils of deltaic areas, the possibilities for diversification are great.

(c) Improvement of agricultural institutions, such as experimental farms, demonstration farms, extension services, research institutes, co-operatives, extension of credit and marketing systems, etc.

(d) Multi-cropping and crop rotation.

(e) Land consolidation.

(f) Mechanization.

Items (a) and (b) may be achieved without the extension of the existing water control system in most countries, and may be considered as a first step towards intensifying agriculture. However for items (d), (e) and (f), a good water control system is a prerequisite and thus further development or improvement of hydraulic works is required.

b. *Enlargement of the size of family holdings*

In some European countries where there is competition for labour between agriculture and industry, agricultural productivity has been increased through increasing the size and efficiency of farm holdings. The result is an increase in agricultural production even with a decrease in farm population.

Such a change is only possible when there is sufficient employment outside agriculture. In Nobi delta where such a great expansion of industry took place, the agricultural production may have to be maintained by land consolidation. The part time farming practices there at the present which result in decreasing yield should be discouraged.

At some other places in the deltaic areas, enlargement of undersized holdings appears possible if associated with reclamation of non-cultivated areas to provide land for displaced farmers. However, opportunities for such expansion seem to be limited.

3.5.2 Hydraulic development—partial schemes and master plans

In the foregoing much attention has been paid to the gradual further development of the deltaic areas in the ECAFE region. It has been pointed that, by comparatively inexpensive measures in the field of agricultural techniques, productivity can be substantially raised, yet these measures do not require the execution of major water control works. On the other hand, further utilization of the natural resources of the deltaic areas does require the execution or extension of major hydraulic works. The examples of the Irrawaddy delta (paragraph 3.2.3.) and of the Chao Phya delta (paragraph 3.3.3.) show that further improvement of major water control can be implemented by steps based on partial schemes.

There are both technical and economic reasons for adopting a gradual extension of the major water control system. The various steps can be judiciously planned so as not to upset the hydrologic conditions. Priority can be given to those areas which, by virtue of location, topography and soil conditions, are either the most promising from the economic point of view or the most attractive from the technical point of view. The improvement, for example, of the drainage conditions of the coastal regions in the deltaic area of the Chao Phya will have favourable repercussions on the hydrologic conditions in other parts of the delta. From the economic point of view, priority may be given to areas situated in the vicinity of growing commercial and industrial centres (Calcutta, Khulna, Rangoon, Bassein, Bangkok and Saigon).

Improvement by stages is in accord with the policy for the development of the vast deltaic areas already adopted by many countries in the ECAFE region.

There is, however, one essential factor which should be taken into consideration, but which up till now has not received sufficient attention. This factor, which underlies the ultimate object of all works to be carried out, can be defined as the perfect control of natural conditions. This means that any partial scheme should fit into a well-balanced master plan in which the deltaic area, together with its river basin, is considered as one entity. It is only in this way that a satisfactory situation will finally be attained.

Examples of unsatisfactory situations due to a lack of overall-planning in the early stages of the development are: bad alignments and poor design of the "village-bunds" (ancient coastal embankments) in the delta of the Sundarbans and the poor drainage facilities of the bunded areas, the unsatisfactory drainage conditions in the areas protected by the horseshoe-shaped embankments in the deltaic area of the Irrawaddy river, the improvement of certain areas in the delta of the Chao Phya river without improving the major drainage outfalls to the sea, the improvised lay-out of the dense network of canals in the deltaic area of the Mekong river, etc. Other examples can be found in the gradual extension of reclamation of tidal foreland in Japan without considering the ultimate situation, and the lay-out of major drainage cum irrigation canals in areas exposed to salt intrusion in the deltaic area of the river Rhine in the Netherlands.

Good examples of planning with a view to the future are provided by the investigations aiming at a scheme for enclosing major creeks and estuaries in the Sundarbans in India and the provisions for supplementary irrigation in the Chao Phya area by means of the Chao Phya headworks at Chainat (paragraph 2.3.1.).

Overall planning of reclamation works in deltaic areas is more urgent than planning the upstream river reaches, firstly because of the intimate relation between flood protection drainage and irrigation and the greater degree of mutual influence of these works on various parts of a delta, and secondly because adequate water control in a deltaic area can only be achieved by comprehensive large-scale measures.

The elaboration of the master plan should be carried out concurrently with the collection of basic data (Paper I). In this way the most urgently needed data can be collected and any gaps in the information will be noticed at an early stage.

Master plans are subject to periodic revision to make allowance for the actual execution of the partial schemes as dictated by the economic conditions and to make allowance for porgress in technical methods. Yet they do effectively guide development.

In conclusion, before embarking on a scheme for the gradual improvement of deltaic areas, it is desirable to check whether the partial schemes would fit into a comprehensive master plan.

APPENDIX I

SOIL FORMATION IN DELTAIC AREAS *

Preface

This appendix outlines the soil formation processes in deltaic areas. Stress is placed upon the importance of soil classification and of the knowledge of agriculture gained from the research carried out. It serves as additional information for the chapters on soils in the Report of the ECAFE Mission on Deltaic Areas submitted as a background paper for discussion at the Regional Symposium on Flood Control, Reclamation, Utilization and Development of Deltaic areas (ECAFE, Bangkok, 2-9 July 1963).

The basic information used in this appendix was taken from the publications mentioned in the bibliography attached, from field experience gained in temperate areas, mainly in the Netherlands, discussions with various specialists, field observations and from analytical data of about a hundred soil samples collected from the deltaic areas of the rivers Ganges and Brahmaputra (the Sundarbans delta in India and East Pakistan), Irrawaddy (Burma), Chao Phya (Thailand), Mekong (Cambodia), Cho Shui (Taiwan), Kiso, Nagara and Ibi (Nobi delta, Japan).

The field observations were made and the samples were collected by the author during the field inspection trip of about three months of the ECAFE Mission on Deltaic Areas. Pedological investigation was not the main object of the field inspection, consequently the taking of samples and the observations were of a more haphazard nature than they would have been for purely pedological purposes. Nevertheless the results should be useful, considering the fact that it was possible to analyse samples of such diverse origins by identical methods in a single laboratory specializing in soil chemistry and the physics of alluvial soils.

The results of analysis seem to correspond with facts collected in temperate areas; some cast a new light on old problems. There was not much opportunity to make ecological observations from the vegetation point of view. Some ecological notes were included in the report of the mission mentioned above. The lack of time made it impossible for the author to make a more elaborate study of Asiatic literature on the subject. Consequently, important data that were available might have been neglected, and the conclusions arrived at might not be new. Nevertheless, the author hopes that this appendix will be of interest to soil scientists working on these very important soils.

The author wishes to thank all the authorities concerned in India, East Pakistan, Burma, Thailand, Cambodia, the Republic of China, and Japan for their help in collecting as much information as possible. The author also thanks the head of the "Bodemkundig Laboratorium van de Rijksdienst der Ijsselmeerpolders" and his staff for their kind assistance and skilful analytical work and Dr. L. J. Pons for the valuable data and information on deltaic area soils of Surinam. The author also thanks the translation department of the Netherlands Ministry of Foreign Affairs for its linguistic assistance. The cost of transporting the samples and of laboratory analysis was borne by the Netherlands Government.

The author bears the responsibility for the final form of this paper and would ask the reader's indulgence for the absence of a broad study of the literature on the subject and for any omissions and shortcomings in the discussions or conclusions.

1. Introductory notes

It is convenient to subdivide the study of alluvial soil formation into geogenesis and pedogenesis, the former being a geological process and the latter a pedological process in a narrow sense. For sediments deposited in the rising and falling water zone, the dividing line between them can be determined at the very moment the sediment (the parent material for soil formation) is deposited. Any acquisition or alteration of properties before that moment is geogenesis. Any subsequent process is pedogenesis. Geogenesis comprises all the sedimentation and erosion processes that give rise to and influence the physical, chemical and biological properties of the sediment, which is the parent material of alluvial (i.e. marine and fluviatile) soils.

Pedogenetic studies concern changes in the sediment after deposition. A principal factor in pedogenesis is aeration, but pedogenesis can also take place under reducing, anaerobic conditions (e.g. sulphate reduction, decalcification, fermentation). In underwater sediments on lake bottoms etc., it is useful to regard pedogenesis as starting at the moment the

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covering water is removed (in most cases artificially) and the sediment is more or less suddenly exposed to the air and/or the direct influence of plants. In regularly flooded areas such as river plains, coastal plains and deltas, sedimentation (geogenesis) and soil formation (pedogenesis) alternate or even occur simultaneously.

The influence of both geogenesis and pedogenesis on the actual ecological (agricultural) properties and condition of the soil is important. It must be grasped before one can understand the soil.

2. Geogenesis

2.1 *Mineral texture*

A very important geogenetic property of a sedimentary soil is its mineral texture. It depends on:

a. the material available in the hinterland;
b. the velocity and turbulence of the sediment-bearing current during sedimentation.

The turbulence depends on:

1. general hydrological conditions;
2. the distance from the main current;
3. vegetation;
4. the actual height, frequency and duration of submergence.

A great turbulence during sedimentation causes deposited sediments to consist of coarse sand or even gravel. Very quiet conditions produce finely textured, often clayey deposits. Alternating conditions of current occurring in flood plains and coastal plains cause a stratification of textures ranging in depth from a few millimetres to a few metres. The latter depths only occur as a consequence of great geological changes, such as changes in sea level in relation to the level of the land.

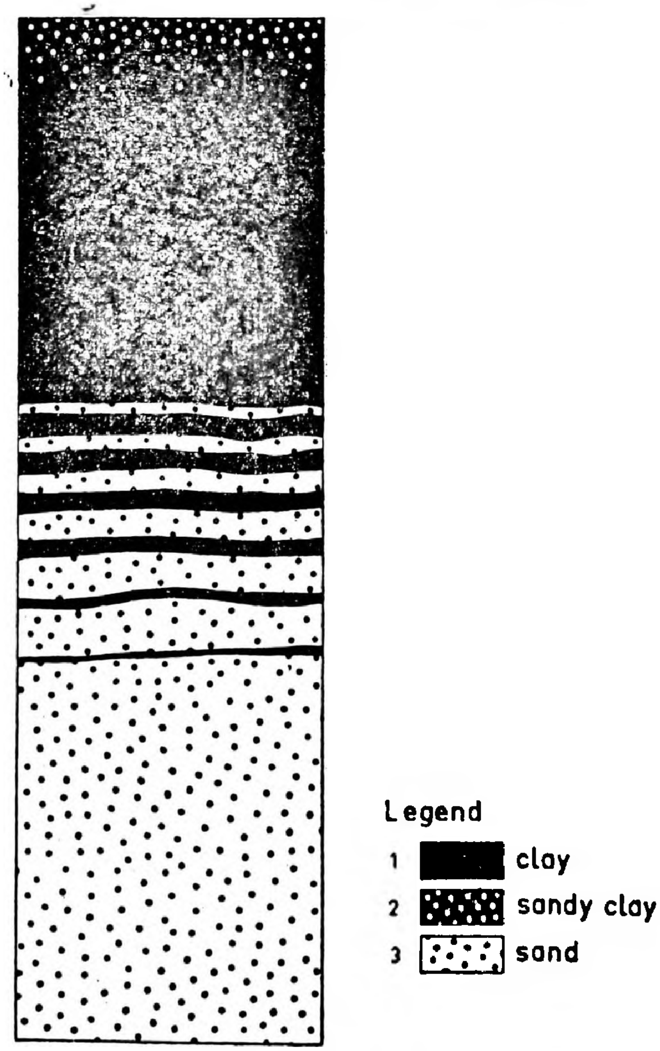
Stratification occurs because a higher current velocity is required for the erosion of a sediment of a certain textural composition than for its sedimentation (Hjulström's Law). So sediments with a fine texture deposited in quiet conditions may be covered by sandy sediments during periods of greater turbulence without the finer textured sediment being eroded. Cohesion between the fine particles themselves and adhesion due to organic matter from living organism are responsible for that phenomenon. Moreover, current velocity just above the soil surface is lower than higher up i.e. in the sedimentation zone. This elementary hydrodynamic phenomenon is accentuated by the presence of vegetation.

Mineral texture influences the process of pedogenesis, the actual chemical fertility of the soil and the structure and workability of the land (because the clay fraction is the major adsorption complex for cations and water). Mineral texture determines permeability. Coarse sediments are always permeable, whereas soils with a high clay content are permeable in dry conditions (because of cracking) but very impermeable when permanently water-logged (see also 3.2). Capillarity makes silty subsoils difficult to drain.

What can be done in the way of hydrological improvements and the planning of these improvements largely depends on how much is known about the horizontal and vertical extent of the texture.

The clay content in the vast flat deltaic areas of large lowland rivers (e.g. the Ganges, the Brahmaputra, the Irrawaddy, the Chao Phya) is generally higher than in small deltas with a mountainous hinterland in their proximity (Cho Shui, Taiwan, the Nobi delta, Japan).

In the latter two deltas, the fine silt fraction appears to be relatively greater than in the larger deltas of the lowland rivers in the Far East and in Western Europe. In these larger deltas the ratio of particles $< 2\ \mu$ to particles $< 16\ \mu$ is about 2:3 in most marine sediments and from 1:2 to 2:3 in the brackish and fresh areas (see table 1). The analytical data show, however, that in the Cho Shui and Nobi plains this ratio is often lower than 1:2. Apparently this is partly due to the fact that shale fragments do not have time to disintegrate in the relatively short rivers and partly because in the small deltas hydrodynamic conditions are not calm enough for the deposition of clay.



Appendix I: Figure 1. SKETCH OF THE PROFILE OF A SEDIMENT FORMED UNDER STABLE GEOLOGICAL CONDITIONS

Soils of different textures are distributed throughout the deltaic areas in very definite patterns closely related to the topography (see 2.2). The diagram in fig. 1 shows a sediment formed under stable geological conditions. Which material will dominate depends on the hydrodynamic situation during sedimentation. Sometimes it may be the sandy basic layer (sandy ridges), sometimes the clayey layer (back swamp). The levee will often be intermediate. The lighter texture of the top soil is due to the fact that the high floods that deposit the top layer sediments are relatively more turbulent than those which deposit the lower ones.

2.2 *Topography and physiography*

Sedimentary soils are characterized by a flat yet very distinct topography, one which is very important in relation to "associated land features", especially to the hydrology. In water-logged areas, such as deltas, a difference in ground height of a few decimetres may affect the sedimentation a great deal. As a rule the deltaic area slopes from its apex to the sea, but the gradient is steeper at the apex than it is near the sea. The area nearest the sea is often a little higher as a result of the formation of coastal ridges or higher flats caused by the relative rise in the level of the sea during the formation of the delta.

Each of the deltaic areas visited can be divided into three zones according to the differences in topography, soil conditions, ecology, etc. as follows:

a. the marine zone, where most of the sediments are deposited in salt or brackish water under tidal conditions;
b. the transitional zone, where the effect of tides is still felt but the salinity ranges from brackish to zero;
c. the upper zone, which is unaffected by tidal movements and where salinity is zero.

There is often considerable water-logging in the transitional zone and in the back swamps of the upper zone.

As a rule, there are some slightly elevated strips (natural levees, coastal ridges) along the river channels and the seashore. These strips usually have a slightly lighter or much lighter soil texture than the back swamps or basins between the channels, because the most easily deposited (i.e. the more sandy) component and also the largest mass of sediment per unit of area settle nearest to the source of the sediment.

The contrast between sediments at the levee and in the basin decreases from the apex of the delta towards the sea, due to the levelling effect which the area close to the sea has on all natural phenomena, such as floods and the concomitant precipitation. Therefore, it is in the upper part of a delta that the contrast is greatest.

Artificial or natural "spill soils" occur at several places; they are the result of breaches in dikes or in natural levees (Ganges, Kobadak).

There are some variants on the principles of soil formation of the levee-basin phenomenon in areas where tidal movements are considerable and counteracting flood and ebb currents occur. Here the hook-shaped or horse-shoe shaped initial levees of sand and silt are formed where ebb and flood currents meet (ebb and flood "schaar" system) which silt up and form islets (called "opwas" in Dutch, in contrast to "aanwas" which is a lateral accretion linked with the shore). The saucer-shaped islets called "dwip") of the Sundarbans in Bengal are typical "opwas" islands in an area where there are counteracting ebb and flood currents.

Often several series of coastal ridges were formed parallel to each other with back swamps in between.

Parallel ridges occur in many places where currents run roughly parallel to the coast (Surinam, the Netherlands, parts of the Mekong delta, etc.) and are probably related to periodical changes in sea level and river discharge. A coast with a relatively large number of "opwas" islands is probably a sign that there has been a relative rise in the level of the sea (Sundarbans), whereas "aanwas" is probably a sign that the level of the sea is either stable or falling.

If enough sand is supplied by the rivers and/or the sea, coastal ridges may have a very sandy texture, causing sand beaches and sand dunes to form. Dunes often shift inland, as was the case with Frasergange and Sundarbans in India.

As a rule the levees and ridges are better drained than the back swamps. Peat formation often occurs in the wettest part of the swamps, especially in a natural fresh water environment in the transitional zone of deltaic areas, in constantly humid climates (see also 3.2.2). Peat may even occur in brackish water in such a climate.

If the horizontal growth of the alluvial plain is rapid, peat formation may even become ombrogenic, i.e. proceed vertically to well above the level up to which the influence of groundwater is felt.

The formation of peat is often interrupted by the precipitation of mineral sediments as a result of the transgression of the sea. Therefore stratification of peaty and mineral layers is seen in deltaic areas all over the world. Transgression also causes stratification in purely mineral sediments.

In areas with a distinct dry season, some peat formation in the permanently wet parts of the back swamps in the transitional zones of the deltas has also been found (Sundarbans delta in India and Pakistan).

In cultivated areas in the tropics, water-logged back swamps are generally used as rice fields and occasionally for jute and other crops that can be grown in water-logged soil. Houses, villages and towns are built on the natural levees, and several types of horticultural crops are grown.

2.3 *Some other physical and chemical properties of sediments*

The source of a sediments determines some of its chief properties. The mineralogical characteristics of sand and clay and their lime content are also indicatives of the sources. The hinterlands of some tropical deltas are composed of heavily weathered geological formations that can only produce relatively senile material.

Richer parent materials can be expected where there are young mountains or young volcanic deposits. Marine sediments will usually be enriched with minerals present in seawater (e.g. calcium, potassium and several trace-elements), and clay minerals may be altered somewhat. Mixtures of haloysite, kaolinite, illite, mica, etc. are said to have been found in the deltas of the Far East. Unfortunately, we have not examined any of the clay minerals in our collected materials so far.

The base exchange capacity in most of the samples, except those from Taiwan, is not very low and is similar to that of illite or the above-mentioned mixture (50-60 m val/100 g clay). The Taiwan (Cho Chui Shi) clay minerals have a lower adsorption capacity. Most of the clay minerals in the young delta soils seem to have come directly from the hinterland.

There are sevaral theories as to the origin of the lime. The lime content of river sediments in tropical areas is often low, because the heavily weathered hinterland has lost its lime already. Others probably contain rock fragments, especially in the silt fraction. Marine sediments often contain lime, probably accumulated by organisms (Foraminifera, Molluscs, Echinodermata, etc.). Some of it may have been precipitated by purely physico-chemical means or by such organisms as bacteria or algae. It is the lime content of sediments that determines the characteristics of the soils developed from them. The structure of the soils and whether or not acid sulphate soils will occur depend on the presence of lime (see 3.3.1, 3.3.2 and 3.3.4).

The chemical composition of the river water is another important factor in the ecological nature of tropical deltas. It affects crops not only directly but also indirectly through the effect it has on sediments and soil formation. This is especially true if the area is regularly flooded with river water and no artificial fertilizers are used. It is mainly the minerals that are dissolved in the water and that may be forthcoming from the mineral and organic components of newly deposited sediment that determine the chemical fertility of the soil. If the hinterland is heavily weathered the river water will be poor in chemicals, as it is in the Tista (Bengal). If the river passes through areas which are somewhat richer chemically, its chemical fertility will be more favourable, as it is in the Brahmaputra.

Water passing through cat-clay areas (see 3.3.2) may actually be toxic to crops, because of its free aluminium content (as it is in parts of the Mekong and Rangsit areas in Vietnam and Thailand). Rivers passing through poor soil areas with podzols or peats may carry brown but transparent water. It is coloured by organic acids which have a powerful leaching effect (as in several of the tributaries of the Amazon).

The enriching influence of sea-water (especially of the potassium it contains) on the sediment has already been mentioned. It can only benefit plants (rice, jute and many other cash and horticultural crops) as soon as the toxic concentrations of sodium and chlorine have been reduced (desalinization). As already mentioned the organic matter in the sediment also determines the nature of the soil. Before sedimentation, i.e. in the geogenetic phase, some of the organic matter exists in the form of aquatic plants and animals, especially plankton, and some comes from the hinterland. The type of plankton largely determines the characteristics of the organic matter. Organic matter of zooplankton for instance will generally contain more nitrogen and phosphorus than phytoplankton. There is more phytoplankton in rivers and more zooplankton in the sea. In the samples in table 1 there is, however, no clear difference in this respect between sea and river deposits, whereas the difference is obvious enough in the Rhine delta.

2.4 *The fertilizing effect of river floods*

It is clear from the foregoing that although the general belief that flooding with river water increases fertility is well founded, it is not always true. The belief probably originated from the arid areas around the Nile, the Euphrates and the Tigris from which regions our agricultural and urban culture came.

Moisture is indispensable to agriculture and is broadly speaking also part of the fertility brought down by rivers. The matter is not so simple when we consider fertility in the narrow sense of the term (chemical fertility). Moreover, a part of the chemical fertility resulting from flooding only manifests itself indirectly through processes of soil formation in the mineral and organic sediments. These processes and their influence on soil fertility are dealt with in the next chapter.

3. Pedogenesis

3.1 *Introductory notes*

Pedogenesis in alluvial soils can be subdivided into:—

a. Initial alluvial pedogenesis, or in Dutch "Rijping".

b. Subsequent alluvial pedogenesis.

The first includes all the processes that turn a wet and immature sediment, which is often soft, into a more or less firm soil suitable for crops, etc., or at all events turn it into a soil with properties differing from those which the sediment originally possessed (sometimes they may be less desirable properties). The second includes processes ultimately resulting in obsolescence and diminished fertility, degeneration, severe weathering, the translocation of fine particles (lessivage), podzolisation and laterization in tropical areas.

The latter processes only occur in delta deposits several hundreds of years old often occurring in terraces. Most relatively young alluvial soils (both marine and fluviatile) are at some stage of initial alluvial pedogenesis or on the threshold of subsequent soil formation.

Initial alluvial pedogenesis can be subdivided into:—

a. Physical pedogenesis
b. Chemical pedogenesis
c. Biological pedogenesis.

These three groups of processes take place simultaneously and interact; (a) is (by definition) mainly restricted to initial soil formation, (b) and (c) also extend into the subsequent soil formation process. (c) will be discussed in greater detail in 3.2.2 and 3.3.1. The tendency of soil organisms to mix the soil is most important (homogenization). This results in a better structure and prevents the leaching of lime and other soil components.

3.2 *Initial physical alluvial soil formation* (physical "rijping")

3.2.1 *General aspects*

The almost irreversible contraction processes involving the colloidal particles of the soil, clay and humus are summarized under the heading "Physical alluvial pedogenesis". This contraction is due to the capillary attraction resulting from the removal of water (dehydration) by direct evaporation, and in the deeper horizons mainly by the transpiration of plants and partly also by the pressure of the overlying top soil. The water forms a film round the colloidal particles and partly fills up the gaps between them. The particles arrange themselves in a kind of honey comb structure. Rewetting does not cause them to revert to their original arrangement, because the hinge points in the honeycomb structure can only be affected by capillary attraction during dehydration and not by rewetting. Rewetting can only alter the moisture content because of the spongy nature of the honeycomb, of the clay minerals themselves (especially montmorillonite) and of the adsorbed cations (Koenigs, 1960).

One of the consequences of the changes in microstructure is a reduction in the total volume. The gaps between the colloidal particles become smaller and the soil becomes firmer. The most spectacular shrinkage is seen in sediments suddenly exposed to the air, such as deposits in drained lakes. Here horizontal shrinkage produces polygonal patterned cracks.

The water-retaining capacity of the soil is related to its microstructure, growing smaller as initial physical pedogenesis proceeds. So its water-retaining capacity, which is easy to determine, would appear to be a good yard-stick by which to measure the progress of initial physical pedogenesis. The capacity depends, however, not only on the stage reached but also on the quantity of water-retaining components in the soil.

The following formulae, in which the water contents of the main soil components are totalled, give a reasonably simple rendering of what is really a very complicated process. The water content (n) of the clay mineral illite is taken as the standard, called the "water factor" or "rijpingsfactor" or "factor of initial phyical soil formation" (F.I.S.).

$$A = nL_i + nb_1L_1 + nb_2L_2 + nb_3L_3 + \ldots\ldots \text{ etc.} + nb_hH + 0.2R \quad (1)$$

$$\text{or } n = \frac{A - 0.2R}{L_i + b_1L_1 + b_2L_2 + b_3L_3 \ldots\ldots \text{ etc.} + b_hH} \quad (2);$$

in which

n = water-retaining capacity of 1 g illite in g

A = water content of 100 g dry soil in g

L (lutum) = the clay content of 100 g dry soil in g; 1, 2, 3 etc. indicating the various clay minerals, i being illite and b_1, b_2 etc. being the ratio between the water-retaining capacity of the various clay minerals to that of illite

b_h = the ratio of organic matter to illite (for real humus this is about 3:1)

H = organic matter content

R = non-colloidal part of the soil = 100 — H — L

0.2 = approximately the water-retaining capacity of the non-colloidal part of the soil (mostly sand and silt) at each stage of physical initial soil formation, which can be found experimentally and by calculation.

The water-retaining capacity of the mineral clay fractions will be found to be related to the cation exchange capacity. So if no data on clay mineral composition are available, equation (2) may be modified to read:

$$n = \frac{A - 0.2R}{\frac{E}{60} \times L + b_hH}$$

E = cation exchange capacity of 100 g of the clay sampled in m-val,

60 = cation exchange capacity of 100 g clay composed predominantly of illite, in m-val.[1]

In the formulae, the quantities of water retained by the various mineral and organic soil components are simply added up, assuming that the water-retaining capacities of the clay and organic fractions change at the same rate during initial pedogenesis. The water-retaining capacity of the other fractions (mainly sand and silt) in the temperate deltas in Western Europe appears to be constant at about 20 g water to 100 g silt and sand (dry weight).

[1] which is normal in most West European deltaic soils.

As A, L and H are easy to measure, n can be calculated if the values of b are known. It has already been said that the A factor may vary somewhat, although as a rule dehydration is irreversible. Therefore, comparisons should only be made between data from samples taken under comparable conditions, i.e. soil samples taken at field capacity. The figure for n cannot be measured in soils with less than about 8% of clay or less than 3% of organic matter.

The value of b for well-humified organic material is about 3. This is also the ratio of its cation-retaining capacity. For incompletely decomposed organic matter, the value of b for cation exchange capacity is smaller, because the colloidal internal surface for cation adsorption is smaller per unit of organic material. The value of b for water adsorption, however, seems to be greater than 3, owing to the cavities of intact plant tissues, which can hold a great deal of water. Sphagnum water-cells, for instance, can retain large quantities of water. Therefore, the values of b can be very high in peaty material (up to about 9 for young Sphagnum peat).

For mineral soils containing some incompletely decomposed remains of plants (A_1 horizons), b can be from 3½ to 4.

The physical "rijping" of peat soils containing large quantities of incompletely decomposed material also has its problems, because the irreversibility of initial physical pedogenesis is then not so obvious. In some heavily humified kinds of peat (e.g. some gyttjas and old peaty soils) irreversible dehydration can be very extensive, so that the soil no longer holds enough water to support plant life.

The physical "rijping" stage can also be roughly determined in the field by estimating the consistency of the soil either by hand or by means of a penetrometer. After a little study it will also be possible to establish correlations with such physiographical features as the geomorphology of, and particularly the vegetation in, the locality. To find the value of b experimentally, it is theoretically sufficient to collect a number of samples of soil known to be at the same stage of initial physical pedogenesis (at what stage is immaterial).

The only way to determine this is to estimate the consistency of the soil with due regard to the physiography of the locality. The L, A and H content of each sample must be known; b_1, b_2, etc. are known if the nature of the clay minerals or at least their base exchange capacity is known. The values of b and n in equation (1) are constant and can therefore be computed either algebraically or graphically. (See also Pons and Zonneveld—in preparation). Other aspects of initial soil formation, constituting the borderline between physical and chemical pedogenesis, are the variations in content and type of organic matter.

If initial physical soil formation is impossible because of lack of aeration, extremely high concentrations of organic matter may accumulate, resulting in peat formation. This should be regarded as the reverse of pedogenesis, viz. geogenesis. The relation between the organic matter content of mineral soils and the climate explains why deltaic peats are common in temperate areas (Western Europe) and in the permanently humid tropics (South Borneo, South New Guinea, Irian) and are much less common in the areas with a monsoon climate (Sundarbans, Thailand, Burma, etc.).

Constantly water-logged conditions will also give rise to peat formation in the latter areas. The extremely high points in fig. 7 and table 1 reflect such conditions. The fibrous muds under the mangrove forests in Nigeria and Sierra Leone described by Hesse are examples of the transitional stage of peat formation even under saline conditions. The organic matter contents at early and late stages of initial soil formation have two important practical consequences, the first being concerned with chemical fertility. In soils containing clay, the organic matter content determines the storage and supply of onions in particular (phosphorus, nitrogen, see 3.3.6), and in sandy soils it also solely determines the cation exchange capacity. In the second place, the organic matter content largely determines the water-retaining capacity, particularly in respect of the amount of settling to be anticipated after reclamation, because:—

1. The organic matter saturated with water has considerable volume; during "rijping" it may lose much water, consequently much volume.
2. Decomposition removes part of the organic matter and therefore part of the dry substance and all the water retained by it.

We have calculated that in soils in the Netherlands with an H to L ratio of about 0.15, from 10% to 20% of the shrinkage and dehydration is due to the decomposition of organic matter in the early stages only. In sediments with an H to L ratio of about 0.30 in the early stages it amounts to about 50% (Zonneveld 1956 and 1960).

Since the organic matter content of soils in deltaic areas with a tropical monsoon is relatively low, the loss of organic matter is only important in and near peaty areas. The shrinkage of peat layers is often irregular because of the geomorphological structure of the soil; for instance, clayey or sandy creeks may intersect the bog area. This may produce an irregular topography giving rise to irrigation and drainage problems.

In mineral sediments, the effect of the organic matter content on shrinkage is of minor importance but it has a marked effect on fertility. There will always be a shortage of organic matter in relatively, or at all events temporarily, well-drained soils (such as paddy soils) and measures have to be taken to increase the organic content by green manuring, by ploughing in rice straw, etc. Hence our ideas concerning the conservation of organic matter will depend on whether we are considering temperate or tropical areas. The character of organic matter will be dealt with in greater detail section 3.3.6.

3.2.2 *Initial physical soil formation in the soil profile*

In rapidly drained lake beds, "rijping" takes place downwards. In tidal deposits which are gradually silting up, the n-figure (F.I.S.) may be more or less the same for several feet down the profile. This is because the recently deposited top layers are exposed to the soil-forming factors for longer periods during each tidal cycle, whereas the lower layers are exposed for shorter periods over a longer time. Moreover, the biological processes in initial soil formation can enhance this effect. Deep lying material at an early stage of initial pedogenesis can be brought to the surface by some crustaceans (e.g. in the Avicennia tidal forest swamps of Surinam and Sundarbans. The material can then be dehydrated much more rapidly than it would have been far below the surface. In Dutch tidal forest (only occurring in fresh water tidal areas), man does the same by digging and regularly cleaning ditches and by bringing the material from these ditches to the surface.

Several types of worms, etc. are known to mix the less dehydrated material with more "rijp" material. Deep rooting plants (such as Phragmites, Typha and Arum and mangroves such as Avicennia and other species) with air channels in their roots (Telmatopytae) enabling them to penetrate into anaerobic (reduced) layers, withdraw water from these layers and set off "initial physical soil formation" there before aeration starts, also promote homogeneous "rijping".

The decomposition of organic matter at the surface is retarded by fresh additions from vegetation. The organic matter content is therefore higher at the surface than it is deeper in the profile. That is how an A-horizon is formed. Under conditions of imperfect drainage when the climate is such that sufficient organic matter is produced and the water is not too calcareous or too saline, organic matter may even be produced more rapidly than it decomposes (see 3.2.1), and organic soils (peat) will be formed. In the Netherlands, initial physical soil formation, including settling, in a profile of about 3 feet with optimum drainage takes from 50 to 100 years. In the humid tropics, it will take roughly the same time but will be more rapid whenever there is a more intensive dry season.

The relation between initial physical soil formation and physiography (vegetation, topography, etc.) has been dealt with.

Many other soil characteristics are related to the physiography of the location. Therefore, even if certain initial physical soil formation features in a certain soil profile are not regarded as very important for practical purposes (the subsoils of certain paddy soils, for instance), they may indicate some correlation between the physiography and other important soil qualities that cannot be measured directly or can be done only with difficulty.

In this respect, the physiography is just as important as many other soil properties, helping us as it does to obtain an idea of the soil profile as a whole, as a natural body with many known and unknown properties and qualities.

3.2.3 *Factors counteracting initial physical soil formation*

The following factors counteract initial physical soil formation:

a. Poor natural drainage.

b. Seepage, which occurs particularly in deep polders on reclaimed sea or lake bottoms. If the subsoil is relatively permeable it is difficult to drain it so thoroughly that the "rijping" process goes deep enough to produce a soil good enough for profitable agricultural use.

c. Horizons with toxic compounds such as acids, free aluminium and a high salt content, prevent the penetration of plant roots and consequently physical soil formation (see also 3.3.2).

d. Thick soft layers in the subsoil will shrink considerably if the top soil is drained, because this causes the intergranular stress in the deeper layers to increase. The consequence of this shrinkage is that the top layers settle and remain poorly drained in spite of the removal of considerable quantities of water. This is common in peaty areas with thick layers of peat and/or "mud clay", such as are found in the Netherlands. Such soils are used for grassland or for special kinds of horticulture.

e. The addition of new, immature mineral or organic materials. This is a normal process in areas regularly flooded with sediment-laden water. Fresh organic matter from plants can also have a retarding effect.

f. The reverse of initial physical soil formation, viz. to make an initial soil from a more or less mature ("rijp") soil (a special process occurring fairly frequently). It can be due to some simultaneous mechanical disturbance of the microstructure and macrostructure. Just as eroded material suspended in water regains the properties of fresh silt, mechanical disturbance under wet conditions changes the character of the mature soil into a less mature initial soil[1].

Accordingly, the tillage of paddy fields has the same effect. In light-textured soils with a deep natural

[1] It has been noticed in Surinam that roots in soils underlying recent peat layers will cause the microstructure to revert to its initial stages of development under certain natural conditions.

water-table, extreme mechanical disturbance of the structure (puddling) is even widely resorted to. That is done to strengthen two vital properties of initial soils, viz. imperviousness and soft consistency. The first prevents seepage losses, the second facilitates the transplantation of paddy plants. Theoretically such disturbance of the structure is a geogenetic rather than pedogenetic process (re-sedimentation *in situ*).

So in paddy fields there is the constant re-establishment of immature conditions followed by incipient physical "rijping". Table 1 contains many examples of paddy fields with un"rijp" tilth layers and more mature subsoils. Some less favourable aspects of this repeated upsetting of the process of initial soil formation will be dealt with in subsequent sections.

3.3 *Initial chemical and physico-chemical alluvial soil formation* (chemical "rijping")

Chemical and physico-chemical changes also occur during the "rijping" process. They can be due to either oxidizing or reducing conditions. The most important changes are:

a. The leaching of calcium,
b. Desalinization,
c. The formation and oxidation of poly-sulphides,
d. The establishment of the ultimate ratios of adsorption of the exchangeable cations.

Those processes determine the ultimate chemical fertility of the soil as well as its structure.

3.3.1 *Lime*

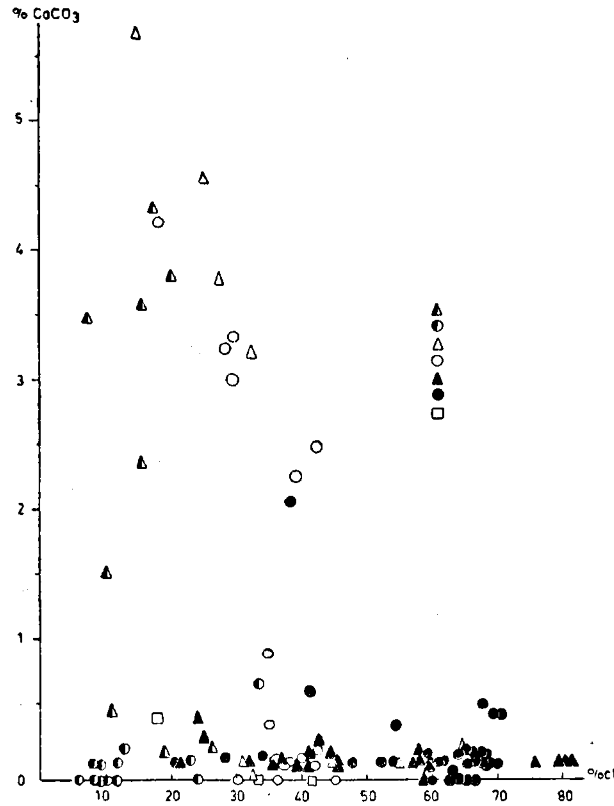
Lime ($CaCO_3$) is a most important component of soils; it largely conditions the physico-chemical processes, soil structure, etc.

From investigations in the temperate areas of north-west Europe, it appears that the lime is concentrated in the silt fraction. Lime may come from various sources. Some of it may be rock fragments from limestone in the hinterland. Some of it, especially in marine conditions, may be in the form of fragments of shells etc. mainly of small organisms, and part may be the result of physico-chemical precipitation.

The Asiatic samples[1] show that the highest lime contents indeed occur in soils with high silt contents as in Taiwan and in the soils of India and East Pakistan, if their textures are not too heavy (see fig. 2). The lower lime content of similar soils may be due to leaching during and after sedimentation or to other processes during sedimentation preventing the precipitation of lime.

Under anaerobic conditions (by fermentations) production of CO_2 and organic acids is high. It may result in the leaching of lime at very early stages.

[1] The lime content was calculated from carbonate tests (see 3.3.4). The samples may have contained a considerable amount of dolomite!



Appendix I: Figure 2 RELATION BETWEEN LIME CONTENT AND TEXTURE

Anaerobic conditions may prevent lime from forming by precipitation.

The oxidation of pyrites occurring under brackish and marine conditions may diminish the lime content (see 3.3.2). This may explain why, in table 1, the marine and brackish clays appear to be poorer or in any case no richer in lime than fluviatile sediments, in spite of the greater quantities of organic lime they originally contained. The tendency for physically immature sediments to have higher lime contents also points in this direction. The formation of cat clay is the extreme situation.

Natural levees generally contain more silt and are less subject to water-logging than backswamp areas. The latter are generally deficient in lime, even when the sediment carried by the rivers contains lime. In this case the levees usually contain some lime. If there is no lime in the river, the levees are of course also deficient in lime. The Ganges and Cho Shui seem to contain fair quantities of lime, as does the Mekong in Thailand. The Chao Phya in Thailand also appears to contain some lime.

The lime content is usually low but in the next paragraph it will be shown that those rivers contain fair quantities of gypsum, which proves that there used to be a great deal of lime.

From as yet unpublished data supplied by NEDECO[1] and analysed by Dr. De Groot, it appears that fresh sediment from the Chao Phya

[1] Netherlands Engineering consultants.

and its tributaries in the lower part of the delta contains a small percentage of lime. The lime content of the river Pasak flowing through the Rangsit area is also very low. The differences in the quantities of lime carried by the rivers are apparently due to the geology of the hinterland. The rate of leaching in Europe has been estimated to be of the order of ½% to 1% per century. How much it is in the Asiatic countries cannot be gathered from the information obtained from samples.

Biological activity greatly affects the lime content of soils, all kinds of leaching processes and the washing down of fine particles ("lessivage"). When soil organisms such as earth worms, and even mammals and crustaceae constantly bring material up from the subsoil to the top soil, the effects of leaching and the other processes are counteracted. Earthworms and mammals live in well-drained soils. This may be another reason why natural levees lose their lime more slowly than back swamps.

As lime is a constant source of Caions, it is a very important component of soils; Caions have considerable influence on the adsorption complex and consequently on the structure, fertility and the rate at which soil formation takes place (see 3.3.3.).

3.3.2 *Polysulphides and acid sulphate soils or "cat clays"*

Polysulphides of iron often occur in young marine sediments. Polysulphides can also form out of the gypsum dissolved in sea water and brackish water and out of the small amounts present in river water in soils rich in organic matter under anaerobic conditions as follows[1]:

$CaSO_4\ 8H = CaS + 4H_2O$
$CaS + H_2O + CO_2 = CaCO_3 + H_2S$
$Fe_2O_3 + 3H_2S — 2FeS + S + 3H_2O$
$FeS + S = FeS_2$.

It is not known if it can form from other sulphates such as $MgSO_4$. It may do so in sedimentary areas with much Mg sulphate and little or no $CaSO_4$.

When aeration sets in, a proportion of the polysulphides is oxidized, resulting in the formation of H_2SO_4. This strong acid attacks the clay minerals, if it is not neutralized with lime. Relatively small quantities of H_2SO_4 cannot do much damage, however, if the clay minerals and the other soil colloids (humus) are almost saturated with Caions. But if they are not, or if relatively large quantities of acid are produced; the clay minerals will disintegrate and Fe and Al sulphates will form and the latter especially will be partly leached out by percolating water. The very acid, yellow coloured $Fe\ (HSO_4)_3$ and related compounds mottle the soil. Such soils are called "katteklei" (cat clay) in the Netherlands. The process by which they are formed is partly microbiological. The environment must be slightly acid to set it in motion, creating as it does optimal living conditions for the bacteria concerned. During the process, the pH may fall below 3. Such a low pH is prejudical to life. Purely chemical oxidation then takes over. Moreover, the free Al compounds are toxic to plants, even under less extremely acid conditions. Examples of potential cat clays that have simply not yet oxidized are found in Cambodia (sample C3 30-80 cm), Burma (samples B6 250-350 cm, B10 40-100 cm), Japan (N1 80-100 cm) and India (S6 80-100 cm). The profiles in Thailand (T5), Pakistan (P1) and Taiwan (P6 and F7) are less extreme cases. Samples T2 and T3 in Thailand are examples of developed cat clays, whereas T1, T9 and P1 (in Pakistan) are partly neutralized. What are called degraded alkali soils in the Sundarbans delta in West Bengal (described by Dr. Mukerjee) may also be cat clay soils. If the source of sulphates dries up and drainage is sufficient, the toxic compounds will be leached out in time, no new polysulphides will form, the pH will rise and less acid soils (H-Al-clays) suitable for some of the less exacting crops will come into being. The time taken by this process may vary from a few years to many centuries, depending on the quantity of FeS_2, the permeability of the soil and the amount of lime and water available. But if fresh supplies of water rich in sulphates are forthcoming and anaerobic conditions temporarily obtain, polysulphides may continue to form, provided, of course, that the $CaCO_3$ formed during sulphate reduction is removed, which can be done by HCO_3 ions and organic acids formed by the anaerobic decomposition of organic matter described above.

Acid sulphates cannot form in soils rich in lime, because the acids will be immediately neutralized and gypsum ($CaSO_4$) will be formed. This gypsum will be leached out in soils in permanently humid climates. In regions with a tropical monsoon climate, however, soils can be found containing well over 10% of gypsum in the form of large crystals running to several mm in size (see Thailand samples T10 and T9—floating rice area). Not all the polysulphides seem to oxidize readily; some of them seem to resist oxidation. It is a subject which calls for research.

In the vast cat clay areas in Vietnam (Valee des Jonc) and Thailand (Rangsit area) with a monsoon climate, the top-layer several decimetres deep already lost most of its sulphides during the centuries following desalinization. Parts of these areas (for example those south of the Rangsit area in Thailand) have been rejuvenated by having young layers containing no sulphides deposited on them. In the first case, the top layer is extremely poor in plant nutrients (P,K) and in the latter case it is not (see 3.3.3 and 3.3.5).

Some rice can be grown on such soils. There is, however, a danger of drainage in the dry season causing the water-table to fall too far below the surface periodically, resulting in the renewal of the oxidation

[1] Gypsum applied artificially on soils under water-logged conditions may produce the same reaction (seems to occur in Bengal—oral information from Dr Mukerjee, Calcutta).

of pyrites. The toxic substances may be transported to the rooting zone by capillary action and damage the crop. The remedy is to keep the soil wet nearly all the year round and only permit oxidation (necessary for the crop) in the neutralized top layers.

In most cases, all that can be done to improve cat clay soils is to remove the sulphides in the top layers. It can be done if enough fresh water and lime are available, although it may take years. Pineapple can be grown in the meantime, because of its resistance to large quantities of free aluminium in the soil. Rice can also be grown on a less acid soil.

Salt water has been used with some success to leach out toxic components from cat clays, and later fresh water is used to leach out the salt. In its initial stages, rice tolerates a higher salt content than it does later on. (Vietnam, Moorman 1961, Sierra Leone, Hesse 1961, Van Beers 1962). The method should be used with judgment, because there is a great danger of new pyrites forming, especially if much organic matter (the reducing medium) is available.

In most cases, it is impossible to neutralize the whole cat clay area, because huge quantities of lime would be required (from 30 to 300 tons per hectare). Mixing the top soil with the subsoil might give good results, provided the subsoil contains enough lime. Such favourable conditions exist in some places in the Netherlands.

As a common rule, it is impossible to turn bad cat clay soils into good soils. If drainage and irrigation can be kept well under control, reasonably good soils for rice, yielding about 1,000 kg per hectare, can be produced. In the temperate areas where no rice is grown, grassland (pasture) is the most suitable form of land use. Pineapple can give good results in tropical areas. But if one can choose between improving an acid sulphate soil or another soil, it is better not to stake funds on the incredibly difficult cat clays.

Oxidizing cat clays can even endanger large areas, because leached Alions and acids can harm crops downstream from the cat clay areas (Valee des Jonc, Vietnam; Rangsit area, Thailand).

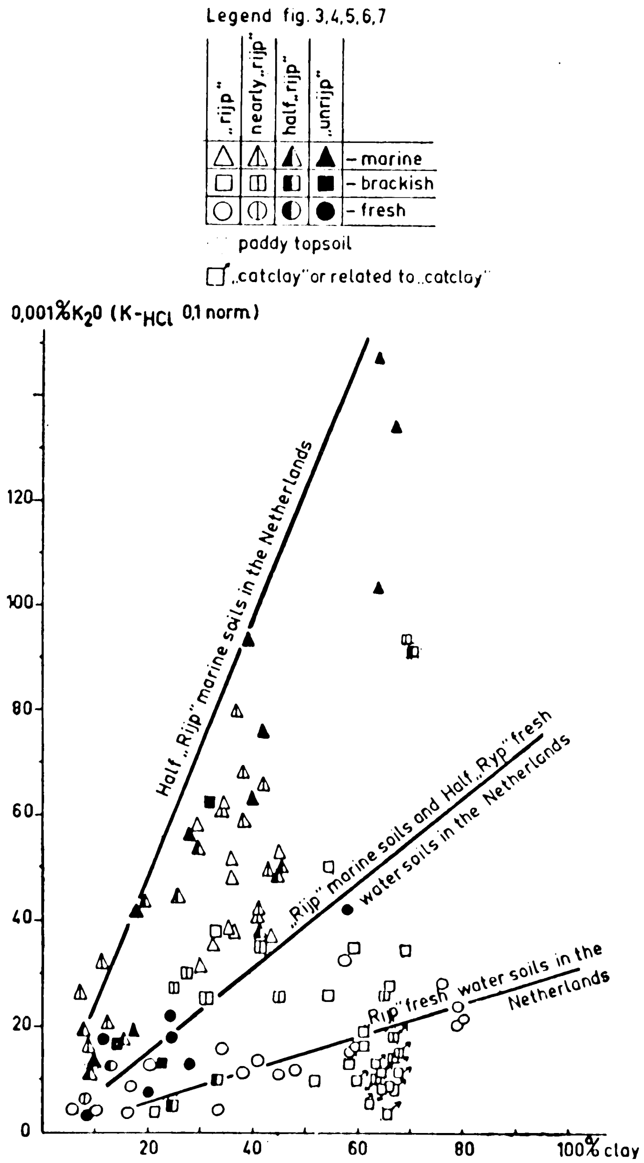
The formation of acid sulphates in soils to be reclaimed can be predicted in several ways:

1. By chemical analysis of the SO_4 and $CaCO_3$ contents. If there is less $CaCO_3$ than SO_4 (their molecular weights—100 and 96 respectively—being almost equal), there is a risk of acid clay forming.
2. By determining the SO_4 content only, and then adding an equivalent quantity of acid to the fresh sample and determining its pH. Neither case 1 nor case 2 provides any data on the resistance of polysulphides under natural conditions.
3. By exposing a soil sample to the air for several months under moist conditions (spread out on a sheet of glass, for instance) and comparing the pH before and after the experiment. This is the most reliable, though most time-consuming, method.
4. By treating a soil sample with H_2O_2 and then determining its pH. This is a quick but rough method. Whether the process is sufficiently true to the natural condition remains to be seen (Van Beers, 1962).

3.3.3 *Potassium*

Fig. 3 and table 1 contain particulars on the potassium soluble in 2N HCl in Asiatic deltas.

There appear to be no major differences between the various Asiatic deltas in this respect. There is a relation between (HCl) and the clay content. The less mature soils (in the sense of initial soil formation) usually have a higher K-content than the mature ones. The marine soils contain more potassium than the fresh water deposits. The cat clay is extremely deficient in potassium. The figures are the same as



Appendix I: Figure 3. RELATION BETWEEN K (HCL) CONTENT AND CLAY CONTENT those found in West European soils. The percentage of K in the adsorption complex seems to indicate fairly well whether the sediment is marine or fluviatile, as it does in Holland. After desalinization the marine sediments always have a K-percentage greater than 3%, while the fresh water sediments have less than 3%.

We believe that the higher K-content of marine sediments is due to the enrichment of clay minerals with potassium from sea water, probably during pedogenesis. This may be due to a change (restoration) in the clay minerals (open illite or K-fixing illite). Most of the fluviatile clays in the Rhine and Maas basins have fixed potassium because they are largely open illite (and in extreme cases Ammerzodite). The fixation of potassium can also reduce the soluble K in HCl 2N. No information is available yet regarding K-fixation in the Asiatic samples. The occurrence of open illites is quite likely. The larger quantities of potassium in the early stages of "initial alluvial soil formation" are due to (a) higher organic matter content, (b) potassium liberated from decomposing organic matter and (c) less firmly adsorbed potassium that can be removed relatively easily by plant roots. The relatively lower potassium surplus in the early stages of tropical soils compared with that in the Netherlands shows how important the role of organic matter is in this respect. There is more organic matter in the temperate climate of the Netherlands (see 3.2). The extremely low K-content of cat clays may be due to leaching by acids and may also be ascribed to fixation by the broken-down clay minerals.

As far as fertility is concerned, it can be concluded that there are no important differences in the availability of potassium when one compares the tropical and Asiatic deltas under consideration with those in the Netherlands. The rather strong potassium fixation that may occur in fresh and brackish sediments remains to be studied.

So far there has been no appreciable potassium deficiency in the soils with not too light a texture used for rice growing. When endeavouring to increase yields by various methods, however, it should be borne in mind that the addition of a potassium fertilizer will be necessary, especially on fluviatile soils. The application of acid fertilizers (e.g. ammonium sulphate) tends to decrease the potassium content by leaching. This is often the case (see samples N5 and N6) in the rather coarse textured, intensively fertilized soils in Japan.

3.3.4 *The exchangeable cations of the adsorption complex, desalinization and soil structure.*

The exchangeable cations of the absorption complex have an important effect on two things: (a) the chemical nutrition of plants and (b) the structure of the soil.

As a rule, sodium and magnesium are the dominant cations in young marine sediments that are still under the influence of sea water. In river sediments, calcium is the dominant cation under basic and neutral conditions and hydrogen under acid conditions. The quantities of potassium in the adsorption complex are closely related to the K(HCl) content (see 3.3.3); nothing further is said about the subject here. Plants do not take such large quantities of the other cations (Na, Mg, Ca, H) from the soil.

Those cations are important mainly because they determine the degree of flocculation of the soil colloids and so affect the stability of the microstructure and hence of the macrostructure. Caions and Hions have a powerful flocculating effect. Naions usually have the opposite effect. Opinions on the effect of magnesium are divided (see below). The flocculating effect of cations is due to the fact that cations above a certain concentration (differing for every cation) neutralize the colloidal soil particles. Once neutralized, the London—Van der Waals forces come into action and the particles attract each other and form firm flocculates which provide a good base for the macrostructure.

Non-neutralized silica-clay mineral particles have a negative charge and repel each other; the colloid is deflocculated (peptized), thus preventing a stable macrostructure from forming and making the soil slushy after every rewetting and stone-hard when dry.

As a rule, higher concentration of monovalent cations than of polyvalent cations are needed in the soil solution to neutralize the soil colloids.

The clay will be thoroughly flocculated if calcium ions predominate. Flocculation will also occur if hydrogen ions predominate, notwithstanding the fact that they are monovalent cations. The probable explanation is that the aggressive hydrogen ions displace tri-valent aluminium ions, the latter producing considerable flocculation.

When the adsorption complex contains a relatively large quantity of sodium, as is the case with young marine soils, and the sodium content of the soil moisture is high, the clay will be relatively well flocculated. But if the sodium content of the soil moisture decreases, for example by leaching with fresh water (desalinization), the sodium ions will lose contact with the colloids, in other words, they will diffuse out of the electrical double layer. The colloid particles then regain their negative charge and the soil deflocculates.

Initial solonetz soils (alkaline magnesium soils, "knip" soils) having, when dry, a columnar structure due to deflocculation, appear to have a relatively high proportion of magnesium in the adsorption complex, Ca/Mg < 3 (data Netherlands Soil Survey Institute 1961). According to Dutch and German soil scientists (Veenenbos, Schuylenborgh, Müller) and others, the columnar structure and deflocculation are due to the magnesium.

In the Asiatic soil samples, however, relatively large quantities of magnesium are also found in purely fresh water soils and in completely desalinized marine soils without any sodium in the adsorption complex, even when the calcium content is high. We had little opportunity to study soil structure (we could only use the auger) but we saw that the B1 sample, which had a Ca/Mg ratio of only 1.7, had a very good crumble structure. On the other hand, the soil of profile T8, which had a Ca/Mg ratio between 3 and 4, was rather hard when dry, so it was more or less deflocculated.

Pons reports (in private correspondence) that soils which have a very good structure and high Mg-values in the adsorption complex are found in Surinam. He says that it is probably due to the fact that biological activity rather than physico-chemical conditions are ultimately decisive. In fact, the alkaline sodium-soils occurring under European grassland are not easily flocculated either.

It may also be put this way; the flocculating or deflocculating effect depends on the number of ions, both in the electrical double layer and in the soil moisture around the double layer. Neutralization of the soil particles is achieved by a much lower concentration of bivalent magnesium ions in the soil moisture than of monovalent sodium ions.

Enough magnesium may be available in the soil moisture under tropical climates with a distinct dry season to neutralize (i.e. flocculate) the soil particles. Profile B1 is regularly flooded with Irrawaddy water that may contain some magnesium. Some of the samples obtained from Japan, i.e. the most temperate part of the areas visited, contained the smallest quantities of magnesium. The higher values of magnesium are found in the more saline soils, the soil moisture of which has a high sodium content, i.e. in soils that are not alkaline in the narrow sense of the term. This theory may be linked with the fact that even fresh water soils rich in carbonate have high Mg-values in the complex (F3). Apparently there is so much magnesium that it cannot readily be replaced by calcium. As stated in 3.3.1 and 3.3.2, gypsum crystals are often permanently present in the soil and do not dissolve and leach away (T9 and T10) as they do in European and other soils in humid temperate climates. Then why should magnesium ions not resist leaching more strongly under those conditions than they do in temperate areas and so remain in the soil moisture in sufficient concentration to neutralize the soil particles? A tentative explanation is put forward here, but it should be tested in a laboratory.

The high magnesium content of tropical soils in general compared with those in temperate areas may be due to:

(a) More intensive weathering in the hinterland or the liberation of magnesium from certain minerals. The fresh-water silt, newly deposited in Cho Shui Chi in Taiwan, has a very low Ca/Mg ratio in spite of its high calcium carbonate content (dolomite?). Teensma reports that the Mg content of Brahmaputra water is high.

(b) The fact that dolomite is more resistant to weathering than pure limestone so the proportion of magnesium increases. In fact, the figures in table 1 show that there is a negative relation between the Ca/Mg ratio and acidity. The lowest ratio as far as non-saline soils are concerned is found in cat clays.

Now let us turn to sodium soils. If there is enough fresh water, saline soils can be relatively easily desalinized. The change in the ratio of exchangeable cations in a Netherlands marine deposit is shown in table 2.

Appendix I: Table 2

Exchangeable bases from a topsoil from a Dutch saline coastal marsh, half way through the initial physical soil formation ("rijping") process, in a humid temperate climate during desalinization (Zuur 1954).

Time of sampling	100 parts of replaceable bases contain:				
	Ca	Mg	Ca/Mg	K	Na
On completion of dikes ..	25	36	0.7	8	31
1 years later	40	34	1.2	7	19
3 years later	52	29	1.8	6	13
5 years later	57	29	2.0	6	8
Usual final state of well-drained desalinized soils ..	87	8	11.0	4	1

The leaching of sodium salts may be retarded, however, in regions having one dry season annually. Accordingly, though the sodium content of the soil moisture is low, the adsorption complex may have a fairly high sodium content, creating alkaline soils of poor structure. Such soils are relatively wide-spread in Bengal and the other deltas (see table 1, soils described as physically mature ("rijp") or nearly mature but rich in sodium.) Part of the immature soils having high n-figures soon pass this stage (see table 2,1 year later). The heavier the soils, the more difficult it is to remove the salt from the adsorption complex. If the soil moisture in alkaline soils is desalinized before the initial physical soil formation process has reached its final stage, the leaching of sodium out of the adsoption complex will be very slow, because physically immature soils tend to be less permeable than mature soils.

The oxidation of pyrites is a most important factor in the desalinization or dealkalinization of soils. If lime is available, gypsum will be formed constituting a rich source of calcium ions capable of being exchanged with the sodium ions of the complex[1]. This process is also set off artifically with gypsum to recondition deflocculated soils (see also the ECAFE Mission report). If no lime is available, the acids formed will supply hydrogen and aluminium ions to replace the sodium. But if there is too much pyrites cat clays will be formed, as stated in 3.3.2.

[1] Part of the lime may be dolomite. If so, magnesium will also be liberated and may be adsorbed to the adsorption complex.

What cations will be adsorbed to the complex is determined by the proportions of calcium, hydrogen, magnesium, sodium and potassium cations in the soil solution, together with other ions present in small quantities. The proportions are determined by:

1. the composition of the flood water;
2. the mineralogical (chemical) composition and rate of weathering of the soil particles;
3. the presence of free lime and dolomite;
4. the presence of polysulphides.

Factors 1,3 and 4 decide the ultimate structure of young soils. The following conditions are met with in nature:

Item	*Salts Na (Mg)*	*Oxidi-zable poly-sulphides*	*Lime*	*Type of soil*
A	+	+	+	Calcareous clayey marine soil
B	+	—	+	Calcareous clayey marine soil
C	—	—	+	Calcareous clayey fluviatile soil
D	+	+	—	Acid-sulphate soil (cat clay)
E	+	—	—	Alkaline ("knip") soil, if there is no biological activity or if the Mg or Na content of the soil moisture is not permanently high.
F	—	—	—	More or less acid clayey fluviatile soil.

Item A. This condition often occurs in marine sediments. The H_2SO_4 formed by oxidation is soon neutralized by $CaCO_3$. The soluble $CaSO_4$ produced is a strong and active compound that helps to dislodge the Na and Mg from the adsorption complex. A Ca-clay with favourable properties is rapidly formed in this way. Here the sulphides are actually beneficial.

Item B. Polysulphides are lacking, in some marine and brackish conditions. They have either been removed or were never formed, due to the absence of a reducing medium, for example in old land flooded by some catastrophe or due to natural conditions. Since there is free lime, the final result will be the same as that under (A), but the process will be much slower, because the Caions are derived from calcium carbonate dissolved in carbonic acid.

Item C. This is the normal condition in river sediments having a high Ca content (e.g. Ganges, Mcklong, Mekong natural levees). Good Ca clay will soon be formed, because there are no injurious cations to be removed.

Item D. This is the case in marine and especially in brackish conditions where there is much reducing (organic) matter, so that polysulphides can be formed and the $CaCO_3$ can be dissolved before reclamation (or natural oxidation) starts. Oxidation results in the formation of an acid-sulphate clay in the manner described in 3.3.2. When the acid components have been leached out, the soil structure will be fairly good (H-clay = Al-clay). There will also be considerable flocculation before leaching, but no macrostructure can develop yet, because toxic compounds preclude the development of animal and plant life.

Item E. This is normal in slightly desalinized deltaic areas, particularly in heavy soils. It may also be encountered in fresh water soils having an extremely high magnesium content; its structure in relation to the magnesium content has yet to be studied, however. It is confined to places where there are no polysulphides at all or at all events not enough to produce acids to leach the sodium and magnesium from the adsorption complex and no lime to provide a source of Caions to protect the adsorption complex against the destructive influence of those ions. If the biological activity is not very great, a non-flocculating clay will be produced that will be very plastic and sticky every time it is wetted and which will form stonehard prisms when dried.

Theoretically, addition of $CaSO_4$ (gypsum) is the remedy. The difficulty in heavy-textured soils, however, is that the impermeability which prevents the magnesium and sodium from being leached away also prevents the $CaSO_4$ from penetrating the soil. The poor structure maintains itself and the vicious circle is difficult to break. This is also why very fine textured soils (clay) often have typical Mg-clay features.

The vicious circle can be broken more easily by nature itself in a humid climate, than in an arid climate, where there is a lack of water for leaching. Moreover, the addition of $CaSO_4$ under wet conditions is harmful because it may give rise to sulphate reductions (pyrite formation) (see 3.3.2, 3.3.7 and the report of the ECAFE Mission on Deltaic areas, part III).

Efforts to improve alkaline soils should start with measures to promote biological activity. The addition of gypsum is worth trying, but only if the soil is not water-logged. Rice does not call for the best soil structure; in fact, tillage under wet conditions followed by long inundation periods will not produce the best structures. The addition of gypsum may, however, be beneficial to other crops.

Biological activity can be promoted in the following ways:

1. By keeping the soil permanently not too dry and not too wet;
2. By applying organic fertilizers and green manure. In other words, by creating conditions generally regarded as favourable for the growing of crops.

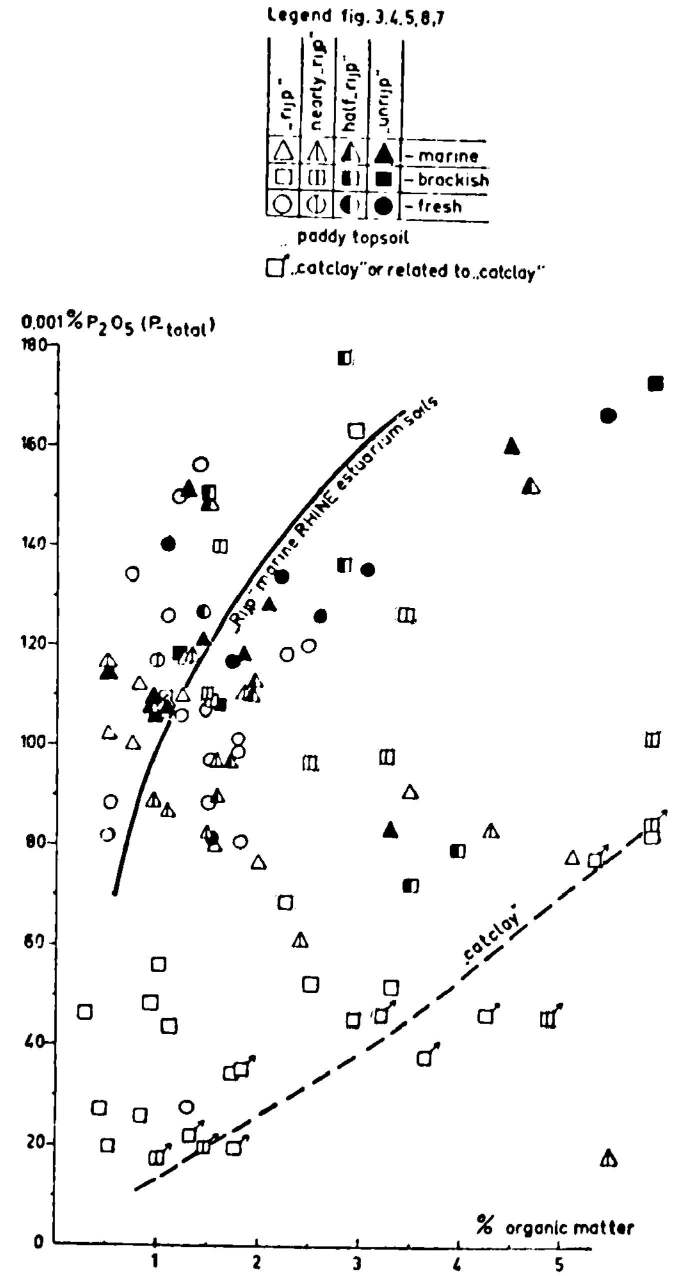
Item F. Here we are mostly concerned with fairly acid soils the structure of which need not be poor. Such soils are very common along rivers bringing sediments down from a hinterland devoid of parent materials containing lime.

The very important part played by calcium, especially in cases in which salts and sulphides occur, is apparent from the above. Examples of all the cases dealt with above are given in table 1.

3.3.5. *Phosphates*

It is assumed that most of the phosphates in alluvial soils in north-west Europe (the Netherlands) are contained in the organic matter. Therefore it might be useful to compare the phosphate contents of various sediments in proportion to the respective quantities of organic matter.

It is obvious, however, that some of the phosphates that will be dissolved in the standard "total phosphate" determination test will be of inorganic origin. It will have little effect on the result in soils rich in humus, but in soils poor in humus it may be of considerable consequence, producing as it does the curve in Fig. 4.



Appendix I: Figure 4. RELATION BETWEEN P (TOTAL) CONTENT AND ORGANIC MATTER

It is clear from table 1 and fig. 4 that there is a broad correlation between total phosphates and organic matter. The P-total of the organic matter in soils from the Ganges, the Brahmaputra, Japan and Taiwan is approximately equal to that in comparable Dutch soils.

The soils of Burma differ widely. It appears that the samples extremely rich in phosphates per unit of organic matter are very poor in organic matter, and vice versa. This may be partly due to the flaw in the method of presentation. But apparently the Irrawaddy carries sediments less rich in phosphates.

In Western Europe the stage of initial soil formation at which samples are taken appears to have some influence on the P-total content per unit of organic matter. The marine soils are somewhat richer in phosphate, but the soils taken from Asiatic deltas are not so.

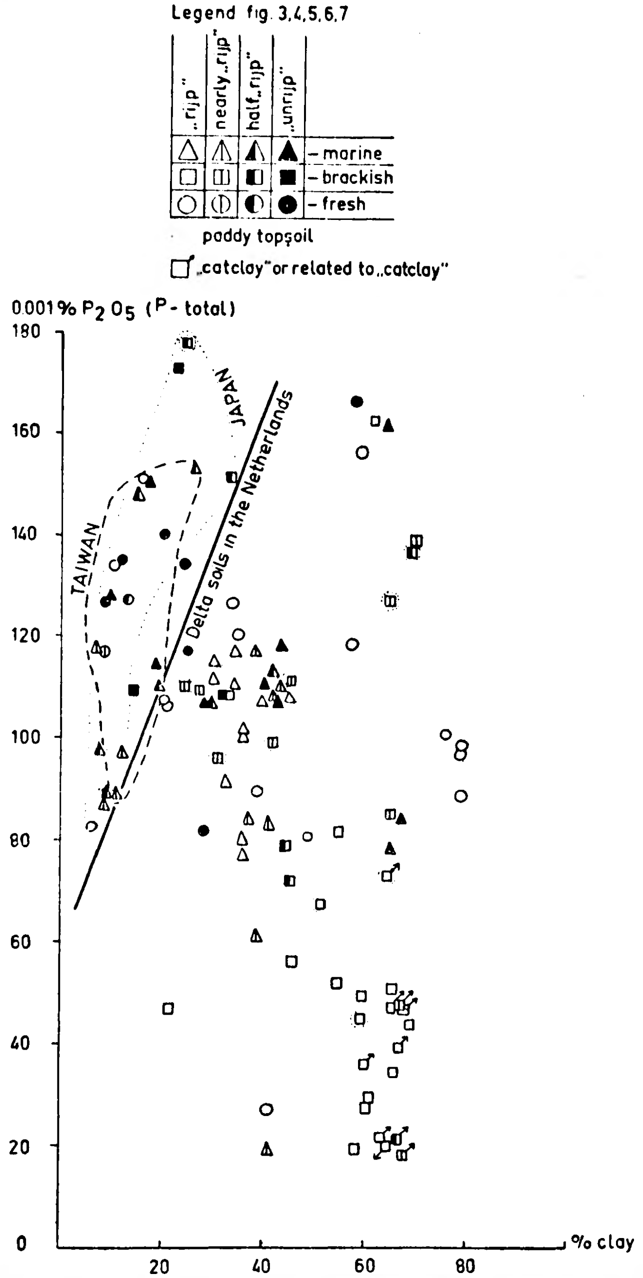
Cat clays and related soils prove to be extremely poor in toatl phosphates. This is apparently caused by the leaching by acids in the cat clays. It might also be due to a certain strong fixation of phosphorus to clay mineral fragments (with free aluminium valencies).

The fairly close correlation between organic matter content and phosphates shows how important organic matter is. The phosphorus soluble in citric acid evinces a similar trend. Cat clays do not contain any slightly soluble phosphorus, due to their acidity. It should be noted, moreover, that free aluminium ions in patricular hamper the uptake of phosphorus by plant roots. That is why crops grown in cat clays always show the effects of phosphorus deficiency which cannot be cured, however, merely by fertilizing with phosphorus, as is clear from the foregoing.

The ratio $\frac{\text{P-cit}}{\text{P-total}} \times 100$ gives some impression of the solubility of phosphates. The fairly old soils (B2, B8, B9) and also the cat-clay-like soils give very low ratios, the most leachable phosphates having being leached away.

The fairly young, non-acid soils in the Taiwan and Pakistan series also have relatively low ratios. There would seem to be some connection between lime content, P-ratio and the stage of maturation (the quantity of fresh organic matter). In fact, in soils poor in organic matter, an excess of $CaCO_3$ might reduce the solubility of phosphorus.

It may generally be concluded that the phosphate content of alluvial soils per unit of organic matter in the deltaic areas is of the same order as that in temperate climates. The solubility of phosphates at the early stages is somewhat lower; at the mature stages it is almost equal. But the total available phosphates in tropical alluvial soils is much lower, because there is less organic matter. Consequently, fertilizing wlth phosphates is even more important there, than it is in temperate areas. This is clearly shown in figs. 5 and 6, where the phosphate content is plotted against the clay content. The most temperate area (Japan) has the largest quantities of phosphates. When there is serious phosphate deficiency in fairly young soils, it should be borne in mind that cat clays may be the cause.



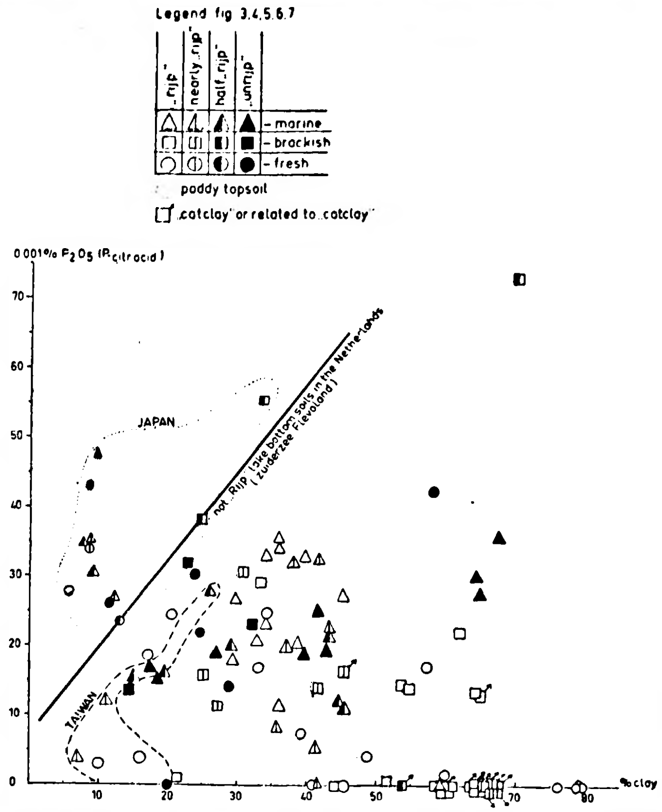
Appendix I: Figure 5. RELATION BETWEEN P (TOTAL) CONTENT AND CLAY CONTENT

3.3.6 *Nitrogen and organic matter.*

It has already been stated that the difference between deltaic soils in tropical monsoon climates and those in temperate areas is largely a question of organic matter content.

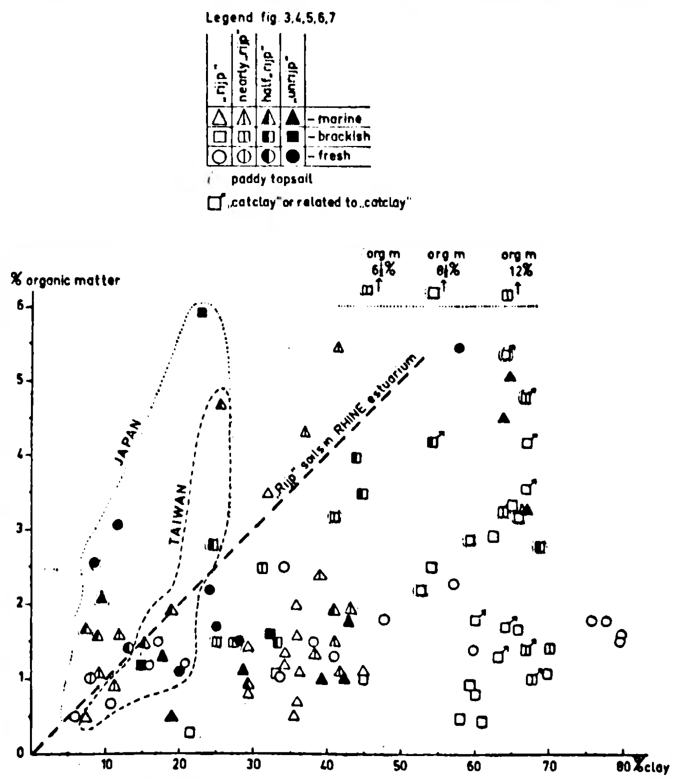
Except in some peaty soils, the quantity of organic matter is rather low during the very early stages.

Experience in north-west Europe has shown that, in initially mature soils, the ratio between organic matter content and clay content tends to settle down at about 0.1% per 1% clay. It is higher at the earlier stage and less at the mature stage. As a rule marine sediments have less organic matter, which is more



Appendix I: Figure 6 RELATION BETWEEN P (CITRIC ACID) CONTENT AND CLAY CONTENT

humified, however, whereas fresh water sediments have more organic matter, which is less humified. The samples from Japan have similar characteristics viz. approximately 0.1% organic matter per 1% clay in initially mature sediments (see fig. 7 and table 1).



Appendix I: Figure 7. RELATION BETWEEN ORGANIC MATTER CONTENT AND CLAY CONTENT

The ratio of organic matter per 1% clay for Taiwan is about 0.07%. Sample T7 comes from north Taiwan, the most temperate part, and its organic matter content is what one would expect it to be under such climatic and local conditions. The fresh samples from Cambodia tend to have a lower content than those from Taiwan (though the marine sample is somewhat peaty).

The initially mature soils of Thailand have, on an average, about half the value of the ratio found in Taiwan. The cat clays (subsoils) have very low figures. The formation of fresh organic matter is impossible under cat clay conditions but decomposition continues.

Figures of the same order are found for soils in Burma that are not too old. The extremely low figures refer to relatively old soils that already show some signs of subsequent soil formation (low phosphorus content, low base saturation, etc.).

Pakistan also presents the same picture. The extreme figures come from some peaty soils. Indian soils (all marine) also have a very low organic matter content in both mature and immature conditions, viz. about 0.03% per 1% clay (S6 is a distinctly peaty layer). These figures make it clear that a tropical climate with a distinct dry season is not conducive to the maintenance of a high organic matter content, even in more or less imperfectly drained, young alluvial soils. Unfortunately, no samples from permanently humid tropical regions are available. As explained in 3.2, the relative organic matter content is very probably higher there.

The C/N quotient can be used to assess the character of the organic matter. A low ratio (about 10) is associated with well humified organic matter. A high ratio (20) indicates that the plant remnants in those relatively young soils are less well decomposed.

It appears from table 1 that most of the samples have a C/N quotient approaching 11. There are no clear differences in the C/N quotient corresponding to the various stages of initial maturation ("rijping"). Only a few peaty soils with dense vegetation in the most temperate parts of the areas visited (F7 0-30 and N4) have a somewhat higher ratio owing to the constant addition of a certain amount of undecomposal materials. The ratio is low in the really tropical areas, even under dense vegetation, indicating very rapid decomposition. Very low C/N ratios occur in the sandy and silty samples from Taiwan marine salt flats, which are dry and wet alternately, a condition that fosters decomposition.

Experience in north-west Europe shows that many young soils are very fertile indeed during the first few years after reclamation. That is because the organic matter content tends to establish itself at a level appropriate to arable land. The nitrogen in the humus and the phosphorous and potassium absorbed on the organic matter are liberated. But if the initial content is lower, as it is in some 'Zuiderzee" sediments in the Netherlands, the organic matter content would have to be raised. Nitrogen is needed for the first few years for this process. So such soils are not fertile at all but are very deficient in nitrogen.

The fact that the organic matter content of the mangrove soils in the tropical deltas is not particularly high leads one to conclude that, as a rule, very great initial fertility due to the decomposition of organic matter need not be anticipated. In fact, under certain conditions the new soils might even be expected to be deficient in nitrogen. The organic matter content of the soil should be raised, for instance by ploughing in rice straw and other green manure, both to improve the structure and to enhance the phosphorus regimen (or the potassium regimen when there is potassium fixation). It is clear, however, that only part of the nitrogen in the green manure will be available for the crop, because part of it will be used for the formation of humus, if any humus is formed at all.

How much nitrogen will be available for the crop depends on the rate of decomposition and other circumstances. That is one of the main reasons why it is so important to use N-fixating plants (leguminosae, etc.) as green manure. Nitrogen fertilizing will always be beneficial and generally necessary, especially if humus must be formed.

The uptake of nitrogen from organic matter depends on whether the organic matter can decompose. Under permanently water-logged conditions no decomposition can take place, even in tropical climates. So a certain period of drought is necessary to liberate the nitrogen. This is seldom a problem in the vast tropical deltas visited, as opposed to certain parts of Japan and Taiwan. There the period of drought is too long, so that too much organic matter is decomposed and the nitrogen is leached or escapes before plants can use it. The same thing holds goods for phosphorus bound to organic matter. Therefore, planting a second crop or more than one rice crop a year coupled with irrigation will tend to keep the soil in better condition and will enable its fertility to be used to greater advantage.

3.3.7 *Reduction phenomena, iron and manganese*

In young soils at the initially immature stage, the reduction or oxidation conditions are very important. In tropical regions, wet conditions are artificially created for rice growing.

Three soil components are greatly affected by water-logged conditions, viz. iron, manganese and organic matter. The behaviour of the latter has already been described. It cannot decompose in wet conditions, because there is insufficient oxygen, the small amount of oxygen present is consumed by the organic soil compounds and chemical reduction starts. Iron and manganese are dissolved by organic acids and by the bicarbonates formed, and sulphate reduction may take place. Even in fresh water soils enough sulphate is available to produce H_2S, which is very harmful, even to rice roots. Therefore sufficient oxide to prevent sulphate reduction must be stored in the soil. This can be done with iron (as in human blood). If enough iron is available, periods of drought will enable the iron to form iron oxides. So this in another reason why paddy soils should be allowed to dry periodically.

Unfortunately, there was no time to determine the iron content of the samples. Most of the soils, especially the clayey ones, probably have a fair iron content; only some light-textured paddy soils in Japan and Taiwan and older soils in other areas may have lost much of their iron. Long periods of fertilizing with acid fertilizers (such as ammonium sulphate) tend to leach the soil and enrich it with sulphates. This increases the danger of harmful sulphate reduction taking place. Relatively large quantities of soluble iron and particularly of manganese may be harmful. This will only be so under acid conditions (such as are found in cat clays).

There may be a shortage of manganese if it is leached away too much, or if large quantities of decomposing organic matter are present, which may temporarily fixate the manganese in intermediate compounds (C/N ratio > 11). This has been found to occur under Dutch conditions (De Groot), and may also be expected to occur in Japan. It is less likely to occur in the tropical deltas, because the organic matter decomposes very rapidly during the dry periods. The active part of the manganese compounds is formed from the inert manganese (De Groot) as the soil alternately reduces and oxidizes. Each sediment carries its own specific quantity of inert manganese. Recently deposited silt only contains inert manganese. "Reduceable" manganese is formed during initial soil formation. This shows once more how necessary it is to allow paddy soils to dry periodically. The reduceable manganese only was determined in the samples. Both very high and very low values were found. The cat clay soils have very low figures, probably due to leaching. In subsoils, that may be partly due to the fact that only inert manganese occurs. This may also be the case in the subsoils of many not initially mature profiles other than cat clays.

No conclusions regarding manganese deficiency can be arrived at yet. The requirements of tropical crops, especially rice, should be studied first.

Some conclusions

The general processes of initial soil formation in the young soils of the Asiatic deltas under consideration are identical with those in north-west Europe. Accordingly, the experience gained in western countries in the field of soil science and the use of soils can be applied to Asia; estimates can be made of the shrinkage, the occurrence of cat clays can be predicted, cat clays can be managed, the soil structure improved, etc.

The results may differ widely, however. The most important difference is the rate of decomposition of organic matter; decomposition is much more rapid in tropical areas with a distinct dry season. The phosphorus and nitrogen content and the content of other soil components depending on organic matter will therefore be lower. These valuable components are lost particularly during dry periods.

The organic matter content is also low at the very early stages and in fresh sediments. Shrinkage of the soil after reclamation is therefore less than in soils in temperate areas with the same clay content. On the other hand, the great fertility during the first few years, which is common in temperate climates, may not be expected in the tropics. Recently reclaimed areas may suffer from nitrogen deficiency. The behaviour or organic matter in Japan soils (Nobi delta) is very similar to that in Western Europe, in spite of its "tropical" summer climate.

Not only the high temperature but also the occurrence of a distinct dry season is probably a main cause of the low organic matter content of the silt carried by the rivers and of the rapid decomposition seen in the soils of the tropical deltas visited.

The behaviour of phosphates supports the theory that the phosphorus in alluvial and marine soils is mainly part of the humus. The solubility of phosphorus (P-citr.ac.: P-total-ratio) decreases as soil formation proceeds, (it is very low in the older soils, due to leaching), it decreases because of fixation by aluminium in older soils and in cat clays, it decreases as humification proceeds and it may be influenced by the lime content. Magnesium plays an important role in the absorption complex in all the tropical deltas, including the fresh-water areas. It is not certain if magnesium has the same unfavourable effect on soil structure here as it is presumed to have in temperate climates. Physico-chemical conditions in soils in regions with a dry winter climate and probably high amounts of free magnesium may differ from those in humid temperate areas. This is a subject for laboratory research.

Location and rough description of the samples shown in table 1

BURMA

B1. Dec. '62. Henzada, Irrawaddy delta.
"Kani" land = relatively young sediment of Irrawaddy. Fresh water deposit. So-called "Immature Meadow Gleysoil". Relatively high elevation, well drained, friable structure. *"Kain Crops"* (among others-corn).

In the sense of initial physical soil formation—mature, grey-brown soil. No subsequent soil formation. Sample taken at 20-50 cm below surface.

B2. Dec. '62. Henzada, Irrawaddy delta.
"Old alluvium", so-called Meadow Gleysoil, compact structure. Fresh water Irrawaddy

sediment from the Holocene.

Beginning of a subsequent soil formation. Sample taken at 20-50 cm below surface.

B3. Dec. '62. Zalun, Irrawaddy delta.
Recently deposited sediment in small gully behind the village situated on a sand bar. In dry season, no currents. Fresh water sediment of Irrawaddy. *No vegetation.*
Immature intial soil
0-1 cm—oxidized
1-5 cm and deeper—reduced
Samples taken at 0-1 cm and 1-5 cm below surface.

B4. Dec. '63. Tapa, Irrawaddy delta.
Fresh water sediment of Irrawaddy. Horse-shoe-shaped embanked islet. Transition from natural levee to back swamp, relatively high spot; about 300 m towards the centre of the back swamp the growth of wild paddy starts. More or less a "Meadow Gleysoil". *Paddy.*
Big earth heaps (biological activity). Samples taken at 0-20 and 50-60 cm below surface.

B5. Tapa, near B4, Irrawaddy delta.
Non-embanked fringe along river. Fresh water Irrawaddy sediment, recently deposited in an excavated spot. *"Kain" vegetation (among others a Phragmites-like plant).* Sample taken at 0-5 cm below surface.

B6. Dec. '62. Mangrove island between Hlwaza chaung and Pyamalaw river near Ngayokkaung, Irrawaddy delta. Approximately 100 metres from river bank and 20 metres from small gully. Non-embanked. Brackish sediment of Irrawaddy, soil surface about at high as mean high water level. *Vegetation: Kanazo mangrove (Heritiera littoralis) and many other plants; somewhat devastated.*
Clayey profile (approx. 35% clay)
0-40 cm 5Y2/1-4/1 physically mature or nearly mature profile with iron oxide mottles. Penetrometer M $>$ 4.5 locally 2.3-4.5
40-70 cm iron oxide mottles. Pen. M=2.5-3.5
70-85 cm iron oxide mottles. Pen. M=1.0-2.5
ca. 85 cm wood remnants
85-100 cm iron oxide mottles. Pen. M=2.8-3.0
110-150 cm totally reduced clay 5Y4½-5/1. Pen. M=2.3-2.5.
Samples taken at 0-20, 30-50, 70-90, 110-125 and 250-350 cm below surface.

B7. Dec. '62. In gully near B6, Irrawaddy delta.
Brackish Irrawaddy sediment. Non-embanked. No vegetation *(many fishes living on silt).*
Immature initial soil
0- 3 cm yellowish
3-30 cm deeper greyish
Samples taken at 0-3 and 3-30 cm below surface.

B8. Des. '62. Myaungmya, Experimental Farm, Irrawaddy delta.
Non-embanked. Fresh to brackish relatively old Irrawaddy sediment fringing tertiary terrace. *Paddy field.*
Subsequent soil formation, red clay with bright red spots. Sample taken at 50-100 cm below surface.

B9. Dec. '62. Myaungmya, Experimental Station. Non-embanked. Relatively young, fresh to brackish Irrawaddy sediment. *Paddy field.*
Physically more or less mature initial soil, reduced with oxidized spots. Sample taken at 40-100 cm below surface.

B10. Dec. '62. Kan-Ywa along the Panmawadi river.
Non-embanked young tidal accretion of fresh to brackish Irrawaddy sediments slightly above mean high water level. *Good paddy* (not many weeds : grasses, Alisma and Myosotis-like plants).
Physically nearly mature initial soil profile with non- or half-mature subsoil.
0-10 cm relatively many iron oxide mottles, physically nearly mature
10-50 cm physically nearly mature, a few iron oxide mottles
50-52 cm wood remnants
52-80 cm physically half mature
80 cm buried wood.
Sample taken at 0-20, 40-60 and 80-100 cm below surface.

B11. Dec. '62. Methwechaune, Yandoon Island, Irrawaddy delta.
Fresh to brackish tidal sediment. Transition from levee to back swamp, horseshoe-shaped, embanked *Vegetation "wild grass" etc. Never used for culture.*
Samples taken at 0-20, 20-30, 30-60, 60-90, 90-120 cm below surface.

THAILAND

T1. Jan. '63. Ban Tha Khon.
Fresh (to brackish) water sediment of Chao Phya and tributaries. Subsoil in neighbourhood is "cat clay" (Spill from new canal) *Paddy.*
0-20 cm soft E.5YR4/1 Fe + ; Mn–
20-50 cm some yellowish iron colours 10YR5/1 + 10YR2/0-2/1
50-80 cm "cat clay" spots; 7.5YR5/2 Fe + ; Mn-, Fe-
80-100 cm 10YR3/1 Fe + Mn + .
Samples taken at 0-20, 20-50, 50-80 and 80-100 cm below surface.

T2. Jan. '63. Ban Lam Tin Tai (Rangsit area). Fresh to brackish sediment of Chao Phya and Pasak rivers.
Bare spot in paddy.
Down to 90 cm physically nearly mature initial soil profile, with distinct "cat clay" phenomena and distinct polygonal crack pattern at surface. Also cracks down 90 cm depth causing a fairly high permeability.
0-10 cm dark coloured soil (5YR3/1) with a few yellowish mottles, dry.
10-15 cm more grey colours (matrix 7.5YR5/1-5/2), more yellowish mottling.
25-40 cm strong mottling with bright red (10YR4/6-3/6) and yellow (7.5YR5/6-6/6) colours. Matrix 7.5YR5/2.
40-90 cm less red, more yellow mottles (5YR/2 + 7.5YR6/7).
90-130 cm physically half mature, granular yellowish concretions, no red mottles (7.5YR5/2 + 7.5YR6).
130-150 cm grey, not mottled, physically half-mature clay with fairly high organic matter content.
Samples taken at 0-10, 10-15, 25-40, 50-70, 90-130 and 130-150 cm below surface.

T3. Jan. '63. Ban Lam Tin Tai (Rangsit) near T2.
Moderate paddy.
0-20 cm—5YR2½/1 relatively acid; Fe— or +, Mn—*). Moist during sampling, deeper than 35 cm below surface—first yellow mottles (in contradistinction to T2 0-10 cm).
Sample taken at 0-20 cm below surface.

T4. Jan. '63. Sough Khlong.
Outside the sea wall, recently deposited salt water sediment. *Vegetation Nipa palm.* Physically immature initial soil. Many holes in soil due to strong biological activity (Crustaceae).
0-35 cm half mature—immature 7.5YR4/2; + 50-110 cm half mature-immature 10Y4/1; F_2 + !, Mn-
110-150 cm half mature, somewhat cracked*) 5GY4/1-10GY5/1; + !, Mn —
Samples taken at 0-30, 50-100 and 100-150 cm below surface.

T5. Jan. '63. Songh Khlong.
Several km east of T4. Inside the seawall, salt water sediment. *Paddy (and fish).*
Physically nearly mature subsoil or wholly mature profile (except for the ploughed layer) down to a depth of more than 100 cm.
0-10 cm 10BG3/1
10-30 cm 10GY4/1
30-50 cm 2.5Y4/2
> 50 cm 5Y4/1
Samples taken at 0-20 and 30-60 cm below surface.

T6. Jan. '63. Ban Phai Dam, several km north of Yang Manee, along Noi river.
Recently deposited fresh-water sediment in small back swamp. *No vegetation.*
0-½ cm brownish
½- 5 cm grey
Physically immature, Fe +, Mn —.
Sample taken at 0-5 cm below surface.

T7. Jan. '63. Ban Phai Dam, north-east of Bang Thong Kung (north of Yang Manee) along Noi river.
Recently (approx. 5 years) reclaimed marsh area close to river. *Floating rice.*
Physically immature subsoil.
0-40 cm physically mature clayey soil, iron concretions, matrix 10YR4/1, spots 5YR4/6
40-90 cm physically half-mature loamy soil 7.5YR5/2 + 5/6 + 5/4 ground water at 90 cm. Profile poor in carbonate.
Samples taken at 0-20 and 60-90 cm below surface.

T8. Jan. '63. A few km north of Phai Cham Sin, along Noi river.
Fresh water sediment. Silty clay. Natural levee, several metres from river-bank. *Vegetation : cucumber, vegetables etc.*
Very hard lumps with clay transport phenomena, dry.
Also vermicular holes with coatings.
Samples taken at 0-10 and 30-40 cm below surface.

T9. and T9a. Jan. '63. Ban Na Khu Khlang.
Back swamp of Chao Phya river (west side). Brackish to fresh water heavy clay sediment. *Floating rice.*
0-30 cm black
30-80 cm grey with iron concretions along former roots and gypsum crystals, physically half to nearly mature. colour: 5YR3½/1 and 2.5 to 5YR3/4.
Sample T9 taken at 0-20 cm, T9a at 40-70 cm below surface.

T10. Jan. '63. Ban Khlong Sing Kanat.
Back swamp Chao Phya river. Brackish-fresh water clay sediment. *Embanked horticultural garden amidst the floating rice area, growing chilli.*
0-40 cm black 10YR3/1 with some iron concretion
40-60 cm physically mature or nearly mature greyish clayey soil, yellow (10YR4/6) and red (10R4/6) mottling in grey (2.5 6/2),

* Field test for reduced Fe inconclusive, for reduced Mn negative.
* "korte klei" Dutch term for short (not ropy, friable) clay.

matrix, along ditch walls efflorescense of gypsum.
60-120 cm ditto with many large gypsum crystals (4 to 5 mm).
Samples taken at 10-30 and 60-120 cm below surface.

T11. Feb. '63. Rajburi right bank of Meklong river. Fresh water silty sediment of Meklong river. Natural levee. Eroded vertical bank. *Grass vegetation.*
0-30 cm yellowish grey (gypsum efflorescense (lime?))
30-40 cm white
40-50 cm black
50 cm and deeper: yellowish grey.
Samples taken at 10-30 cm and 40-50 cm below surface.

T12. Feb. '63. Ban Paeed (or Paew). Dam near Damnern Saduak canal.
Coastal back swamp of salt to brackish water clay sediments. Meklong sea area. *Small embanked horticultural garden with chilli, cabbage.*
0-30 cm black
30-50 cm blackish with yellowish spots
50 cm and deeper greyish with bluish and greenish spots.
Physically mature down to 100 cm.
Samples taken at 10-20 and 40-100 cm below surface.

T13. Feb. '63. Ban Dhont (Bangkok).
Salty to brackish clay sediment of Chao Phya River.
Resalinization of water in canals. *Orange orchard.*
White carbonate efflorescense on surface.
Samples taken at 0-20, 40-60 and 70-90 cm surface.

CAMBODIA

C1. Feb. '63. Ph. Prek Doung à Thmey, south-east of Phnom Penh.
± 500 m from "colmatage" (= silt) sluice. Young, about 5 years old, "spill", fresh sandy-loam sediments of Mekong river. Irregular relief. *Corn and melon.*
0-20 cm topsoil—very sandy.
Deeper than 20 cm, physically not totally matured subsoil. Colour—6Y4/2½.
Sample taken at 20-60 cm below surface.

C2. Near Ph. Tual 10 km south-east of C1.
Fresh water Mekong sediments on natural levee, superficially rejuvenated by sedimentation. *Corn.*
Physically mature brown intial alluvial clay soil 5YR3½/3.
Sample taken at 30-80 cm below surface.

C3. Between Veal Traong and Veal Rhen, south-west Cambodia.
Salt water sediment, not embanked, slightly above mean high water level in open contact with the sea. *Paddy (and Nipa and salt ferns),*
0-25 cm cracks, physically mature clay soil (relatively acid)
Deeper than 25 cm immature clay soil (alkaline).
Sample taken at 30-80 cm below surface.

JAPAN

N1. Nov. '62. Fujisate (Genroku), Nobi delta.
About 1 km from river mouth, salt water sediment of Kiso river, 200 metres from left bank. Polder about 50 years old. *Paddy.*
0-20 cm oxidized; "spill" soil
50-100 cm reduced soil.
Sample taken at 20-40, 50-70 and 80-100 cm below surface; heavy rain during sampling.

N2. Nov. '62, Nishi-Taiganchi, Nobi delta.
About 5 km from river mouth. Salt water sediment of Kiso River. Polder about 50 years old. *Paddy.*
0-20 cm oxidized
20 cm and deeper: reduced.
Samples taken at 0-20 and 40-60 cm below soil surface.

N3. Nov. '62, Near Shinsho, Nobi delta.
Fresh water tidal sediment of Kiso river about 12 km from river mouth, non-embanked land with *Phragmites (spec.; non communis) vegetation.*
Physically approximately mature, permeable aerated soil down to > 120 cm depth.
Sample taken at 0-20, 40-60 and 70-90 cm below surface.

N4. Nov. '62, Alongside diversion dam in Nagawara river, Nobi delta, about 12 km from river mouth, fresh water tidal sediment of Nagawara river under *Phragmites vegetation.*
Sample taken at 0-20 cm below surface; inundated during sampling.

N5. Nov. '62, Takasu, Nobi delta. *"Waju"* area. Fresh water sediment of Ibi river about 24 km from river mouth on transition back swamp and natural levee. *Paddy.*
0-20 cm mottled with grey and brown reduction and oxidation colours.
20-80 cm predominantly reduction colours, only on cracks iron oxide concretions.
50 cm limelike concretions.
Samples taken at 0-20 and 40-70 cm below surface.

N6. Nov. '62, Kitagatamura, Nobi delta.
Fresh water sediment of Kiso river about 38 km from river mouth in small depression in natural levee. *Paddy.*
0-60 cm oxidized, physicaly mature.
Samples taken at 0-20 and 40-100 cm below surface.

CHINA (TAIWAN)

F1. Nov. '62. Hsin Chu Hsien, west coast.
Marine foreland. Salt water sediment. About mean high water level. *No vegetation.*
Sample taken at 0-20 cm below surface.

F2. Nov. '62. Cho Shui delta.
Fresh water sediment of Cho-Shui river system (top soil possibly removed). *Sweet potatoes.*
Physically mature initial soil profile with iron oxide concretions and mottles down to 125 cm below surface.
Samples taken at 0-20 and 40-60 cm below surface.

F3. Nov. '62. Cho Shui delta.
Recently deposited fresh water sediment under immature conditions in irrigation channel. *No vegetation.*
Sample taken at 0-20 cm below surface.

F4. Nov. '62. Yunlin tidal land (near profile F5) Cho Shui delta. Salt water sediment influenced by fresh water, on marine foreland above mean high water level. *Short grass vegetation.*
Sample taken at 0-15 cm below surface.

F5. Nov. '62. Yunlin tidal land (near profile F4) Cho Shui delta. Salt water sediment influenced by fresh water, on marine foreland above mean high water level. *No vegetation.*
Sample taken at 0-20 cm below surface.

F6. Nov. '62. Yunlin tidal land, west coast.
Between low bamboo dams redimenstasion experiments) above mean high water level. *No important vegetation.*
Sample taken at 0-2 cm below surface.

F7. Nov. '62. Young accretion in salty part of estuarium of Tan Shui river (near Taipei). *Dense young mangrove vegetation (Kandelia candel)* no aerial roots. Surface between mean high water level and mean sea level.
Immature soil without lime.
0-30 cm clayey soil (class D) 2.5Y4/2. Penetrometer M. 0.7-1.3.
30-100 cm 10Y3/1 Penetrometer M. 1.0-1.5.
Samples taken at 0-30 and 40-80 cm below surface.

INDIA

S1. Dec. '62. Frasergang, Sundarbans, West Bengal. Behind small dune strip moving toward land. About 500 years old salt-water sediment of river Ganges, lowly embanked, *Paddy* (800-1,000 kg/ha).
Physically mature to > 80 cm. Iron oxide mottles deeper than 100 cm.
Matrix colour on 80 cm = 5Y4/1. Application of compost and manure, no artificial chemical fertilizer.
Samples taken at 0-20, 30-50 and 60-80 cm below surface.

S2. Dec. '62. Takuran (or Ajmalmari) river, Sundarbans, West Bengal, about 15 km from the sea. Salt water silt recently deposited on bottom of gully.
Sample taken at 0-10 cm below surface.

S3. Dec. '62. West side "Tiger Island" situated between Ajmalmari river and Matla river, Sundarbans, West Bengal. Salt water sediment of Ganges river. Natural levee of "dwip" (tidal accretion) above mean high water level. *Virgin vegetation of small Phoenix (palm) mixed with several mangrove species.* Tiger footprints, intersected by small cracks.
0-40 cm Physically mature initial soil (2.5Y4/2) iron oxide mottles.
40-100 cm Nearly mature initial soil with iron oxide mottles.
> 100 cm Nearly to half mature, no mottles. Colour: 5Y5/1-2.
Samples taken at 0-20, 30-50 and 60-100 cm below surface.

S4. Dec. '62. Tiger Island, Sundarbans, West Bengal.
Small tidal creek near S3, sloping wall with newly deposited mud (partly originated by erosion), about mean sea level with scarce vegetation of mangrove seedlings.
Sample taken at 0-20 cm below surface.

S6. Dec. '62. Accretion along Sherpal Khal near Maipit, Sundarbans, West Bengal.
Non-embanked fringe of lowly embanked island. Salt water sediment of Ganges river. *Vegetation: div. mangrove species and Sueda c.f.*
Half matured soil
0-10 cm nearly mature initial soil, Penetrometer M = 1.2-3.0.
10-60 cm half mature initial soil, 2½Y5/2, many iron oxide mottles. Penetrometer M = 1.0-1.5.
60-80 cm 10Y5/1 few iron oxide mottles. Penetrometer M = 2.0-2.5.
80-100 cm N5/0 no iron mottles. Penetrometer M = 2.0-2.5. on 96 cm shell layer.
Samples taken at 0-5, 20-50, 80-100 cm below surface.

S7. Dec. '62. Near Experimental Farm near Gosaba, Sundarbans, Salt (or brackish) water sediment of Ganges river, non-embanked fringe along Bidya river, with *vegetation of Sueda c.f.*
Sample taken at 0-20 cm below surface.

S8. Dec. 162. Experimental Farm near Gosaba (Bidya river), Sundarbans. Embanked area. Salt water sediment of the Ganges river. *Paddy.*
Samples taken at 0-30 and 30-50 cm below surface.

S9. Dec. '62. Near Experimental Farm near Gosaba, non-embanked fringe along Bidya river, Sundarbans. Near eroded bank. Salty (brackish) Ganges sediment. *No vegetation;* on slightly higher elevation: Tamarix.
Sample taken at 0-5 cm below surface.

S10. Dec. '62. Young accretion in Sapta Mukhi river, near Namkhana, Sundarbans.
Salt water Ganges sediment. *Mangrove without forest floor vegetation.*
Not to half mature in the sense of initial alluvial soil formation.
Samples taken at 0-10 and about 20-40 cm below surface.

PAKISTAN

P1. Dec. '62. Bill Dakathia near Khulna (N.W.), East Bengal.
Pabla silty clay loam with peat in subsoil. Recently reclaimed brackish water marsh that had been a paddy field 20 years ago; brackish fresh Ganges sediment. *Paddy and weeds.*
Very wet.
Samples taken at 0-20 and 30-50 cm below surface, submerged during sampling.

P2. Dec. '62. Chalna alongside the Bhadra river, East Bengal. Fresh water tidal clay, periodically brackish (dry season), Baitaghata series. Ganges sediment. Natural levee about 10 metres from river bank. Non-embanked area, only small dams (1 foot high) around paddy fields, soil surface about 1 foot above mean high water level. *Paddy (and Sonneratia).*
Subsoil immature in the sense of initial physical soil formation.
Samples taken at 0-20 and about 30-60 cm below surface.

P3. Dec. '62. Near P2. Chalna (Bhadra river), East Bengal. Fresh water tidal clay, in summer season brackish (Ganges deposit). Recently deposited silt. *No vegetation, but nearby among others "Leersia" and "Salt water holly".* Soil surface + 75 cm below mean high water level.
Immature.
Samples taken at 0-5 cm below surface.

P4. Dec. '62. Bedkan between Arpangasia and Sakbaria near Kobadak. East Bengal.
Brackish water Ganges sediment. Amadi à Burogualine series. Small embanked polder with *paddy.*
Samples taken at 0-20 and 30-50 cm below surface.

P5. Dec. '62. Asasuni Khodpedla river, East Bengal.
Non-embanked fringe of brackish water Ganges sediment, about 1 m below mean high water level. *Vegetation among others Cyperus and Avicennia.*
Half mature.
Sample taken at 0-20 cm below surface.

P6. Dec. '62. South of Satkhira along Tiket Nadi river. East Bengal.
Amadi series, brackish Ganges sediment. *Paddy.*
0-30 cm "plough" layer
30-60 cm "organic" black coloured horizon
about 60-100 cm compact soil with sharp edged limelike concretions.
Sample taken at 30-50 cm below surface.

P7. Dec. '62. "Dacca-Savar," East Bengal.
Fresh road-side exposure in basin site, 1½ miles west of Mirpur bridge on Dacca-Savar road, older (pleistocene?) Ganges sediment.
Physically mature. Black "organic" clay.
Sample taken at about 30 cm deep, wet when sampled.

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APPENDIX I: TABLE I

ANALYTICAL DATA OF SOIL SAMPLES COLLECTED DURING FIELD INSPECTIONS OF ECAFE MISSION ON DELTAIC AREAS

(November 1962 – February 1963)

LABORATORY NUMBER Soil survey laboratory DIRECTION WIERINGERMEER KAMPEN, HOLLAND	FIELD NUMBER	LOCATION	VEGETATION	The environment of deposition of the sediment (marine-fluviatile)	DEPTH OF SAMPLING in cm	ORGANIC MATTER = H in %	ORGANIC CARBON = C in %	FRACTION < 16μ in % of the mineral soil of < 2 mm	CLAY (FRACTION < 2μ) = L in % of the mineral soil of < 2 mm	SAND in % of the mineral soil of < 2 mm	RATIO < 2μ/< 16μ x 100	SPECIFIC SURFACE OF THE FRACTION 16μ–2000μ in cm^2/g
		BURMA										
82900	B1	Henzada, Irrawaddy	Kain crops	F	20- 50	1.2	0.7	48.9	20.6	51.5	42.1	309
82901	B2	Henzada, Irrawaddy delta		F	20- 50	1.4	0.8	79.5	39.6	19.1	75.1	228
82902	B3	Zalun, idem	No vegetation	F	0- 1	1.7	1.0	64.8	24.7	36.4	38.2	331
82903	B3			F	1- 5	2.2	1.3	63.6	24.3	36.5	39.8	324
82904	B4	Tapa, idem	Paddy	F	0- 20	2.9	1.7	95.0	58.9		62.0	
82905	B4			F	50- 60	1.0	0.6	92.5	45.3		48.9	
82906	B5	Near to sample B4	Kain vegetation	F	0- 5	5.5	3.2	89.5	57.8	3.1	64.6	258
82907	B6	Elwasa chaung and Pyamalaw river near Ngayokkaung	-Heritirera littoralis- and many other plants	B	0- 20	3.5	2.1	78.0	32.4	24.3	41.5	324
82908	B6			B	30- 50	2.0	1.1	78.0	36.0	14.1	46.2	295
82909	B6			B	70- 90	1.6	0.9	76.0	35.7	14.9	46.9	310
82910	B6			B	110-125	1.5	0.9	82.2	41.1	7.9	50.0	268
82911	B6			B	250-350	2.4	1.4	77.5	33.6	20.7	43.4	305
82912	B7	In gully near B6	No vegetation	B	0- 3	1.8	1.1	84.0	43.0	12.8	51.2	342
82913	B7			B	3- 30	1.9	1.1	85.0	41.4		48.7	
82914	B8	Myaungmya experimental station	Paddy	F/B	50-100	0.8	0.4	92.1	60.4		67.0	
82915	B9	Myaungmya	Paddy	F/B	40-100	0.5	0.3	97.4	58.3		59.9	
82916	B10	Kan-Twa along Panmawadi river	Paddy with Alisma-and Myosotis like plants	F/B	0- 20	3.2	1.8	87.7	41.4		47.2	
82917	B10			F/B	40- 60	4.0	2.3	86.5	44.4		51.3	
82918	B10			F/B	80-100	3.5	2.0	85.9	45.2		52.6	
82919	B11	Methwechaune, Yandoon Island	"wild grass" never in culture	F/B	0- 20	2.3	1.3	97.0	57.3		59.1	
82920	B11			F/B	20- 30	1.6	1.0	95.5	76.0		79.5	
82921	B11			F/B	30- 60	1.8	1.0	96.2	78.9		82.0	
82922	B11			F/B	60- 90	1.6	0.9	94.2	79.6		84.5	
82923	B11			F/B	90-120	1.6	1.0	94.7	79.1		83.5	
		THAILAND										
82965	T1	Ban Tha Khon	Paddy	F/B	0- 20	4.8	2.8	90.4	66.9		74.0	
82966	T1			F/B	20- 50	3.6	2.1	91.9	66.7		72.6	
82967	T1			F/B	50- 80	1.8	1.0	91.1	59.8		65.6	
82968	T1			F/B	80-100	4.2	2.4	91.2	67.3		73.8	
82969	T2	Ban Lam Tin Tai (Rangsit area)	Bare spot in Paddy	F/B	0- 10	3.2	1.8	91.7	65.7		71.6	
82970	T2			F/B	10- 15	1.7	1.0	92.0	64.4		70.0	
82971	T2			F/B	25- 40	1.3	0.8	90.6	63.2		69.8	
82972	T2			F/B	50- 70	1.0	0.6	93.2	67.5		72.4	
82973	T2			F/B	90-130	1.4	0.8	91.1	66.6		73.1	
82974	T2			F/B	130-150	4.2	2.4	81.1	53.8	13.2	66.3	235
82975	T3	Ban Lam Tin Tai (near T2)	Paddy	F/B	0- 20	5.4	3.1	89.2	64.3		72.1	
82976	T4	Songh Khlong	Nipa palm	M	0- 20	4.5	2.6	90.2	64.3		71.3	
82977	T4			M	50-100	5.1	3.0	88.2	64.8		73.5	
82978	T4			M	100-150	3.3	1.9	90.1	67.4		74.6	
82979	T5	Songh Khlong	Paddy	F/B	0- 20	2.8	1.6	92.3	69.2		75.0	
82980	T5			F/B	30- 60	1.6	0.9	93.4	70.2		75.2	
82981	T6	Ban Phai Dam	No vegetation	F	0- 5	1.5	0.8	61.6	27.8	38.4	45.1	306
82982	T7	Ban Phai Dam North East of Bang Thong Kung	Floating rice	F	0- 20	2.2	1.3	77.0	51.6	21.1	67.0	304
82983	T7			F	60- 90	0.3	0.2	33.1	21.3	66.9	64.4	244
82984	T8	North of Phat Chum Sin	Cucumber vegetables	F	0- 10	2.5	1.4	70.8	34.1	29.8	48.2	342
82985	T8			F	30- 40	1.8	1.0	88.6	48.3		54.5	
82986	T9	Ban Na Khu Khlang Chao Phya river	Floating rice	F/B	0- 20	3.4	2.0	93.2	64.2		68.9	
82987	T9a			F/B	40- 70	2.9	1.7	92.2	62.4		67.7	
82988	T10	Ban Khlong Sing Kanat	Horticultural garden	F/B	10- 20	1.7	1.0	92.8	66.0		71.1	
82989	T10			F/B	60-120	4.0	2.2	87.6	61.0		69.6	
83379	T11	Rajburi Right Bank of Meklong River	Grass	F	10- 30	1.5	0.9	65.3	37.9	32.1	58.0	307
83380	T11			F	40- 50	1.3	0.7	62.6	41.0	36.8	65.5	346
83381	T12	Ban Paeed-Damnern Saduck canal	Horticultural garden	M/B	10- 20	2.5	1.5	74.3	54.3	23.3	73.1	351
83382	T12			M/B	40-100	0.9	0.5	78.2	59.2		75.7	
83383	T13	Ban Dhont (Bangkok)	Orange orchard	M/B	40- 50	3.3	1.9	89.0	65.3		73.4	
83384	T13			M/B	50- 80	1.1	0.6	93.3	68.7		73.6	
		CAMBODIA										
83385	C1	ph. Prek Doung à Thmey	Corn, Melon	F	20- 60	1.5	0.9	37.8	16.9	61.9	44.7	312
83386	C2	ph. Tual South East of C1	Corn	F	30- 80	1.1	0.6	79.5	33.4	23.4	42.0	358
83387	C3	Veal Traong and Veal Rhen	Paddy, Nipa	H	30- 80	5.5	3.2	72.4	41.5	24.0	57.3	349
		JAPAN										
82558	N1	Fujisate (Genroku), Nobi-delta	Paddy	M	20- 40	1.7	1.0	22.9	7.7	75.7	33.6	124
82559	N1			M	50- 70	1.6	0.9	35.6	11.9	63.1	33.7	186
82560	N1			M	80-100	1.1	0.6	24.4	8.7	73.3	35.7	164
82561	N2	Nishi-Taiganchi Nobi-delta	Paddy	M	0- 20	2.1	1.2	23.4	9.4	74.5	40.2	131
82562	N2			M	40- 60	1.6	0.9	23.9	9.1	74.4	38.1	148
82563	N3	Near Shinsho, Kiso river, Nobi-delta	Phragmites spec.	F	0- 20	3.1	1.8	38.8	11.5	58.2	29.6	189
82564	N3			F	40- 60	1.0	0.6	26.8	7.9	72.3	29.5	132
82565	N3			F	70- 90	0.5	0.3	16.7	5.7	82.3	34.1	122
82566	N4	Nigawara River	Phragm. spec.	F	0- 20	6.4	3.6	62.2	22.4	32.4	36.0	304
82567	N5	Takasu "Wadju" area Nobi-delta	Paddy	F	0- 20	2.8	1.6	58.9	24.4	39.1	41.4	246
82568	N5			F	40- 70	1.5	0.9	72.2	33.2	25.9	46.0	270
82569	N6	Kitagata mura Nobi-delta	Paddy	F	0- 20	2.6	1.5	22.4	8.5	75.6	37.9	173
82570	N6			F	40-100	1.4	0.8	42.8	12.8	57.6	29.9	288
		TAIWAN										
82664	F1	Hsin-Chu-Hsien, west coast	No vegetation	M	0- 20	0.9	0.5	23.3	11.1	75.3	47.6	155
82665	F2	Cho-Shui-delta	Sweet patatoes	F	0- 20	1.2	0.7	54.3	15.8	43.9	29.1	261
82666	F2			F	40- 60	0.7	0.4	34.2	10.2	65.3	29.8	221
82667	F3	Cho-Shui-delta	No vegetation	F	0- 20	1.1	0.6	83.3	20.0	13.4	24.0	349
82668	F4	Yunlin tidalland	Short grasses	B	0- 15	1.5	0.9	45.3	15.2	51.1	33.6	256
82669	F5	Yunlin tidalland	No vegetation	B	0- 20	1.3	0.8	56.7	17.3	41.2	30.5	299
82670	F6	Yublin tidalland	No vegetation		0- 2	0.5	0.3	17.9	7.0	77.7	39.1	270
82671	F7	Tan-Shui river near Taipai	Dense young Mangrove	M	0- 30	4.7	2.7	73.5	25.7	28.4	35.0	347
82672	F7			M	40- 80	1.9	1.1	46.7	18.7	54.6	40.0	301
		INDIA										
82828	S1	Frasergang, Sundarbans West Bengal	Paddy	M	0- 20	1.4	0.8	68.4	29.7	32.4	43.4	199
82829	S1			M	30- 50	0.7	0.4	72.7	35.8	26.0	49.2	180
82830	S1			M	60- 80	0.5	0.3	74.5	35.7	23.1	47.9	149
82831	S2	Takuran (or Ajmalmari) river		M	0- 10	0.5	0.3	37.9	18.4	58.3	48.5	290
82832	S3	Westside "Tiger island" between Ajmalmari river and Matla river	Virgin vegetation of small phoenix and Mangrove spec.	M	0- 20	1.2	0.7	78.4	34.2	19.9	43.6	337
82833	S3			M	30- 50	1.1	0.6	86.8	39.6	8.4	45.6	330
82834	S3			M	60-100	1.1	0.6	89.1	41.7	6.5	46.8	307
82835	S4	"Tiger island"	Mangrove seedlings (scarce)	M	0- 20	1.1	0.7	54.8	27.7	33.4	50.5	289
82836	S6	Sherpal khal near Maipit	Mangrove species	M	0- 5	1.3	0.8	75.0	34.1	15.8	45.5	339
82837	S6			M	20- 50	1.3	0.7	82.4	38.1	11.0	46.2	329
82838	S6			M	80-100	4.3	2.5	81.5	36.9	15.8	45.3	311
82839	S7	Gosăba	Sueda cf.	M/B	0- 20	0.8	0.5	62.3	28.9	29.2	46.4	339
82840	S8	Gosăba Bidya river	Paddy	M	0- 30	1.9	1.1	89.5	43.0	8.0	48.0	291
82841	S8			M	30- 50	1.1	0.6	91.5	45.0		49.2	
82842	S9	Gosăba, Bidya river	Tamarix on higher elevation	B	0- 5	0.9	0.5	57.9	29.1	37.2	50.3	325
82843	S10	Sapta mukhi river near Nămkhăna	Mangrove without forestfloor vegetation	M	0- 10	1.0	0.6	73.8	42.3	22.3	57.3	321
82844	S10			M	20- 40	1.0	0.6	71.1	39.2	21.7	55.1	334
		PAKISTAN										
82845	P1	Bill Dakathia near Khulna (N.W.)	Paddy and weeds	B	0- 20	6.5	3.8	86.4	45.1		52.2	
82846	P1			B	30- 50	12.0	7.0	84.6	64.9		76.7	
82847	P2	Chalna Bhadra river	Paddy and (Sonneratia)	F/B	0- 20	1.5	0.9	65.7	24.8	28.1	37.7	346
82848	P2			F/B	30- 60	1.5	0.9	73.3	27.2	22.6	37.1	336
82849	P3 P3	Chalna Bhadra river	No vegetation near "Leersia"	F/B F/B	0- 5	1.2	0.7	34.1	14.3	59.6	41.9	299
82850	P4	Bedkan near Arpangasia and Sakbaria (Kobadak)	Paddy	B	0- 20	2.5	1.5	79.0	30.8	19.7	39.0	336
82851	P4			B	30- 50	1.1	0.6	80.4	32.8	23.5	40.8	329
82852	P5	Asasuni Khodpedla river	Cyperus and Avicennia	B	0- 20	1.6	0.9	76.4	31.8	21.0	41.6	334
82853	P6	Satkhira along Tiket Nadi river	Paddy	B	30- 50	8.5	4.9	78.8	54.5	10.2	69.2	335
	P7	Daoca-Savar		F	ca. 30	4.3	2.5	85.5	48.0	9.6		319

LABORATORY NUMBER	FIELD NUMBER	Water soluble Ca in me/100 g. soil	$CaCO_3$ in %	Exchangeable SO_4 in me/100 g/soil	TOTAL SO_4 in %	TOTAL SO_4 in me/100 g. soil	pH H_2O	pH KCL	cation exchange capacity, me/100 g. soil	cation exchange capacity (C.E.C.)/(L+3H) 100 = C m/100 g. clay	EXCHANGEABLE CATIONS: sum of the exchangeable basic cations Ca + Mg + K + Na in me/100 g. soil	Ca in me/100 g. soil	Mg in me/100 g. soil	K in me/100 g. soil	Na in me/100 g. soil	BASE SATURATION sum cations/cat. ex. cap. x 100	Ca in % of sum cations	Mg in % of sum cations	K in % of sum cations	Na in % of sum cations	Ca/Mg ratio
82900	B1		0.05	0.0	0.0	0.0	7.1	5.9	19.8	81.8	17.78	11.10	6.37	0.25	0.06	21.8	62.5	35.8	1.4	0.3	1.75
82901	B2		0.05	0.12	0.03	0.25	6.7	5.4	38.1	59.7	30.03	14.66	14.69	0.35	0.31	50.3	48.9	48.9	1.2	1.0	1.00
82902	B3		0.25	0.12	0.03	0.62	7.3	6.5	21.4	71.8	19.17	12.26	6.43	0.37	0.11	26.7	64.0	33.5	1.9	0.6	1.91
82903	B3		0.4	0.0	0.05	1.04	7.7	7.0	21.7	70.2	21.02	13.51	6.68	0.47	0.16	29.9	64.3	32.7	2.2	0.8	1.97
82904	B4		0.0	0.03	0.01	0.20	5.4	4.2	57.8	55.9	24.22	9.61	13.63	0.37	0.61	43.3	39.7	56.3	1.5	2.5	0.71
82905	B4		0.05	1.66	0.03	0.62	7.1	6.6	31.4	65.0	29.22	8.90	17.53	0.25	2.54	45	30.4	60.0	0.9	8.7	0.51
82906	B5		0.15	0.04	0.21	4.36	6.6	5.6	39.8	53.6	25.85	14.28	10.41	0.97	0.19	48.2	55.2	40.3	3.8	0.7	1.37
82907	B6		0.05	0.18	0.08	1.56	5.8	4.6	31.4	73.2	21.02	6.30	11.26	0.77	2.69	28.7	30.0	53.6	3.6	12.8	0.56
82908	B6		0.05	0.12	0.01	0.20	6.7	5.5	31.1	74.0	21.08	4.70	11.14	0.85	4.39	28.5	22.3	52.9	4.0	20.8	0.42
82909	B6		0.05	0.14	0.00	0.0	6.9	5.7	28.5	70.4	22.29	4.38	11.67	0.88	5.36	31.7	19.7	52.4	3.9	24.0	0.38
82910	B6		0.05	0.71	0.17	3.54	6.7	5.8	30.2	66.2	23.45	4.17	12.58	0.96	5.74	35.4	17.8	53.6	4.1	24.5	0.33
82911	B6		0.05	2.26	2.94	61.26	7.2	6.5	28.9	63.1	26.50	4.43	13.60	1.51	6.90	42	16.7	51.3	5.9	26.1	0.33
82912	B7		0.15	0.06	0.17	3.54	7.3	6.5	32.9	68.0	28.72	9.70	14.06	0.77	4.19	42.2	33.8	48.9	2.7	14.6	0.69
82913	B7		0.15	0.51	0.34	7.08	6.9	6.2	31.1	66.0	26.92	6.73	13.42	0.79	5.98	37.8	25.0	49.9	2.9	22.2	0.50
82914	B8		0.05	5.10	0.31	6.46	4.7	3.9	33.0	52.5	25.94	5.93	15.72	0.57	1.72	45.2	25.0	66.2	1.6	7.2	0.38
82915	B9		0.05	0.20	0.00	0.0	7.3	5.6	33.3	55.7	30.51	7.41	20.64	0.29	2.17	54.8	24.3	67.6	1.0	7.1	0.36
82916	B10		0.05	0.72	0.15	3.12	5.6	4.8	31.3	61.4	21.29	5.47	12.03	0.76	3.03	34.7	25.7	56.5	3.6	14.2	0.45
82917	B10		0.10	0.64	0.58	12.08	6.6	5.7	32.7	58.0	23.45	5.20	13.27	1.03	3.95	40.4	22.2	56.6	4.4	16.8	0.30
82918	B10		0.05	1.68	1.27	26.46	6.3	5.6	32.9	59.1	24.50	5.29	13.95	1.15	4.11	41.5	21.6	56.9	4.7	16.8	0.38
82919	B11		0.05	0.0	0.04	0.84	5.6	4.5	40.7	63.4	29.92	18.11	10.94	0.69	0.18	47.2	60.5	36.6	2.3	0.6	1.65
82920	B11		0.05	0.01	0.01	0.20	6.3	4.8	46.7	57.4	27.02	16.30	15.36	0.66	0.40	57	49.8	47.0	2.0	1.2	1.06
82921	B11		0.05	0.01	0.01	0.20	6.7	5.4	48.0	56.9	37.13	16.60	19.00	0.59	0.94	65.3	44.7	51.2	1.6	2.5	0.87
82922	B11		0.05	0.85	0.05	1.04	6.3	5.3	49.0	58.3	37.13	16.14	17.93	0.49	1.49	61.8	44.8	48.3	1.2	4.1	0.91
82923	B11		0.05	1.76	0.05	1.04	6.2	5.3	46.3	58.3	40.81	18.01	20.40	0.50	1.90	70	44.1	50.0	1.2	4.7	0.88
82965	T1	0.11	0.0	0.01	0.25	5.20	5.8	4.8	40.4	49.7	21.61	15.22	5.44	0.61	0.34	43.5	70.4	25.2	2.8	1.6	2.79
82966	T1	0.40	0.05	2.08	0.26	5.42	4.6	3.9	39.3	50.7	13.85	8.69	4.39	0.26	0.51	27.3	62.7	31.7	1.9	3.7	1.97
82967	T1	0.59	0.0	2.25	0.22	4.58	4.4	4.0	30.4	46.6	8.89	4.54	3.68	0.33	0.34	19.1	51.1	41.4	3.7	3.8	1.23
82968	T1	0.42	0.05	0.75	0.24	5.00	4.8	4.0	39.9	49.9	17.24	11.89	4.56	0.33	0.46	34.5	69.0	26.4	1.9	2.7	2.61
82969	T2	1.77	0.05	7.39	1.40	29.16	3.9	3.7	36.5	48.5	8.56	3.36	4.52	0.16	0.52	17.6	39.2	52.8	1.9	6.1	0.74
82970	T2	1.86	0.0	6.05	0.59	12.3	3.9	3.6	33.4	48.1	8.31	3.05	4.62	0.20	0.44	17.3	36.7	55.6	2.4	5.3	0.66
82971	T2	1.85	0.0	6.27	0.76	15.84	3.8	3.5	32.3	48.1	8.05	3.18	4.66	0.23	0.33	17.5	37.9	55.5	2.7	3.9	0.68
82972	T2	1.86	0.05	6.69	1.43	29.8	3.6	3.4	31.6	44.8	8.15	2.76	4.71	0.27	0.41	18.2	33.9	57.8	3.3	5.0	0.58
82973	T2	1.51	0.05	8.25	1.49	31.0	3.3	3.1	32.4	45.8	8.15	3.50	4.19	0.25	0.41	17.8	40.5	51.4	3.1	5.0	0.78
82974	T2	1.94	0.05		1.62	33.76	3.4	3.2													
82975	T3	0.50	0.05	2.29	0.99	20.62	4.3	3.9	40.6	50.8	9.42	4.96	3.73	0.42	0.31	18.7	52.6	39.6	4.5	3.3	1.32
82976	T4	0.70	0.10	5.72	0.80	16.66	6.9	6.5	45.1	58.0	40.55	6.77	17.40	2.48	13.90	89.9	16.7	42.9	6.1	34.3	0.38
82977	T4	0.54	0.15	6.68	6.74	140.4	7.7	7.4	41.5	51.4	42.30	6.94	17.14	3.57	14.65	82.3	16.4	40.6	8.4	34.6	0.40
82978	T4	0.57	0.50	7.19	6.73	140.2	8.1	7.8	41.0	53.0	45.59	9.88	18.61	3.49	14.61	87.9	21.2	39.9	7.5	31.4	0.53
82979	T5	0.07	0.40	1.31	0.58	12.08	7.8	7.1	41.1	53.0	35.50	4.50	22.35	2.35	6.30	67	12.7	63.0	6.6	17.7	0.20
82980	T5	0.04	0.40	2.13	0.21	4.38	8.6	8.0	40.6	54.1	35.02	4.43	22.66	2.38	8.41	70	11.7	59.8	6.3	22.2	0.19
82981	T6	0.23	0.10	0.03	0.03	0.62	6.8	5.9	17.4	53.9	11.28	8.13	2.80	0.26	0.09	20.9	72.1	24.8	2.3	0.8	2.90
82982	T7	0.13	0.05	0.57	0.07	1.46	5.4	4.8	27.4	47.1	14.28	10.78	2.83	0.41	0.26	30.3	75.5	20.0	1.6	2.9	3.78
82983	T7	0.20	0.05	0.18	0.01	0.20	8.3	7.3	11.2	50.5	10.61	8.69	1.60	0.06	0.26	21	81.9	15.1	0.6	2.4	5.42
82984	T8	0.35	0.10	0.33	0.07	1.46	5.5	4.8	23.3	56.0	13.82	10.12	3.36	0.31	0.03	24.7	73.3	24.3	2.2	0.2	3.01
82985	T8	0.13	0.05	0.0	0.04	0.84	6.0	4.9	27.5	51.2	19.59	14.90	3.43	0.25	0.17	28.3	80.3	17.5	1.5	0.9	4.58
82986	T9	4.91	0.0	8.60	0.63	13.12	4.5	4.0	35.1	47.4	25.91	19.75	2.59	0.34	0.13	50.4	87.3	10.0	1.3	1.1	8.00
82987	T9a	14.15	0.05	19.69	1.24	25.84	3.8	3.6	35.0	46.4	25.07	19.77	4.42	0.14	0.74	54	78.8	17.6	0.6	3.0	4.47
82988	T10	0.83	0.05	5.23	0.29	6.04	5.9	5.4	34.6	48.7	28.59	15.02	11.04	0.25	2.28	58.7	52.5	38.6	0.9	8.0	1.36
82989	T10	115.12	0.05	41.07	6.17	128.54	6.3	6.1	27.2	43.7	142.52	126.43	13.2	0.30	2.77		88.8	9.1	0.2	1.9	9.75
83379	T11		0.50	0.05	0.03	0.62	8.0	7.4	22.0	51.9	21.17	16.40	4.36	0.28	0.13	40.8	77.5	20.6	1.3	0.6	3.76
83380	T11		0.60	0.31	0.07	1.46	7.9	7.3	26.8	59.7	26.33	19.62	6.23	0.36	0.12	44.1	74.5	23.6	1.4	0.5	3.15
83381	T12		0.35	0.07	0.09	1.88	8.0	7.2	44.2	71.5	40.14	25.88	11.90	0.78	1.58	56.1	64.5	29.7	1.9	3.9	2.17
83382	T12		0.10	0.15	0.02	0.40	7.9	7.1	37.9	61.2	35.26	18.85	13.54	0.98	1.89	57.6	53.4	38.4	2.8	5.4	1.39
83383	T13		0.0	0.09	0.07	1.46	6.8	5.8	45.4	60.4	36.78	15.60	17.38	0.78	3.02	60.9	42.4	47.3	2.1	8.2	0.89
83384	T13		0.05	1.51	0.03	0.62	7.6	6.9	36.7	51.0	31.81	9.89	16.13	1.12	4.67	62.4	31.1	50.7	3.5	14.7	0.61
83385	C1		0.40	0.04	0.01	0.20	7.6	7.1	15.1	70.6	13.86	11.07	2.60	0.15	0.04	19.6	79.9	18.7	1.1	0.3	4.27
83386	C2		0.0		0.01	0.20	7.3	6.4	20.0	54.5	17.72	11.74	3.82	0.08	2.08	32.5	66.2	21.6	0.5	11.7	3.06
83387	C3		0.0		1.16	24.17	5.9	5.7													
82558	N1		0.05	0.0	0.20	4.16	6.3	6.0	8.1	63.3	6.28	2.88	2.21	0.32	0.87	9.9	45.9	35.2	5.1	13.8	1.30
82559	N1		0.05	0.68	0.29	6.04	5.9	5.5	9.4	56.3	6.61	2.79	2.55	0.36	0.91	11.7	42.2	38.6	5.4	13.8	1.09
82560	N1		0.00	0.46	1.31	27.30	5.6	5.2	7.9	65.8	5.54	2.00	2.53	0.33	0.68	8.4	36.1	45.7	5.9	12.3	0.79
82561	N2		0.05	0.0	0.13	2.70	6.3	5.9	10.1	64.3	6.67	3.28	2.21	0.22	0.96	10.4	49.2	33.1	3.3	14.4	1.48
82562	N2		0.00	0.15	0.17	3.54	6.3	5.5	7.7	55.4	4.66	1.94	1.87	0.22	0.63	8.4	41.6	40.2	4.7	13.5	1.04
82563	N3		0.00	0.0	0.10	2.08	6.7	6.1	14.4	69.2	8.07	5.22	2.18	0.41	0.26	11.7	64.7	27.0	5.1	3.2	2.39
82564	N3		0.00	0.41	0.04	0.84	6.1	5.0	9.3	85.3	3.85	2.82	0.79	0.14	0.10	4.5	73.3	20.5	3.6	2.6	3.57
82565	N3		0.00	0.02	0.04	0.84	6.2	5.0	5.9	81.9	3.14	2.11	0.87	0.07	0.09	3.8	67.2	27.7	2.2	2.9	2.43
82566	N4		0.05	0.00	0.14	2.92	6.1	5.1 5.5	20.1	48.3	6.36	3.04	2.20	0.31	0.81	13.2	47.8	34.6	4.9	12.7	1.38
82567	N5		0.00	0.0	0.12	2.50	5.9	4.8	17.6	53.7	8.43	5.89	2.19	0.09	0.26	15.7	69.9	25.9	1.1	3.1	2.70
82568	N5		0.65	0.0	0.08	1.66	6.2	5.3	15.9	42.2	6.41	3.74	2.15	0.19	0.33	15.2	58.4	33.5	3.0	5.1	1.74
82569	N6		0.00	0.0	0.10	2.06	5.9	5.4	9.7	59.5	5.35	4.57	0.65	0.03	0.10	9	85.4	12.1	0.6	1.9	7.06
82570	N6		0.15	0.12	0.09	1.88	6.2	5.3	11.7	68.8	7.17	5.18	1.60	0.25	0.14	10.4	72.2	22.3	3.5	2.0	3.24
82664	F1		0.45	2.15	0.12	2.50	8.1	7.9	6.2	44.9	9.13	3.78	2.68	0.65	2.02	20.3	41.4	29.4	7.1	22.1	1.41
82665	F2		2.35	0.00	0.07	1.46	8.0	7.6	5.9	30.4	6.74	5.33	1.23	0.06	0.12	22.2	79.1	18.2	0.9	1.8	4.35
82666	F2		1.50	0.11	0.02	0.40	8.2	8.0	3.3	26.8	3.58	2.67	0.82	0.04	0.05	13.4	74.6	22.9	1.1	1.4	3.26
82667	F3		3.80	0.78	0.29	6.04	7.9	7.7	2.9	12.4	4.20	2.69	1.39	0.07	0.05	33.9	64.0	33.1	1.7	1.2	1.93
82668	F4		3.60	0.00	0.41	8.54	7.5	7.2	6.1	31.0	6.31	1.88	2.99	0.31	1.13	20.4	29.8	47.4	4.9	17.9	0.63
82669	F5		4.30	0.40	0.68	14.16	7.8	7.5	6.3	29.7	6.79	2.09	3.12	0.35	1.23	22.9	30.8	45.9	5.2	18.1	9.67
82670	F6		3.45	1.83	0.35	7.30	8.2	8.2	2.4	28.2	4.99	1.17	1.64	0.32	1.86	17.7	23.4	32.9	6.4	37.3	0.71
82671	F7		0.15	1.88	0.53		6.7	6.5	16.8	42.2	15.13	3.29	6.09	1.06	4.69	35.9	21.7	40.3	7.0	31.0	0.54
82672	F7		0.15	1.49	0.92		6.8	6.5	10.7	43.9	10.19	1.79	4.07	0.96	3.37	23.2	17.6	39.9	9.4	33.1	0.44
82828	S1		0.00	0.67	0.03	0.62	6.7	5.5	16.3	46.7	12.45	4.36	6.27	0.62	1.20	26.7	35.0	50.4	5.0	9.6	0.70
82829	S1		0.05	0.70	0.02	0.40	8.4	7.3	19.2	50.7	15.83	3.60	7.65	1.04	3.54	31.2	22.7	48.3	6.6	22.4	0.47
82830	S1		0.00	0.20	0.01	0.20	8.5	7.3	19.1	51.3	17.26	2.88	8.10	1.14	5.14	33.6	16.7	46.9	6.6	29.8	0.36
82831	S2		4.25	1.41	0.21	4.38	8.4	8.0	10.0	50.3	11.15	2.35	5.14	0.72	2.94	22.2	21.1	46.1	6.5	26.3	0.46
82832	S3		0.45	1.14	0.07	1.46	8.1	7.5	20.6	54.5	18.95	2.66	8.24	1.34	6.71	34.8	14.0	43.5	7.1	35.4	0.32
82833	S3		0.10	1.73	0.07	1.46	7.7	7.2	23.4	54.5	21.37	2.95	9.02	1.41	7.99	39.2	13.8	42.2	6.6	37.4	0.33
82834	S3		0.05	1.98	0.11	2.30	7.4	6.8	23.8	52.9	21.94	3.05	8.70	1.58	8.61	41.5	13.9	39.7	7.2	39.2	0.35
82835	S4		3.25	1.26	0.37	7.70	8.3	7.8	15.7	50.6	17.7	3.42	7.92	1.05	4.68	35	20.0	46.4	6.2	27.4	0.43
82836	S6		0.9	2.12	0.18	3.76	8.1	7.6	20.4	53.7	21.19	4.29	8.71	1.35	6.84	39.5	20.2	41.1	6.4	32.3	0.49
82837	S6		0.1	2.03	0.08	1.66	7.2	6.6	22.3	53.1	20.29	2.85	8.44	1.35	7.65	38.2	14.0	41.6	6.7	37.7	0.34
82838	S6		0.1	3.40	2.63	55.78	7.1	6.5	26.8	53.8	24.67	4.11	10.06	1.82	8.68	45.9	16.6	48.8	7.4	35.2	0.41
82839	S7		3.0	2.37	0.29	6.04	8.4	7.9	15.6	49.8	17.49	3.73	6.98	1.12	5.66	35.1	21.3	39.9	6.4	32.4	0.53
82840	S8		0.15	1.12	0.19	3.96	7.0	6.2	24.3	49.9	20.42	6.16	12.14	1.05	1.07	40.9	30.2	59.5	5.1	5.2	0.51
82841	S8		0.0	1.26	0.04	0.84	6.6	5.8	26.4	54.7	23.01	6.71	13.93	1.16	1.21	42.1	29.2	60.5	5.0	5.3	0.48
82842	S9		3.35	2.45	0.34	7.08	7.9	7.5	16.3	51.3	17.62	3.26	8.16	1.06	5.14	34.3	18.5	46.3	6.0	29.2	0.39
82843	S10		2.5	2.33	0.27	5.62	7.9	7.5	23.5	51.9	24.41	4.92	10.54	1.60	7.35	47	20.2	43.2	6.5	30.1	0.47
82844	S10		2.25	2.22	0.23	4.80	8.1	7.7	21.7	51.4	22.63	3.92	8.97	1.87	7.87	44	17.3	39.6	8.3	34.8	0.44
82845	P1		0.05	0.03	0.20	4.16	6.7	5.8	39.7	61.5	27.29	16.88	8.44	0.58	1.39	44.4	61.9	30.9	2.1	5.1	2.0
82846	P1		0.15	0.0	0.32	6.66	6.5	5.7	63.5	62.9	50.83	33.98	13.47	0.64	2.74	80.8	66.8	26.5	1.3	5.4	2.52
82847	P2		4.55	0.05	0.13	2.70	8.1	7.3	17.3	59.0	16.77	8.93	5.91	0.48	1.45	28.4	53.3	35.2	2.9	8.6	1.51
82848	P2		3.75	0.38	0.08	1.66	8.4	7.4	19.8	62.5	19.54	9.38	6.84	0.59	2.73	31.3	48.0	35.0	3.0	14.0	1.37
82849	P3 P3		5.65	0.00	0.26	5.42	7.9	7.4	11.5	64.2	11.87	6.37	4.49	0.28	0.73	18.5	53.7	37.8	2.4	6.1	1.42
82850	P4		0.05	1.23	0.15	3.12	5.9	5.1	20.3	53.0	14.91	5.5	7.6	0.53	1.28	28.1	36.9	51.0	3.5	8.6	0.72
82851	P4		0.00	1.75	0.07	1.46	7.6	6.8	20.2	56.0	19.54	7.9	8.76	0.74	2.14	34.9	40.4	44.8	3.8	11.0	0.90
82852	P5		3.2	1.05	0.64	13.32	8.0	7.4	19.6	53.6	19.56	4.9	9.35	1.14	4.17	36.5	25.1	47.8	5.8	21.3	0.52
82853	P6		0.05	5.61	0.78	16.26	5.0	4.5	51.7	64.6	34.80	9.59	14.63	1.48	9.10	53.9	27.6	42.0	4.3	26.1	0.66
	P7		0.05				7.4	7.6													

LABORATORY NUMBER	FIELD NUMBER	Reduceable Mn in p.p.m.	A = % water in air dry sample	B = % NaCl in air dry sample	C = % SALT (NaCl) content of soil moisture = B/A x 1000	n = (A−0.2R)/(L+3H)	P. TOTAL (P_2O_5 sol. in $HClO_4$ – HNO_3) in p.p.m.	P. citr.: (P_2O_5 sol. in citric acid) in p.p.m.	(P citr.: P. Tot.) x 100	(P : H) x 100	(P : L) x 100	K. HCl in p.p.m.	K/L x 100	N. TOTAL in %	RATIO C/N	H/L x 100
82900	B1	389	13.9	0.0	0.0	0.05	106.6	24.6	22.7	2050	119	13.0	62	0.08	8.8	5.8
82901	B2	198	24.3	0.0	0.0	0.29	157.9	4.5	1.1	121	3	16.6	28	0.07	11.4	2.3
82902	B3	298	65.1	0.0	0.0	1.54	121.7	22.9	18.9	1305	90	18.6	74	0.10	10	6.9
82903	B3	509	72.1	0.015	0.2	1.69	137.8	30.3	22.5	1372	124	22.8	92	0.15	8.7	9.1
82904	B4	115	24.2	0.021	0.86	0.27	52.3	0	0.0	0	0	16.5	20	0.12	14.2	4.9
82905	B4	224	26.5	0.070	2.65	0.35	55.9	0	0.0	0	0	11.0	21	0.05	12	2.2
82906	B5	354	106.3	0.019	0.18	1.67	164.8	43.5	25.6	790	74	42.8	73	0.32	10	9.5
82907	B6	224	35.8	0.052	1.45	0.45	94.8	21.1	22.8	552	64	31.6	110	0.14	15	10.8
82908	B6	302	35.4	0.059	1.67	0.46	78.9	11.3	14.7	570	32	38.7	106	0.10	11	5.5
82909	B6	305	41.0	0.137	3.33	0.64	80.2	8.9	10.4	518	23	38.2	107	0.08	11.3	4.5
82910	B6	559	50.2	0.242	4.81	0.77	86.9	8.6	6.5	360	13	41.2	98	0.08	11.3	3.6
82911	B6	45	57.8	0.312	5.40	1.00	60.7	21.7	32.8	837	52	69.6	176	0.09	15.6	6.2
82912	B7	402	97.8	0.285	2.91	1.63	117.3	21.7	18.2	1183	58	36.9	86	0.11	10	4.2
82913	B7	305	79.1	0.10	1.26	1.31	111.8	26.3	22.2	1315	60	38.5	91	0.11	10	4.6
82914	B8	29	29.7	0.012	0.4	0.44	26.4	0	0.0	0	0	18.9	32	0.05	8	1.3
82915	B9	24	34.4	0.014	0.4	0.49	20.3	0	0.0	0	0	12.6	22	0.04	7.5	0.9
82916	B10	180	58.8	0.069	1.16	0.9	96.2	14.9	14.1	437	34	35.5	85	0.16	11.3	7.7
82917	B10	46	68.7	0.156	2.26	1.12	79.0	13.2	15.2	300	27	48.2	110	0.16	14.4	9.0
82918	B10	36	72.8	0.14	1.91	1.25	73.3	12.0	15.5	320	25	49.8	110	0.13	15.4	7.7
82919	B11	507	35.1	0.007	0.21	0.42	119.1	18.6	14.6	752	30	32.3	47	0.13	10.0	4.0
82920	B11	232	40.5	0.011	0.26	0.49	100.9	14.8	5.6	33	8	28.4	47	0.09	11.1	2.1
82921	B11	77	44.5	0.020	0.44	0.53	98.6	2.2	0.0	0	0	24.2	30	0.09	11.1	2.3
82922	B11	38	42.4	0.036	0.86	0.51	86.9	0.4	0.0	0	0	29.9	26	0.06	11.1	2.0
82923	B11	19	44.0	0.064	1.46	0.53	95.4	0.4	0.0	0	0	21.2	26	0.07	14.3	2.0
82965	T1	64	65.1	0.013	0.20	0.91	46.5	0	0.0	0	c	18.8	27	0.19	14.7	7.2
82966	T1	31	42.5	0.009	0.22	0.59	39.2	0	0.0	0	0	10.0	13	0.15	14.0	5.4
82967	T1	17	40.0	0.009	0.23	0.71	34.9	0	0.0	0	0	9.8	17	0.08	12.5	3.0
82968	T1	47	43.1	0.008	0.19	0.59	46.1	0	0.0	0	0	11.3	17	0.16	15.0	6.2
82969	T2	35	24.6	0.027	1.10	0.31	47.7	0	0.0	0	0	3.7	6	0.14	12.9	4.9
82970	T2	34	32.2	0.027	0.82	0.46	20.9	0	0.0	0	0	9.2	14	0.07	14.3	2.6
82971	T2	36	35.2	0.022	0.62	0.52	26.0	0	0.0	0	0	12.7	20	0.05	16.0	2.1
82972	T2	35	47.9	0.030	0.63	0.84	24.0	0	0.0	0	0	15.1	22	0.04	15.0	1.5
82973	T2	30	41.7	0.013 0.035	0.21 0.57	1.09	27.3	0	0.0	0	0	14.4	21	0.05	16.0	2.1
82974	T2	32	69.8	0.029	0.41											7.8
82975	T3	377	45.3	0.014	0.31	0.61	76.5	0	0.0	0	0	11.1	17	0.24	12.9	8.4
82976	T4	577	115.7	2.27	19.66	1.56	165.0	31.1	18.4	658	46	101.0	160	0.18	14.4	7.0
82977	T4	134	125.1	2.65	21.23	1.86	67.5	27.0	33.7	513	40	144.2	227	0.18	18.8	7.9
82978	T4	365	129.8	3.32	25.56	2.00	87.1	34.9	41.5	1037	51	137.7	199	-	-	4.9
82979	T5	321	95.7	0.28	2.95	1.45	137.7	73.3	53.4	2618	106	94.4	136	0.13	10.5	4.3
82980	T5	501	54.1	0.35	6.48	0.72	137.2	83.0	60.4	518	118	52.1	130	0.07	12.9	2.3
82981	T6	186	58.6	0.012	0.21	1.72	81.4	14.0	17.2	933	50	12.9	46	0.08	10	5.4
82982	T7	234	22.3	0.008	0.37	0.32	66.8	0.5	0.8	3	1	10.4	20	0.13	10	4.3
82983	T7	226	22.9	0.006	0.24	0.41	46.8	1.7	3.6	233	8	4.5	20	0.02	10	1.4
82984	T8	349	3.0	0.0	0.0	0.26	120.3	23.9	19.8	955	70	15.4	46	0.14	10	7.3
82985	T8	255	11.9	0.0	0.0	0.44	81.0	4.2	5.2	233	9	11.9	25	0.11	9.1	3.7
82986	T9	77	47.1	0.010	0.20	0.78	127.3	12.9	10.1	380	20	11.0	17	0.16	12.5	5.3
82987	T9a	78	42.5	0.019	0.20	0.76	162.5	22.1	13.6	762	35	5.4	9	0.16	12.5	4.6
82988	T10	50	31.3	0.012	0.39	0.44	123.3	8.6	7.0	355	19	9.1	14	0.16	10.0	5.1
82989	T10	84	34.7	0.015	0.44	0.72	28.9	0.1	0.3	25	0.1	16.1	22	0.08	18.1	0.7
83379	T11	379	3.8	0.017	4.43	2.19	89.8	7.4	8.4	493	20	11.0	31	0.06	15	4.0
83380	T11	113	6.4	0.009	1.45	1.26	26.8	0.4	1.5	31	1	12.7	33	0.04	17.5	3.2
83381	T12	219	41.3	0.047	1.13	0.48	52.2	14.1	27.0	564	26	26.1	48	0.10	15.0	4.6
83382	T12	296	46.6	0.044	0.94	0.62	49.0	0	0	0	0	34.2	59	-	-	1.5
83383	T13	39	32.2	0.055	1.71	0.34	51.1	0	0	0	0	26.7	42	0.11	17.3	5.1
83384	T13	18	36.8	0.161	4.37	0.53	44.3	0	0	0	0	34.5	50	0.05	12.0	1.6
83385	C1	402	28.0	0.004	0.15	0.50	107.0	18.6	17.3	1240	110	8.0	12	0.08	11.3	8.9
83386	C2	565	24.3	0.067	2.76	0.34	125.9	16.7	13.2	1518	50	4.3	18	0.07	8.6	3.3
83387	C3	7	41.2	0.617	15.0		19.3	0.3	1.9	5	1	41.0		0.17	18.8	13.3
82558	N1	20	34.3	0.073	2.13	1.19	97.3	34.4	35.4	2023	445	19.3	250	0.09	11.1	22.1
82559	N1	24	32.6	0.089	2.72	0.97	96.9	26.8	27.7	1675	225	20.6	173	0.08	11.3	13.4
82560	N1	13	28.6	0.069	2.42	0.80	87.0	35.0	40.2	3181	402	16.5	189	0.05	12.0	12.6
82561	N2	50	42.2	0.121	2.87	1.46	127.8	43.7	37.2	2266	506	13.8	146	0.12	10.0	22.3
82562	N2	34	32.2	0.019	0.60	1.12	89.6	30.5	34.0	1906	335	11.8	126	0.08	11.3	17.6
82563	N3	312	52.7	0.010	0.19	1.49	134.7	25.9	19.2	835	225	18.0	154	0.14	12.9	27.0
82564	N3	82	29.5	0.006	0.21	0.73	117.2	34.1	29.0	3410	431	6.7	80	0.06	10.0	12.7
82565	N3	49	24.0	0.005	0.19	0.53	82.5	27.8	33.7	1390	487	5.4	82	0.03	10.0	8.8
82566	N4	70	145.4	0.056	0.39	3.86	172.3	32.0	18.6	500	142	13.3	59	0.25	14.8	28.6
82567	N5	209	52.0	0.007	0.15	1.27	178.4	38.2	21.4	1364	157	5.5	22	0.16	10.0	11.5
82568	N5	131	43.6	0.008	0.19	1.16	151.5	55.2	36.5	3686	166	10.4	31	0.09	10.0	4.5
82569	N6	12	43.4	0.006	0.13	1.71	126.5	43.1	34.1	1657	507	3.8	43	0.12	12.5	30.6
82570	N6	184	40.7	0.006	0.14	1.20	126.9	23.6	18.6	1685	184	12.7	99	0.06	13.3	10.9
82664	F1	126	21.4	0.583	27.3	0.65	88.6	12.0	13.5	1333	108	32.0	290	0.05	10.0	8.1
82665	F2	297	30.0	0.008	0.26	1.35	150.9	4.8	2.6	325	25	3.8	23	0.11	6.4	7.6
82666	F2	359	20.5	0.00	0.00	0.47	134.4	3.0	2.2	428	29	4.2	41	0.07	5.7	6.9
82667	F3	99	66.6	0,00	0,00	10.81	139.8	1.8	0	0	0	8.1	40	0.11	5.5	5.5
82668	F4	116	43.4	0.291	6.70	2.62	148.2	15.4	10.4	1033	102	17.9	116	0.12	7.5	9.9
82669	F5	117	50.5	0.243	4.81	3.23	151.1	18.4	11.1	1292	97	19.2	110	0.12	6.7	7.5
82670	F6	118	23.2	1.206	52.0	1.18	116.7	6.2	3.5	820	58	26.7	374	0.04	7.5	7.1
82671	F7	150	71.0	0.809	11.39	2.05	152.9	28.1	18.4	597	109	45.9	174	0.16	16.9	18.3
82672	F7	28	42.9	0.781	18.23	1.56	109.8	16.6	14.3	826	84	44.2	233	0.08	13.8	10.2
82828	S1	50	32.1	0.022	0.67	0.67	121.0	26.6	23.1	1900	90	32.0	104	0.08	10	4.7
82829	S1	49	24.5	0.045	1.85	0.37	100.6	35.6	35.4	5085	99	47.9	134	0.05	8	2.0
82830	S1	100	26.0	0.079	3.02	0.41	101.8	34.1	33.5	6820	96	52.3	145	0.04	7.5	1.4
82831	S2	100	42.6	0.608	14.28	1.58	114.2	15.4	13.6	3100	84	42.4	227	0.04	7.5	2.7
82832	S3	138	30.0	0.613	20.43	0.50	110.3	31.8	30.2	2775	97	62.3	179	0.06	11.7	3.5
82833	S3	172	38.2	0.749	19.61	0.67	106.8	32.8	30.7	2931	83	64.0	160	0.06	10	2.8
82834	S3	207	43.3	0.935	21.62	0.81	108.2	32.4	29.9	2945	78	66.4	157	0.06	10	2.6
82835	S4	114	55.0	0.854	15.52	1.52	10.7	18.0	17.8	1736	69	57.0	202	0.06	11.7	4.0
82836	S6	95	35.0	1.004	28.68	0.65	116.8	22.0	19.9	1784	68	63.9	182	0.07	11.4	3.8
82837	S6	37	44.1	0.619	14.02	0.86	117.0	32.1	27.4	2469	84	60.7	155	0.06	11.7	3.4
82838	S6	4	56.1	1.00	17.82	1.00	84.4	20.1	23.8	467	54	81.1	216	0.08	31.3	11.7
82839	S7	176	31.6	0.728	23.03	0.67	112.1	18.2	16.2	2275	63	58.7	202	0.05	10	2.8
82840	S8	227	51.0	0.006	0.13	0.99	109.8	22.5	20.5	1138	52	50.4	115	0.11	10	4.4
82841	S8	146	33.4	0.018	0.52	0.51	107.3	27.3	25.4	2481	61	54.0	117	0.06	10	2.4
82842	S9	136	52.8	0.856	16.22	1.42	107.2	21.0	18.4	2200	68	54.6	186	0.06	8.3	3.1
82843	S10	213	75.4	1.076	14.28	1.63	106.8	19.8	18.5	1980	47	77.4	179	0.07	8.6	2.4
82844	S10	88	69.0	1.157	16.77	1.57	110.6	19.1	17.2	1900	48	94.1	139	0.06	10	2.6
82845	P1	56	65.1	0.039	0.59	0.83	100.9	16.2	14.6	249	35	26.3	56	0.35	10.9	14.4
82846	P1	40	95.8	0.072	0.75	0.86	84.4	12.8	15.1	106	20	26.4	40	0.55	12.7	18.5
82847	P2	122	40.7	0.055	1.36	0.90	110.0	16.4	14.6	1073	65	27.8	110	0.07	12.9	6.0
82848	P2	91	40.6	0.058	1.41	0.80	109.3	11.8	10.6	773	43	30.3	110	0.08	11.3	5.5
82849	P3 P3	96	54.6	0.052	0.95	1.96	117.9	16.3	12.8	1166	98	17.7	120	0.05	14.0	8.4
82850	P4	36	46.7	0.063	1.35	1.00	96.0	30.2	32.4	1244	101	25.3	82	0.14	10.7	8.1
82851	P4	57	33.8	0.077	2.28	0.61	109.0	35.2	27.1	2681	90	37.9	116	0.06	10.0	3.4
82852	P5	110	72.0	0.38	5.27	1.80	109.0	29.2	21.4	1450	73	62.0	197	0.08	11.3	5.0
82853	P6	15	63.6	0.629	0.88	0.65	81.8	13.7	17.3	165	26	50.1	92	0.36	13.6	15.6
	P7		29.0	0.001	0.02											

Appendix II

BRIEF NOTE ON RICE

Rice, the staple food of the population of Asia, is a cereal of great adaptability. Even when grown negligently, the yield is quite satisfactory as compared with other cereals sown under similar conditions. With intensive culture, a yield as high as 6 tons of brown rice per ha. per crop (10 tons for double cropping) is possible. It is also the only single crop which can be grown on the same land continuously with higher calorie yield per unit area. The classification of rice varieties and breeds is so vast as to necessitate their division into sub-species. One group was selected for intensive culture in Japan from an early date. This type is known as sub-species Japonica. The tropical indigenous group is called Indica. These two types represent the extremes in rice classification. There are fundamental differences between these two varieties in photoperiodic sensitivity and ability to assimilate nitrogen (fertilizer response). Other differences are in grain shape, quality, plant colour, straw stiffness, etc.

Indica rice is generally divided into three groups, namely, winter, autumn and spring rice, or Aman, Aus and Boro in Bengal and Kankkyi, Kankti and Mayin in Burma, according to the time of harvest. Winter rice, the principal variety in the Indica group, has a long vegetative growth period and high photoperiodic sensitivity and is called the season fixed-type. Floating rice is one variety of winter rice, while deep water rice is an intermediate type which can withstand flood water up to a depth of about 1 m. However, deep-water rice has no capacity for extending the internode at a rate of 5-10 cm per day and cannot grow to 4 or 5 m like floating rice. Nevertheless, these two varieties are known under an identical name in some countries like Burma.

Autumn rice has comparatively short growth duration and low sensitivity and is usually classified as the duration-fixed type. This variety is mostly grown on highlands by broadcasting.

Spring rice does not differ much from autumn rice, but is grown on river-flooded beds after the retreat of flood water. Although both belong to a rather primitive type, they are closely related to Japonica rice (sterility percentage of F_1 hybrid is usually used as an indicator of mutual relationship). Thus they are considered as an intermediate type between Indica and Japonica. In China: Taiwan these two groups are known under the name of "Chailai" for Indica rice (near autumn rice) and "Ponlai" for Japonica rice. At present Japonica are not grown in tropical countries because of their short duration. Some trials have however been made and given good results in the winter season. Hybridization of Indica rice with Japonica has already been started by FAO. More attention should be given to the "Ponlai" variety of the Japonica as it has greater adaptability to tropical climate. In this connexion, the recent high yield of chailai rice obtained through intensive cultivation is also worth mentioning (see 2. 5. 2).

Each member of the above group is further divided into paddy (or lowland) and upland rice according to water requirement. The differences due to endosperm characteristics are classified under non-glutinous and glutinous varieties.

B. PAPERS PRESENTED AT THE SYMPOSIUM

Paper No. 1

UTILIZATION AND DEVELOPMENT OF THE DELTAIC AREA OF EAST PAKISTAN*

Abstract

Prompt utilization and development of East Pakistan's deltaic area is essential for the well-being of 54 million people living in an area with a population density of nearly 1,000 persons per square mile. The land is rich and fertile, the climate ideal for multicropping, and the combination of copious rainfall, mighty rivers and groundwaters creates one of the world's greatest natural systems. Yet hunger stalks this predominantly agricultural land because of the hazards of destructive floods, inadequate drainage, erratic rainfall and daily sea-water inundation.

Rivers originating in other countries come down the hill slopes toward East Pakistan's boundaries with sufficient gradient and velocity to transport vast quantities of silt. In flowing through the flattened delta, however, these rivers spill over their banks during floods and deposit their silt burden on the submerged lands. Thus the spill area rises gradually, but along with it the river bed and flood level also rise, so that for some years the relative position is not materially altered; indeed perhaps not until after many centuries, when a river unable to spill bursts through the high banks and diverts its course to perform similar delta building in other areas. Thus has the deltaic area of East Pakistan been formed by silt-laden rivers.

To determine a functional pattern of water usage, scientific planning must evaluate the needs and resources of each community, district and region so that a programme may be prepared that will satisfy basic human needs and serve the overall developmental requirements of both the province and the nation. Preparation of such a programme requires acquisition of a vast fund of data relating to the geomorphology, topography, hydrology, pedology and plant ecology of the area.

Because of long centuries of neglect, East Pakistan is today in the earliest stage of development. Since 1959, the East Pakistan Water and Power Development Authority has been entrusted with the task of developing the water and power resources of the province. The basic objectives of the East Pakistan WAPDA programme are to protect lands from flood damage and increase food production by developing the water resources of the province to the fullest possible extent. Already several major projects have been completed, and together with many others currently under execution, will, within a few years, diminish the need for importation of foodstuffs. At the same time schemes have been planned to stimulate a widespread expansion of industry by providing generation, transmission and distribution facilities to meet the steadily mounting needs for electrical power throughout the province. This accelerated development of power will make it possible to supplement the agricultural economy with an industrial economy, thus raising national income, gaining foreign exchange, providing large-scale employment and promoting commercial interchange of agricultural and manufactured products.

The possibilities for the ultilization and development of the delta are immense, and the problem is greatly complicated; but the work has been initiated with vigor and the promise for the future is bright. By the end of the third five-year plan in 1969/70, East Pakistan will be enjoying the benefits from a great number of completed schemes. Thus will East Pakistan reach a more advanced stage of development and approach the attainment of self-sufficiency under a modern, well-balanced economy.

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INTRODUCTION

East Pakistan, situated in the north-eastern part of the Indo-Pakistan subcontinent, was established as a province of Pakistan at the time of Independence in 1947. This region is comprised of the eastern part of the former province of Bengal together with Sylhet district of Assam. East Pakistan extends about 270 miles from north to south and about 200 miles from west to east. It is bounded on the north, east and west by India except for the south-eastern tip which adjoins Burma, and on the south by the Bay of Bengal. The total area of East Pakistan is 55,126 square miles.

According to the 1961 Census, the population of East Pakistan is 50,840,235. This gives an average density of 922 persons per square mile. The province, primarily rural in character, is composed of 17 districts. It has about 60,000 villages. There are many towns of commercial importance but only two major cities: Dacca, the capital of East Pakistan, and Chittagong, the principal seaport.

In general, the land slopes from north-east to south-west, starting at an elevation of about 200 feet at the northern boundary of Rangpur. In a distance of 100 miles, the elevation gradually reduces to about 60 feet, whence the slope flattens to an elevation of about 15 feet in the vicinity of centrally located Dacca city and only a few feet above mean sea level at the coast. Most of the area lies below 80 feet, the approximate elevation at the point of entry of the Brahmaputra at the Indian border. Almost half the province has less than 15 feet elevation above mean sea level.

Except for the Chittagong districts, the province comprises the world's largest and most fertile deltaic area, formed by the activity of two great rivers, Ganges and Brahmaputra, and a third big river Meghna and their tributaries. The higher reaches of all the major rivers lie outside the international boundaries. The river catchments receive an abundant rainfall during monsoon, which occurs from June to October. Annual rainfall in East Pakistan varies from 60 to 200 inches. But for several months after the monsoon season there is insufficient rainfall to permit double cropping of cultivable lands. The heavily silt-laden rivers meet the Bay of Bengal in low tropical delta plains laced with distributaries, so that the sea-water floods large areas with each high tide, and the blocked river passages spill over the interior areas. The rivers, the tidal estuaries and the creeks provide a network of channels for inland waterways transport, but these are adversely affected by the high waters of the flood season and by the low flows in the winter.

With agriculture as the backbone of the economy, tremendous problems are created by destructive floods; the limited land area having most of the culturable area largely under cultivation; and the pressure of a rapidly expanding population presently subsisting on low incomes and meagre diets. The utilisation and development of this rich deltaic area calls for a dynamic programme to protect the lives and lands of the people from the vagaries of its mighty rivers and the fury of the sea; to drain the low-lying malaria-stricken areas; and to increase production of foodstuffs through flood-protection and irrigation measures as a basis for development of a self-sufficient agricultural and industrial economy.

The East Pakistan Water and Power Development Authority was created in 1959 for the unified and co-ordinated development of the water and power resources of the Province. The basic objectives of its programme are to:

1. Protect lives, lands and property from floods by constructing flood embankments.
2. Reclaim low areas and improve drainage by excavating canals and providing regulators.
3. Provide irrigation for agriculture to permit multi-cropping, by diverting river flows with barrages; by pumping from rivers; and by tapping groundwater through use of tube-wells.
4. Protect lands in the tidal zone from saline sea water inundation by means of embankments.
5. Improve navigation by constructing new channels and re-excavating existing ones.
6. Wherever practicable, generate hydel and tidal power for integration in a hydro-thermal grid system to supply adequate power at reasonable cost for industrial, agricultural and domestic consumption.

In the development plan for East Pakistan, production of adequate foodgrains to meet the needs of the growing population must have the first priority. Of the 35 million acres of land area, 22 million acres, now producing extremely low yields, represent nearly the total of land in East Pakistan available for cultivation. Perennial irrigation will open up the possibility of growing crops in all seasons and provide far-reaching diversification, a rich variety of rotations, and thereby effect a fundamental transformation of the agricultural economy.

So that the solutions to the deltaic problems proposed under the programme may be appropriate and economical, it is necessary to plan developments that conform to the behaviour of the delta. The old history of the river systems is presented in the following pages so that we may observe the changes of the past, see those now in process and foresee changes likely to occur in the future. Then we shall briefly describe the data required for development, the present stage of development and the possibilities and problems involved in furthering the development of the East Pakistan delta.

I. NATURAL FRAMEWORK OF THE DELTAIC AREA AND DATA AND INFORMATION REQUIRED FOR DEVELOPMENT

a. The rivers

East Pakistan, except for the Chittagong areas is a delta, formed by deposition of materials of the

Ganges, Brahmaputra and Meghna Rivers, which combined drain a catchment area of about 600,000 square miles of which only about 48,000 square miles are within the province. Because of the relatively flat slope of terrain, these river systems have all developed highly meandering courses.

The Ganges, fed by rivers in the southern slopes of the Himalayas, is 1,600 miles long, enters the western side of East Pakistan and flows in a south-eastern direction to its confluence with the Brahmaputra river in the central part of the province. The highest recorded stage of the Ganges was recorded in 1910. A flood discharge of about 2.5 million cfs would be a reasonable expectancy.

The Brahmaputra rises in Tibet, flows north of the Himalayas in an easterly direction, then turns south through the mountains entering East Pakistan's north-central area as an extremely wide river with a total length of about 1,800 miles from its headwaters to the confluence with the Ganges. The maximum recorded flood in the Brahmaputra occurred in 1958 with a corresponding discharge of 2.5 million cfs, but it is estimated that a large flood flow could be about 3 million cfs.

The Meghna system is about 500 miles long and for half this length flows through East Pakistan draining the north-east part of the province. The maximum recorded flood occurred in 1955 with a discharge of about 456,000 cfs.

b. Physical aspects of delta formation

The delta of the Ganges and the Brahmaputra is the largest of its kind in the world and has certain special characteristics: the existence of the shallow tidal bay in which the rivers laden with enormous quantities of silt and sediment discharge fresh water throughout the whole year; the daily tidal movement hampering easy flow of the fresh water discharge to the sea; the shape of the bay which gradually opens out to the ocean affecting tidal movements; and three major river systems uniting before discharging their combined waters through a common channel to the sea.

c. Geological surroundings

The East Pakistan delta is a formation of old and new alluvium, but the whole delta including the West Bengal (India) part is bordered by rocks of all ages. The delta itself represents deposits of the recent period. Crystalline gneiss and granites abound in the Chotanagpur plateau lying just to the west of the delta. The plateau sporadically exposes rocks—the volcanic traps of the Rajmahal hills and the Sylhet traps in the south-west corner of the Shillong plateau. In the north, along the southern border of the Himalayas in Sikkim and Bhutan, lies a series of metamorphic gneiss and granites associated with various other igneous rocks.

In Assam the southern part of the Shillong plateau is the catchment area of the Surma River in East Pakistan and contributes a huge quantity of water during the rainy season to the tectonic depression to the south—the Surma valley or the Sylhet haors, converting the area into a vast inland sea.

To the south-east of Shillong plateau lie the Tripura hills and the hills of Chittagong and Chittagong Hill Tracts. These formations are mostly sandstones, shale, shaly limestones, conglomerates and the like.

There is a wide difference in constituents and characteristics of the materials from the Chotanagpur plateau deposited over the West Bengal (India) piedmont plain and those materials brought down by the wash of the Meghna system. The northern piedmont gradually slopes southward from the foothills of the Himalayas and merges into the recent alluvial plains of the Ganges and the Brahmaputra to the south, through the patches of the old alluvium known as the Barind and the Madhupur. Thus the Ganges-Brahmaputra delta is confined by the stable rock formations within which has developed a vast alluvial deltaic plain, the major part of which to the east comprises the East Pakistan delta.

d. Hydrographic changes

As already stated, this vast alluvial delta has been formed by the activity of the three rivers systems of Ganges, Brahmaputra and Meghna. The estimated total average annual run-off of the three rivers in East Pakistan, is of the order of 1,000 million acre-feet. The load carried by the Brahmaputra is estimated to be about 900 million tons and that by the Ganges to be about 500 million tons yearly. Much literature has been written on the hydrographic changes in the delta. According to Spate, "The cardinal factor in the later history of the delta has been the eastward shift of the Ganges waters from western margins—the Bhagirathi Hoogly—to the present main course, the Padma—Meghna, with such streams as the Ichamati, Jalangi, Mathabhanga and Gorai representing intermediate (not necessarily successive) positions of the most important channels. Whether this is mainly due to alluviation at the heads of successive main spillways, to tectonic change, to shift in the balance of the delta due to changes of course elsewhere (e.g. the great shift of the Teesta), or to a secular swing to the east are questions which admit of large and inconclusive debates." This has been the assumption since the earliest days of the study of river morphology in this area starting from Sir William Wilcox, Reaks, Lang, and others. Chowdhury of the Dacca University who has carried out research on the subject is of a different opinion, because all maps from the days of Ptolemy (150 A.D.) to W. Bolt (1760) (pre-Rennel), show both channels of the Ganges viz. the East and West, as equally important. In Ptolemy's map, the prominence is laid on the East channel as the main outlet. This does not support the theory of successive changes or shifting of the course of the Ganges from west to east.

Of the many changes that have taken place in the rivers of the delta, the change of the Brahmaputra along with its ancillary channel—the Teesta is the most important. In 1764-70 when Major Rennel had started his survey of the Rivers of Bengal, the Brahmaputra flowed eastward near the present off-take head of the Old Brahmaputra, and flowing through Mymensingh and Dacca discharged its waters into the Meghna mouth. The Teesta during this time used to flow southward and was an affluent of the Ganges. But in 1787, the Brahmaputra suddenly deserted its old bed, forced its way through the Jenai channel—the course of the present Jamuna—and ultimately took its present course. The cause of this sudden change of the Brahmaputra is assigned to the devastating flood of the Teesta which during this time severed all connection with the Ganges and, cutting a new channel, became an affluent of the Jamuna. It not only brought this change in the course of the Brahmaputra and the Teesta but also severely threatened the course of the Ganges. The back-water profile from Jafferganj near Goalundo was such that it was supposed then that the course of the Ganges could be diverted through the Gorai-Madhumati channel making it the main stream of the Ganges. But in course of time the beds of the Ganges and Brahmaputra adjusted themselves well, and the anticipated change of the Ganges was not effected. Prior to this unification of the Ganges and the Brahmaputra, the Ganges had a separate course to the sea. In the later half of the 18th century, the mouth of the Ganges in Rajnagar area shifted about 45 miles to the north and unified with the Meghna near Chandpur. The Baral and the Dhaleswari-Buriganga at some time in the past had once been the course of the Ganges. The former has now become an affluent of the Jamuna and the latter an affluent of the Meghna—the course of the Ganges has shifted several miles to the south. Such changes of the river courses of the delta are now numerous.

It is generally accepted that, as the banks are formed and the beds raised, the waters being impeded by the diminution of slopes seek a new channel. In large and constantly flowing streams this process is repeated until at last the general surface of the country is so much raised that the river is effectively controlled by the mass of its own deposits, limiting its changes to a series of reflections between two lines, parallel as in large rivers, at five, eight or ten miles apart. Thus the rivers raise both their own beds and the adjoining country and then seek new channels with suitable gradients.

In rivers where there are regular annual pulsations of high-water during the rains and low-water during the dry season, this process of filling up by sedimentation is all the more accentuated. Thus the channel fill deposits accumulate in the stream channels where the transporting capacity has been insufficient to remove the load as rapidly as it has been delivered. The process is not of a simple sorting out and deposition of the coarsest material, but a net accumulation from alternate scouring during rising flood stages and deposition during the falling stages. As the average amount of scour had always been less than the average amount of deposition, the net result has been the aggradation of the land. This principle had been acting in the delta formation.

e. The Ganges-Brahmaputra delta

Developed under geological conditions and fluvial processes previously described, the delta proper—the triangular tract of land in the south of the Ganges (Padma)—may be separated into three divisions: (i) the moribund delta (ii) the mature delta and (iii) the active delta: The contrast between the moribund delta in the west and the mature delta in the east is evident from comparisons of their physiography, the character and behaviour of the rivers, vegetation, agriculture and health and prosperity of the inhabitants. The moribund delta is a region of decadent rivers, stagnant bils, and degraded forests, whereas the mature delta is a region of prosperity with most fertile agricultural lands revivified by the silt of a very active river-system.

The delta of the Ganges and Brahmaputra, according to Lyell, has two delta heads; and intermingled into one by a complicated process of sedimentation. Thomas Oldham was of the opinion that the first distributary of the Ganges — the Bhagirathi-Hooghly had formed secondary deltas of their own, and it is in this manner that the Ganges delta had been formed. To sum up, it is evident that "the deltaic plain of Bengal has a double or even a multiple, origin: one should not say the delta, but rather the deltas." The growth and development of the Ganges-Brahmaputra delta originated after the Garo-Rajmahal Gap had opened out by block-faulting so that the courses of these two rivers were changed from westerly flowing into two rivers flowing south into the Bay of Bengal.

f. Swatch of no ground

No description of the delta would be complete without a reference to the 'Swatch of no Ground' in the Bay of Bengal. Just to the south of the middle of the developed part of the delta there exists a submarine canyon around which soundings of from 30 to 60 feet abruptly drop to elevations of 1,200 to 2,000 feet below mean sea level in the form of a long narrow estuary to the deep sea. This remarkable depression, which, during the rains is associated with a peculiar thunder-sound known as "the Barisal gun", lies north-east to south-west.

Fergusson (1863) has assigned the cause of the existence of this great canyon to the scouring of the bed of the Bay by the sediment-laden under-currents produced by the meeting of the tides from both the east and the west coasts. Referring to a similar canyon near the mouth of the Mississippi, Bates suggested "that a turbid current carrying coarse grained material during glacial stages eroded the Mississippi submarine canyon and supplied the material for the submarine delta off the canyon's mouth." In the case of the Ganges delta, the coarse scouring materials may be associated with the shingles and coarse pebbles found at 481' depth, in the Boring operation in Fort William, Calcutta, from 1835 to 1840; and these materials instead of being carried during glacial stages as in the erosion of the Mississippi submarine canyon, may have been deposited during a devastating flood some 4,000 years ago, and eroded the 'Swatch of no Ground' of the Bay of Bengal. It has been ascribed to local sinking, but this depression may also be the remainder of some prehistoric valley. The formation of these submarine canyons is very controversial. Actually their effects upon shore evolutions are of more immediate concern in development planning for the area than are their origins.

Much additional study must be made on the nature and types of deposits of this vast delta and the coastal and submarine morphology, so that conclusions can be drawn regarding its formation, growth and development. The United Nations has recently assigned a team of experts to the hydrology section of EPWAPDA. With their assistance, it is hoped to gather and evaluate data and make extensive investigations to broaden our knowledge of significant changes occurring to-day in the East Pakistan delta.

g. Soils

The soils of the deltaic area of East Pakistan can be divided into two main groups: the new alluvial soils found generally in the delta and the old alluvium distinguished by a characteristic red color, found in the Barind Area and Madhupur Jungle Tracts. The soils found in the new alluvium vary considerably from place to place, but medium sands, fine sands, silts, silty sands, sandy silts and clay silts are generally found throughout the overflow areas. Fat clay deposits are rarely found near the surface but have been found at medium depths. Based on their origin, location and properties, the deltaic soils of East Pakistan have been broadly classified into six tracts.

1. *Brahmaputra tract* — Brahmaputra alluvium occurs in the north-eastern and central-eastern parts of the province. The soil is rich and fertile, being replenished every year by fresh deposits of sediment from the flood waters. The soil is acid having a pH range from 6.5 to 6.8. The application of fertilizer is unnecessary on the lower lying lands where the broadcast aman and aus-aman are grown, but on the higher lands jute and transplanted aman give a good response to fertilizers, as do the small grains, oilseeds, pulses, and vegetables.

2. *Gangetic tract*—The Gangetic alluvium lies south of the Ganges River from the western provincial boundary to the Meghna River. This soil is not acid and is characterised by a high lime content. The texture varies from clay loam to loam, according to its formation from various tributaries of the Ganges. The low lying areas that are annually flooded are rich and fertile while higher lands and those further from the river are less fertile. In this area jute, pulses, fruits and vegetables are grown as well as the main rice crop of transplanted aman.

3. *Teesta tract*—In the north-western part of East Pakistan, the Teesta river has deposited sandy loam soils which are slightly acid and generally low in fertility. Sugarcane, tobacco and rice are the main crops with pulses, oilseeds, and fruits as minor crops.

4. *Madhupur tract*—North of Dacca to the Old Brahmaputra river runs a broad belt of old alluvium, popularly known as the Madhupur Jungle. This represents a red lateritic-type soil in a high land tract above flood level intersected by numerous depressions which are highly valued for Aman rice. The soil has a high clay content, many ferruginous concretions, and low fertility. The acidity ranges from pH 5.5 to 6.0.

5. *Barind tract*—In the northern part of the province along the western border lies a large tract of old alluvial soil known as the Barind Tract. This clay soil has a pale reddish-brown color that turns yellowish with weathering. The fertility of the soil is low, the acidity ranges from pH 6 to 6.5, and iron concretions are common as in the Madhupur Tract. This area is well suited to sugarcane but needs irrigation to assure the crop.

6. *Saline tract*—Along the southern part of the province, tide waters from the Bay of Bengal have a great influence on the soil. Very high tides inundate a great part of this land, and peat deposits allow sea water to move laterally under the land. In general, the soil is saline and salt efflorescences occur in many places. The Sundarban forests are in the western part of this area and newly formed lands are found along the entire coast line particularly in the vicinity of the Meghna River.

h. Land use

In the deltaic area of East Pakistan, the land use pattern is determined by the significant soil and by the topographic conditions which govern the depth of flooding, extent of tidal inundation and the need for drainage. Land use is as follows:

1. *New alluvium*

a. *Shallow flooding*—Of recent alluvial soils, subject only to flooding about three feet deep, about 75 per cent of the gross area can be cultivated. On this type of land, the cropping intensity is higher than on other areas, being around 120 per cent. The principal crop is transplanted aman, which on the average is grown on about 60 to 70 per cent of the land. The aus and jute season precedes that of transplanted aman, and these two crops account for roughly 35 and 15 per cent of the land respectively. Rabi or winter season crops of pulses, oilseeds, spices, vegetables, etc., are grown on a relatively high percentage of the land. Sugarcane may occupy from 0 per cent to 20 per cent, depending on proximity to a sugar mill.

Average yields per acre are generally slightly lower than on lower lying lands. This is due to more droughty conditions and a slightly lower general soil fertility level. However, due to fairly good yields and a relatively high cropping intensity, the average gross income per acre probably averages higher than on other land. Gross income averages around Rs. 250 to Rs. 280 per acre.

The principal limitations to higher yields and more intensive use on this land are a shortage of moisture during the winter season and near the beginning and end of the monsoon season. Floods sometimes damage crops, but drought limits production to a much greater extent.

b. *Deep flooding*—On this land flood levels range upward from 3 feet in depth for most of the monsoon season. Houses are built on elevated mounds. The percentage of the gross area which is cultivated averages around 70 per cent. The average cropping intensity on the cultivated land is lower than on the higher lying land, averaging around 110 to 120 per cent. The practice of sowing broadcast aus and aman together and harvesting each separately as it matures, results in a higher intensity than would otherwise be the case. The principal crop is broadcast aman (deep-water paddy) which is grown on about 60 to 70 per cent of the land. On about one-half of this land, broadcast aus is sown mixed with the aman. A relatively important cash crop on this land is jute which is grown in the less deeply flooded areas. It is grown on about 15 to 20 per cent of the land. The percentage of rabi crops fluctuates widely from area to area and from year to year, depending on moisture conditions. Rice yields generally average quite close to those on the higher land in spite of deep flooding. Jute yields are relatively high.

Soil fertility is comparatively high due to finer textures and higher organic content. Deep flooding either from local ponding or from river spill, and from poor natural drainage are the dominant conditions which limit more intensive land utilisation and yields. In the winter months, moisture deficiency is also a limitation. In general, this land is the most densely populated in East Pakistan and also includes the principal jute growing areas. Gross income per acre is only slightly less than on the higher land, averaging around Rs. 230 to Rs. 250 per acre.

c. *Very deep flooding*—The cropping intensity on this land averages around 70 to 80 per cent with the one and practically only crop being boro rice, which grows during the winter season under irrigation. These are about the most fertile soils, but only one crop of boro rice is possible. More intensive utilization of these lands is dependent on flood protection during monsoon and the availability of irrigation water during winter. Average yields are quite high although wide fluctuations occur due to moisture deficiencies and early flooding. Gross income averages around Rs. 160 per acre.

d. *Lower delta*—Because of numerous waterways and idle land, the percentage of the gross area that is cultivated is comparatively low, averaging only about 60 per cent. The cultivated land has a cropping intensity of about 95 per cent. The principal crop is transplanted aman, with rabi crops occupying only about 15 per cent of the area. A small percentage of aus is grown on some of the higher lands. Very little jute or sugarcane is grown. Cocoanuts and betel nuts are relatively important although the actual acreage is not great. Average yields are lower on this land and fluctuate widely from polder to polder, depending on the amount of tidal inundation.

This land comprises a majority of the delta tidal lands. Soil and moisture conditions are generally quite favourable to good yields. The principal limitation to more intensive utilization and higher yields are the tidal inundations of those areas not fully protected by embankments. The salinity of the water varies inversely with the volume of fresh water coming down the tidal rivers. During the dry winter months there is an accumulation of salt in the upper layers of soil, thus limiting the production of winter and spring crops. As in all areas of East Pakistan, supplemental winter irrigation would intensify production when the salinity condition has been controlled. Gross income averages about Rs. 160 per acre.

e. *Tidal forests*—These are typical mangrove forests of the Sundarbans, the natural habitat of the Bengal Tiger. The forests are thick masses of trees, stems and pneumatophores. The most common species of trees are sundri and gewa. The quality of the timber depends upon the degree of exposure to the saline waters. The sundri is a useful wood for a wide variety of construction purposes and the gewa is used for newsprint, matches and cheap furniture. Most of the area is under water with each high tide. Not much is known of the soil conditions in this area.

2. *Old alluvium*

The percentage of the gross area that is cultivated is quite high in the districts in the north-western part of the province, where the average is around 85 per cent. In the districts of Dacca and Mymensingh the percentage of cultivated land is much lower due to extensive areas of forest and brush land. The average cropping intensity on the cultivated land is around 95 per cent. About 70 to 80 per cent of the land is devoted to transplanted aman, and from 15 to 25 per cent is used for aus and various rabi crops. In Rangpur, tobacco is a relatively important crop under irrigation. Very little jute is grown on this land. Because of fairly good drainage conditions, fruit is a relatively important crop on some of this land. Rice yields are about average or only slightly below average on this land.

The soil fertility level is comparatively low, but it lies above flooding, and conditions are quite favourable for transplanted aman during the monsoon season. The soil dries out very quickly when the rains cease and becomes too dry for rabi crops. The principal limitation is moisture deficiency and a slightly lower fertility level. Also on some of this land the topography is quite uneven. The gross income is about Rs. 200 per acre.

I. DATA AND INFORMATION REQUIRED FOR DEVELOPMENT

Prior to Independence, the part of the Indo-Pakistan subcontinent now comprising East Pakistan was relegated to neglect. There was no industry and there existed hardly any data necessary for even the most preliminary planning for dvelopment. The first task of EPWAPDA was to prepare the programme for the second five-year plan, posing the difficult problem of devising schemes without applicable data. Contour maps to the required scale were not available, hydrological data were inadequate, and soil and agricultural surveys had not been conducted.

EPWAPDA immediately set up the necessary organisation to proceed with the acquisition of all data and information required both for planning and execution of its development works. The personnel of the Survey of Pakistan were increased and foreign firms were engaged to survey and prepare maps to scales suitable for irrigation planning; a Hydrology Directorate was set up to collect, assemble and evaluate hydrological and meteorological data; and soils and agricultural surveys were started by EPWAPDA's own personnel.

The following data and formation have been found necessary for planning EPWAPDA's development projects for East Pakistan's deltaic area.

1. *Topographic*

Because of the relatively flat terrain, it is essential that topographic surveys are carried out and maps prepared showing a foot contour intervals at scales 4″ = one mile. To date, surveys and mapping to required scale have been completed for 8,300 square miles; surveys have been completed and mapping is in progress on an additional 5,450 square miles; and survey is proceeding on an area of 15,230 square miles.

2. *Hydrological*

Because of the magnitude and complexity of water resource problems, it is necessary to collect and compile the following hydrological data:

a. *River level and discharge data*
   (1) Review of existing water level data.
   (2) Compilation of all water level data gathered by private concerns and particularly by the Pakistan Eastern Railway to be used in conjunction with or as a check on regular gauging stations.
   (3) Compilation of daily discharge at all discharge stations for as long a period as possible. Records to be extended by rainfall—runoff studies or other means if necessary and feasible. Plot rating curves and discharge hydrographs.
   (4) Areal water balance studies — by comparing discharge hydrographs, using rainfall data, etc.
   (5) Flood frequency studies — care should be exercised as, in case the regime of the stream is changing, the frequency studies are likely to be misleading.
   (6) Flow duration studies — for initial studies. Actual record of low and high years to be used for more detailed studies.
   (7) Depth-area-duration of flooding — for before and after conditions for flood relief projects.
   (8) Water level and discharge data for streams originating outside the country.

b. *Tidal data*
   (1) Continuous water level records at key stations.
   (2) Data on velocity, direction of flow, discharge and sediment movements in tidal areas.

c. *Sediment*
   (1) Sediment transport data on major rivers by survey of river reaches before, after, and during flood seasons.
   (2) Studies to determine areas of origin and deposition of sediment.
   (3) Study of the tendency of rivers to silt or scour on a long term basis, that is the low-water and high-water changes for the period of record.

d. *Groundwater resources*
   (1) Groundwater elevation data.
   (2) Yield of underground source.
   (3) Groundwater recharge, depletion and movement.

e. *Quality of water*
   (1) Study of limits of salinity.
   (2) Chemical analysis of water in major rivers and for specific projects.

f. *Climatology*
   (1) Rainfall.
      (a) Compiling of all daily rainfall data available (at present this is available in usable form for 1935, 1941 to present).
      (b) Monthly summaries of rainfall (available from 1912 for all East Pakistan stations).
      (c) Collecting of all rainfall records around the periphery of East Pakistan and for areas which contribute flow into the province.

(d) Isohyetal maps for:
(i) Average annual rainfall.
(ii) Average rainfall by months
(iii) Major storms, for use in spillway and outlet design.

(2) Humidity — maps showing max., min. and average by month.
(3) Temperature — same as (2) above.
(4) Evaporation — same as (2) above.
(5) Wind — maps showing monthly average and maximum values and direction.
(6) Sunshine hours — maps showing average hours by month.

g. *Rainfall* — runoff studies of typical areas.

h. *Geology* — Past and present rate of settlement or build up. Present rate might be checked by returning a survey to Survey of Pakistan bench marks and structures whereon reference elevations were established 10 to 50 years ago.

i. *Morphology* — A general history of the river systems over a long time (say from the 16th century) and a more detailed history for the past 10 to 50 years.

j. *Aerial photographs* of the river systems during dry season and photos of selected areas or sites during flood season.

k. *Roughness coefficient studies* of rivers of varying size and slope.

l. *Miscellaneous measurements* of low-water flows during extreme low-water periods.

The hydrological requirements are being provided by the Hydrology Directorate of EPWAPDA which has established in the province the following hydrological observation stations:

Type of observation	*Nos.*
Rainfall	294
River gauge	307
River discharge	136
Silt	45
Sub-soil water level	153
Evaporation	36

3. *Soils surveys*

To intensify yields and introduce new crops and new varieties of existing crops suited to irrigation it is necessary to acquire preliminary soils data prior to establishment of project feasibility and to collect, assemble and evaluate more extensive data before project completion. The following soils data are required:

a. *Soil perspective* — Origin, nature, type, soil profile and classification.

b. *Plant Nutrients* — Soil and plant inter-relations and fertility inferences.

c. *Physical properties* — Classification and mechanical analysis, specific gravity, texture, structure and pore space.

d. *Chemical properties* — Classification and analysis.

e. *Soil water and plant relationships* — Water adjustment and retention; evaporation, transpiration, humidity, temperature and wind; critical and optimum moisture.

f. *Soil reaction* — Acidity, alkalinity.

g. *Nitrogen economy* — Nitrogen cycle and transformations; aeration, temperature and moisture, control of soil nitrogen.

h. *Fertilizers and Effects*—Nitrogen, phosphate, potassium and methods of application.

i. *Farm and green manure* — Crop response and practical applications.

j. Fertility management

EPWAPDA has the services of its own soil specialists and, with the help of those of FAO, the Department of Agriculture of East Pakistan and special consultants, it has conducted reconnaissance type soil surveys for projects having a gross area of 9,950,000 acres, located in the Districts of Kushtia, Khulna, Jessore, Dacca, Mymensingh, Comilla, Rajshahi, Sylhet and Dinajpur. More than 100,000 acres have been surveyed in detail and further detailed surveys are currently being conducted for projects now under execution.

4. *Agricultural studies*

Agricultural studies are being continually performed to ensure the optimum benefits to the farmer. It is necessary to establish an experimental farm at each major project area so that the agricultural studies will be able to determine the following:

a. *Most suitable crops* — For soil, climate, quality and quantity.

b. *Irrigation studies* — Crop requirements and irrigation efficiencies.

c. *Cropping pattern* — For balanced farm budget, soil fertility and by-products.

d. *Economic selection* — Farmers welfare, local and inter-regional need and foreign exchange.

Agricultural studies provide the farmers with cropping systems and recommended water requirements for each crop and variety of crop. The success of the EPWAPDA agricultural portion of the programme is ensured by the Agriculture Research and Extension Services under which sound agricultural practices are established on experimental farms located in project areas; and trained agronomy and agricultural officers demonstrate to the farmers the correct procedures and the latest techniques to increase agricultural yields. Typical of the farms thus established is that located in the area of the Ganges-Kobadak Project, as described below.

Since the concept of irrigation farming is a departure from past agricultural practices in East Pakistan, it was decided to open a research station for the study of cropping under irrigated conditions. After a reconnaissance soil survey of the Ganges-Kobadak region, a site for this research was selected at Amla, about 16 miles west of Kushtia Town. The Amla Experimental Farm commenced operation in 1955. Field trials were introduced in 1956 and further extended under an enlarged programme in 1958.

The Farm has an area of 111 acres comprising soil and topography typical of the Kushtia Unit. The buildings include: office, godown, showroom, inspection bungalow, threshing floors, implement shed, cattle shed, living quarters for staff and labour, and necessary animals and equipment. The exparimental farm is divided into eleven blocks and each block is further sub-divided into one-acre rectangular plots suitable for field trials of crops under irrigation. Irrigation facilities include two irrigation pumps each of 3 cusec capacity, lined canals having a total length of 7,000 feet and storage tanks serving both as reservoirs and for fish culture.

The broad research policy of the station aims to:

(i) Test local crop varieties and to introduce and experiment with growing new varieties of food and cash crops from areas within the country and from abroad.
(ii) Assess results of fertilizer treatment.
(iii) Develop suitable double or triple cropping systems and crop rotations under irrigation system.
(iv) Determine irrigation requirement of principal crops.

Observations suggest that in a normal rainfall period paddy yield may go up by 23 per cent to 24 per cent by timely application of irrigation water. On other crops the effect of irrigation has been more pronounced and the following average increased responses to irrigation have been recorded at Amla:

		per cent			*per cent*
Wheat	+	65	Maize	+	32
Peanuts	+	89	Soyabean	+	52
Potatoes	+	72	Linseed	+	16
Onions	+	130	Chillies	+	78

II. PRESENT STAGE OF DEVELOPMENT

a. General

Until recently, flood-protection and drainage measures were executed on a local and limited scale, and irrigation was not practised in East Pakistan; except where farmers used river water by human or animal lift or with very small diesel pumps. The Ganges-Kobadak Project is the first irrigation project in the province. Under landlords called "Zamindars", efforts had been made to prevent tidewater inundation of certain areas along the Bay of Bengal. Inland waterway transport has for centuries been the most important means of transporting cargo and passengers within the province; but all the navigation channels are subject to siltation and are limited during the dry season. Installed power capacity in East Pakistan in 1947 was only 21,000 kilowatts. With the establishment of the East Pakistan Water and Power Development Authority, a planned development programme has been launched for the utilisation and development of the water and power resources of the province. At present East Pakistan is in the initial stage of that development.

The major water development projects completed or under execution include the Karnafuli Multipurpose Project, the Ganges-Kobadak Irrigation Project, the Coastal Embankment Project, Teesta Barrage Project, the Dacca-Narayanganj-Demra Project, the Tubewell Irrigation Project, and Low-Lift Pumping Schemes. There are also numbers of drainage, flood-protection and navigation projects.

b. Drainage and flood protection

Drainage measures include a great many schemes under preparation as well as schemes under execution, such as: the Comprehensive Drainage Scheme in Faridpur district for improvement of about 250 miles of rivers and khals in the northern and central part of the district; the improvement of Old Dakatia and Little Feni rivers in Comilla and Noakhali districts by river re-excavations to eliminate drainage congestion over an area of 280 square miles; dredging the Gumti river and strengthening the Left and Right Embankments will protect about 60,000 acres and effect channel improvements along the 76-mile length of the river in East Pakistan. Other drainage schemes are in progress in the Sadar and Feni sub-divisions of Naokhali district, where a total of 119,000 acres will soon be benefited by drainage and flood-protection measures.

Flood-protection measures have been undertaken to save particular areas by embankments and riverbank protection, viz, at Rajshahi, Sirajganj, Gaibandha, and Kurigram and along the Jamuna, Teesta, Gumti, Surma and other rivers. A major Flood Embankment Scheme to protect the eastern part of the Rangpur, Bogra and Pabna districts now subject to inundation by the floods of the Teesta and the Brahmaputra-Jamuna rivers has been taken up for execution. This 135-mile long embankment composed of about 20 million cubic yards of material will start from Kaunia on the Teesta and will extend southward along the western bank of the Jamuna upto the confluence of the Hurasagar river below Sirajganj. The embankment top width will be 24 feet for a distance of 85 miles and 14 feet for 15 miles. Six inflow regulators equipped with hand-operated gates will regulate the amount of water to be admitted to the project area; two outflow regulators are to be equipped with flap gates to prevent entry of Brahmaputra flood waters and to permit outflow when the Brahmaputra stage has fallen. Flood protection is also provided in the Tippera-Chittagong multi-purpose Project (Phase I) which is shortly to start. The protective embankments will have a top width of 24 feet, an average height of about 12 feet and will contain approximately 22 million cubic yards of materials. Many other flood-protection schemes are under study to protect areas lying in Chittagong, Sylhet and other districts.

c. Protection against saline inundation

The Coastal Embankment Project now under construction is one of the outstanding undertakings in the world. Estimated to cost Rs 590 million it will reclaim a gross area of 3.4 million acres of paddy-growing land from inundation by saline sea water, in the districts of Khulna, Jessore, Barisal, Noakhali and Chittagong. The project extends from the Indian border on the west to the Burma border on the east, roughly parallel to the Bay of Bengal along a 300-mile strip. The project provides for construction of about 3,000 miles of embankments along rivers and tidal estuaries to form protective enclosures for units of areas called polders. The embankments containing over 185 million cubic yards of material, will have 14 feet top width, 3 to 5 feet of freeboard and side slopes of 10:1 on the seaside and 3:1 on the country side. About 5,200 large metal pipe sluices equipped with flap gates will automatically allow excess water to leave the polder areas during ebb tide and will close to prevent entry of saline water during high tide. Agricultural benefits are realised as soon as each polder is completed. About 950 miles of embankments have already been completed, protecting a total area of about 1 million acres.

d. Irrigation

The Teesta Barrage Project which will cost Rs 620 million provides for a barrage across the Teesta to irrigate about 1,800,000 acres of land in the districts of Rangpur and Bogra.

Tubewell and low-lift pump irrigation projects estimated to cost Rs 110 million will supply irrigation water to a net area of 168,400 acres lying in the northern districts of Dinajpur, Rangpur, Bogra and Rajshahi in the vicinity of Thakurgaon; 380 tubewells will draw groundwater from a depth of about 250 feet and 860 low lift pumps of 2 cusecs capacity installed on the banks of various rivers will lift surface water. About 300 tubewells have been drilled and 700 low lift pumps installed so far. A 7,500 kW power station is being constructed at Thakurgaon for supply of power to run the tubewells. Transmission lines are also being set up for the purpose.

The Kushtia Unit of the Ganges-Kobadak Project now under execution will cost Rs 197.8 million and will provide irrigation, flood protection and drainage benefits to a net area of 350,000 acres of land. The project is so named as the source of irrigation water is the Ganges river and the main feeder was proposed to be the Kobadak river. The scheme provides for pumping of water from the Ganges near the Hardinge Railway Bridge. The 8,500 kW power plant is in operation and twelve medium size pumps are operating to irrigate the completed first phase of the work covering about 130,000 acres. Three pumps each of 1,300 cusecs capacity are being installed for irrigation of about 500,000 acres of Kushtia Phase II and part of the Jessore Unit. Simultaneously with engineering works, agricultural extension work has been instituted in the area through demonstration farms and education in the field to acquaint the farmers with the best cropping pattern to suit irrigation farming and the technique of constructing field channels for irrigation.

Also under execution is the Dacca-Narayanganj-Demra Project which will provide irrigation to an area of 14,000 acres and flood protection to a gross area of 20,600 acres, 17,000 of which are culturable. The major features of the project are the pumping plant, irrigation system and flood-protection features. The pumphouse, a reinforced concrete structure, will house four 48-inch diameter, 300 HP propeller pumps each rated at 57,000 gallons per minute. Pumps will be used both for irrigation and for pumped drainage during monsoon. Six miles of main canals will supply irrigation water to the project and protective embankments will afford flood protection to the project areas.

e. Navigation improvements

To date, all completed drainage and flood protection schemes have provided extensive waterway improvements throughout the province. The dam at Kaptai has a reservoir which renders accessible about 400 miles of navigable slack channels thus promoting economic extraction of forest products. The regulation and silt-free discharge below the dam has improved navigation by providing greater channel depth and permitting maintenance of a deep water channel from the Bay of Bengal to the Port of Chittagong. Improvement of the Waterway Route from Narayanganj to Chalna is one project specifically designed for navigation improvement by reduction of navigation mileage from 154 miles to 80 miles.

f. Power

The scope of hydro-power generation in East Pakistan is very limited because of the flat slope of the country except in the south-east. The first hydro-power project in East Pakistan is the Karnafuli Multipurpose Project at Kaptai in the Chittagong Hill Tracts with a present installed capacity of 80,000 kilowatts and provision for a further 40,000 kilowatts unit. The earth-fill dam is 153 feet high and has a crest 1,800 feet long. The reservoir impounded by the dam contains a total storage volume of about 4.4 million acre feet. The 745-foot long spillway located on the left abutment of the dam provides for a maximum flood discharge of 525,000 cfs through 16 tainter gates.

The power available from this project has been accelerating the establishment and expansion of industries in East Pakistan with an appreciable saving in foreign exchange required for import of manufactured goods. The availability of power in the area will permit pumping of water to achieve widespread irrigation and drainage benefits. The reservoir flood storage, designed to prevent serious flood damage to the area downstream of the dam, has already saved the city of Chittagong from severe flooding. The development of the fishing industry in Kaptai reservoir will annually produce 1,42,000 maunds of fresh water fish.

With the construction of a transmission network extending from Karnafuli through Chittagong to Dacca, East Pakistan has for the first time a pool of electrical energy produced in part from falling water and in part from fuel sources. The present installed capacity in East Pakistan is 258,000 kW of which 175,000 kW is run by East Pakistan WAPDA. Until 1958, there was no system of power transmission in East Pakistan. Since then, 525 miles of high tension lines have been put up. Distribution lines have also been set up and are in operation in the principal cities and towns.

By the concluding year of the second five-year plan, i.e. 1964-65, the present on-going projects are expected to provide drainage and flood protection to 750,000 acres, irrigation to 400,000 acres and prevention of saline inundation to 1,200,000 acres. The power generation of WAPDA installations is expected to be raised to 223,000 kW.

III. POSSIBILITIES AND PROBLEMS INVOLVED IN FURTHERING THE DEVELOPMENT

At present East Pakistan is only at the very early stage of development. With a population growth of more than 10 per cent during each five-year plan period, it is a matter of urgent necessity to proceed with all possible speed to execute the East Pakistan WAPDA developmental programme for prompt enhancement of the economy. In the following pages are described the immense possibilities and complex problems involved in furthering the development of Flood Protection and Drainage, Irrigation, Prevention of Saline Inundation, Inland Navigation and Electric Power in East Pakistan.

a. Flood protection

1. *General* — As a prerequisite for all other developments, flood protection must be provided with all possible speed. Recurrent floods, extending over 13,000 to 15,000 square miles, annually take many lives and destroy much property particularly food crops. In the flood of 1962, an area of 13,800 square miles was flooded with an estimated loss or damage to the rice crop of Rs 408 million; additionally, enormous losses of lives, homes, and business properties were followed by widespread epidemics, caused by hunger, exposure and unsanitary conditions in the flood-affected areas.

The rivers drain a huge catchment area embracing one of the heaviest rainfall areas in the world. Unfortunately, by the time these rivers reach East Pakistan they have lost practically all their head and flow towards the Bay of Bengal on a very flattened slope. Further, these rivers carry enormous quantities of silt and sand, thus creating special problems in flood abatement. Flood frequency studies indicate that floods of low severity occur once in every two years; moderate or severe floods occur once in every four years; severe floods once in seven years and catastrophic floods two or three times a century.

Causes of floods vary for different parts of the province: localized rainfall is the most important cause of flooding in the north-western districts; the main cause of the flooding of the districts bordering the major rivers is the high flood levels during monsoon of these streams which spill onto adjoining lands, thereby impeding drainage from local rainfall; cyclonic storms from the Bay of Bengal impede river flows and contribute to flooding throughout the province; whereas in the north-eastern districts, large depressed areas called haors receive river water, flowing from the hills of Assam, together with extremely heavy local rainfall for drainage release into the upper Meghna. But high river levels in the Ganges and Brahmaputra impede the drainage into the Meghna so that vast areas of low-lying lands are inundated for long periods during and following monsoon. It is evident that different areas require varied flood-protection treatment.

2. *Methods of flood protection* — the usual methods of controlling floods are by catchment conservancy, creation of storage and detention reservoirs, diversion of flood water and channel improvement or by protecting land against high flood through the erection of protective embankments. But since the upper catchments of all major rivers lie outside East Pakistan and there are no suitable reservoir sites within its borders, except in the Chittagong Hill Tracts, there is a definite need for schemes to: divert flood flows, effect channel improvements, provide protective embankments, and pump monsoon drainage. Whenever possible, the multipurpose aspects of each development will be exploited by combining the benefits of flood protection, irrigation and drainage with those of navigational improvements and hydro-power.

Accordingly flood protection will be provided by over-flow regulation, by judicious training of rivers, by extensive construction of protective embankments combined with regulators to drain surplus water when river levels have subsided; by construction of barrages for diversion of flood peaks; by pumping plants to remove drainage; by flushing channels and drainage channels; by efficient use of dredgers to improve river flows and navigation; and by flood warning systems based upon snow surveys, rainfall intensities and river stage levels.

b. Irrigation

1. *General* — Second only to provision of flood protection, it is important to prepare and execute irrigation schemes which will provide increased production of foodstuffs. For several months after monsoon there is inadequate rainfall to permit double-cropping of cultivable lands, so that much of the rich land lies fallow for half the year.

A special urgency attaches to the problem of bringing water under greater control for agricultural purposes. Domestic food production is not presently sufficient to support even as low a level of per capita foodgrain consumption as the present average of 14 ounces per day. As a result of the destructive flooding of 1956, widespread famine was only avoided by imports of more than 550,000 tons of foodgrains from abroad. Heavy imports of foodstuff continue and will be necessary for sometime to come unless weather and flood conditions are unusually favourable. The large agricultural programmes of the Five-Year Plans must be fully implemented, so that this deficit condition will soon be eliminated.

For centuries, annual floods have been an accepted part of the agricultural pattern in East Pakistan, and formerly the people learned to adopt themselves to these conditions; but the pressure of increased population on the land has now driven millions of persons to dwell in areas subject to recurrent flood damage. It has been generally believed that floods are necessary to maintain the supply of plant nutrients in a region where neither scientific crop rotations nor the extensive applications of manures or other fertilizers are practised. Therefore, one of the effects of flood protection in the flood areas could be the loss of this source of plant nutrients. However, nutrients can be supplied at a cost by use of commercial fertilizers and organic manures. Also nutrients may be furnished by the river waters carried to the lands through irrigation canals in the dry season or by controlled inundation during floods.

This relationship between soil fertility and flooding makes it clear that flood protection programmes must provide benefits in excess of the value of fertility losses or the cost of replacing these losses.

Most of the crops now grown in the dry season will give higher yields if provided with supplemental irrigation. Dry season irrigation would raise yields on existing crops, provide increased acreages and the introduction of new crops, use more labour during an otherwise low employment season, and give greater diversity of crops with important nutritional advantages.

Rainy-season crops are vulnerable both to inadequate and excessive amounts of water, so that poor spacing of rainfall brings serious consequences. Aus and jute, which are started with the first pre-monsoon rains, often suffer from drought before the monsoon sets in. Transplanted-aman rice is usually safe from moisture deficiencies, but drought at the end of the monsoon often prevents full maturing of the grain. On the other hand a rapid rise in water levels will drown even deep-water aman when the growing crop cannot keep ahead of the rising water. Early floods also drown crops such as aman seedling beds before they are established. Late floods may catch the broadcast aman rice in the generative stage when it will grow no taller. Drought and flood are the main causes for failure of the rice crop and for low average production.

2. *Large scale flow irrigation*—Large-scale flow irrigation may provide an effective solution in some parts of the province. It requires large supplies of water from the rivers, either by diversion or by large-scale pumping. The supply of surface water available in the perennial rivers of East Pakistan is adequate for extensive irrigation, provided consideration is given to requirements for other purposes, such as navigation, and also provided feasible means are devised for bringing water to the land. Another requirement is that the area irrigated be protected from floods, since inundation would do great damage to any extensive system of canals and drains. The minimum discharges of the two main rivers are about 110,104 cfs in the Brahmaputra at Bahadurabad, 41,421 cfs in the Ganges at Hardinge Bridge with low supply of the order of 60,000 cfs. Plant nutrients are especially plentiful in the dry season flows of the Ganges and Brahmaputra. Higher western areas of the province are most suitable for irrigation although some of these would require flood protection simultaneously. In many areas, the topography is not very suitable because of the large number of cross-drainage works which would be required. Accordingly, a careful survey of soils and subsoils is required before any irrigation scheme is undertaken to ensure that they are suitable and not liable to damage by waterlogging. Provision for land drainage should be included where necessary.

3. *Pump irrigation*—Substantial surface supplies are available through the dry season for pumping irrigation water from rivers, channels and beels. Pumps of different sizes are suited to different conditions. Large pumps are mechanically more efficient, but this advantage may be offset by proportionately greater losses through evaporation and seepage from the larger canal system required. Where irrigation schemes are provided with flood protection through use of protective embankments and regulators, large pumps may be effectively used for pumpage of both irrigation water and monsoon drainage, as has been done in several East Pakistan WAPDA schemes. Small pumps of from 1 to 5 cusecs capacity can be used to command land with a fall-away from the natural banks of rivers. This type of irrigation can be used in areas free of flooding using permanent distribution installations. In flooded areas, construction and maintenance of major permanent canals and structures would present serious difficulties but temporary distributions systems could be re-established each year; and portable pumping units, mounted on pontoons, skids,

or wheels, can be moved with the water as it recedes in the dry season, and can be stored safely during the flood season.

4. *Tube-well irrigation*—Irrigation by tubewell pumping is most suitable where groundwater supplies are plentiful and near the surface, and the sub-strata are suitable. There are some areas of the province where the topography is too irregular for canal irrigation and where surface water is not adequately available for small pump irrigation. In these areas, tubewells are the only remaining possibility. The extreme north and western parts of the province are such areas, further favoured by an availability of excellent groundwaters.

c. Prevention of saline inundation

A gross area of 3.5 million acres along the coastal belt of the Bay of Bengal is adversely affected by the rise of the sea with usual tidal cycle, drop in barometric pressure and strong winds form the Bay. The highest tide levels, occurring during the flood season, from June to September inclusive, are 5.3 to 6.4 feet above mean sea level, with highest mean at 0.6 to 1.9 feet above m.s.l. The range of tide is 10 to 10.5 feet. The mean of the lowest combination of tides in these months is 0.6 to 1.0 feet above m.s.l. The coincidence of high or low mean tide levels can make a difference of 0.9 to 1.2 feet in sea level to meet a flood coming down the rivers. A drop of one inch in barometric pressure can raise the sea one foot, and if accompanied by a steady south wind for a day or two, such as frequently occurs in the flood season, the sea level can rise considerably more.

In the dry season, tidal movement is found as far inland as Goalundo, near the junction of Ganges-Jamuna, and north up the Meghna to beyond Markuli in the Meghna depression. The tidal range at Chandpur is 3.0 to 3.5 feet, but during a high flood the range is normally 0.6 to 1.2 feet. At Narayanganj the dry season tidal range is up to 2 feet, and at high flood is reduced to about 0.3 feet. At Khulna the maximum tidal range is about 10 feet. In spring tides, a tidal bore forms with the rising tide in the Meghna estuary. The wave is sometimes 15 feet high and travels 15 miles per hour. Fortunately this phenomenon dies away early, and does not effect the port of Chandpur. Cyclones from the Bay of Bengal frequently cause extensive salt water inundations with consequent loss of lives and property.

In order to protect the land from saline tides, most of the low cultivated lands in the coastal areas must have protective embankments enclosing the areas in polders with drainage effected by regulating sluices installed in these embankments.

d. Inland waterways transport

East Pakistan's inland waterways, in addition to carrying most of the cargo and passengers within the province, also transport traffic between Assam and Calcutta. Highway and railway transport come second. The unbridged Brahmaputra presents a barrier to east-west traffic. Railway and road embankments create some flood and drainage problems. The East Pakistan Water Transport Authority has been set up for the coordinated development of inland water transport.

The craft employed on the rivers of East Pakistan range in size from 15 feet to 350 feet in length. These are classified as follows: Boats are generally 20 feet in length, launches are less than 60 feet and vessels are more than 60 feet long. The registered fleet number more than 700 dumb craft comprising of flats, barges and boats, and nearly 1,000 steam or mechanised vessels. Unregistered fleet consists of more than 300,000 passenger and cargo carrying country boats.

The navigable channels of East Pakistan are limited in the dry season, but at time of minimum flows even the larger vessels can ply about 2,500 miles of waterway channels. Many hundreds of additional channel miles are used by country boats with shallower draft during the dry season, and these crafts move about freely during high water season. The principal ports served by the inland water transport industry include Narayanganj, Khulna, Chalna and Chittagong. All the navigation channels are subject to siltation, which is also an important port maintenance problem, especially in Narayanganj and Chittagong. On the main rivers, river training must be depended upon for channel maintenance. The same channels and tidal estuaries which are used for inland water transport are used to discharge flood waters to the sea. They also may be used as sources of water for irrigation, or to receive drainage.

All East Pakistan WAPDA water developments are thoroughly investigated to determine if waterway transport and travel benefits may be derived from inclusion of navigational improvements. Many projects have been carefully planned to provide navigational improvements as part of the multipurpose aspects of the work. The scheme for improvement of the waterway route from Narayanganj to Chalna, however, is one specifically planned to improve navigation by shortening the waterway route from Narayanganj to Chalna by about 80 miles or 55 per cent of the present distance.

e. Electric power

Prior to 1957, electrical power supply in East Pakistan was dependent upon isolated thermal-electric generating plants, publicly and privately owned, principally powered with diesel engines. Only one

33 kV transmission line was in operation, this in the Dacca-Siddhirganj area.

Some industrial enterprises of East Pakistan have provided their own generating facilities, and will no doubt continue to operate them as long as it is economical to do so. However, with an adequate supply of power available at reasonable cost from a modern power system, few industrialists will continue to depend completely upon their own supplies. There is now no electrification in the villages. When a base requirement for rural services such as power needs for irrigation pumping develops, the future will be entirely different, and the benefits of electric service will be made available for industrial and other uses in villages and rural areas where the electric pumps are located.

The basic objectives of the power programme of East Pakistan WAPDA are to meet the steadily mounting needs for electrical power throughout the province by provision of generation, transmission and distribution facilities. In every developing country, this increasing consumption of power has been an unfailing index of national socio-economic progress.

The power development programme will make it possible to balance the predominantly agricultural economy of East Pakistan with an industrial economy. By diminishing the need for import of many manufactured goods, foreign exchange may be diverted to other development purposes, broadened employment opportunities provided and commerce increased between the rural and urban areas. A province-wide availability of electrical power will promptly and effectively improve the well-being of the people, presently depending largely upon agriculture for subsistence and upon foreign import for those manufactured articles necessary for a modern economy.

Wherever feasible, hydro-electric generation facilities will be included as part of water-control schemes. Existing diesel and steam plants will be enlarged and new generation stations constructed, together with interconnectors, transmission and distribution lines. A nuclear power plant is scheduled for early construction, and as various sections of the Coastal Embankment Project are completed studies will be initiated to determine the feasibility of tidal power-generation plants.

f. Proposed water developments

In addition to the specific projects previously described as on-going, there are many schemes which are ready for execution or are under active preparation. These are described below. All these projects require prompt implementation to improve the physical, social and cultural well-being of the people as quickly as possible. These will ultimately fit into the Provincial Master Plan which envisages the development of entire segments of East Pakistan by extremely large projects involving construction of barrages across the major rivers.

1. *Ready for execution*

a. *Old Brahmaputra multipurpose project (Phase I)* — The region to be benefited lies in the north central part of the province. The project envisages the diversion of water from the Brahmaputra river into the Old Brahmaputra channel, where it will flow to a check dam and 40,000 kW power plant, to be located a little upstream from the town of Mymensingh.

The project is divided into three phases. Phase I, estimated to cost Rs 680 million, provides for the irrigation of 650,000 acres of land and the construction of a power plant which can produce 280 million kWh of electrical energy every year; flood protection will be provided by embankments, and a drainage system will draw off excess waters.

b. *Southern Rajshahi irrigation project* — The project estimated to cost Rs 70.7 million is located in the southern portion of the Rajshahi district. This project will provide flood-control, irrigation and drainage for a gross area of 165,000 acres of which 129,000 are irrigable.

c. *Manu river project* — The project is located near Maulvi Bazar in Sylhet district along the right bank of the Manu river just upstream of its confluence with the Kushiyara river. The purposes of the project are to provide flood protection, irrigation and drainage for an increased agricultural production.

A gross area of 55,600 acres of which 27,600 are irrigable will be protected from flooding by constructing along the banks of both rivers embankments which will terminate in the Bhatera Hills. The project is estimated to cost Rs. 25.6 million.

d. *Karnafuli multipurpose project — Third Unit* —Provision for the future installation of the third 40,000 kW generating unit in the powerhouse at Kaptai has been provided for in the initial construction of those civil installation features such as major intake and embedded penstock facilities required for the third unit. The third unit addition to the power house will involve procurement and installation only of generator, turbine, transformers, and related equipment. The work is estimated to cost Rs 23.62 million.

2. *Under preparation*

a. *Sangu river project* — The Sangu river in the Chittagong Hill Tracts will provide both electrical power and irrigation water and at the same time supply flood-control and navigation benefits. Power will be generated at the Sangu project with one 20,500 kW generator. The irrigable lands are located north and south of the Sangu river about 31 miles downstream of the main dam in the Dolu Khal valley near the village of Dohazari. Of the gross area of 192,000 acres, the irrigable area will be 100,000 acres. The cost will be about Rs 120 millions.

b. *Ganges-Kobadak project — Jessore Unit* — This scheme envisages the provision of flood-protection, irrigation and drainage to an agricultural area of

844,000 acres in the western portion of the province. Phase 1, under review by East Pakistan WAPDA, will provide pumped irrigation to 250,000 acres.

c. *Gumti river project* — This scheme aims to provide permanent flood protection to Comilla town and an extensive agricultural area in Comilla district, and at the same time provide the needed irrigation from the Gumti to the fertile lands adjacent to the river.

d. *Haor reclamation*

(1) *Bara Haor project* — This scheme will include a diversion dam on the Gogain river, canals and lateral system to provide irrigation and drainage facilities to benefit an area of 119,000 acres.

(2) *Hakaluki Haor* — This project will provide irrigation and drainage to benefit an area of 78,000 acres.

(3) *Jadukata flood control scheme* — The purpose of this scheme will be to provide flood protection for a depressed area of 250 square miles of low delta lands in the north central part of the Meghna valley, where large acreages of winter rice crops are periodically damaged by early spring floods. The plan will include embankment, control structures and pumping facilities as required for flood protection to about 150,000 acres.

e. Comprehensive drainage, flood protection and irrigation scheme in Rajshahi, Pabna and Bogra districts

The project area covering about 6,000 square miles suffers from drainage congestion in the monsoon season due to lack of adequate outlet on the badly silted outfall rivers. Crop productivity of an extensive area is very low and health and sanitation conditions are in urgent need of improvement. Collection and evaluation of data related to topography and hydrology are proceeding with a view to development of several major schemes to effect the desired improvements.

f. *Ganges barrage project in East Pakistan* — A firm of consulting engineers of international reputation is preparing a report for this project — one of the largest under consideration by WAPDA. The purpose is to provide for the general economic development of the Lower Ganges River Basin by an increased crop production through irrigation, flood protection, drainage and land reclamation and by generation of large blocks of hydro power. The gross project area is 5.26 million acres of which a net of 3.48 million acres are planned for development.

g. *Control over Brahmaputra river for flood control survey* — The purpose of this survey is to prepare large-scale projects along the Brahmaputra river for implementation during third and subsequent plan periods. Included in these schemes are the Brahmaputra Left Flood Embankment and the Dacca South-West Irrigation Development.

3. *To be investigated*

In the following paragraphs are listed large schemes which very preliminary surveys have indicated to be appropriate for investigation. Some of these projects will, after feasibility has been established, be completed during the third five-year plan; but virtually all of these will be in some stage of execution during the third plan period.

a. *Brahmaputra left bank flood embankment*— This project will consist of a flood embankment along the left bank of the Brahmaputra river, beginning at the proposed intake to the Old Brahmaputra channel and running south along the Brahmaputra to the Dhaleswari and thence down the Dhaleswari river a distance as yet undetermined but perhaps as far as Sabhar. It is estimated that about 640,000 acres will be benefited by this project.

b. *Western Rajshahi irrigation project*—The purpose of the proposed project is to provide for the general development of the area in the western part of the district of Rajshahi called Barind Area by means of a coordinated plan for irrigation. It will be possible to greatly increase crop production by year round irrigation of 400,000 acres, thus encouraging the growth of local industry and the development of central communities and market areas.

c. *Karnafuli irrigation project*—The scheme comprises large areas lying on both sides of the lower Karnafuli river which are currently under some form of cultivation and are producing food crops. The most important of these is the Halda river basin with an estimated irrigable area of 80,000 acres or more. Three other areas aggregate 35,000 acres of additional land for a total area to be benefited of 115,000 acres.

d. *Rangpur irrigation project*—This tubewell project will be located in the area between the rivers Atrai and Teesta in the general vicinity of Nilphamari of Rangpur district. The area is not now included in any active project and is not subject to monsoon flooding. The gross area to be investigated will be about 300 square miles, and of this probably about 85,000 acres will be selected for final development with a view to increasing productivity by double and triple cropping.

e. *Noakhali reclamation project*—This scheme envisages the construction of a cross dam across one of the deltaic channels of the Meghna to change the flow pattern of fresh water and the tidal currents, thereby causing the formation of a substantial acreage of 100,000 acres of new land for cultivation of rice and other crops.

f. *Dacca south-west irrigation project*—Lying east and north of the Padma river and enclosed on the remaining sides by the Brahmaputra, Dhaleswari and Buriganga rivers is in irrigable area of some 440,000 acres of low lands. The project comprise of a continuous flood embankment surrounding the project area and pumping plants for removing surface runoff and also for supplying irrigation water from the adjacent rivers during the dry season.

g. *Matamuhari multipurpose project*—The Matamuhari multipurpose project lies in the southern hilly part of Chittagong district. Head-waters of the Matamuhari river are near the Pakistan-Burma border with the upper reach of the stream flowing north-west from the border some 35 miles before the river runs west into the Bay of Bengal. The river, having a peak flow of perhaps 50,000 cfs in the monsoon season, presents an opportunity for a storage dam which will permit the generation of hydroelectric power and release of water for irrigation of lands lying below the dam.

4. *New third-plan schemes*—Construction will be initiated on the following major projects or later phases of on-going or prepared projects during the third-plan period:

a. *Old Brahmaputra project—phases II & III*—for irrigation to a net area of 800,000 acres.

b. *Khulna irrigation unit*—irrigation, flood protection and drainage of about 650,000 acres in the south-western part of the province.

c. *Meherpur irrigation unit*—irrigation, flood protection and drainage of about 100,000 acres.

d. *Faridpur irrigation unit*—irrigation, flood protection and drainage of about 1,000,000 acres in Faridpur district.

e. *Sylhet irrigation unit*—irrigation, flood protection and drainage of about 500,000 acres in the north-western part of the province.

f. *Noakhali and Comilla project*—flood protection and drainage of about 1,000,000 acres in the south-eastern part of the province.

g. *Tippera-Chittagong multipurpose project—phase II*—flood protection and irrigation of about 870,000 acres in the southern part of the province.

By the concluding year of the third five-year plan in 1969-70, the projects completed by that date are expected to provide drainage and flood protection to about 4,100,000 acres, irrigation to 1,700,000 acres and prevention of saline inundation for 2,400,000 acres.

g. Proposed power developments

The Power Development programme of the East Pakistan WAPDA during the third five-year plan includes the following:

1. *Generation*—50 megawatt thermal-generation installations are contemplated for Sylhet, Mymensingh, Tongi, Khulna, Chittagong and Saidpur, together with a 50-megawatt nuclear station at Bheramara. With the expansion and development of hydro-power generation to an installed capacity of 160,000 kW, the total power generation of WAPDA installations is expected to reach about 603,000 kW by 1969-70.

2. *Transmission*

a. Transmission lines of 132 kV are proposed linking Siddhirganj-Tongi-Mymensingh-Brahmanbaria; Bheramara-Domar; and Sylhet-Mymensingh.

b. Transmission lines of 66 kV will link Chittagong-Cox's Bazar; Kushtia-Rajbari-Faridpur-Magura-Jhenaidah; and Faridpur-Barisal.

c. Secondary transmission lines of 33 kV will extend more than a thousand miles to make power available for a variety of provincial uses, such as pumping for irrigation and drainage, manufacturing and large scale commercial areas.

3. *Other*

Secondary distribution of 11 kV and 400 volt lines will provide power for light manufacturing, cottage industries and commercial and domestic consumers.

Electrification of 5,000 villages will be provided. Electric Equipment Pool will make machinery and electrical equipment readily available to facilitate provincial industrialization.

Broad programmes are envisaged for training engineers and technicians as well as operational and maintenance personnel.

It will thus be evident that the utilization and development of the deltaic area of East Pakistan is one of the largest, most difficult and challenging undertakings. It has been observed by a United Nations technical mission which studied the problem at site that the task is stupendous and the human implications of the work staggering. The programme will take much time and large expenditure. Much investigative work must be done, many studies and surveys be carried out, and many difficult problems solved. But the rewards for successful planning to utilize and develop the abundant waters and rich, deltaic lands of East Pakistan will be a transformation of the economy of fifty four million people, presently living at less than subsistence level, who will advance to a new and better way of life.

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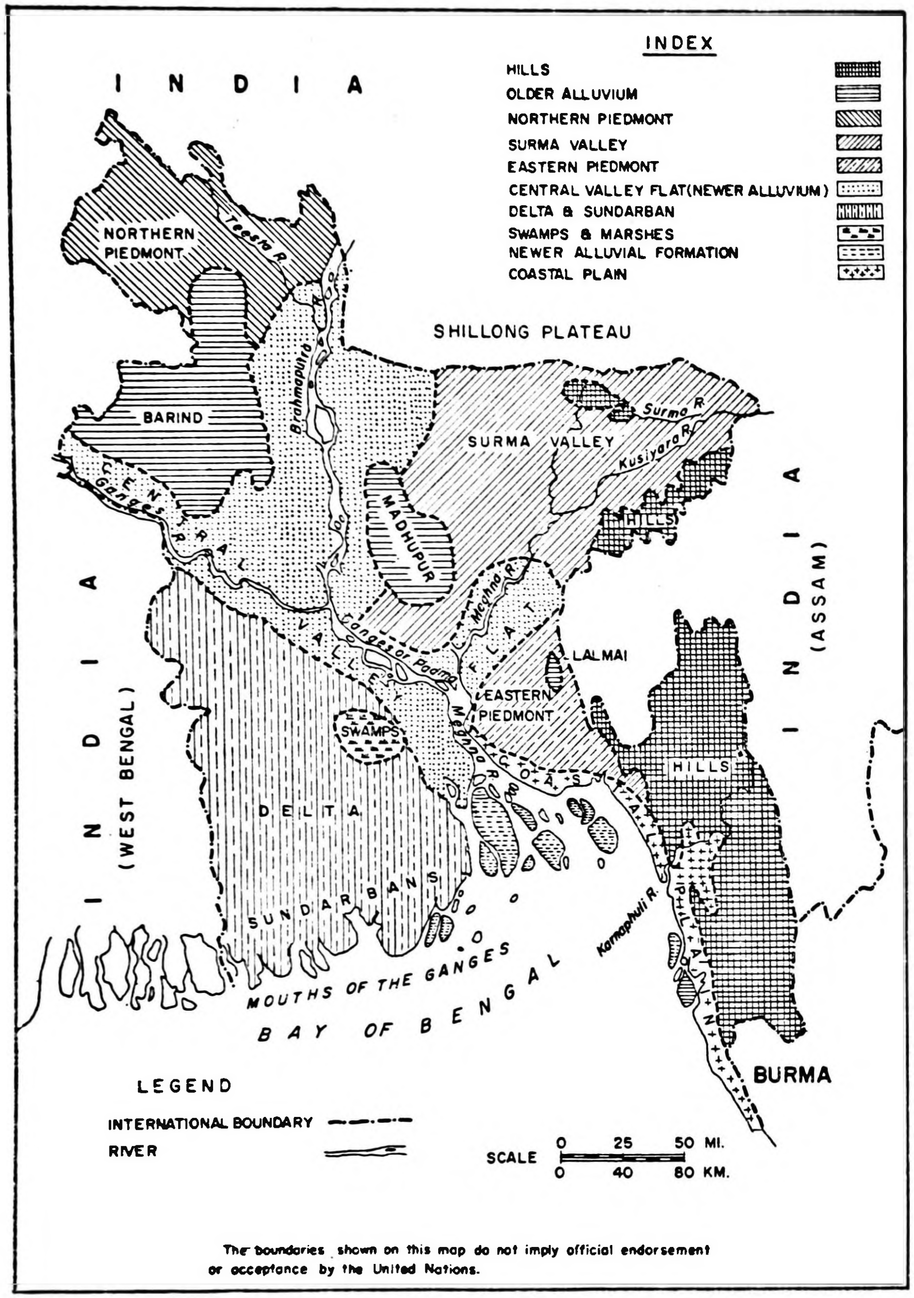

Figure 28. PHYSIOGRAPHIC DIVISION OF EAST PAKISTAN

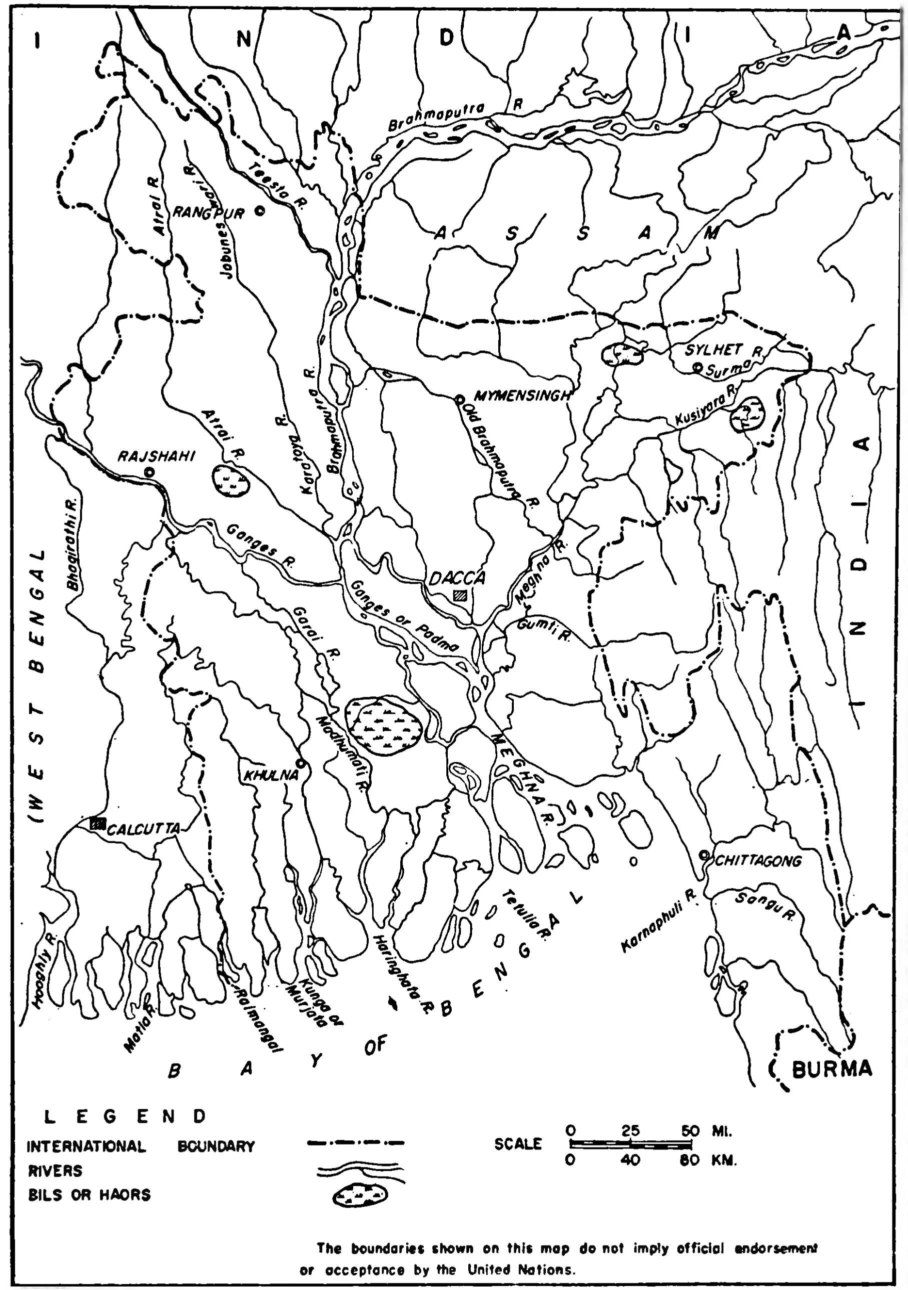

Figure 27. RIVERS OF EAST PAKISTAN

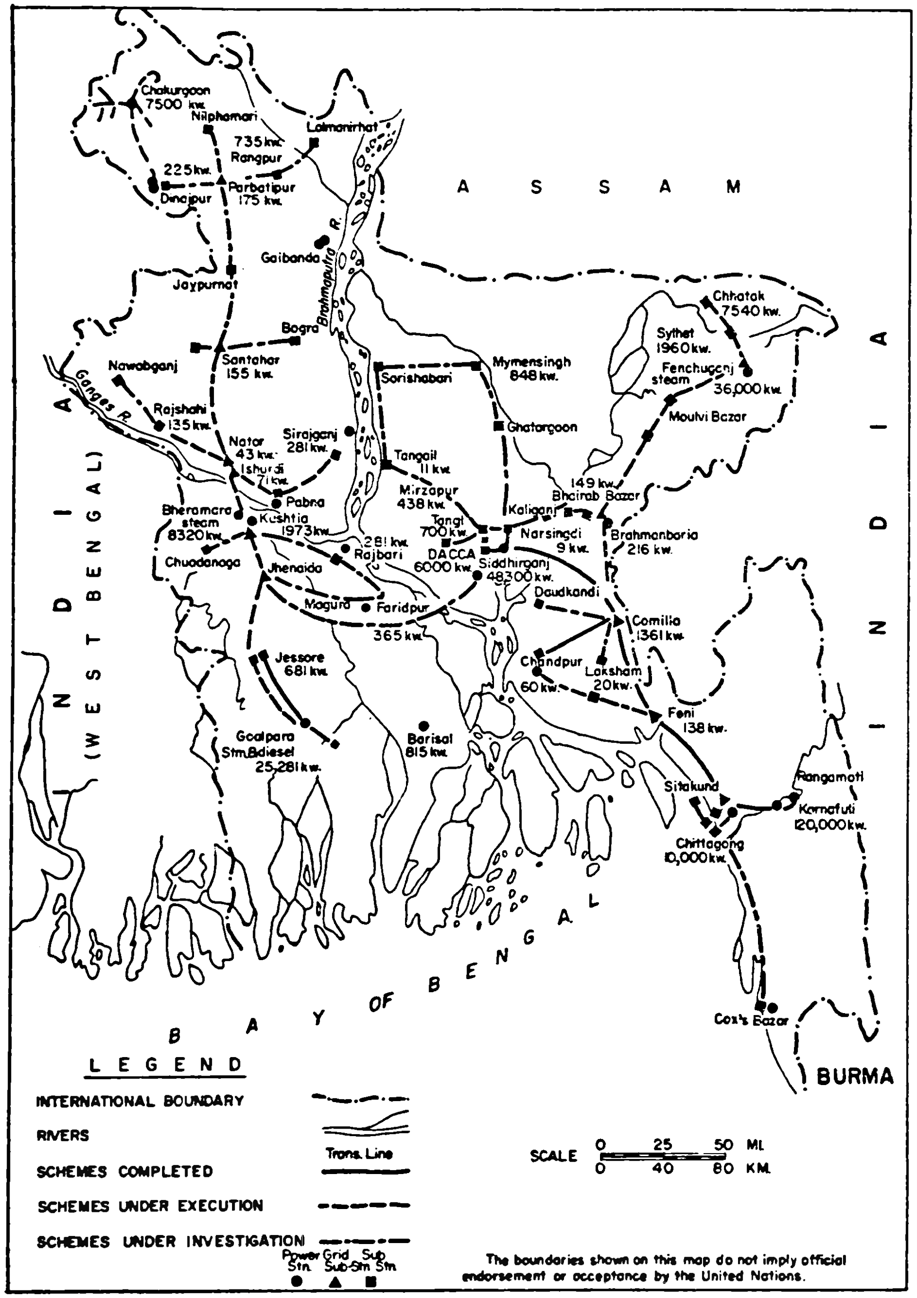

Figure 30. POWER DEVELOPMENT PROGRAMME OF EAST PAKISTAN

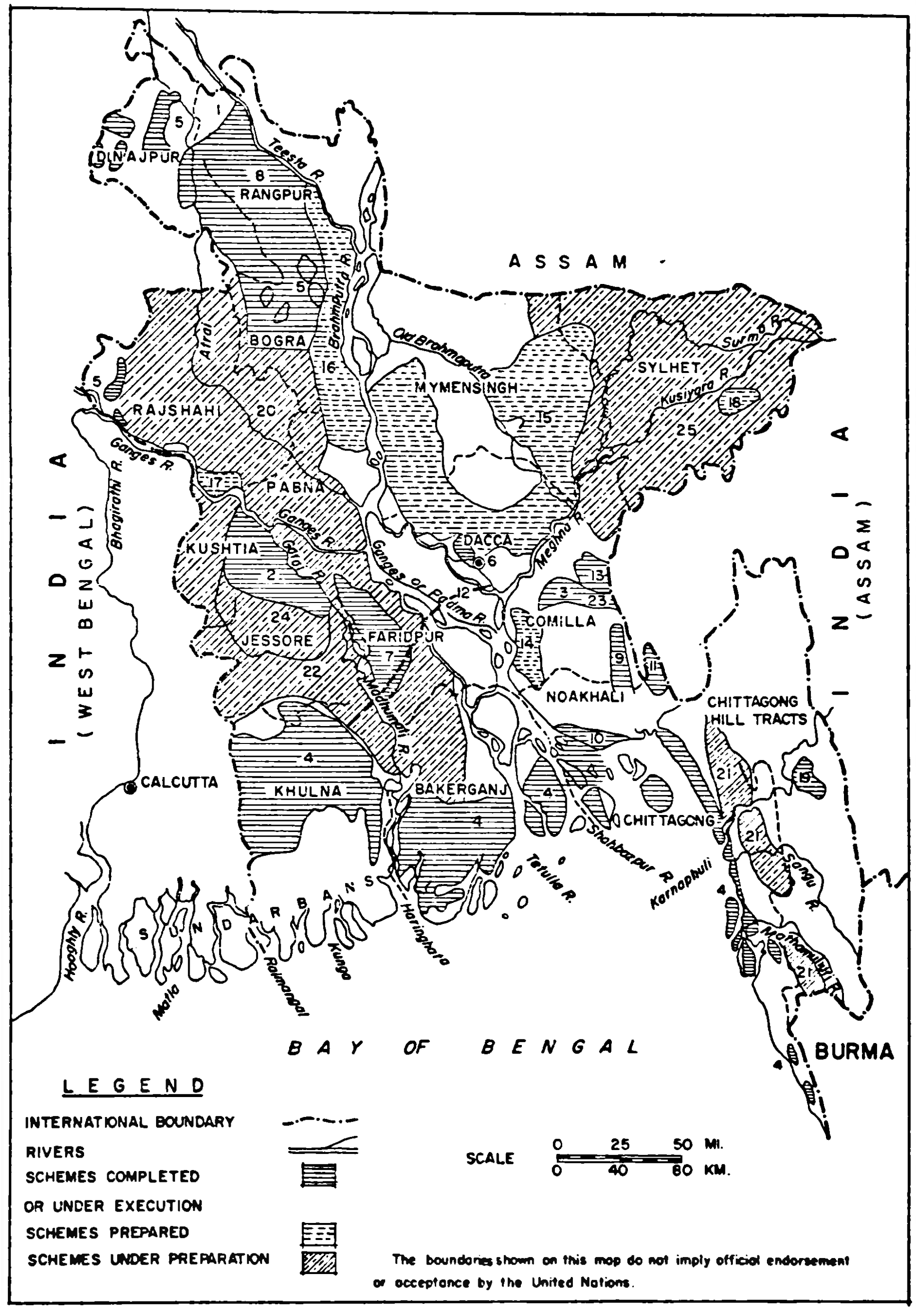

Figure 29. WATER DEVELOPMENT PROGRAMME OF EAST PAKISTAN

EAST PAKISTAN WAPDA WATER DEVELOPMENT PROGRAMME

Schemes completed or under execution

1. Karnafull multipurpose project.
2. Ganges - Kobadak project — Kushtia unit.
3. Dredging Gumti river and strengthening the left and right embankments.
4. Coastal embankment project.
5. Groundwater development and pump irrigation in the northern districts of East Pakistan.
6. Dacca - Narayanganj-Demra project.
7. Comprehensive drainage scheme in Faridpur district.
8. Teesta barrage project.
9. Improvement of Old Dakatia and Little Feni rivers in Comilla and Noakhali districts.
10. Comprehensive drainage scheme for Saddar Sub - Division of Noakhali district.
11. Prevention of flood in Feni Sub-Division of Noakhali district.
12. Improvement of the waterway route from Narayanganj to Chalna.
13. Re - excavation of Ghungur, Salda and Buri Nadi in the district of Comilla.

Schemes under preparation

14. Tippera - Chittagong multipurpose project —First phase (Chandpur Area).
15. Old Brahmaputra multipurpose project.
16. Brahmaputra embankment (Kaunia to Sirajganj).
17. South Rajshahi irrigation project.
18. Manu river project.
19. Karnafuli project — Third unit.

Schemes under investigation

20. Investigation of comprehensive drainage, flood protection and irrigation scheme in Rajshahi, Pabna and Bogra districts.
21. Development of the Sangu, Matamuhari and Haida rivers.
22. Ganges barrage.
23. Gumti river project.
24. Ganges - Kobadak, extension to Jessore unit.
25. Meghna valley project (Haor reclamation).

Paper No. 2

DEVELOPMENT OF THE COASTAL REGION OF EAST PAKISTAN BY EMBANKMENT*

Abstract

The coastal region of East Pakistan along the shore of the Bay of Bengal comprising nearly 5,400 sq miles (excluding forest) is periodically inundated by salt water during high tides. Saline water inundation not only damages the standing crops but also makes the land useless till the salt is leached out.

An embankment project has now been taken up to protect crops of nearly 2.14 million acres of cultivated land from monsoon flood and saline water inundation by constructing nearly 3,000 miles of embankment in ten years. Approximately 5,200 automatic pipe sluices are to be provided for the drainage of monsoon rain water from the area during low tide. The estimated cost of the project will be nearly $121,000,000. It is expected that after completion of the project the value of the yearly increase in crop yields of the project area over the present production will be nearly $21,600,000.

INTRODUCTION

At present the production of food in East Pakistan is short of the requirements. The food shortage is increasing every year due to higher percentage of population growth and poor crop yields due to floods, cyclone, tidal inundation and other destructive forces of nature. As a result, large quantities of food are imported each year from abroad, at the cost of much needed foreign exchange. It has been proved by executing small schemes that the crop yields of the lands now under cultivation in the project area can be increased and additional land can be reclaimed by putting protective embankments.

Solution of the problem is complicated due to complex river and tidal channel system along with the variable cause and effect of the problem in different zones covering a very wide scattered area. For the purpose of increasing agricultural yields by protecting lands against monsoon floods and tidal saline inundation of the coastal regions of Khulna, Bakerganj, Noakhali and Chittagong districts of East Pakistan, embankment project has been taken up.

DESCRIPTION OF AREA AND PROBLEMS

The project area is located along the coast line of 300 miles long strip flanged by India on north and Burma on south. Parts of the four coastal districts of Khulna, Bakerganj, Noakhali and Chittagong covering an area of nearly 5,400 sq miles are included in the project. Execution of the project will give protection to 2.19 million acres of culturable land of these districts out of which 2.14 million acres are currently under cultivation.

The whole of the project area is built up by sediments of the major rivers interconnected by branches and tidal estuaries. The general level of the project area is above mean sea level but below high tide level. Considering the natural topography and the river system the area has been divided into 73 individual polders of various sizes. Soils of the project area consist of marine sediments overlying older river deposited materials and peat.

There is considerable variation in flood water and tide level in the project area. The maximum reading is over 23.5 M.S.L. on the Feni river and minimum is minus 8.5 M.S.L. in Khulna district. A wide variation of diurnal tide range in different seasons and locality is observable. The maximum range is 16.5 feet and minimum is 2 feet. The maximum difference between the highest and lowest tide level at a particular location is 18 feet.

Temperature in the area range from a minimum of 45° to a maximum of 107° Fahrenheit. Due to proximity of the Bay of Bengal, the diurnal range of temperature rarely exceeds 30 degrees but the humidity is generally high especially during monsoon. Mean annual relative humidity varies from 86 to 95 per cent.

There is an extreme variation in annual rainfall over the project area varying from 65 inches in the western part of Khulna district to over 140 inches in the southern portion of Chittagong district. The normal monthly rainfall in the project area in inches is shown in table 9.

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TABLE 9. MEAN MONTHLY NORMAL RAINFALL IN COASTAL REGION OF EAST PAKISTAN
(in inches)

Station	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Total*
Satkhira	0.38	1.03	1.84	2.93	6.87	12.20	13.50	11.57	8.78	4.50	0.75	0.17	64.51
Khulna	0.44	0.93	1.64	2.91	7.75	12.40	14.44	13.79	7.92	4.26	1.12	0.19	67.85
Barisal	0.42	0.94	2.05	4.23	8.25	16.05	16.32	14.94	10.08	6.14	1.54	0.25	81.21
Noakhali	0.25	0.97	2.37	5.47	11.45	20.56	23.56	24.33	16.10	8.13	1.53	0.28	115.00
Chittagong	0.24	1.10	2.46	5.93	10.42	20.99	23.53	20.42	12.64	7.09	2.17	0.64	107.93
Cox's Bazar	0.14	0.47	1.49	4.20	12.74	31.14	35.52	27.75	15.25	7.16	3.26	0.98	140.10

It is evident from table 9 that the 90 per cent of the annual rainfall precipitates during the monsoon which occurs from mid May to mid October. Pre-monsoon and post-monsoon rains are usually accompanied by high winds with velocity in excess of hurricane force, 75 miles per hour. These types of storm have produced tidal surges causing extensive damage to installations along the shore. Within eight months from October 1960 to May 1961 four cyclonic storms with varying wind velocity of 100 to 140 miles per hour hit the coastal areas at different places.

East Pakistan is one of the most densely populated areas of the world. According to 1961 census, the population of the country was 50,844,000 people with an average density of 922 persons per square mile. Most of the inhabitants of the province live in rural areas and are dependant on agriculture.

As the principal means of transportation within the project area is water craft, provision has made to keep the wide tidal estuaries open for cheap transportation of agricultural produces. Due to want of good roads in the area vehicular traffic is practically non-existant. To facilitate road traffic in the area the crest width of the embankment has been increased from 8 feet to 14 feet.

The gross area included within the project is estimated to be about 3,455,000 acres. The estimated cultivated acreage of the area is about 2,140,000 about 50,000 acres within the project area is cultivable waste which can be reclaimed by putting embankment. Allowing for a certain amount of double cropping in the project area, the estimated total cropped area is 2,440,000 acres. Approximately 36.5 per cent of the gross acreage is not available for cultivation which includes cities, towns, waterways, pastures, graves, tanks and homesteads. The crop pattern is dictated primarily by soil salinity conditions which vary due to periodic flooding by saline water and leaching by monsoon rains.

The average of land and crop statistics for the period 1954 through 1959 has been considered for estimating the average present yields. Yields vary considerably from polder to polder depending on the extent of salinity and flooding conditions. Crop failure due to saline inundation and monsoon flooding have been included in estimating the average yields.

The yields of winter paddy (Aman) are estimated to be 14, 12, 11 and 15 maunds of paddy per acre in the Khulna, Bakerganj, Noakhali and Chittagong districts respectively. Average yields of summer paddy crop (Aus) are estimated to be about 12, 10, 9 and 13 maunds of paddy per acre in the Khulna, Bakerganj, Noakhali and Chittagong districts respectively. The yields of winter crop (Rabi) have been estimated to be about 7 maunds per acre in the project area. Yields are expected to increase to a level attained on adjacent area protected from flood and saline inundation. In estimating the increased future yields, the use of fertilizer or any improved practices except those already being used are not taken into consideration. Use of fertilizer, improved seed and better cultural practices in future will surely show a further increase in yields. Table 10 shows the present and expected future acreages, yields, and value of crops in the project area.

Flooding and saline inundation in the project area are not new. The "Zamindars" or large land owners who were also principal revenue agents for the Government did construct and maintain dikes around the arable land. They were, however, of poor specification and required considerable yearly maintenance. In 1951 the Zamindari system was abolished by the "East Pakistan State Acquisition and Tenancy Act, 1950". As a result, there were none left to maintain the existing dikes or to construct new ones, so they gradually deteriorated, were breached and overtopped by tides and became practically useless.

Individual cultivators, attempted to protect their land by dikes similar to those previously constructed by the Zamindars. Lack of technical knowledge, funds and manpower prevented them from constructing suitable dikes. The farmer with land near the river bank is interested only in his small plot and is unable to invest sufficient time and funds for the construction of adequate dikes. Due to small holdings, the farmer builds his dikes to save as much of his land as possible for cultivation. No slope protection against erosion by wave action or rain cut is provided and the farmer's ability to construct even small dikes is very limited. Due to inadequate drainage facilities, dikes are cut when drainage is necessary. Often a portion of the cut dike is eroded during the drainage season and later when it becomes necessary to prevent salt water inundation, attempts are made to close the cut. Poorly constructed closures often fail or in some cases closure become impossible and the land is submerged. As a result of all these poor construction techniques, the dikes are constantly breached and overtopped with

TABLE 10. CROP PRODUCTION AND VALUE IN COASTAL REGION OF EAST PAKISTAN

District and crop	Unit price in rupees	Present: Acreage (thousand)	Present: Yield in Mds.	Present: Production in maunds (thousand)	Present: Gross value in rupees (thousand)	Future: Acreage (thousand)	Future: Yield in Mds.	Future: Production in maunds (thousand)	Future: Gross value in rupees (thousand)
Khulna									
Aman	12	968	14	13,552	162,624	1,008	18	18,144	217,728
Aus	12	81	12	972	11,664	81	16	1,296	15,552
Other crops	20	40	7	280	5,600	40	10	400	8,000
Sub-Total		1,089			179,888	1,129			241,280
Bakerganj									
Aman	12	636	12	7,632	91,584	640	18	11,520	138,240
Aus	12	67	10	670	8,040	67	16	1,072	12,864
Other crops	20	33	7	231	4,620	33	10	330	6,600
Sub-Total		736			104,244	740			157,704
Noakhali									
Aman	12	252	11	2,772	33,264	256	16	4,096	49,152
Aus	12	80	9	720	8,640	80	14	1,120	13,440
Other crops	20	13	7	91	1,862	13	10	130	2,600
Sub-Total		345			43,724	349			65,192
Chittagong									
Aman	12	190	15	2,850	34,200	192	20	3,840	46,080
Aus	12	70	13	910	10,920	70	18	1,260	15,120
Other crops	20	10	7	70	1,400	10	10	100	2,000
Sub-Total		270			46,520	272			63,200
Total		2,440			374,376	2,490			527,376

Note: \$ 1 (U.S.A.) = 4.75 rupees.
1 Maund = 82 pounds.

disastrous results. Poor yields due to ever increasing salinity have forced farmers of certain areas to abandon their land.

EMBANKMENT SCHEMES

The most effective way to protect the land from upstream monsoon flooding and tidal saline inundation is found in embankment. So, it has become necessary to improve and raise the existing embankments if possible and to construct many miles of new embankments. Drainage, as well as topographic and tidal problems, resulted in a project layout consisting of a number of individual areas called polders. It is found that for an economic solution nearly 73 polders with about 3,000 miles of embankment will be required. The location of the polders has been shown in figure 31.

Construction of embankment may give rise to internal drainage problems such as salinity and impounding rain water. When the saline inundation during tide is stopped, deposited salt will be leached out by direct monsoon rainfall within a reasonable period of about 3 years. To facilitate effective drainage of monsoon runoff nearly 5,200 numbers of masonry corrugated metal or concrete pipes sluices will be provided. The sluices will be fitted with flap gates on the salt water side to allow drainage during low tide and stop entry of salt water during high tide. The country side of the sluices will be provided with draw shutters to close them at the end of the monsoon. This will help to store water at a desired level in the channels within the polder with a view to retain moisture in the ground for a longer period. It will also provide a source of fresh water for irrigation during winter.

Some of the rivers carry fresh water during a part of the year. Back water effects during high tide cause the water level to rise above the ground. At this time fresh water can be admitted to the drainage channel to replenish the loss due to seepage and evaporation or the lands can be flooded though flushing sluices, if desired.

Transportation facilities affected in the project area are navigation and roads. No major navigation channel of the area will be impaired by construction of the embankment. Reasonable water ways within the proposed polder will be kept to facilitate cheap communication and transportation of increased agricultural produce for better marketing. Wider crest of the embankment from 8 to 14 feet is being provided to facilitate quick transportation by road.

DESIGN CRITERIA

Only two features, the embankment and the drainage facilities, require careful design consideration. The most important design data utilized was the flood flow-tidal variation gauge readings of large number of gauge stations. Actual location of the polder boundaries was based on a number of considerations. Large tidal closures in the polder were avoided not only because of difficulty and expense but also because they would interfere with navigation in the area. In addition, a large area of water passage must be left through the project area to allow the upland monsoon runoff to pass without damage to the embankment.

In designing an embankment, it was decided to provide sufficient section and strength to minimize the chances of breaching or overtopping. The sections adopted are shown in figure 32. The embankment is not designed to provide protection against tidal surges of such magnitudes as those produced by the cyclone of October 1960, but it will give protection against surges of the usual intensity. One of the primary reasons for embankment failure at present is due to inadequate maintenance resulting from lack of inspection of narrow dikes which has to be carried out on foot. As a result, the present embankment has been designed with sufficient top width for vehicular inspection to ensure proper maintenance.

The free board provided for the embankment varies with the expected wave action. The maximum free board of 5 feet is being used for the embankment subject to direct wave action from the bay or large tidal estuaries with long fetches. In well protected areas, where there is only minor wave action, a free-board of 3 feet has been provided. The crest elevation of the dikes has been set using the maximum gauge reading from the available records and the freeboards discussed above. Side slopes of three horizontal to one vertical on the salt water side and 2 horizontal to one vertical on the country side will be provided for the embankment, except where it faces the bay. The slope of the salt water side of the embankment facing the bay will be 10 horizontal to one vertical below the maximum high tide level.

The embankment has been located so that the minimum distance from the outside toe of the dike to the river bank is 100 feet. The alignment is to be as straight as possible with the tangents connected by smooth long radius curves to minimise erosion.

Embankment slopes are to be protected against erosion caused by wave action and runoff from rainfall. Salt resistant granes and bushes are to be planted on the outside slope. Trees and bushes which can live in saline water are to be planted on the outer berm. The inside slope of the embankment is to be protected by normal grass and bushes which have a shallow root structure to hold the top soil in place.

For the design of drainage sluices it is necessary to consider the maximum volume of water to be drained at any particular time and the type of structure best suited to the area concerned. Extensive theoretical rainfall studies, similar to flood routing studies, have been made to determine the proper rate of runoff for use in establishing the required sluice discharge capacity. Using the rainfall, the assumed discharge capacity and area elevation curve for a particular polder, the maximum depth, duration of flooding and amount of damage was computed. Since rice is the principal crop in the area, it was assumed that there would be no damage to the crop if the depth of flooding is less than six inches. A comparison of the results of the studies permitted the selection of the proper rate of runoff. A rate of 1.00 inch runoff per day has been adopted for the design of drainage facilities in the polders where the mean annual rainfall in 70 inches. Type of sluices is to be selected according to the size of structure, availability of the materials and foundation condition.

COSTS AND BENEFITS

Each of the 73 polders is considered to be a separate unit for construction and economic evaluation purposes. For the preparation of cost estimates, unit costs for embankment, back fill, execution and structures, etc., the prevailing schedule of rates was used. Cost for procurement of corrugated metal pipes, steel, cement, sand and brick, etc., and transportation to the site along with the cost of procurement, survey and maintenance of construction and transport equipment have been taken into consideration. The organizational costs for engineering, execution and supervision, the overhead charge, land cost and interest during construction, have been included in the cost estimate.

From the total cost of execution of each polder, annual costs are being computed. These include the amortization, interest, cost of operation, maintenance and collection fee.

Table 11 shows the total estimated cost of construction, the annual cost and the required assessment per acre to defray the annual costs for each polder of the project area.

TABLE 11. CONSTRUCTION COST AND ASSESSMENT OF EACH POLDER IN THE COASTAL REGION OF EAST PAKISTAN

	Cost of construction			Annual cost			
Polder No.	Domestic currency (rupees)	Foreign currency (dollars)	Total rupees	Domestic currency (rupees)	Foreign currency (dollars)	Total rupees	Annual assessment per acre (rupees)
1	2	3	4	5	6	7	8
1	6,605,000	335,000	8,196,000	618,600	30,900	765,400	12.40
2	5,618,000	211,000	6,620,000	526,800	19,600	619,700	14.80
3	5,481,000	222,000	6,536,000	513,600	20,400	611,100	14.00
4	6,692,000	157,000	7,438,000	628,800	14,600	698,200	29.80
5	15,313,000	686,000	18,571,000	1,438,500	63,600	1,740,700	13.20
6	5,327,000	139,000	5,987,000	498,800	13,000	560,400	17.80
7	7,839,000	215,000	8,860,000	734,200	19,900	828,800	23.10
8	4,702,000	294,000	6,099,000	441,500	27,400	571,700	9.30

1	2	3	4	5	6	7	8
9	1,686,000	34,000	1,848,000	157,000	3,100	171,700	35.00
10	1,110,000	13,000	1,172,000	104,200	1,200	109,900	57.80
11	2,308,000	42,000	2,507,000	215,700	3,900	234,400	37.90
12	5,335,000	146,000	6,029,000	499,700	13,500	563,800	18.90
13	3,593,000	60,000	3,878,000	336,200	5,400	361,700	34.70
14	7,490,000	170,000	8,298,000	701,900	15,900	777,400	23.60
15	2,494,000	60,000	2,779,000	234,300	5,500	260,900	31.00
16	8,120,000	418,000	10,105,000	761,000	38,900	945,700	9.00
17	4,442,000	91,000	4,874,000	416,000	8,400	455,900	36.20
18	763,000	8,000	801,000	71,300	700	74,700	67.90
19	2,766,000	47,000	2,989,000	259,400	4,400	280,300	41.20
20	1,382,000	27,000	1,510,000	129,200	2,600	141,700	35.40
21	1,258,000	18,000	1,344,000	117,800	1,700	125,900	45.00
22	2,007,000	27,000	2,135,000	188,300	2,500	200,200	50.10
23	3,172,000	76,000	3,533,000	297,700	6,900	330,500	28.20
24	3,614,000	361,000	5,328,000	342,400	33,700	502,400	5.70
25	5,325,000	370,000	7,083,000	502,100	34,600	666,600	7.20
26	2,091,000	44,000	2,300,000	195,600	4,200	215,500	32.70
27	1,987,000	30,000	2,129,000	186,200	2,900	199,700	45.40
28	3,108,000	130,000	3,725,000	291,700	12,100	349,200	12.60
29	6,214,000	134,000	6,850,000	583,000	12,300	641,400	23.80
30	3,485,000	91,000	3,917,000	325,700	8,500	365,900	21.80
31	6,442,000	164,000	7,221,000	602,400	15,200	674,600	25.70
32	5,914,000	112,000	6,446,000	554,400	10,300	603,400	31.80
33	4,175,000	119,000	4,740,000	391,900	11,000	444,100	17.20
34	11,441,000	512,000	13,873,000	1,055,200	47,300	1,280,100	10.30
35	13,818,000	676,000	17,029,000	1,272,000	62,800	1,570,400	11.50
36	14,642,000	606,000	17,520,000	1,355,100	56,400	1,623,100	11.80
37	9,585,000	476,000	11,846,000	887,900	43,900	1,096,300	12.80
38	3,674,000	103,000	4,163,000	340,900	9,500	386,000	24.60
39	18,342,000	1,117,000	23,648,000	1,710,100	103,400	2,201,500	12.10
40	4,039,000	129,000	4,653,000	375,700	12,000	432,700	27.00
41A	8,860,000	523,000	11,344,000	822,100	48,500	1,052,500	13.80
41B	7,279,000	263,000	8,529,000	675,800	24,500	792,100	21.80
42	2,543,000	66,000	2,857,000	235,700	6,100	264,700	33.90
43	16,976,000	894,000	21,223,000	1,581,700	83,300	1,977,400	15.60
44	8,593,000	333,000	10,175,000	796,700	31,000	943,500	20.70
45	3,175,000	95,000	3,627,000	294,500	8,800	336,300	30.00
46	3,790,000	103,000	4,279,000	351,000	9,600	396,700	33.90
47	9,130,000	310,000	10,603,000	848,200	28,600	984,100	26.20
48	4,567,000	118,000	5,128,000	419,000	11,000	471,300	29.80
49	2,490,000	40,000	2,680,000	230,800	3,700	248,400	50.70
50	2,506,000	50,000	2,743,000	232,600	4,600	254,400	42.40
51	2,734,000	45,000	2,948,000	255,400	4,200	273,300	49.20
52	2,786,000	58,000	3,062,000	259,500	5,500	285,500	38.60
53	3,816,000	78,000	4,187,000	356,200	7,200	390,500	40.30
54	4,096,000	124,000	4,685,000	379,700	11,500	434,300	29.10
55	16,674,000	716,000	20,075,000	1,552,400	66,600	1,868,800	18.40
56	11,452,000	1,027,000	16,330,000	1,069,500	95,800	1,524,600	9.90
57	9,744,000	539,000	12,304,000	915,500	50,100	1,153,600	16.40
58	7,992,000	263,000	9,241,000	754,400	24,500	870,800	26.40
59	25,477,000	2,097,000	35,438,000	2,405,500	194,400	3,329,000	10.20
60	5,154,000	242,000	6,303,000	483,600	22,300	589,400	20.50
61	7,365,000	698,000	10,680,000	689,700	64,600	996,700	15.90
62	2,424,000	113,000	2,961,000	225,200	10,600	275,500	22.00
63	8,142,000	951,000	12,659,000	760,500	88,300	1,180,100	37.90
64	12,393,000	983,000	17,062,000	1,163,300	90,800	1,594,500	29.10
65	7,501,000	244,000	8,660,000	701,800	22,600	809,100	40.90
66	4,997,000	418,000	6,982,000	469,000	38,800	653,300	45.40
67	3,305,000	214,000	4,322,000	309,700	19,800	403,700	56.10
68	3,706,000	116,000	4,257,000	345,100	10,800	396,400	32.50
69	5,683,000	446,000	7,802,000	531,700	41,400	728,100	30.10
70	3,492,000	98,000	3,958,000	325,200	9,200	368,900	40.10
71	5,326,000	195,000	6,251,000	495,900	18,100	581,900	32.10
72	9,877,000	542,000	12,451,000	919,600	50,600	1,160,000	15.00
73	12,976,000	745,000	16,515,000	1,213,600	69,500	1,543,500	15.10
Total	470,420,000	22,417,000	576,901,000	43,933,000	2,081,000	53,818,000	

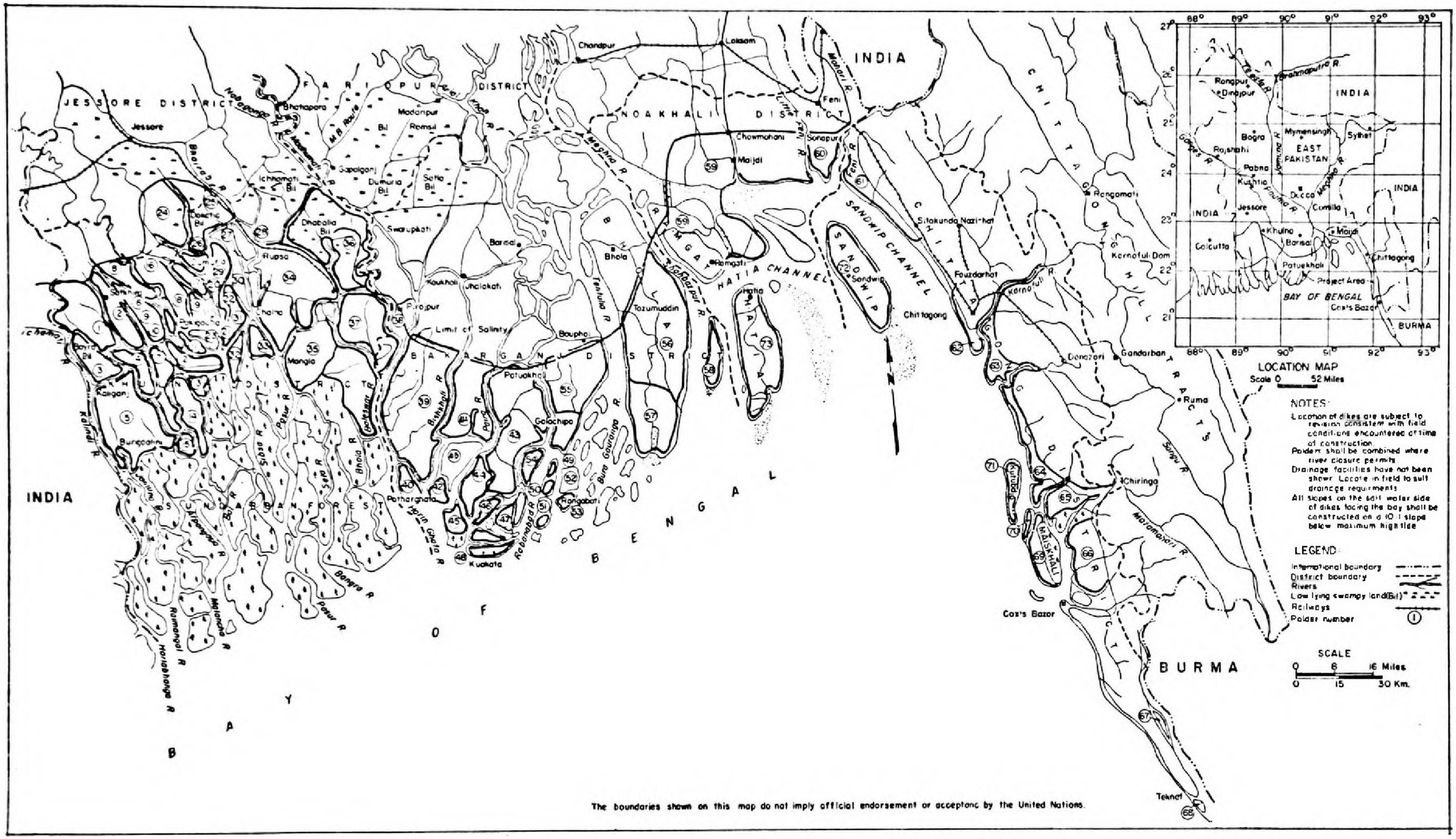


Figure 31. GENERAL PLAN OF COASTAL EMBANKMENT PROJECT OF EAST PAKISTAN

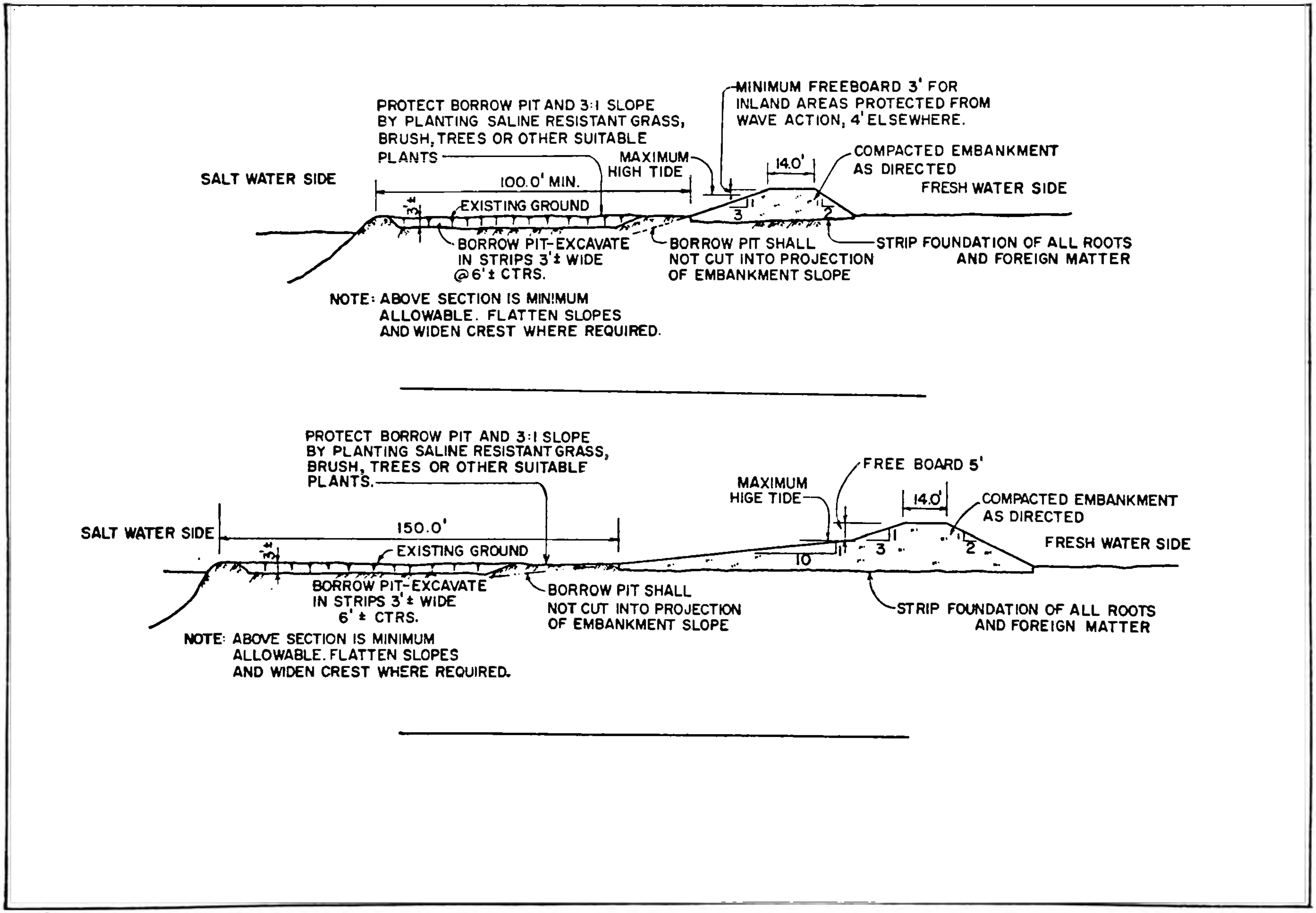


Figure 32. TYPICAL SECTIONS OF EMBANKMENTS IN THE COASTAL REGION OF EAST PAKISTAN

Exact financial appraisal of benefits for major development projects is most difficult as some of the indirect benefits cannot be evaluated in terms of money. Execution of the project will produce immediate results by providing employment for a large number of people during construction period and will also improve overall economy of the area. Other intangible benefits are use of embankment as road, improvement of sanitation after elimination of the saline water from the polder.

In assessing benefits from this project, only the direct benefit from the increase of agricultural production arising from the prevention of saline or monsoon flooding was considered. No benefits were claimed for prevention of flood damage to the structures within the polders or the other intangible items discussed before.

The benefits are applicable on the districtwise basis. Polderwise benefits were determined by multiplying the district average by the number of acres in the polder. The polder benefits thus derived were added together by years, according to the construction programme, and a benefit, representing average conditions was determined. This was applied against total annual costs to give an annual benefit cost ratio. This ratio is presented in table 12.

The cost of execution of the project is to be recovered from the owners of the land benefited in a period not exceeding 20 years.

CONSTRUCTION

Maximum utilization of local manual labour for the construction of the project is being made; it provides much employment for the people of the area during idle period after harvesting and at the same time keeps foreign exchange expenditures to minimum. Equipment is to be used only where hand methods are expensive or impractical.

Construction of the project can proceed only during the dry season, but the labour force is not available during November and December as they are harvesting the Aman crop. So practically only 5 months, from January to May, are available for execution of embankment work. However, work for the execution sluices can be taken up from October.

The execution of the project was started in 1960-61. During the last three working seasons, nearly 1,000 miles of embankment protecting about 1 million gross acreage at a cost of rupees 200,000,000 have been completed. Earthwork of the embankment has been done by manual labour only. In 1961-62, 1,200,000 labourers were employed to put 40 million cubic yards of earth in the embankment in one season.

TABLE 12. ANNUAL COSTS, BENEFITS AND BENEFIT-COST RATIO OF POLDER PROJECTS IN THE COASTAL REGION OF EAST PAKISTAN BY YEARS

Year	*Annual cost in rupees*	*Annual net benefit in rupees*	*Benefit cost ratio*
1962-63	4,640,000	2,997,000	0.65
1963-64	10,181,000	11,999,000	1.18
1964-65	15,991,000	24,428,400	1.53
1965-66	22,289,000	41,029,500	1.84
1966-67	27,026,000	53,652,500	1.99
1967-68	32,188,000	64,886,700	2.02
1968-69	37,979,000	73,732,800	1.94
1969-70	43,799,000	85,594,200	1.95
1970-71	49,048,000	98,189,100	2.00
1971-72	53,818,000	112,455,500	2.08
1972-73	53,818,000	121,313,800	2.25
1973-74	53,818,000	126,286,800	2.35

Paper No. 3

THE PRESENT DEVELOPMENT CONDITION ON THE CHO SHUI ALLUVIUM FAN, TAIWAN, CHINA*

I. INTRODUCTION

Taiwan is located between 119°—122° longitude East and 22.4°—25.1° latitude North. It forms part of the Pen-Hu archipelago consisting of 64 small islands, the geology of which is mostly basalt. These islands once formed a basalt plateau; due to erosion by the sea and to earth moving, this plateau was broken into so many islands. The main Taiwan island is located at the east side of the archipelago; its principal axis runs from the north in a somewhat southeasterly direction and then continues due south all the way down to the southern tip; it makes a large radius of curvature. The total length is about 380 km; the average width in the middle is about 140 km; the length of the coastal line is about 1,144 km; the total area is 35,774.68 km² or 35,988.75 km² if the whole archipelago is included.

Taiwan is mountainous with mountain ranges running parallel with the axis. The plateau is formed by a series of parallel mountain ranges. The highest of these, called the Central Mountain Range, lies on the eastern part; its elevation is up to 3,997 metres and it separates the rivers to the east and west. The rivers in the eastern part of the island are shorter than those in the western part, because the Central Mountain Range lies closer to the former. So the catchment area for the rivers on the western side takes about two thirds of the total area, leaving only one third for the rivers on the eastern side. From the geological point of view, the eastern side of the water divider is schist and the western side is mostly shale. Due to shale being easily eroded and to the large scale of the catchment area, the western side of Taiwan has a large alluvium plain, the edge of which extends into the Taiwan strait.

The Choshui, which is the longest and largest river in Taiwan, originates from the valley between the main peak and the east peak of the Ho-Huan mountain of the Central Mountain Range. The length of this river is about 167 km. The upstream is formed by the Wu-Sheh Chi, which collects the water from the western side of the Ho-Huan mountain, flows along the longitudinal valley north-north-west and joins the Talowan Chi in the vicinity of Fu-Shi-Hsih; then flows together with the Wan-Ta Chi in the vicinity of Wan-Ta; afterwards, it flows together with the Tan-Ta Chi and Chun-Ta Chi; finally, it collects the Chen-You-Lan Chi and Ching-Shui Chi and flows westwards down to the Taiwan strait. In times of flood, the water overflows throughout the area and deposits sediment which is responsible for large alluvium fan along the western side of Taiwan.

The Chinese characters Cho-Shui mean muddy water, for the river carried a very heavy silt-load and the water is muddy throughout the year. The sources of the muddy water are the Wan-Tan and Tan-Ta Chi. The other streams are clear enough, being muddy only in times of flood.

II. TOPOGRAPHY OF THE CHO-SHUI RIVER

To the east of Tamalowan is the upstream of the Cho-Shui Chi, which meanders within the confines of a continuous narrow valley; from Pi-Tze-Tou to Tamalowan is the central reach of the stream, where there are several narrow gaps formed by ridges of hard rocks crossing the valley from north to south. One of such gaps is located in the vicinity of Chi-Chai and another in the vicinity of the junction of the Chen-You-Lan Chi. These gaps are very narrow, so the water flows rapidly through them. But the river bed between the confining ridges is very wide with water flowing through many channels. The depositing action shows very clearly on the beds, part of which have already become river terraces. From the western side of the Pi-Tze-Tou gap, the Cho-Shui Chi divides into five tributaries, called the Mei-Hsu Chu (or Tang-Lu Chi), Hsi-Lo Chi, Hsin-Hu-Wei Chi, Hu-Wei Chi and Pei-Kang Chi, flowing separately westward down to the sea. In the past, the Cho-Shui Chi has frequently changed its flowing channel among the five tributaries; this has created the alluvium fan which is still at the development stage and not yet stable. In 1911, Japanese engineers built a series of dikes downstream of the Pi-Tze-Tou gap near Lin-Nei to separate the four tributaries from the main channel of the Cho-Shui Chi and to bring the flowing water of the Cho-Shui Chi into the Hsi-Lo Chi to reduce damage by floods. After the completion of the dikes, the four tributaries became local drainage channels no longer related to the channel of the Cho-Shui Chi (i.e. Tsi-Lo Chi). Thenceforth, the rate of increase of the alluvium fan became minimal. (Figures 34 and 35).

* By Ren-jen Sun, Deputy Director, Planning Department, Tidal Land Development Planning Commission, Taiwan, China.

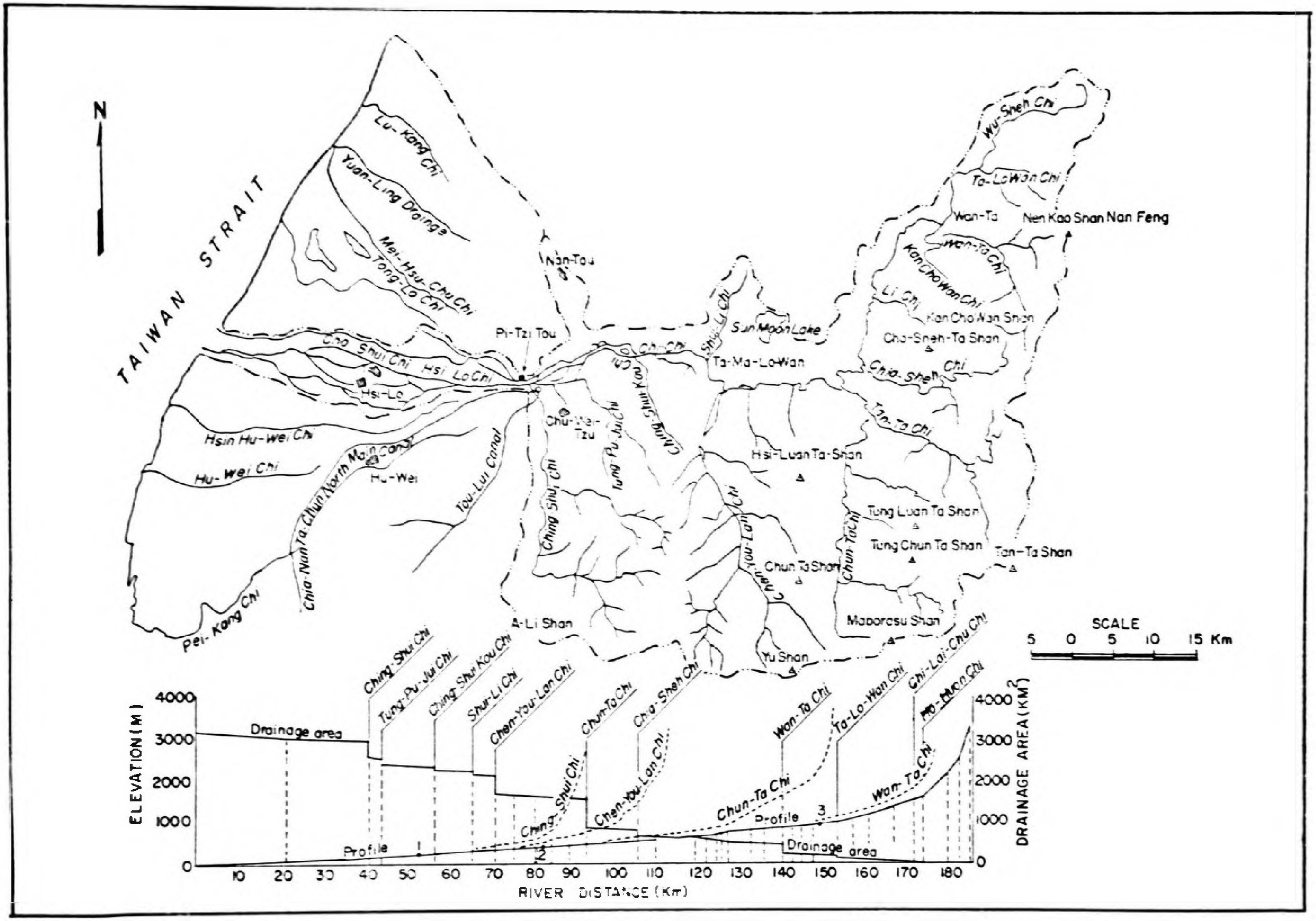


Figure 33. PLAN AND PROFILE OF CHO SHUI CHI, TAIWAN, CHINA

The river profile contains three rapidly changing points. The first point which is about 53 km from the mouth in the vicinity of the Pi-Tze-Tou gap is formed by excessive deposition; its elevation is about 18 metres. Immediately downstream from that point, the river bed is wide and the flowing channels are braided like a net. The deposition action is apparently high. The second point which is formed by rock and has high resistance is located about 83 km from the mouth and 2 km east of Tamorowan; its elevation is about 480 metres. Upstream of this point, the river bed is intrenched in a meandering valley; downstream, it deposits silt, but at a slower rate than the part downstream from the Pi-Tze-Tou gap. The third point is located about 150 km from the mouth and has an elevation of about 1,000 metres; downstream from the point is a continuous river valley; upstream, the river valley is shallow and narrow. (Fig. 33).

The profile shows the slope of the river bed; the downstream part is very flat, about 1/1000—4/1000. The river bed spreads widely from downstream of the Pi-Tze-Tou gap, so the velocity of the water flow is reduced; the silt-load carried by floods is rapidly deposited on the bed. The bed slopes of the central and upstream are much steeper, about 1/200, so the velocity of flow is much higher than it is downstream. Moreover, due to the easily eroded shale, the mountains often slide down, so the silt-load carried by the water is very heavy; most of it is deposited downstream, for which reason the alluvium fan is not yet stable.

III. THE HISTORY OF THE ALLUVIUM FAN

Before the alluvium fan has been deposited, the mouth of the Cho-Shui Chi was at the Pi-Tze-Tou gap. After the uplifting of the Pa-Ku and Chu-Kou tablelands, the Pi-Tze-Tou gap became a point of changing slope between up and downstreams. The alluvium fan started to be gradually deposited at that time, because the natural force tended to reduce the slope between upstream and downstream, thereby smoothing the river bed.

The alluvium fan has the Pe-Tze-Tou at its apex. Its elevation is about 100 metres. The radius of the fan is about 40 km.

From records made one hundred and seventy odd years ago, it appears that the streams were still to change their courses. In 1793, the Cho-Shui Chi took the Hu-Wei Chi as its main flowing channel; thus, after a certain time, it changed to the Hsi-Lo Chi. In 1898, there was a big flood and it changed its main flowing channel to the Mei-Hsui-Chu Chi. In 1793, there was a big slide at Tsao-Lin-Tan upstream of the Ching-Shui Chi; a flood brought a heavy silt-load flowing along the Ching-Shui Chi channel to the Cho-Shui Chi main channel; during that time, the Hu-Wei Chi was the main channel for the Cho-Shui Chi. Because of the big silt-load, the Hu-Wei Chi channel was not enough to carry away the flood, so a new tributary called the Hsin-Hu-Wei Chi was formed at that time; it flowed between Hu-Wei and the Hsi-Lo Chi and south of Mei-Liao to the sea. The tidal land outside Mei-Liao and Ta-Hsi was deposited at that time. The Cho-Shui Chi took the Hsi-Lo Chi as its main channel for some years and then changed to the Mei-Hsu-Chu Chi after a big flood; a new tributary was formed from the Mei-Hsu-Chu Chi, called the Lu-Kang Chi. The alluvium fan was mostly deposited during floods when the Cho-Shui Chi changed its main flowing channel from one stream to another. (Fig. 34).

The western part of the fan along the coast is a marine deposit. Part of the silt-load carried by the Cho-Shui Chi is deposited on the river bed, part of it is sent out to sea through the mouth to be deposited in a shallow sea; there it forms a series of off-shore bars, which are effected by wind and waves, so that the materials of the bars are transported again and uniformly deposited along the coast to form a tidal land. When the elevation of the tidal land reached a certain height, the people made simple dikes to reclaim the land and it became a part of the alluvium fan. The edge of the fan is extending gradually outwards. The famous reclaimed areas of the tidal lands on the fan are the Lun-Pei and Tai-To reclamation areas. From 1911 to the present time, due to the dikes near the apex, the main channel of the Cho-Shui Chi has remained in the Hsi-Lo Chi, the floods having been controlled since that time. The tidal land in the vicinity of the mouth of Hsi-Lo Chi is still extending outwards, because each year the silt-load carried by the floods is plentifully deposited in the shallow sea; but the tidal land south from the mouth of Hsin-Hu-Wei Chi has begun to be eroded because of lack of drifting sand.

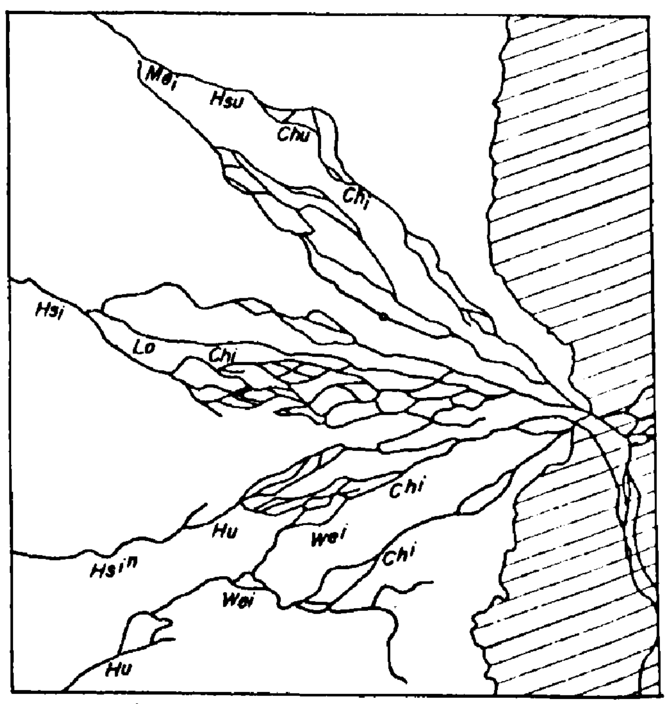


Figure 34. TRIBUTARIES OF CHO SHUI CHI IN 1905

IV. THE PRESENT DEVELOPMENT CONDITIONS ON THE FAN

In the early stage of the alluvium fan, people started the reclamation work. To-day, the fan has become the centre of the food production in Taiwan. Descriptions of the soil conditions, hydrology, use of water resources, agricultural management and flood control follow, showing development conditions on the fan.

1. *Soil condition*

The geological formations upstream of the Cho-Shui Chi are easily eroded shale, black slat and sandstone; shale forms the major part. For this reason, the soil on the fan is dark grey and contains plenty of lime materials; the texture is silt and sand.

At places where the elevation is more than 3,000 metres, rocks are exposed, there being no top soil at all. Soil is generated where the elevation is less than 3,000 metres. The soil on the tableland and terrace traversed by the central stream is deluged deposition; on the downstream alluvium fan area, most of it consists of alluvial deposits, though part is saline soil. The reason for the formation of saline soil is that the silt-load carried by the Cho-Shui Chi flood is deposited in a shallow sea near the mouth, from where it is again transported by wind and waves to form tidal lands. These lands are submerged by tide twice a day during flood time. After ebbing, the soil on the tidal lands is saturated by sea water and the salt content of the sea water is deposited into the soil of the tidal lands by evaporation during ebbing. So that the soil becomes saline. After the elevation of the lands becomes high enough by siltation, people reclaim them by simple diking; the salt content in the soil is washed out by rainfall or irrigation water and then the soil becomes normal. Thereafter, due to poor drainage and to the highly saline groundwater of the tableland along the coast, the soil again becomes when the irrigation water is stopped; because of evaporation of the excess water ponding in the area and also on account of capillary action, the saline groundwater comes out to the top soil. That is the big problem on the fan for the coast area.

As to the textural classes of the soil, it can be divided into loamy sand, sandy loam, loam, silty loam, sandy clay loam, silty clay loam and small part of clay. (Fig. 35).

2. *Meteorology and hydrology*

The Cho-Shui alluvium fan has had a long history of development, so meteohydrological observations have long been recorded. The earliest rainfall station was established in 1903. The observation stations have been established by different agencies, such as the Provincial Water Conservancy Bureau, the Taiwan Sugar Corporation, the Taiwan Power Company and the Irrigation Associations, etc., according to their own needs. The station density is too concentrated; at one spot, there are three or four stations. At the present time there are 47 stations for rainfall observation. The average density is about one station per 67 km. The majority of the stations are located below 1,000 metres elevation; very few of them are found above that elevation. For the basin as a whole, the rainfall records are still not enough; the Government should unify the management system and uniformly distribute the stations to all important points in the basin.

The same situation obtains with the stations. The Taiwan Power Company is only interested in power development; the Provincial Water Conservation Bureau is interested both in flood control and irrigation. The discharge gauging stations are established each for a special purpose by the different agencies, not for the basin as a whole. Some important points require stations for considering the whole basin, but no one is interested in establishing them. The Government should unify the whole hydrological observation system. The silt-load carried by the Cho-Shui Chi should be also tested frequently. This work was started in 1955, but only at a few points. It should be extended from upstream to downstream.

According to a series of rainfall records, the average annual rainfall is 2,555 mm; maximum annual rainfall was 3,380 mm (in 1947); minimum average annual rainfall was 1,967 mm (in 1954). The intensity of rainfall is small along the coast, about 1,554 mm, and bigger in the mountain area, about 5,087 mm.

From October to the following March is the winter monsoon season; the wind blows very hard in a NNE direction at an average velocity of about ten metres per second. Inland, the velocity of wind is reduced by the friction of wind-breaks and buildings, to about 2 to 5 metres per second.

The monsoon is a big force for reducing the crop yield. According to a five-year report (from 1927-1931), the agricultural yield near the foothills where the effect of the monsoon can be negligible is 100 per cent; in the central part of the fan, the yield is 96 per cent, for it is little effected by monsoon; but in the coastal area the yield is only 80 per cent, for there the monsoon blows very hard.

During the monsoon season, there is high air pressure coming from the Mongolia; it is cold and dry and rainfall is very slight; in the mountain area, the rainfall is only 15-19 per cent; the plain area receives 11-15 per cent of the whole amount of the annual rainfall.

From June to October each year is the summer monsoon. The direction of the wind changes daily, unlike during the winter monsoon when the wind blows in the same direction for a long time, but the major direction of the summer monsoon is SW. During this season, the weather is hot and humid and rainfall is heavy, being over 50 per cent of the total annual amount. From April to December is the typhoon season. When a typhoon hits the island, storms and floods always accompany it. Sometimes, a typhoon is stopped or deflected at the eastern side of Taiwan by the Central Mountain Range; then often a tropical low air pressure is induced at the western side, making a very heavy storm; the huge flood on 7 August 1959 was due to such low air pressure.

Typhoons mostly come in July, August and September, so the floods usually occur in those three months. The rainfall during a typhoon is concentrated within a short duration, so the flood peaks are high, which is very dangerous for the river levees. (Table 13). Typhoons constitute the most dangerous destructive force for the fan.

From December to the following March is the dry season. The discharge in rivers is very small; sometimes there is none. From April, the discharge gradually increase; June to October is the wet season, rainfall becomes heavy; June is the wettest month and the discharge in the rivers reaches the maximum for the normal flow. During the wet season, the intensity of rainfall is small, but the duration is long enough, so the discharge water level in rivers is not as high as during a typhoon flood. No trouble is caused to the fan area.

The evaporation on the fan area is higher than rainfall, especially in the monsoon season when rainfall is small, evaporation high and the discharge in rivers almost zero. Crops need water for irrigation at this time. Groundwater is the best source of supply.

The temperature after April is above 20°C for seven to eight months. June to September is the hottest period. The temperature at this time averages 22°-26°C; it can reach 29°C on the fan area but only 6°C in the mountain area. From December to the following March, the temprature declines to 14°-20°C on the fan area and to 0.8°-4°C in the mountains. Strictly speaking, on this alluvium fan area, there is no winter at all, only summer, autumn and spring. This is good for agriculture.

The relative humidity is between 50 to 100 per cent on the fan area; 60-90 per cent in the mountains. Because Taiwan is surrounded by sea, although the seasons are divided into wet and dry periods, the average annual relative humidity is as high as 70 per cent. In a dry year, the most relative humidity is at 50 per cent.

3. *The usage and development of water resources*

Water is one of the important resources of a nation. At present, water on the alluvium fan is used for power generation, irrigation, water supply, etc. Drainage should be developed with irrigation.

(a) *Power generation*

The power-generating plants on this basin are the Wa-Ta, Ta-Kuan, Chu-Kung and Wei-Hsu power plants. The Wa-Ta plant is located downstream from the juncture of the Wa-Ta Chi with Wu-Hseh Chi. The catchment area of this reservoir is 149 km. The diversion dam is an overflow gravity concrete dam, 12 metres in height, 47.7 metres in length. The generating capacity in 15,000 kW. Due to poor soil conservation upstream of the Wa-Ta Chi, the landslides frequently occur in the mountain area. The silt-load carried by the Wa-Ta Chi is very heavy. The diversion dam and intake have silted up by in 1947. So the plant could not generate power for two years.

The Ta-Kuan and Chu-Kun plants belong to the Sun-Moon Lake generating system. The Sun-Moon Lake was actually two lakes shaped like the sun and moon respectively. The catchment area of the lakes was about 15 km; its storage capacity is 18.33 x 10^6M^3. Then two dams were constructed in 1931, to close the lakes and a diversion dam was built at Wu-Chih to bring the water of the Cho-Shui Chi to the lakes through a tunnel.

As a result, the water level in the lakes rose so that the two lakes joined together and became a huge reservoir. The effective storage capacity of the reservoir is 148.5 x 10°M^3. The Ta-Kuan plant which takes the water from the Sun-Moon Lake generates 100,000 kW. The tail-water from the Ta-Kuan power plant flows to the Chu-Kun power plant, and produces 43,500 kW of power. The total generating capacity of the Sun-Moon Lake system is 143,500 kW.

The Wu-Hseh gravity arch concrete dam is located on Wu-Hseh Chi about 2.9 km upstream of the juncture joint of the Wu-Hseh Chi and Wa-Ta Chi. The height of the dam is 114 metres; the length is 205 metres and its storage capacity is 148.6 x 106 M^3. The generating capacity is 20,700 kW (Table 14).

(b) *Irrigation*

In Taiwan, the dry season lasts about half a year, during which the crops need irrigation to maintain the moisture content in the soil. For this reason, the irrigation work on the fan is fully developed and managed by hydraulic associations organized by the water users. The Government only supervises and helps them. There are six associations on the fan, three of them are located at the northern side of the Hsi-Lu Chi, i.e. the Hsin-Kao, Nan-Tou and Chang-Hwa Hydraulic Associations; the other three are at the southern side, i.e. the Chu-Shan, Tou-Lu and Chai-Nan Hydraulic Associations. The total length of the main irrigation canals of the six associations is 680,000 metres. The irrigated area is about 77,306 ha, comprising about 50,918 ha. of double crop rice, 7,127 ha of single crop rice and 19,261 ha planted according to a three year rotating system (Table 15). This rotating system is used owing to lack of irrigation water, rice is planted in the first year, sugar cane in the following year, and dry crops such as peanuts, sweet potatoes, etc. in the last year. Thus crops consuming different amounts of water are planted in rotation within a three-year period. Recently, parts of the irrigation canals have been lined with concrete to prevent seepage loss through canals as as to save water. Groundwater resources have also been developed in recent years, so the area for the three-year rotating system has been reduced. This helps food production. The water resources, both surface and groundwater, should be developed carefully corresponding to the crop pattern, because there are about 20,000 ha of tidal land ready to be developed in the near future, so the supply of irrigation water will become a difficult problem.

(c) *Water supply*

Four sugar factories located on the fan area consume a large amount of water for cooling. They are run only in the dry season when it is very difficult to maintain their water supply, so most of them use groundwater to supplement it. Fortunately, the sugar factories only use the water for cooling, so they can send it back to the ditches again for the farmers to use for irrigation.

The city water requirement is limited because of the small size of cities on the fan. Moreover, people use water from wells for their domestic use.

(d) *Drainage*

In a certain area, the salt in the irrigation water is left deposited on the soil after evaporation, so that the soil becomes saline. Unfortunately, people only paid attention to develop irrigation and neglected the drainage system. Recently, engineers have been giving consideration to drainage first and only then to irrigation. The total length of the main drainage channel on the fan is about 700,000 metres, which seems insufficient for the whole fan area. It should be improved immediately.

(e) *Development of groundwater resources*

Surface water resources are not enough for irrigation and water supply during the dry season, but the fan is full of groundwater. The writer conducted a survey team to investigate the groundwater resources in the whole fan area in 1955-1957; They are now being developed. The aquifers are about 100-200 metres under the ground surface. Most of the wells are artesian, their capacity being about 700-1000 gpm. (Fig. 36)

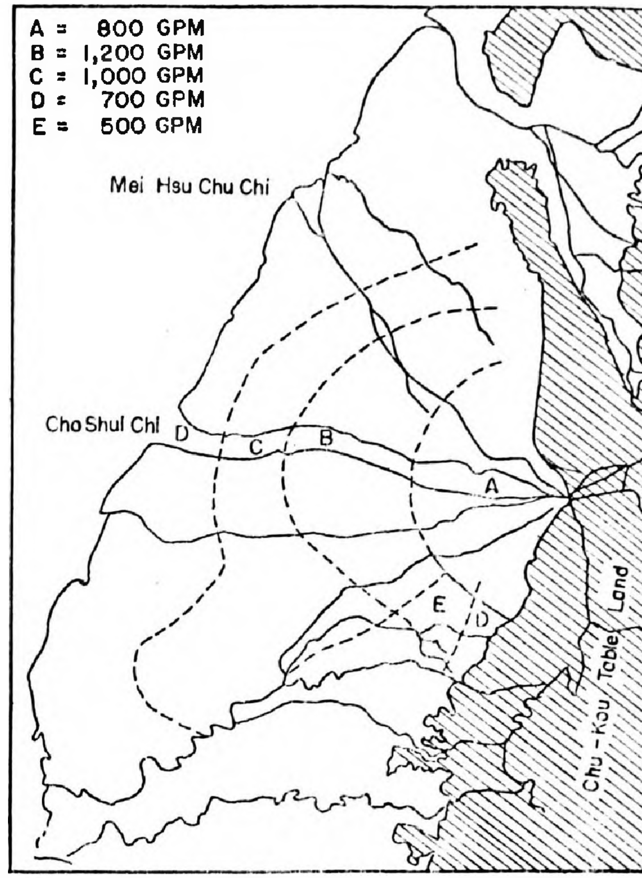


Figure 36. GROUNDWATER DEVELOPMENT IN THE CHO SHUI CHI DELTA

4. *Agricultural management and land use*

To increase the cultivated land is an urgent problem, owing to the heavy density of the population. All land on the area has already been developed. In some places, agricultural production has reached the standard, but in some it is below normal, owing to the different soil conditions and to their situation. If this condition can be changed by such means as improving the soil conditions and drainage system and by constructing windbreaks, then the agricultural production along the coast will be improved.

The total area of the fan is about 1,400 km^2 with a population of one million and one hundred thousand. Each square kilometre has 785 persons. The cultivated area is about 100 thousand ha. The index of the cultivated land is 71. Farmers comprise about 70 per cent of the total population. Each cultivated ha supports 8 farmers. The total crop planted area is about 260 thousand ha, of which paddy occupies 52 per cent. The index of the crop planted area is as high as 260. The paddy planted area is about 52 per cent of the total crop planted area. There are two paddy crops a year, with 3,000-3,500 kg/ha of paddy for the first crop and 2,500-3,000 kg/ha for the second crop.

According to the land classification, there are five classes of land on the fan; first and second class land occupy one-third each of the total cultivated land; the remainder varies from third to fifth class.

Due to the hard winter monsoon, windbreaks are necessary for protecting the crops along the coast area. So far, construction of windbreaks has not been completed; this should be finished right away. Beyond the present sea dikes, there are about 20,000 ha of tidal flats. The ground elevation of the flats is about 2-3 metres. The discharged water from river mouths spreads all over the flats. Hence the river discharge cannot use the head difference between normal low tide and the water level in rivers, so the drainage condition is rather poor. Also the sea dike construction is not done in a proper manner. The dikes are often destroyed by storm waves from outside or by flood from inside, whereupon sea water comes in through the broken points. For these two reasons, the soil along the coast area is becoming saline. If the tidal land is reclaimed, then the present condition along the coast will be much improved.

5. Flood control

The first 3,240 metres of river dike used for flood control was constructed after the big flood in July 1879. It was destroyed a few years after completion owing to poor design, construction and maintenance. The first construction of modern dikes began in 1911. A series of dikes was built near the Pi-Tze-Tou gap to separate the four tributaries from the main channel of the Cho-Shui Chi, i.e. the Hsi-Lo Chi (Fig. 37).

Up to now, about 90,000 metres of dikes and 80,000 metres of protection have been constructed. The river bed of the Hsi-Lo Chi is increasingly silted year by year and the elevation of the bed of the Hsi-Lo Chi is much higher than the adjacent cultivated land, so the river dikes need to be raised higher and higher which is very dangerous as well as expensive. Accordingly, the flood control problem should be thoroughly considered immediately.

V. THE POSSIBILITY OF CHANGING THE RIVER COURSE IN THE FUTURE

Due to silting up of the bed of the Hsi-Lo Chi, its elevation is already higher than adjacent area. If the siltation continues, the river course will change within a few decades. The Government should give thorough consideration to regulating the Hsi-Lo Chi soon to prevent the river from changing its course and thus protect the dense population and develop the fan area.

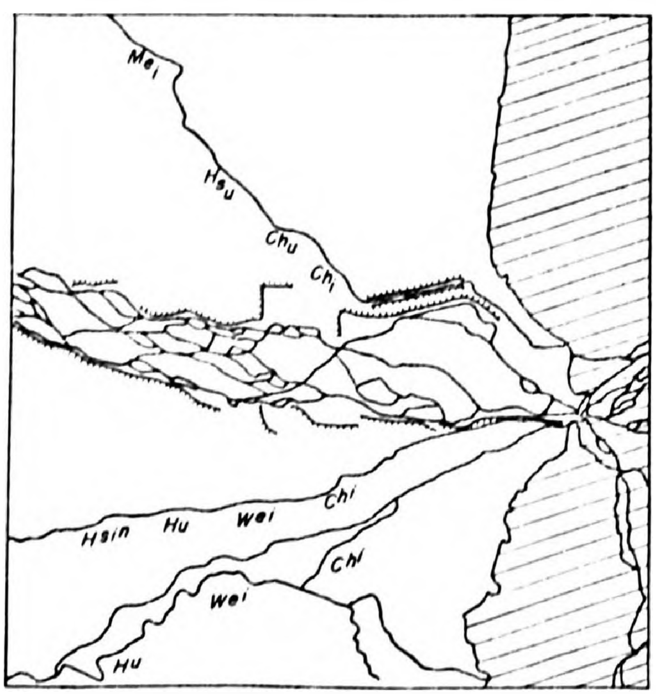


Figure 37. CONDITION OF TRIBUTARIES OF CHO SHUI CHI AFTER DIKING

VI. FEASIBILITY OF FUTURE DEVELOPMENT AND RECOMMENDATION ON REGULATION OF THE CHO-SHUI CHI (HSI-LO CHI)

There are about 20,000 ha of tidal land lying outside the present sea dike. The reclamation and diking of these lands will help to improve the drainage system and reduce the groundwater table for the inland areas inside the present sea dike; so several thousand ha of saline soil along the coast can be improved. The saline soil can be leached and will thus become normal. Due to the construction of windbreaks on the diked tidal land, the effect of the monsoon will be reduced; this will also greatly affect the inland areas. The agricultural production along the coast will be doubled or tripled thereby.

As regards constructing dams in the upstream for reducing siltation of the river bed, there are several possible sites, but at most of them the geological conditions are not good for the purpose. Only the Chi-Chi and Ching-Yun sites are adequate (Fig. 38). These two dams could produce about 320,000 kW of power and provide about $100M^3$/sec of water for irrigation, which will be good for the tidal land reclamation project.

The basic method for regulating the Cho-Shui Chi is to use machines to erode the river bed and allow the silt-load no time to deposit itself. To reach this goal, the velocity of water in the river must be sufficient, so the width of the bed should be reduced to minimum. At present, the river bed is too wide and should be artificially reduced. About 5,000 ha of the river bed will thus become usable for cultivation.

Due to the big difference between normal flow and flood discharges, the distance between the levee at both banks cannot be made too narrow; it should allow the flood to pass between the banks. The best way is to construct cross and spur dikes to control flood and normal flow separately.

Dikes have been completed along most of the central and downstream parts of the river, but the distances between the dikes on each bank are irregular. Cross-diking could regulate the distance by making the flood channel to correspond with the slope, roughness, geological condition, discharge and silt-load content. This method is cheaper than constructing new dikes.

The normal discharge channel should be selected to correspond with the present channel condition, location of irrigation intakes and curvature of the channel. Spur dikes can be constructed to fix the relation between the normal discharge channel and the flood course.

Spur dikes with a suitable slope should be constructed from dikes or high land to the channel. The length of these spur dikes will depend on their distance from the normal discharge channel. Their height and slope should be decided by the flood curve. Their function will be to enable the silt-load in the water to

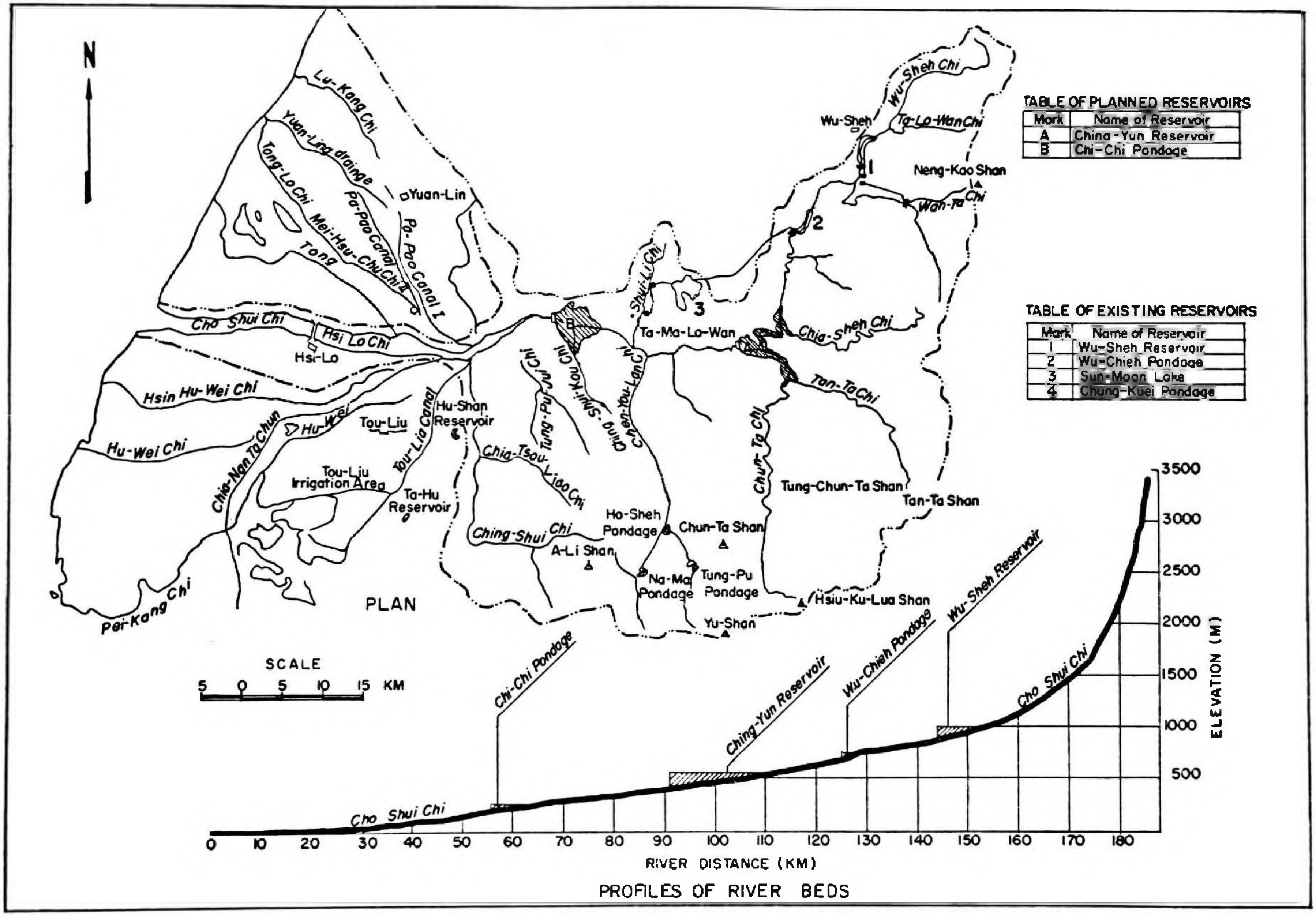


Figure 38. EXISTING AND PLANNED RESERVOIRS IN THE CHO SHUI CHI BASIN

be carried away whatever the water level may be. It must be prevented from depositing itself as a result of changes of water level, or else silt deposited by one flood must be removed by the next.

The flood will be reduced after the completion of reservoirs upstream, so that the land adjoining the normal discharge channel will have less chance of being flooded. With the construction of cross and spur dikes, water will only run along the channel, which will thus be eroded. During flood time, more materials will be deposited between the cross and spur dikes. The channel bed of the river will be eroded deeper and deeper; the land adjacent to the normal discharge channel will be deposited higher and higher and will become cultivable after a certain number of years.

VII. CONCLUSION

The Cho-Shui alluvium fan is one of the highest developed food production centers in Taiwan. The population density is heavy and three sugar factories are located there. The river bed is silted year by year due to the wide width of the river bed and heavy silt-load in the water. The elevation of the bed is higher than the adjacent area. The Government has only constructed dikes along the central and down stream reaches to prevent floods. These dikes should be heightened each year. Without thorough attention to river regulation, the river will change its course within several decades. To prevent this, the Government should make thorough plans and designs for its regulation and put them into action right away, so that the property and lives of people on the fan can be saved and several thousand ha of land can be cultivated as a by-product of this improvement.

There are 20,000 ha of tidal lands lying outside the present sea dike. They should be diked and reclaimed soon. The purpose of this project is not only to obtain 20,000 ha of land, but also to improve the drainage system, reduce the groundwater level and decrease the effect of monsoons on the inland area near the coast. The saline soil will become normal and the agricultural production can thus be doubled or tripled.

There is lack of irrigation water on the fan, so the Chi-Chi and Ching-Yun reservoirs should be constructed very soon. These two reservoirs will not only produce power, but also regulate the irrigation water. If the construction of reservoirs is carried out together with soil conservation, this will greatly benefit flood control as well.

There are plenty of groundwater resources on the fan, which should be fully developed to supplement the irrigation water and thereby increase the crop yield. Generally speaking, river regulation, groundwater development and diking the tidal land are of great importance in further developing the fan area.

TABLE 13. ANNUAL OBSERVED MAXIMUM FLOOD DISCHARGE OF CHO SHUI RIVER AT CHI-CHI STATION, TAIWAN, CHINA

Observed year	*Date occurred*	*Flood discharge* $m^3/sec.$
1952	29 July	3,990
1953	17 August	4,600
1954	5 December	2,108
1955	3 September	5,870
1956	3 September	7,540
1957	14 September	5,300
1958	16 July	4,470
1959	8 August	5,900
1960	1 August	10,500
1961	29 September	3,400

TABLE 15. IRRIGATION SITUATION IN THE CHO SHUI DELTA, TAIWAN, CHINA

Location	*Irrigation area*	*Double rice crop area*	*Single rice crop area*	*Rotating system area*	*Dry crop area*
Northern side of Hsi-Lu Chi	59,908	47,525	—	2,043	10,340
Southern side of Hsi-Lu Chi	17,398	3,393	7,127	6,878	—
Total	77,306	50,918	7,127	8,921	10,340

TABLE 14. ELECTRIC POWER GENERATION IN THE CHO SHUI BASIN, TAIWAN, CHINA

Name of the power plant	*Generating capacity (kW)*	*Type of dam*	*Dimension of the dam*	*Effective hydraulic drop (M)*	*Year constructed*	*Remarks*
Wa-Ta	15,200	Overflow gravity Concrete dam	Height: 12M Length: 47.7M	267.13	1942	Catchment area: 147 km^2
Ta-Kuan	100,000	—	—	304.85	1934	Sun Moon Lakes generating system; storage capacity of the Lakes 148.5 x 106 M^3
Chu-Kun	43,500	—	—	123.64	1938	
Wu-Hseh	20,700	Gravity arch Concrete dam	Height: 114M Length: 205M	109.7	1959	Storage capacity: 148.6 x 106 m^3

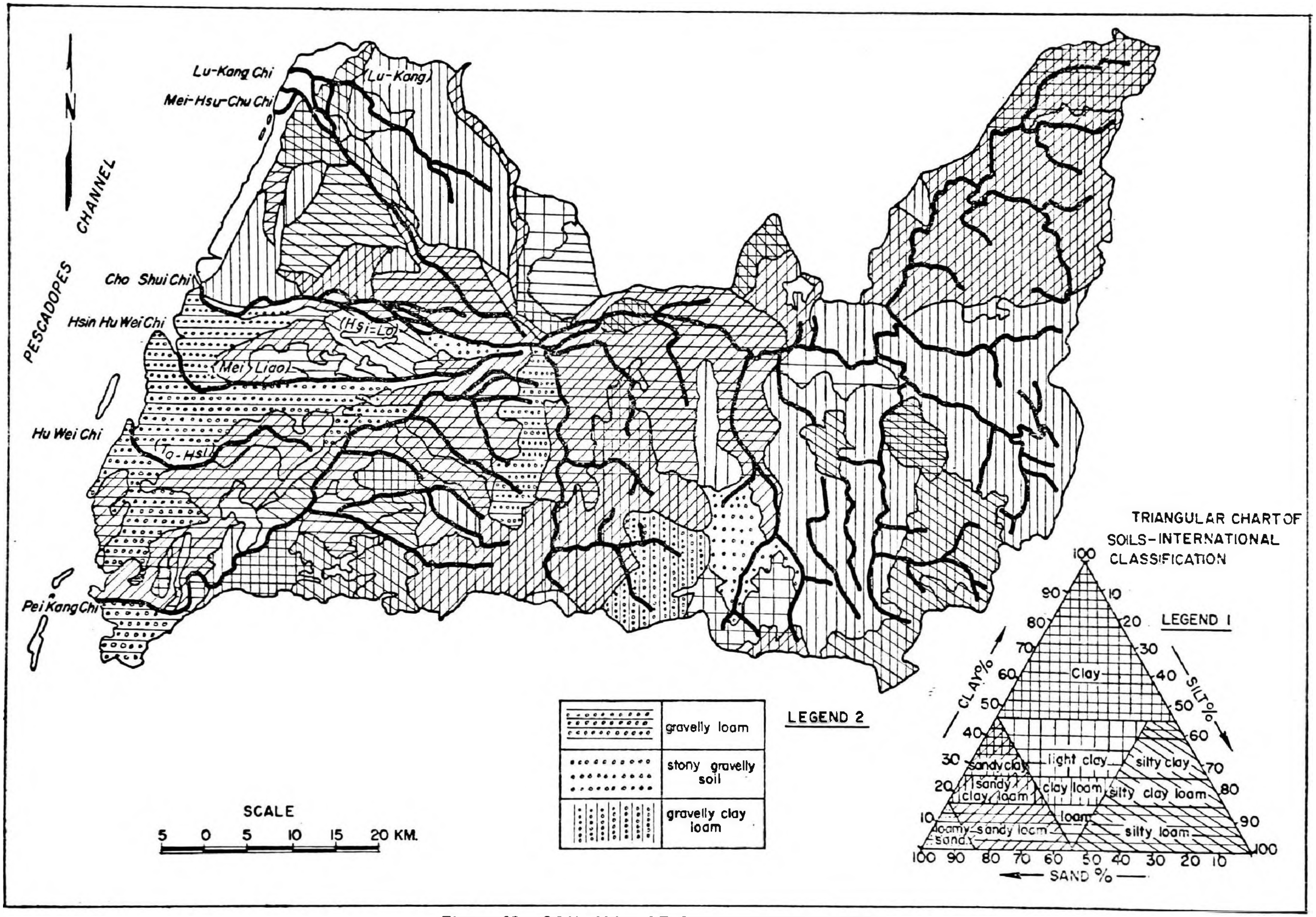


Figure 35. SOIL MAP OF CHO SHUI CHI BASIN

Paper No. 4

RECLAMATION OF ANSONG-CHON TIDAL AREA*

INTRODUCTION

Ansong-chon is the second largest river in the Kyunggi province. About 520,000 people inhabit the watershed area which has 74,000 ha of cultivated land. No notable effort had been made toward land and river reclamation nor for protection from many hazards characteristic of a tidal estuary.

It is only very recently that the Water Resources Bureau of the Government had taken note of the value of unreclaimed tidal land in the lower Ansong-chon. This has led to the undertaking of a preliminary study which is summarized below. This brief article is presented in the hope of introducing a facet of the current efforts of the Korean Government in the pursuit of tidal estuary waste land reclamation.

RIVER CONDITION

RIVER SYSTEM

The Ansong-chon is a river flowing into Asan Bay on the west coast of the Korean peninsula. Asan Bay has a tidal range as great as 9.5 metres and is located to the south of the Kyunggi Bay along which is the Port of Inchon.

The Chinwi-chon, a major tributary, discharges into the Ansong-chon about 22 kilometres from the river mouth.

As far as this vicinity the river bed is relatively narrow and stable. Downstream from the junction, the width of the river bed widens in a manner typical of an uncontrolled tidal estuary. The river bed is over 2 kilometres wide at a point about 5 kilometres from the Chinwi-chon junction and gradually gets wider until it empties into Asan Bay, except at the vicinity of Noyang-ni about 10 kilometres from the junction where a 1 kilometre wide bottle-neck is formed. The distance from this bottleneck to the mouth of Asan Bay is about 30 kilometres.

From the Chinwi-chon junction to the headwaters, the Ansong-chon is about 64.2 kilometres long and has a drainage area of 683.55 square kilometres. The Chinwi-chon is about 63.0 kilometres long and has a drainage area of 722.31 square kilometres. The two streams flow almost parallel through a fertile catchment basin forming an elongated U-shape and meet at its bottom. The main stream has seven tributary streams besides the Chinwi-chon, which is the largest of all. The Chinwi-chon in turn is nourished by five tributaries.

Surrounding water divides to the north and east of the river basin are gently rolling hills of 400 to 580 metre altitudes and to the west and south are lower hills of about 100 metre altitude. The river profile is generally gentle. On the Ansong-chon, the elevation is 20 metres at about 48 kilometres from the river mouth; whereas, on the Chinwi-chon, the same elevation is found at 52 kilometres from the river mouth. The tide reaches as far as 24 kilometres from the narrows along the Ansong-chon at the vicinity of Hwan-kuchi-chon junction.

DRAINAGE BASIN

The drainage basin upstream from the bottleneck has a general shape of a rhomb with a side running south to north about 60 kilometres long, another 40 kilometres long east to west, and a drainage area of 1,422 square kilometres.

Forestation of the watershed area is generally poor except for one small area; hence serious silting occurs in midstream and lower down, which is made worse by extensive erosion. The resulting rise of the stream bed has caused constant shifting of water courses that is evidenced in many places along the river. Most of the drainage basin is of the gneiss series with a limited distribution of granite on the west of the area. Quarternary alluvium is developed. Over-burdens are mostly of degenerated gneiss and sandy loam.

Except the area near the water divides, the topography in general is flat. Land along the river is extensively cultivated. The cultivated land includes 43,000 ha of rice fields, 31,000 ha of other crop land, making a total of 74,000 ha or 52 per cent of the whole area.

Major communities on the drainage basin include Suwon, Osan, Pyungtaik, Sujung-ni and Sunghwan. The Seoul-Pusan trunk railroad and a number of highways and local roads criss-cross the area to serve this major crop land of Kyunggi province.

HYDROLOGY

Precipitation and climate

1930-1940 records available from six rain observation stations in and out of the drainage basin show

* By Bureau of Water Resources Ministry of Construction, Republic of Korea.

a range of annual precipitation from 562.5 mm to 1,861.4 mm, with an average of 1,162 mm. This is about the medium precipitation in Korea. Monthly precipitation varies greatly from wet summer to dry winter. July, with the most rainfall accounts for 359 mm and January accounts for only 11.7 mm. The extremes of this uneven distribution were witnessed in a year when July accounted for 1,087 mm and January for 3.4 mm of precipitation. About 58.7 per cent of rainfall occurs in three summer months from July to September and is representative of the precipitation pattern of this country. Recorded maximum 24-hour precipitations are 253.7 mm at Sung-hwan and 282.1 mm at Suwon.

Evaporation heights are 1,192.5 mm for an average year, 146.1 mm in August for the maximum month, and 43.0 in December for the minimum.

The annual average temperature of the area is 11°C with the highest and the lowest recorded respectively 32.8° and -15.6°C.

Run-off

The watershed area completely lacks stream facilities. Run-off analysis of the stream in the area is, therefore, impossible except by relying on rainfall records. Due to the uneven distribution of rainfall over different seasons of a year, with 58.67 per cent from July to September and 6.79 per cent from October to December, extreme seasonal variation of discharge occurs. Estimated from rainfall, the annual average discharges for the Ansong-chon mainstream and the Chinwi-chon are 48 m^3/s (cubic metre per second) and 52 m^3/s respectively. Normal flows for these streams should be appreciably less. If actual observations of streams of comparable size and conditions elsewhere in Korea are indicative of the general pattern of the streams concerned, the minimum drought flow of both the Ansong-chon and the Chinwi-chon does not materially exceed 1 m^3/s.

Flood

A 24-hour rainfall of about 130 mm results in floodflow. Available past records show minor floods occurring once in every two years and heavy flood occurring once in every five to seven years. The mid-downstream area is constantly subject to severe flood damage, and soils and crops are washed away. Records available for 1931-1940 indicate that in one year the flooded area reached 182 square kilometres and that about 11 square kilometres of cultivated land were washed away. The total flood damage for the year is estimated at 180 million wons.

The magnitude of the floods constitutes the main reason for severe flood damage to this area. But also the instability of the stream course due to heavy silting, caused by land erosion, and the effects of the tide in the lower river basin which prevent fast draw off of flood flow can also be largely blamed. It is common even for medium to lesser floods to create ponding in the mid-stream low land for 10 to 24 hours, and for a duration of from one to three days in the downstream low land.

Past records for water level, discharge and floodflows are not available. Hence many assumptions have had to be made to establish the design floodflow. In one case, the synthetic hydrograph method was employed. The drainage area under the study is subdivided into equal concentrate time zones. For a unit amount of rainfall in the area, flood routing is charted by the Muskingum method, taking storage effects into consideration for the preparation of a unit hydrograph. Assumptions for time lag, and storage factor had to be arbitrary. Besides the amount of rainfall that will create maximum floods in the given area, its duration-intensity characteristics and effective rainfall amount had to be appropriately assumed. The Peak flood flow and shape of the hydrograph based on such an arbitrary hypothesis could not be expected to be sufficiently precise.

Primarily to put the design values on the safe side, all factors were deliberately assumed for their worst conditions. The design floodflows thus obtained —50 year probable floodflow—are 2,100 cms for the Ansong-chon mainstream and 2,300 cms for the Chinwichon at their junction, and 4,350 cms for below the junction. The value corresponds to specific run-off of 3.06 cms per 1 square kilometre and compare favorably with generally accepted average values in Korea. The values are considered acceptable for this stage of preliminary investigation.

TIDAL COMPARTMENT

TIDAL RANGE AT NOYANG-NI NARROWS

Asan Bay has the greatest tidal range in Korea. Published data from the Navy Hydrographic Office for 1958 list 9.5 metres at spring tide and 4.64 metres at neap tide.

As mentioned in River system, a bottleneck is formed in the vicinity of Noyang-ni about 10 kilometres from the mouth of the Ansong-chon. Downstream from the bottleneck, the Ansong-chon becomes over 3 kilometres in width. The left bank area of this lower river basin is nourished by a tributary named the Tunpo-chon and a rolling range follows the right bank of the river course to its literal mouth. Flood from upstream does not affect this area below the Noyang-ni narrows.

The tidal range at Noyang-ni is less than at Asan Bay. An 11-year record shows a high water level at spring tide of +6.00 metres above M.S.L., a low water level at spring tide of -2.00 metres, a high water level at neap tide of +2.60 metres above M.S.L., and a low water level at neap tide of —1.90 metres. These represent a maximum tide range of 8 metres and a tidal range at neap tide of 4.5 metres at this location. From the mouth of Asan Bay to the Noyang-ni narrows, about 30 kilometres in distance, the tidal range diminishes by about 1.5 metres at spring tide. No recorded observation for tidal current velocity and tidal prism is available.

MEANDERING OF RIVER IN THE TIDAL COMPARTMENT

From the Noyang-ni narrows, about 13.4 kilometres of the Ansong-chon and about 19.2 kilometres of the Chinwi-chon are intruded by tide. The low water channels of both streams are about 100 metres wide at a point about 5 kilometres from the Chinwi-chon junction, and from there to the bottleneck at Noyang-ni the channel suddenly widens to 2,000 metres. The river bed has a slope of 1/1,700 from the junction to the bottleneck; the Ansong-chon slopes 1/2,000, and Chinwi-chon slopes 1/5,000. Cultivated land on both banks has a general elevation of 4.0 — 6.0 metres above M.S.L., or about 3 — 4 mertes above the riverbed. The shape of the river course in the tidal compartment is highly irregular. Silting in one place and scouring in another are in a constant progress and deformation is continuously underway. If the degree of meandering is expressed in a ratio of the distance between two points along the stream over the straight line distance between the two, the meandering ratios for the Chinwi-chon and the Ansong-chon are 1.62 and 1.50 respectively. Smallest intersecting angles in a bend for the Chinwi-chon and the Ansong-chon are 31 and 30 degrees, and the smallest radii of curvature for these two streams are 125 metres and 275 metres respectively.

It is understood that the normal discharge of the Ansong-chon, which is only 50 cms, exerts too little scouring force against sediment transports from up and downstream by floods and tides.

Hence there is a continuous rising of the river bed. This, coupled with the tidal effects, seems sure to help accelerate the meandering of the river.

A comparison of the recent topographical map with the one published in 1930 reveals contrasting changes of river course in some of the sections.

At one place, the river has completely reversed its course so that the bend is now on the opposite side and, in another section, the movement of the low water channel has been so unpredictable and swift that the present river bed is at a distance of about 5½ times the width of the river from the 1930 bed. The river course in the immediate upstream vicinity of the Noyang-ni narrows had moved about 1,000 metres during a rather short period. The two maps prepared about 30 years apart do not indicate any change of river course in the upstream Chinwi-chon, but whether this evidence is reliable is still doubtful.

DAMAGE TO CULTIVATED LAND BY TIDE

The area under consideration and its environment form a fertile plain which is one of the major crop lands of Kyunggi province. Of the total land area of 10,500 ha, about 5,300 ha are cultivated. With proper provision and improvement, a considerable amount of land could be reclaimed. The potentially arable land of this region lies between +3.00 metres and +8.00 metres above M.S.L. At present, lands lying+4.00 metres above M.S.L. and higher are extensively cultivated. However, low lying land within the tidal reach is susceptible to damage by tides and land in the upstream river basin is exposed to constant threat of flooding. Cultivated land in the vicinity of the river is devalued owing to the unpredictable meandering of the river bed so that at any time it could be washed away, the rest of the low lying land, which is protected by tidal levees of doubtful reliability, is exposed to hazardous sea water overtopping during high tides, and the residual salinity in higher land make it more vulnerable to drought. As a result, the area surrounding the tidal reach of the Ansong-chon yields less than 60 per cent of crops that could be expected in other regions. The conditions described above are plainly harmful to agricultural industry.

OUTLINE OF CONTROL PROJECTS

PROBLEMS

Straightforward dike construction in this unique case is a doubtful method, for the following reasons. The concept will be to realign the river course and contain it by means of dikes with safety provisions for high water channel and scour protection.

a. Improper realignment of the river course and insufficient provision of the channel cross-section may not achieve successful containment of the river even with the best of dike protection. Protection work for scouring action would be enormously expensive.

b. Due to the instability of the river course within the dikes, the width of the realigned river tends to be much larger than is desirable. The weaker the scour protection, the broader the necessary channel and the lesser the degree of stream realignment achievable; besides much reclaimable land is likely to be lost.

c. Since the fresh water flow is significantly less than the tidal intrusion and as silt transport and deposit by tides are substantial, silting within the tidal reach cannot be prevented. The inevitable rise of the river bed will involve a continuing shift of equilibrium and, however well conceived a plan may be, its aims cannot be fulfilled.

MULTI-PURPOSE RECLAMATION

The width of the Ansong-chon from the Chinwi-chon junction and downstream is about 2,000 metres and its water area amounts to 1,100 ha. Of course such a large area is not necessary if it is to be used only for flood discharge. If this portion of the river course is diverted, the construction of a tidal levee across the present river mouth will facilitate reclamation of this large area for agricultural purposes. At the same time, the provision of a tide gate across the relocated river mouth to convert the Ansong-chon into a fresh water stream, if accompanied by river course realignment and dike containment, will result in a greater stability of river course and permit more economical use of the land. Furthermore, the downstream low water channel with its storage capacity of 6,000,000 cubic metres can be used to store streamflow during the dry seasons for irrigating the reclaimed land.

As the population of the country is increasing steadily, more emphasis should be given to increasing the area of food producing land. As hydro-power development projects in the Chunchon area and other places make it necessary to provide farm land for resettling farmers from areas thus inundated, the proposed scheme of land and river reclamation of the downstream Ansong-chon should serve the best interests and immediate needs of the country.

PROJECT DESCRIPTION

Tidal gates

It is proposed that tidal gates be constructed near the Noyang-ni to its left. A total of 35 gates will shut off the tide. All gates except for the two at the center will be 10 metres wide and 4 metres high. The two at the center will have the same width but will be made 8 metres high for navigational purposes. The bottom of the gates will be placed 1 metre above the lowest tide level or +1.0 metre above M.S.L.

For the worst conceivable condition, when the peak design floodflow of 4,350 cms occurs during maximum high tide, the water level of the inland pool will reach +7.18 metres above M.S.L., i.e. 1.18 metres higher than the maximum high tide. The design maximum flood, the duration of which is 9 hours, could passed in 24 hours. It means that, during a maximum flood, the land will be submerged for only 24 hours or less, which is not risky for rice and other types of crops predominant in the region.

One half of the gates can be placed directly on solid rock foundation, but the remaining one half will have to be placed upon reinforced concrete pile foundations. Steel sheet piling or the equivalent will be necessary to prevent seepage through this piled section. The final selection of the site, hydraulic analysis and more detailed design involve the following stages of detailed investigations.

Relocation of river

Relocation of the river from 3 kilometres below the Chinwi-chon junction is proposed. From that point, a short cut will lead to the tide gates described above and then to the Noyang-ni narrows. The bottom of the channel will be brought to the same level as the tide gates, —1.00 metres above M.S.L.; the width will be 120 metres at the bottom and 450 metres at the top, and average depth will be 5 metres. About 86 ha of land will be required. About 3,144,000 cubic metres of excavation, 826,000 cubic metres of embankment and 1,200 metres of short protection are estimated to be necessary.

Upstream river reclamation

The right hand dike of the relocated channel will be extended across the existing channel to the upstream dike. Upto the Chinwi-chon junction, the channel will be realigned to have a top width of 450 metres. The Ansong-chon mainstream will be realigned and dikes built to provide a top width of 320 metres, and the Chinwi-chon will be provided with a top width of 330 metres. The low water channel of the Ansong-chon will be aligned and excavated to provide a bottom width of 100 metres and a smooth flow line at 1/1,700 slope, and the same will be done to the Chinwi-chon to provide a 100 metres wide low water channel sloping 1/2,500.

Design flood discharges for successive sections are as shown in figure 39. Hydraulic gradients of the flood flow, based on the full level of 7.18 metres above M.S.L. at the tide gates, are 1/17,000 for the Ansong-chon and 1/12,400 for the Chinwi-chon. Heights of dikes are 5 to 5.5 metres for the former and 5 to 6 metres for the latter.

Estimated project cost

Breakdown of estimated cost for the river reclamation is as presented below.

Description	*Cost in Won* [a]
1. Tidal gates	200,000,000
2. Channel relocation	220,000,000
Embankment	68,000,000
Excavation of low water channel	120,000,000
Revetment	5,600,000
Flood gates	1,400,000
Land and right of way	25,000,000
3. Upstream river reclamation	540,000,000
Embankment	220,000,000
Excavation of low water channel	197,000,000
Revetment	33,000,000
Flood gates	64,000,000
4. Total	960,000,000

[a] 130 Won = 1 U.S.$

RECLAMATION OF TIDE LAND

Tidal embankment and sluice gate

It is proposed that a tidal levee be constructed from the right bank of the tidal gates across the present river bed for about 1,200 metres. The embankment will serve later as a highway and will have great economic and military values. A gate, 4 x 4 metre, located on the right bank by excavating the foothill on that side will provide a drain for the 9 square kilometres of land.

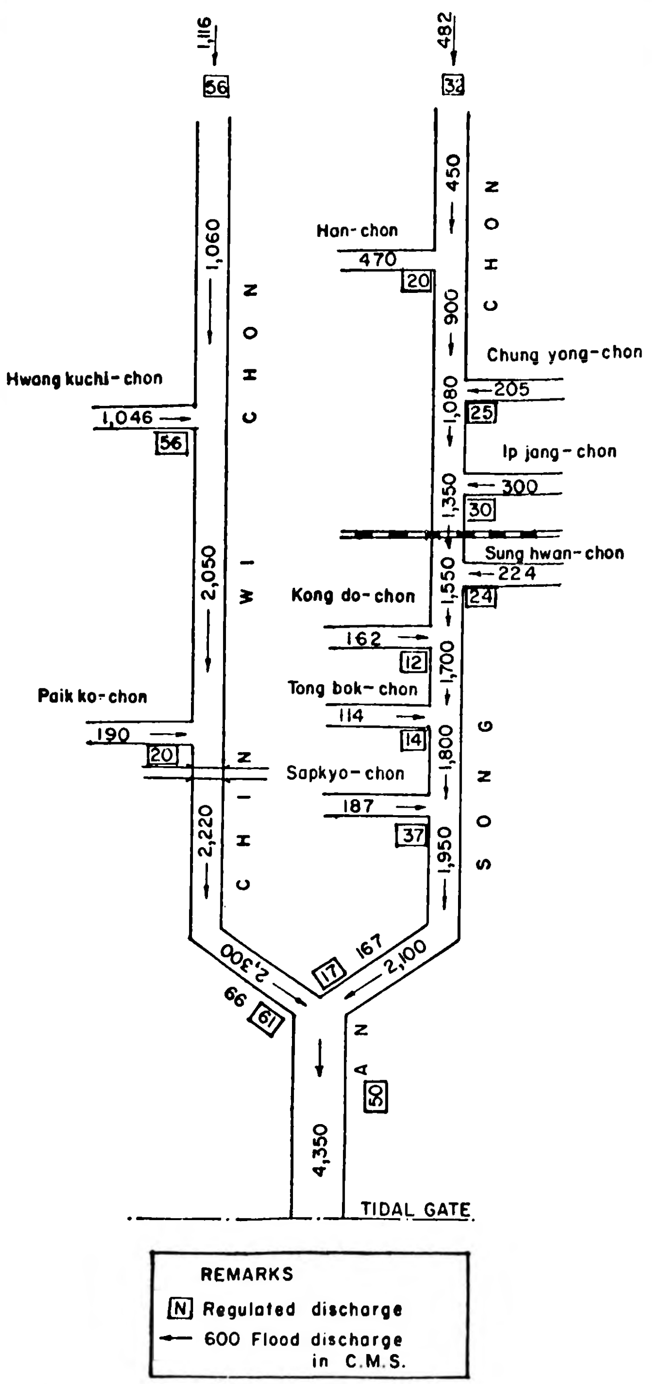


Figure 39. FLOW DIAGRAM OF ANSONG AND CHIN WI RIVERS, REPUBLIC OF KOREA

The area to be reclaimed lies between +1.0 to +3.0 metres above M.S.L. except for deep narrow ebb channels. It is logical to expect that, with the streamflow from above cut off by the relocation of the river, silting caused by tides will eventually fill and raise the ground level in general. From past experience, it is estimated that from two to three years of silting will raise the general ground level to +4.0 metres above M.S.L. The preliminary study is based on the expectation that the general ground elevation will eventually reach +4.0 metres above M.S.L. For the tide levee which will cross the bay, ground levels as low as —3.00 metres for the ebb channel and 0.00 metre for the others are assumed. The embankment will be 8 metres high in general; for the last enclosure, however, the height will be 11 metres. This will place the top of the embankment 3 metres above the maximum sea level. About 193,000 cubic metres of earth and 48,700 cubic metres of rocks are estimated to be required for the tidal levee.

Remodeling of reclaimed land

Of the total reclaimed land area of 1,100 ha within the enclosure, about 900 ha will become available for farming. In the planning for land use, 330 ha of neighboring lands already cultivated are included because of their geographical and irrigational unity. The land will be irrigated with stored water from the Ansong-chon by pumping through canals and ditches. The maximum planned irrigation requirement is 2.46 cms. The unit plot is assumed to be 136 x 36 metres. The ground level is assumed to be +4.00 metres or higher. Consideration is being given to providing access roads and paths. Major works include three lines of irrigation canals totalling 8,800 metres in length, 4,100 metres of main drainage channel, a main farm road 6 metres wide and 5,900 metres long, a pumping facility, and four sluices.

Estimated project costs of land reclamation

Project costs for this portion of the works are estimated as below.

Description	*Cost in Won*
1. Tide levee	65,000,000
2. Drainage gate	5,000,000
3. Irrigation canals and others ...	54,000,000
4. Pumping facility	16,000,000
5. Total	W140,000,000

ECONOMIC FEASIBILITY

The benefit expected from the project is obtained by estimating only the increase or crop yield caused by eliminating tidal effects and flood damage and by removing salinity from previously cultivated and newly reclaimed land. No intangible benefits, nor the increased safety to human and animal life are taken into consideration.

The following comparision summarizes the benefits of the proposed project.

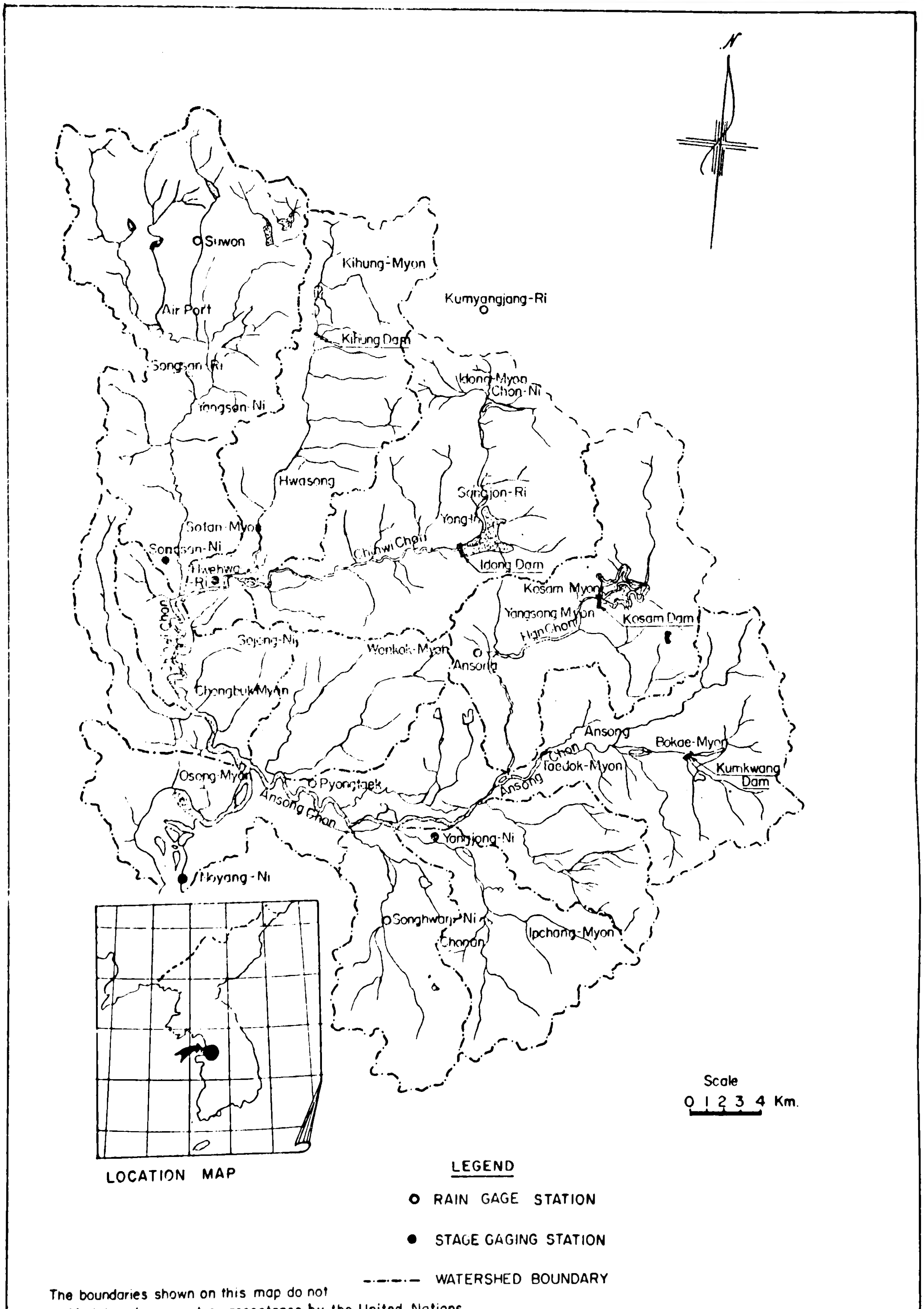


Figure 40. ANSONG AND CHIN WI RIVER BASINS

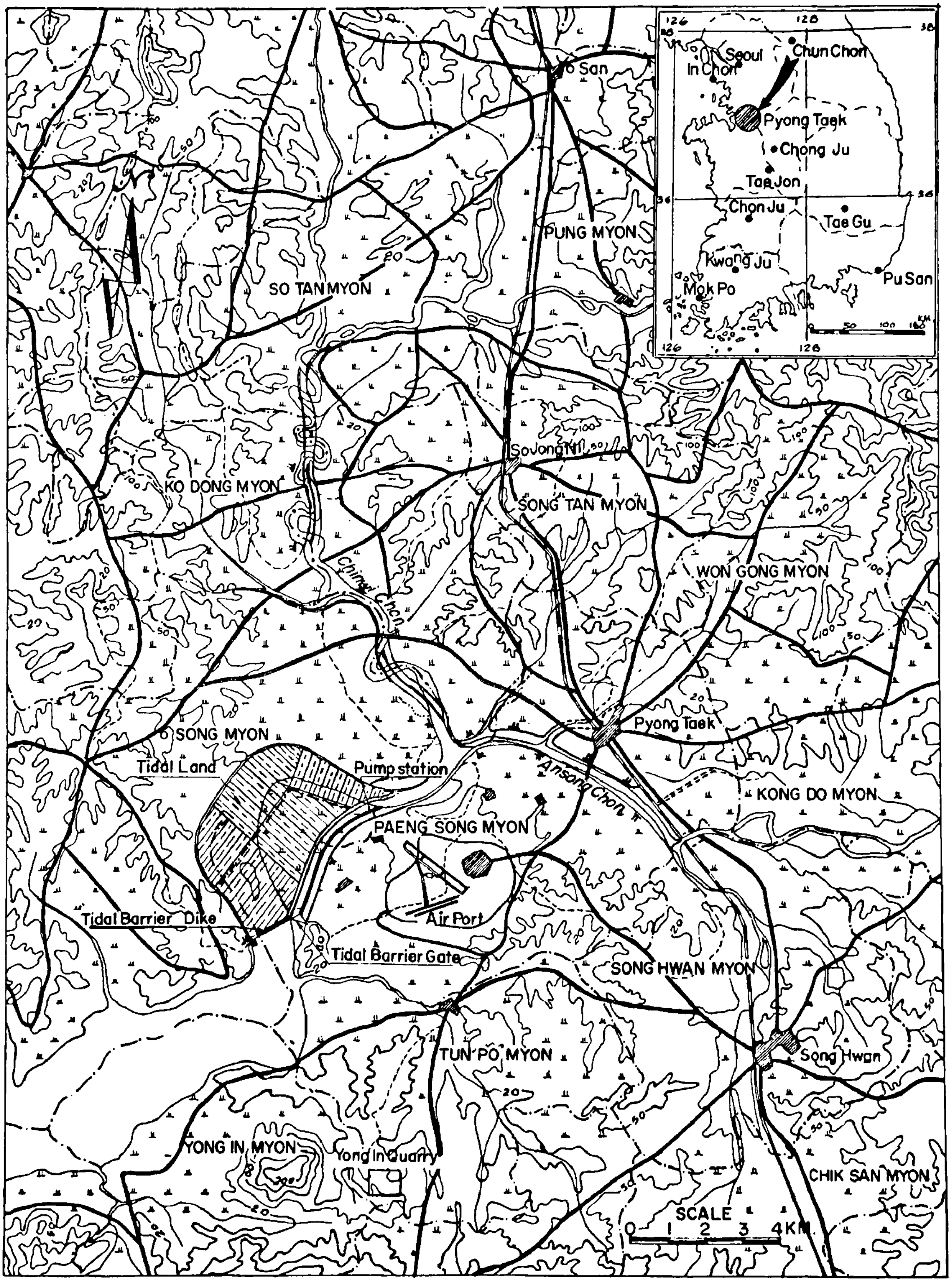
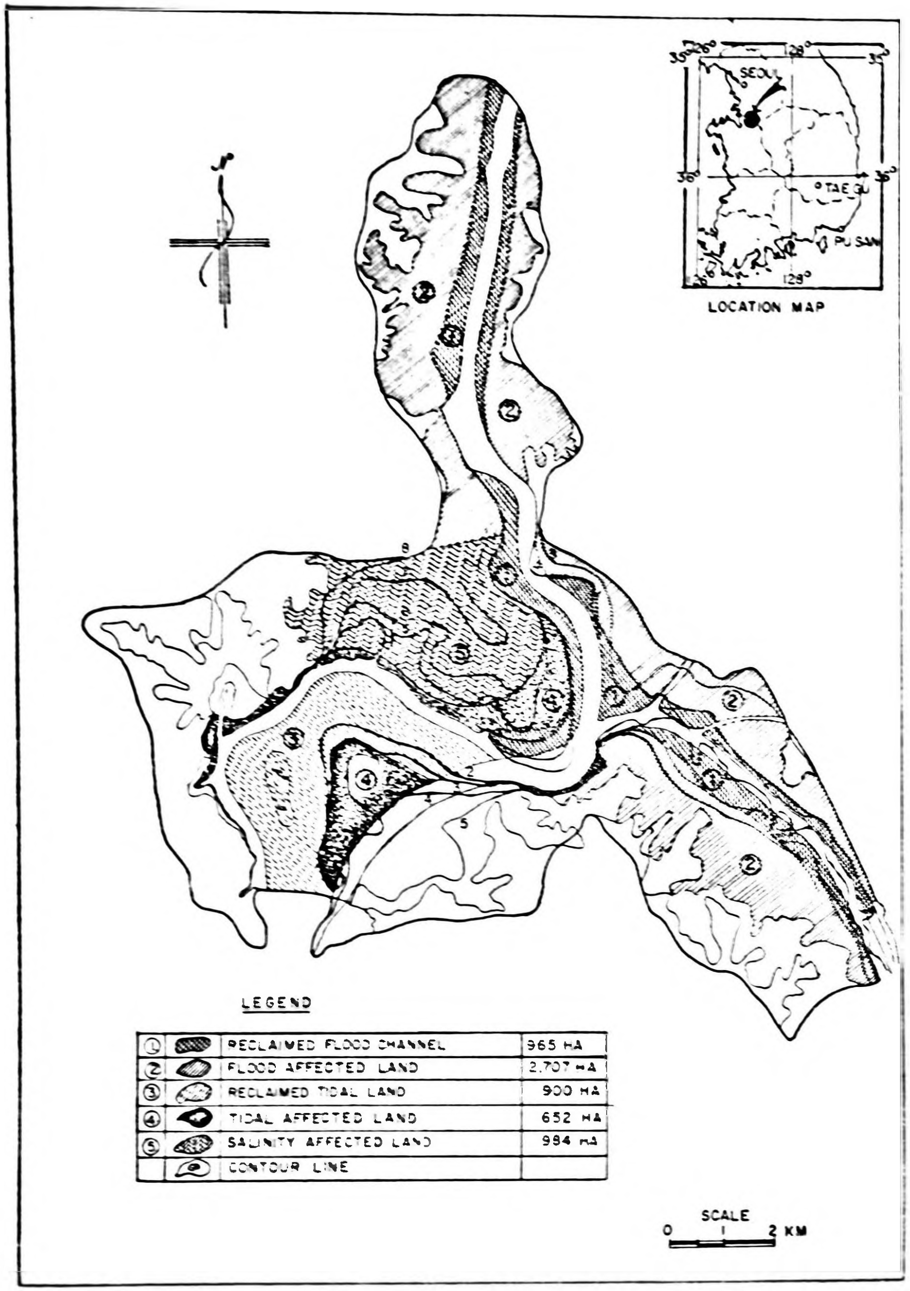


Figure 41. GENERAL PLAN OF ANSONG CHON PROJECT, PYONGTAEK AREA



Figur 43. AREAS BENEFITTED BY THE ANSONG CHON PROJECT

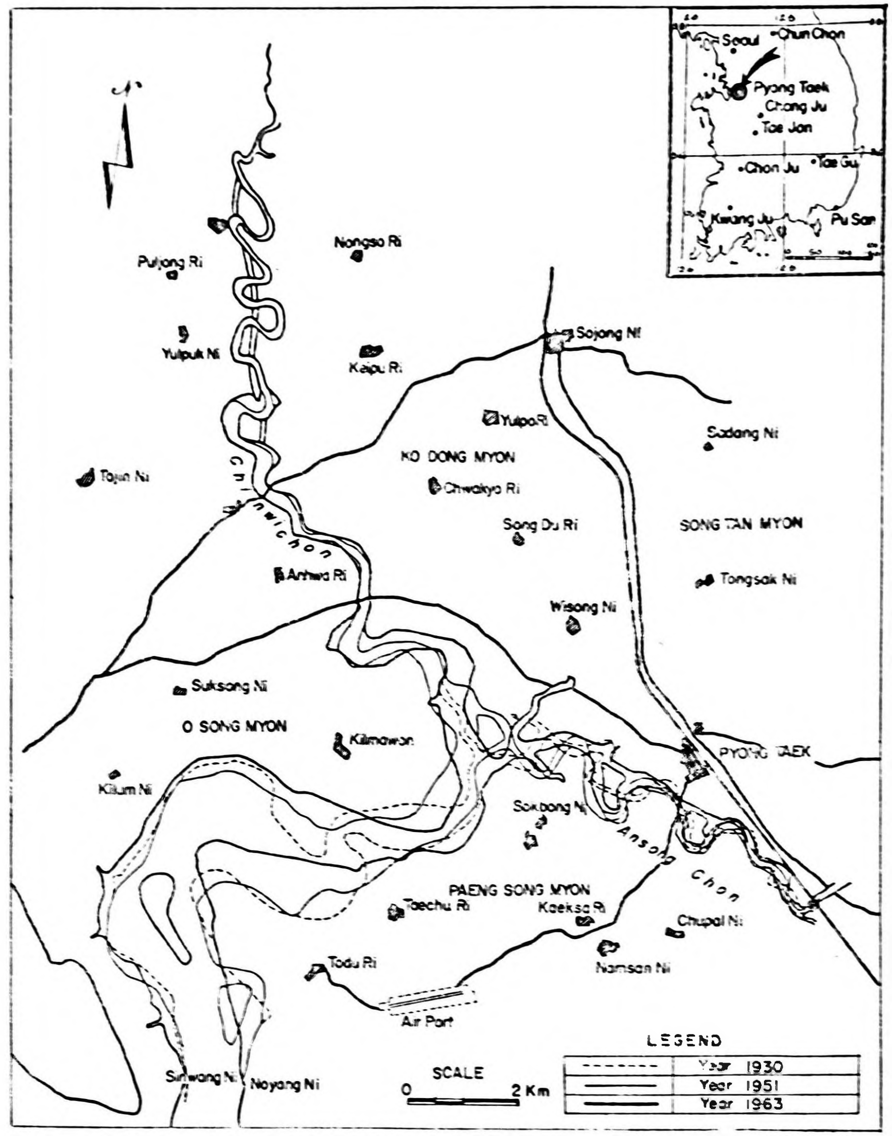
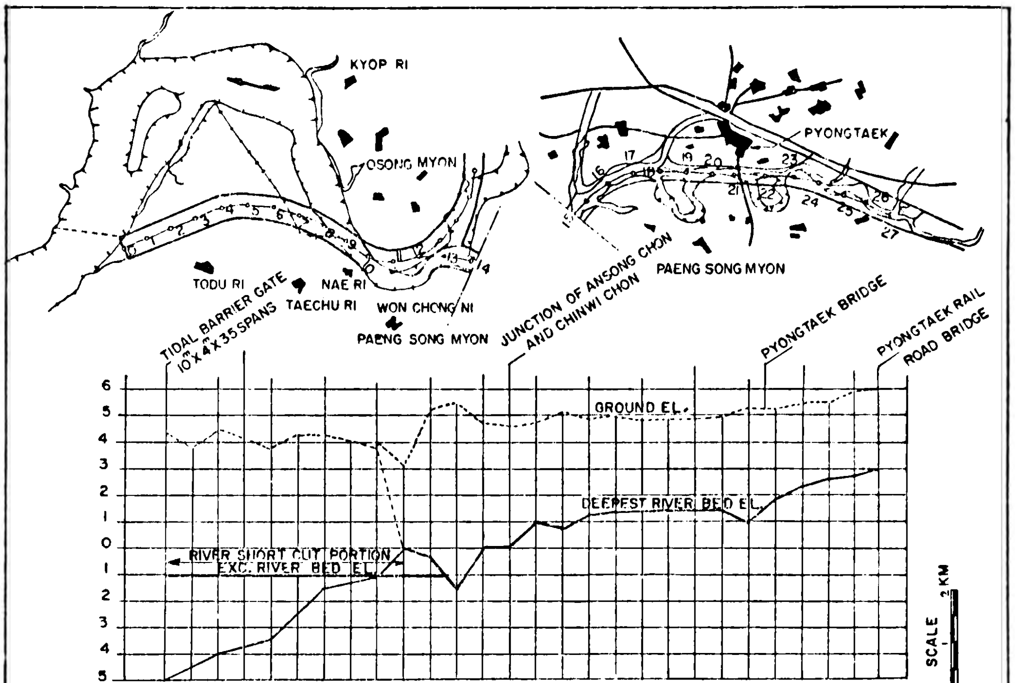
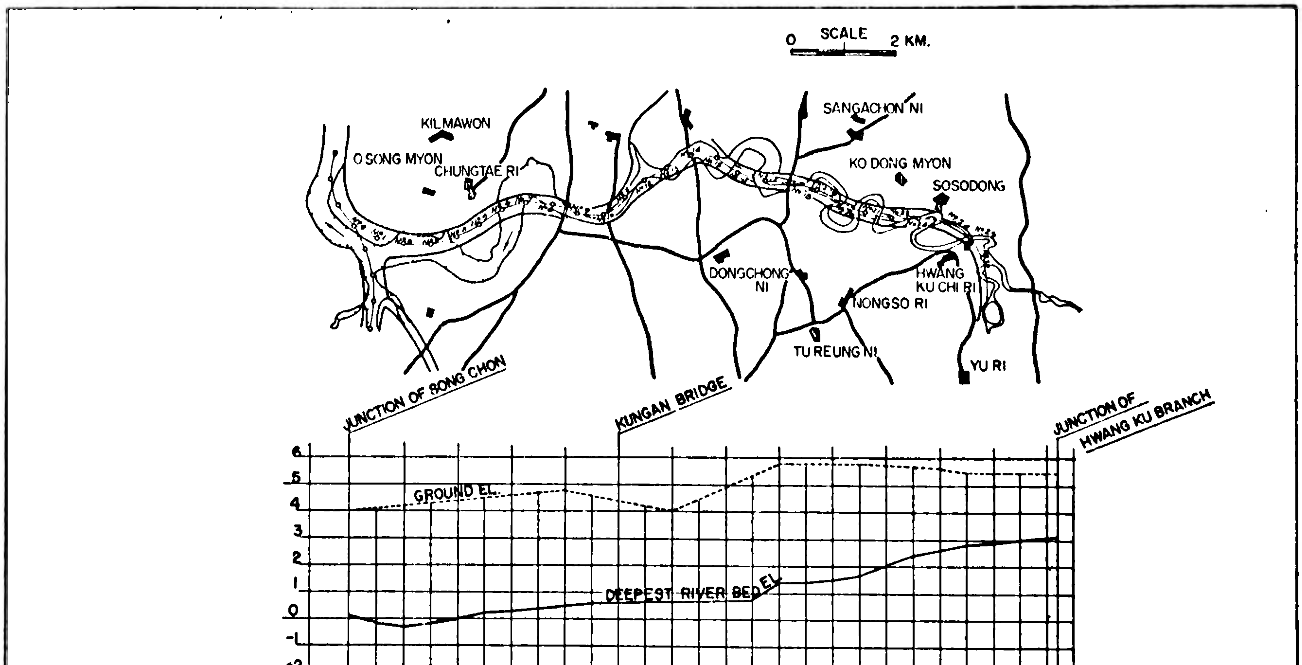


Figure 42. MEANDERING OF ANSONG AND CHIN WI RIVERS



ST.Nº	DISTANCE KM	GR. ELEV.	DEEPEST R.B.EL.
Nº 0	0	4.40	-5.000
Nº 1	500	3.80	-4.500
Nº 2	1.000	4.50	-4.000
Nº 3	2.500	4.20	-3.730
Nº 4	2.000	3.80	-3.480
Nº 5	2.500	4.30	-2.500
Nº 6	4.000	4.30	-1.510
Nº 7	3.500	4.05	-1.300
Nº 8	4.000	3.80	-1.100
Nº 9	4.500	3.100	0.000
Nº 10	5.000	5.250	-0.300
Nº 11	5.500	5.500	-1.500
Nº 12	4.300	4.550	0.100
Nº 13	6.580	4.600	0.100
Nº 14	7.000	4.750	1.000
Nº 15	7.500	6.150	0.000
Nº 16	6.000	4.900	1.300
Nº 17	8.500	4.950	1.430
Nº 18	9.000	4.900	1.450
Nº 19	9.500	4.900	1.480
Nº 20	10.000	4.900	1.500
Nº 21	10.500	4.970	1.470
Nº 22	11.000	5.900	1.000
Nº 23	11.500	5.250	1.900
Nº 24	12.000	5.430	2.400
Nº 25	12.500	5.500	2.650
Nº 26	13.000	5.900	2.750
Nº 27	13.445	6.000	3.000

Figure 44. PLAN AND PROFILE OF REALIGNMENT



St. No.	Distance Km.	Ground elev.	Deepest river bed elev.
Nº 0	0	4.00	0.101
Nº 1	.500	4.100	-0.175
Nº 2	1.000	4.202	-0.285
Nº 3	1.500	4.300	-0.150
Nº 4	2.000	4.380	0
Nº 5	2.500	4.500	0.250
Nº 6	3.000	4.590	0.275
Nº 7	3.500	4.700	0.400
Nº 8	4.000	4.800	0.515
Nº 9	4.500	4.600	0.622
Nº 10	5.000	4.400	0.650
Nº 11	5.500	4.200	0.650
Nº 12	6.000	4.000	0.700
Nº 13	6.500	4.450	0.700
Nº 14	7.000	4.900	0.720
Nº 15	7.500	5.350	0.750
Nº 16	8.000	5.800	1.402
Nº 17	8.500	5.800	1.402
Nº 18	9.000	5.800	1.500
Nº 19	9.500	5.800	1.575
Nº 20	10.000	5.750	2.050
Nº 21	10.500	5.700	2.420
Nº 22	11.000	5.650	2.610
Nº 23	11.500	5.500	2.820
Nº 24	12.000	5.500	2.900
Nº 25	12.500	5.500	3.000
Nº 26	13.000	5.500	3.080
+200	13.200	5.500	3.100

Figure 45. PLAN AND PROFILE OF REALIGNMENT OF CHIN WI RIVER

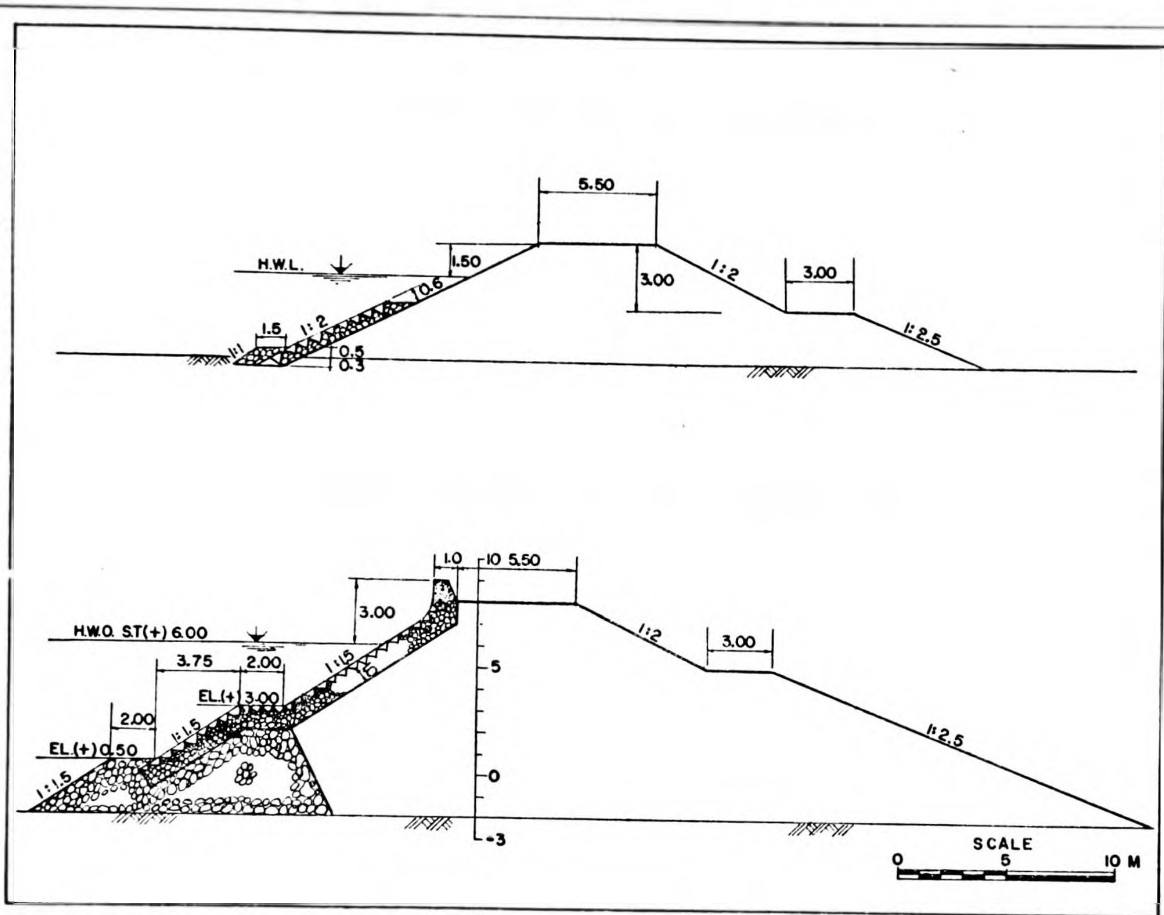


Figure 46. TYPICAL SECTIONS OF EMBANKMENT AND TIDAL DIKE OF ANSONG CHOU PROJECT

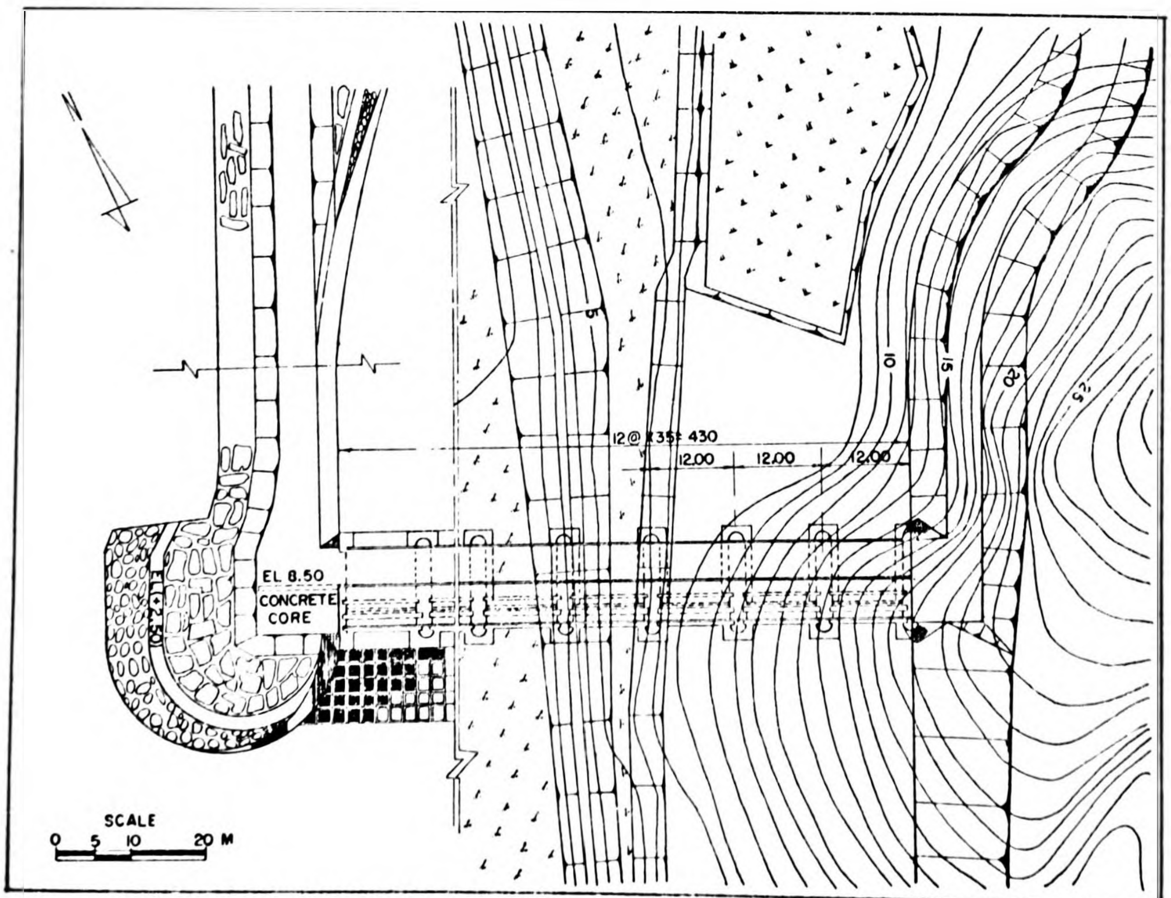


Figure 47. PLAN OF ANSONG CHON TIDAL GATE

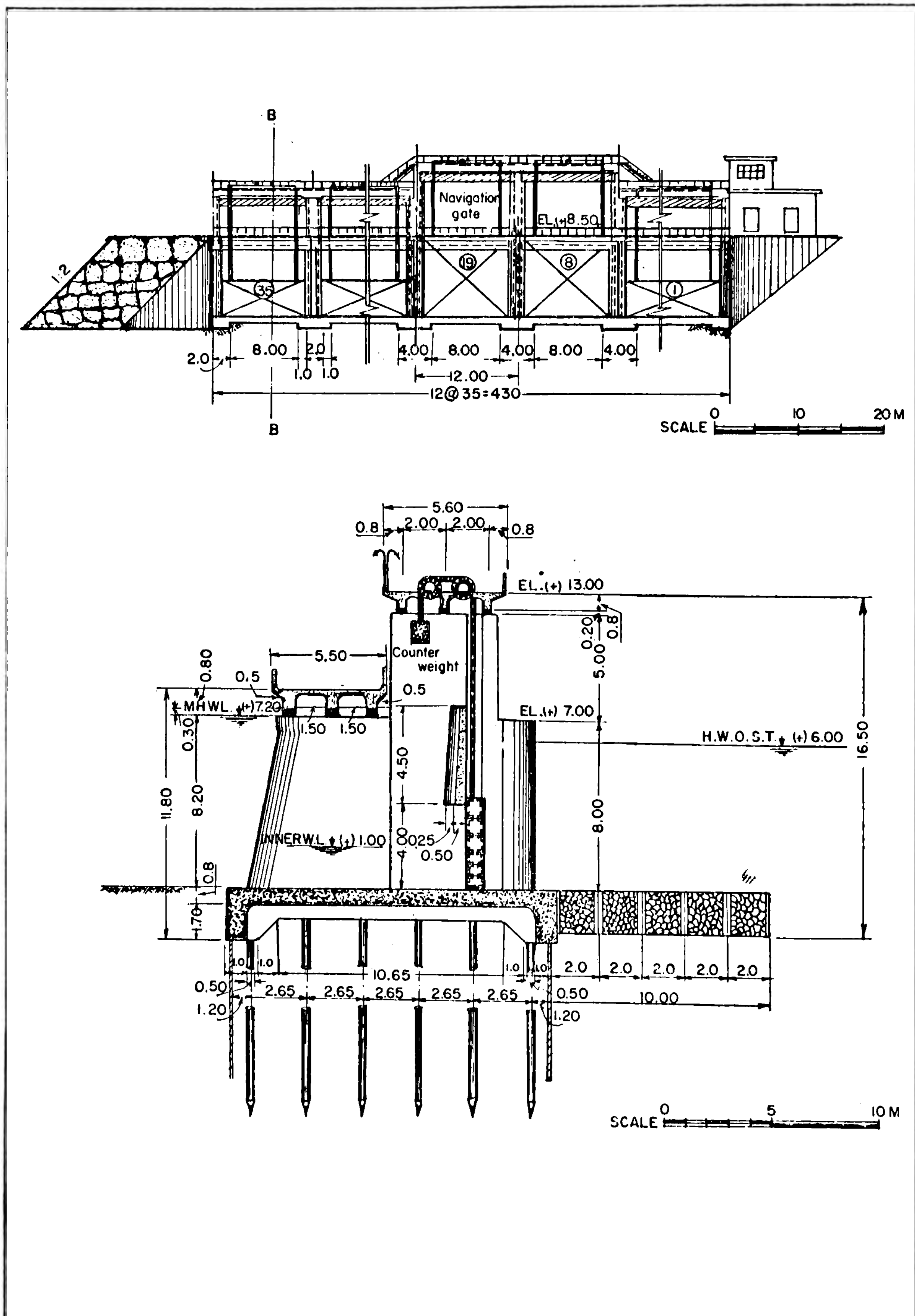


Figure 48. ELEVATION AND SECTION OF ANSONG CHON TIDAL GATE

Description	Area (ha)	Present yield		Future yield		Increase	
		Rice (Sok)	Barley (Sok)	Rick (Sok)	Barley (Sok)	Rice (Sok)	Barley (Sok)
Tide affected area	652	5,868	1,252	10,770	2,086	4,902	834
Reclaimed tidal land	900	—	—	16,200	2,880	16,200	2,880
Reclaimed flood channel	965	3,619	772	14,475	3,088	10,856	2,316
Flood affected land	2,707	36,636	8,227	38,565	8,227	1,929	—
Salinity affected land	984	13,284	2,834	14,760	3,149	1,476	315
Total	6,208	59,407	13,085	99,770	19,430	35,363	6,345

Remarks: 1 sok is equivalent to approx. 5 bushels

The following bases were used for arriving at the benefit-cost ratio.

Crop price	
Rice	W 2,800/sok
Barley	2,000/sok
Straws and chaffs	10 per cent of net grain yield
Production cost	48 per cent of the gross yield from the reclaimed land
Operation and maintenance	3,500 wons per ha. of reclaimed area
Depreciation	Repayment in 50 years at 3.5% annual interest rate

Hence,

a. Total yield per year W122,877,040

b. Production cost 24,537,600

c. Operation and maintenance 3,150,000

d. Depreciation (for total initial cost of W1,100,000,000) . 46,893,000

$$B/C \text{ ratio} = \frac{122,877,040 - 24,537,600}{46,893,000 + 3,150,000}$$

$$= \frac{98,339,440}{50,043,000} = 1.965$$

Paper No. 5

THE SUNDARBANS OF WEST BENGAL*

Abstract

The Sundarbans of West Bengal, built up by the silt-laden Ganges suffered from the river's abandonment of its main course via the Bhagirathi-Hooghly sometime after the 16th century; this rendered vast tracts of land marshy and malarious, lacking in drainage and vulnerable to floods.

Of the 3,100 square miles, about 1,400 square miles have already been reclaimed; but the reclamation has not followed any planned, scientific approach. The embankments built for protection from tidal encroachment have been found unsatisfactory both in design and alignment; they suffer breaches during heavy storms with consequential damage to land and people.

The Sundarbans region is known for its fertility and its planned development will go a long way towards rehabilitating the large refugee population of West Bengal and in increasing food production.

With a view to balancing the forces of nature and human needs, certain criteria are being followed in the programme for developing the Sundarbans of West Bengal:—

(i) Reclamation should be started only when nature has done its part as a delta-building agent.

(ii) Extensive field investigations should be carried out as a prerequisite to the preparation of a master plan.

(iii) Old rivers and river channels should be resuscitated to serve multi-purpose objectives viz., drainage, irrigation, navigation, pisciculture, industry, etc.

(iv) A satisfactory solution for one river (or channel) should not adversely affect the adjacent river (or channel).

(v) To achieve the twin objectives of tackling the drainage problem and providing timely irrigation for raising assured crops, a system of polderization with self-contained units is considered to provide the most satisfactory approach to the Sundarbans problem.

(vi) The development programme should be executed cautiously and in stages, each phase being adapted according to the experience gained.

THE AREA

The Sundarbans area of West Bengal is situated on the southern fringe of the state, projecting into the Bay of Bengal. This area is a result of the age-long delta-building activity of the silt-laden Ganges river and its numerous branches traversing the region. The rivers which helped to build up the land at the sea face have themselves suffered deterioration in course of time, while some of the important arteries of drainage have been changed beyond recognition.

The area was first surveyed and demarcated by Messrs. Dampier and Hodges, two officers of the British Administration in 1830. The Hooghly river marks the western boundary of the Sundarbans, the so-called Dampier-Hodges line marks the northern boundary, and the Indo-Pakistan boundary the eastern limit of subdivision of the Sundarbans area within India. Within these limits, the Sundarbans covers an area of about 3,100 sq. miles. Of this, about 1,400 square miles have already been so far reclaimed.

GEO-MORPHOLOGY

The Bengal delta has been built up from the west to east. Historically, two important changes are of great significance in this study. After the 16th century the Ganges, abandoning its normal course along the Bhagirathi-Hooghly, changed its course into the Padma, and moved gradually eastward, developing

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one channel and another, until it ultimately joined the Meghna. The Brahmaputra which was flowing till the 18th century along its old channel past Mymensingh shifted its course and headed south along the Jumuna and joined the Ganges at Golundo. After these changes occurred, the delta building activity of the Ganges practically came to a standstill on the western side, but progressively increased on the eastern side. Thus, the Sundarbans area in East Bengal is of a much later origin than the corresponding Sundarbans area in West Bengal. For this reason, the ground slope in the East Bengal Delta is somewhat steeper (about 0.4 ft. per mile) than the corresponding delta in West Bengal (0.3 foot per mile); and the ground levels are also lower today in East Bengal than in West Bengal.

Geologically, the Sundarbans is a typical specimen of recent deltaic formation. The surface configuration of the land flanking the river banks is generally flat. The land formation of the area is composed of alluvium carried down for ages by the great rivers, the Ganges and the Brahmaputra. Owing to changes in the river courses, the land has been built up in a very irregular way. The soil, extending to a couple of metres below the ground surface, consists essentially of grey clays and silts in different forms and traces of sand. These soils are variously plastic. At greater depths, the silt and sand contents of the deposit generally increase. In some places, silty clay or clayey silt underlies the sandy and silty deposit. Beyond these deposits lie grey to bluish-grey, medium to fine, sand. The depth of the sand formation appears to extend to a considerable depth. Traces of organic matter such as decomposed leaves, wood and traces of mica are found scattered throughout the deposit. Excavation and borings in the eastern region of the Sundarbans has revealed in places decayed wood and shells about 6 meters below the existing surface.

The surface layer of the deposit is somewhat reconsolidated as a result of desiccation. Below this layer the deposit may be classed as normally loaded since it has not been subjected to loads other than the present over-burden. It is very soft to stiff for cohesive type soils and loose to dense for sands.

FLORA AND FAUNA

The area has certain botanical characteristics. Because of comparatively large reclamation activity, the Sundarbans of West Bengal have poor forests. The wild life is also dwindling gradually. The proverbial royal Bengal tiger and the cheetal (spotted deer) which were to be found in numbers in former times are scarcely seen now. Snipe and different types of ducks are the principal birds found. Fish is plentiful and found all the year round. There are different species of crocodiles and sharks, although, due apparently to increasing salinity, crocodiles appear to be declining in number.

METEOROLOGICAL SELECTION

The area has a pronounced monsoon climate. The total annual rainfall is of the order of about 65 inches, on an average. In some abnormally high years, this is even a little over 80″, while in some subnormal years it is as low as 50″. The bulk of the rainfall (nearly 80 per cent) falls during the months June to September — typically monsoon predominance. During the cold weather there is seldom any rainfall. The rainfall and the rainfall intensity in the monsoon increase progressively eastwards. The temperature starts falling from the middle of October and continues to fall till the middle of January. The humidity, which is about 90 per cent during the monsoon, remains high even during the earlier parts of the cold weather. The mean maximum and minimum temperatures are about 100°F and 55°F, respectively, although there have been years when these averages have been either exceeded or lowered. The temperature begins to rise from February.

Southerly winds appear from the middle of March. Fairly severe storms (Nor-Westers) make their appearance occasionally in April and May. The South-westerly monsoon generally breaks towards the middle of June. Monsoon weather is generally experienced when storms occur near the head of the Bay.

RECLAMATION ACTIVITIES IN THE PAST

The fertility of the Sundarbans has for ages attracted attention of the enterprising inhabitants, who have reclaimed whatever land they could manage. To protect themselves and the land from the floods, on the one hand, and the encroachment of the sea tides on the other, they built embankments. For various reasons, these measures were ill-planned and not foreseeing, so much so that in the subsequent decade a cycle of problems were generated. The embankments were ill-conceived and ill-planned, both in alignment and design and in time, and interfered with the natural delta-building and drainage. Reckless deforestation executed from selfish motives of immediate gain had a devastating effect of silting the channels which were required for proper drainage. The crop raising was entirely dependent upon rain, generally adequate for one crop but now and then untimely leading to failure of the crop or poor crops; and with the embankments causing interference with drainage, the area turned marshy and malarious.

These embankments which were generally constructed before the land was sufficiently raised by nature for reclamation, interfered with the natural process of delta-building activity; and the fertile silt, which normally should have gone into building up the areas, accreted on the river beds, and year by year raised the flood levels; the damage to the embankments themselves correspondingly also increased, therefore.

Maintenance and protection of these ill-conceived embankments have proved a formidable task. A new project is always better than maintaining an existing ill-planned project. Vast sums of money are required for protecting the old embankments by strengthening them, building second lines of embankments, improving drainage conditions, etc., etc., and they still inhibit the building-up process. The scourge of premature reclamation cannot be over-emphasized. As far as the Sundarbans of West Bengal are concerned, there is full realization that it is not desirable to reclaim any land which has not attained a level at least midway between the high waters of the spring and the neap tides.

RECLAMATION CRITERIA

The criterion of reclamation would, as should be expected, differ from country to country. It would ultimately depend on the need for reclamation of the area and the determination and ability to protect the reclaimed land from external forces at the cost it would involve. There has been sometimes a tendency to reclaim land too early, but there is no doubt that the costs have proved inordinately heavy and the risk great, as was evident in the recent calamity in Holland by cyclonic storms resulting in heavy floods over lands reclaimed prematurely. The Sundarbans is a vast area, and it would be extremely hazardous, whether in East Bengal or West Bengal, not to learn from the lessons of too hasty and too early reclamation. Premature reclamation imposes a heavy burden both in capital cost of construction and in the maintenance cost during the years to follow. The recent projects in Netherlands and Japan show a growing appreciation of the correct timing of reclamation. It has, therefore, been rightly emphasized that reclamation should be resorted to only when nature has done its part as a delta building agent.

It is heartening to see that the West Bengal Government, although anxious to reclaim suitable land for rehabilitating the vast and increasing population of the State, has been very cautious in its approach to any programme of new reclamation on a large scale. Due emphasis is laid on a scientific appraisal of all the implications of such reclamation programmes. For this purpose extensive investigations are being carried out including tidal and upland water observations, soil and silt investigations, topographical and geological studies, etc. The Government has also recognised the importance of making sure that there would be no blockage or interference with important estuaries in the reclamation process and programme.

The question of embankments is a rather controversial subject. On the other hand, embankments (dykes) may be unavoidable in conditions similar to those obtaining in the Sundarbans. Not only in Bengal, but throughout the world, experience shows that ill-designed embankments, or embankments in the wrong places on aggrading rivers, raise the river beds and accentuate flood levels, requiring progressive raising of the embankments. This underlines the importance of a correct appraisal of the delta-building activity of the area in question and of evolving such measures as can be expected to satisfy the following criteria before undertaking a system of embankments:—

(i) The protective works should be able to withstand the forces of nature.
(ii) The drainage system should not be adversely affected.
(iii) A satisfactory solution for one channel/river should not adversely affect the adjacent channels/rivers.
(iv) A good local irrigation system is built up for raising assured crops.

It should be recognized that, if there is considerable silt movement in deltaic channels, it will be periodic and depend on the tides from the sea. As it has happened in the past, indiscriminate embankments promote the deposition of the silt on river beds instead of raising the adjoining land. Since the scope of catchment conservancy is extremely limited, the only alternative is a properly-phased river conservancy programme and a guided deltaic formation plan. In other words, the important drainage channels must be conserved and reclamation should proceed in stages, area by area, so that the natural delta-building activity is not hampered, but precedes the reclamation measures and embankments.

Water control is one of the main requisites for reclamation. Thus, drainage and water supply should have priority, and the cost of the drainage and the water supply (for irrigation) for the area determines in the main the cost of a reclamation project. From an economic point of view, the utilization of existing river courses and channels is obviously to be preferred. The resuscitation of old rivers and channels can be made to serve multipurpose objectives, viz., drainage, irrigation, navigation, pisciculture, towns and industries, etc.

IRRIGATIONS IN RECLAIMED AREAS

The soil in the Sundarbans being very fertile, if measures are undertaken to prevent encroachment of the tidal waters from the sea and to ensure effective drainage, paddy and jute can be raised in abundance, as indeed is being done in some of the areas reclaimed and developed in the past.

With an average rainfall of about 65 inches spread over the period from June to September, the water is adequate for a very good aman crop (paddy), and even at present a considerable area is used for raising this crop. Aus (early rice) and boro (winter season) crops are also raised to some extent without river supplies. There is, however, great scope for extending crop raisings by stages and according to a scientific plan.

In an area subject to heavy rainfall, like the Sundarbans, drainage should undoubtedly receive the highest consideration, and the problems of maintenance are greatly minimised if reclamation is done at a stage when the land has risen high enough and if the drainage channels are properly maintained. This should be even more important in the eastern sector of the Sundarbans, where the heavier rainfall and rainfall intensity cause more acute flood and drainage problems. The embankment enclosing the area (a small unit of the delta) would without difficulty then protect the raised land from tidal waters.

The manner of co-ordination of the irrigation and drainage aspects is a matter of tremendous importance in the development of the Sundarbans. The best and the most purposeful technique would be phased 'polderization'. Each polder should be a self-contained unit with a built-in system for irrigation and drainage.

As far as possible, the existing drainage channels (with suitable ring embankments around the area) would be used for draining off and irrigating a part of the area from the fresh water stored-up during the monsoon period. This is potentially an important step in as much as it will help in

(i) providing irrigation supplies towards the end of the rainy season if, at the critical time of the flowering of the paddy crop, rains fail;
(ii) providing irrigation supplies for the rabi (winter) crops;
(iii) village water supply and pisciculture; and
(iv) preventing saline intrusion and leaching the salt out of the enclosed areas.

All the drainage outlets would be provided with sluices opening into the sea for draining out the water, when desired and when the sea levels permit.

It is felt that fresh water for irrigation from outside is neither necessary nor desirable under the deltaic conditions prevailing in the Sundarbans. As a matter of fact, this is in line with the experience in America and elsewhere, where it has been found that, in order to preserve the fertility and infiltration characteristics, a rotation of wetting and drying is beneficial.[1] This is all the more desirable in deltaic areas which suffer from inundations year in and year out. Even the conventional mode of irrigation is restricted in West Bengal to a few patches remote from the coastal regions, but is ruled out for the Sundarbans area there. A judicious storing and utilisation of the monsoon water supply, it is sure, would meet the water requirements for irrigation fully. A judicious rotation of crops would further help in this necessary alternation of wetting and drying for preservation of fertility and infiltration characteristics.

It has further been recognised that, in order to utilize the fresh water resources fully, the saline intrusion from the sea end should be checked. This would entail the closure of some of the less important inlets. Here again, nothing would be done before making certain that important estuarine inlets such as the Hooghly) are not adversely affected in any way.

PROSPECTS

The geo-morphological characteristics of the area, the availability of material and financial resources, and the traditional habits of the populace will preclude the adoption of techniques other than polderisation adopted in the Netherlands and elsewhere. Therefore, it is not intended to move too fast in the reclamation programme of West Bengal Sundarbans. It is proposed to develop the area in phases, each phase being carefully made to suit the stage of development, moving cautiously by experience.

The first of the proposed phases contemplates the development of four independent units:

(1) providing protection to the mainland on the north of the Namkhana Creek, bounded by Calchara or Muralganga on the east (135 square miles);
(2) protection to land south of Namkhana Creek and lying between the Pitt's Creek and Saptamukhi (53 square miles);
(3) protecting Mahisani Island between Barakla and Pitt's Creek (8 square miles); and
(4) protecting Sagar Island (72 square miles).

The attached plan indicates these four zones. Each zone will be protected by dykes. The first zone involves 48 miles of dykes, the second 39 miles, the third 19 miles, and the fourth 40 miles. When these dykes are built, it will be possible to remove about 300 miles of embankments, built haphazardly by Zamindars in the past, and now being maintained at great expense and difficulty.

Investigations are in progress for obtaining the following field data for enabling detailed designs:

1. Cross-sections along tidal creeks.
2. Tidal gauges and velocity and current measurements.
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4. Concerning agricultural aspects, land use, etc.

When all the data become available, it would be possible to prepare a master plan, to be implemented in stages depending on the availability of resources and the readiness of the land for reclamation.

[1] Leonard Schiff — Groundwater Recharge Method based on Site Characteristics and on Sediment in Flood Water — Fifth International Conference on Irrigation & Drainage, 1963.

Maintenance and protection of these ill-conceived embankments have proved a formidable task. A new project is always better than maintaining an existing ill-planned project. Vast sums of money are required for protecting the old embankments by strengthening them, building second lines of embankments, improving drainage conditions, etc., etc., and they still inhibit the building-up process. The scourge of premature reclamation cannot be over-emphasized. As far as the Sundarbans of West Bengal are concerned, there is full realization that it is not desirable to reclaim any land which has not attained a level at least midway between the high waters of the spring and the neap tides.

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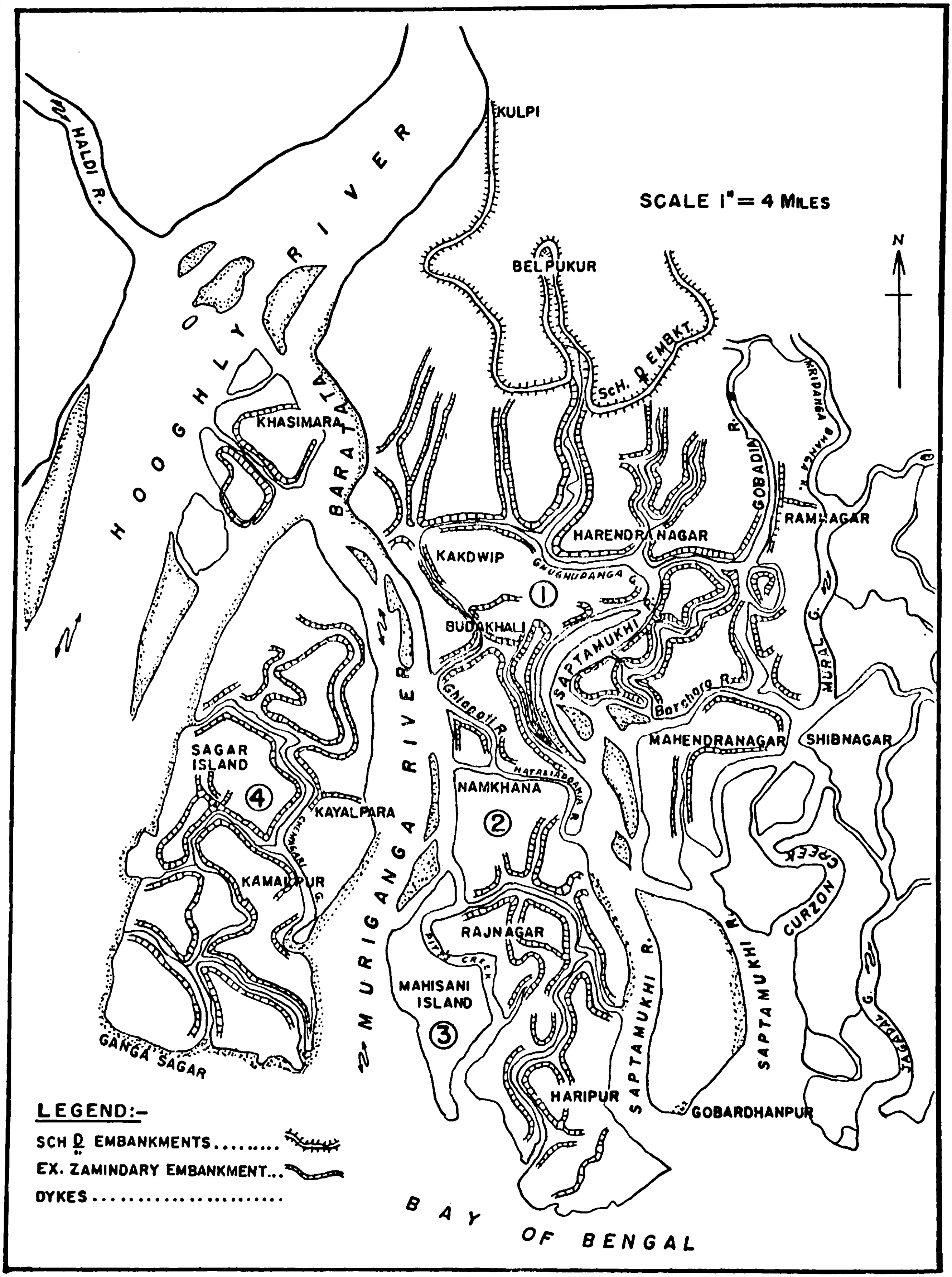

Figure 49. PROPOSED FIRST PHASE DEVELOPMENT OF SUNDARBANS OF WEST BENGAL, INDIA

Paper No. 6

TIDAL IRRIGATION IN THE DELTA OF THE KARUN AND SHATT-AL-ARAB RIVERS WITH COMPLICATIONS FROM INCREASED SALINITY OF WATER*

Abstract

Abadan Island is in the delta of the Karun and Shatt-al-Arab rivers on the southwestern border of Iran. The Karun river divides when it reaches the island, forming the Haffar branch which flows along the north end of the island and into the Shatt-al-Arab at Khorramashar, and the Bahmanshir branch which flows south along the east side of the island and into the Persian Gulf. About six million date palms are grown in bands of one hundred metres to a few hundred metres width along both sides of all the streams, including the Shatt-al-Arab. The date palm gardens are irrigated from canals which have been cut into the banks of the streams and through which water is pushed and returns with each rise and fall of the tides.

During the recent series of drought years, which followed increased irrigation from the Tigris, Euphrates, Karun and other tributaries of the Shatt-al-Arab, the amounts of fresh water reaching the area decreased and shifted in their flow. Their quality has also deteriorated. Sea water has intruded farther up the Shatt-al-Arab and the Bahmanshir, on both sides of the island, than ever before. The sea water first killed the fruit trees other than date palms, and is now killing the date palms, especially in the lower southern parts of the area nearest to the sea. The shallow, heavy, poorly drained soils are becoming gradually more saline.

More fresh water in periods of low flow will probably reach the area through the Karun river from new storage during the next several years. But regulation of the division between the Haffar and the Bahmanshir may be necessary during periods of lowest flow. Possibilities for gravity diversion of Karun water for the date gardens along the Shatt-al-Arab are limited by several factors: (1) flat topography; (2) flood hazards of diversion structures; and (3) very high costs in relation to benefits from construction, including canalization. Delivery of Karun river water from pumping would encounter some of the same difficulties. Comprehensive studies are underway for determining possibilities for development, including probable costs and benefits.

I. INTRODUCTION AND GENERAL

A. Location and description of area

1. *Abadan Island.* Abadan Island is on the southern border of Iran, between east longitude 48° 10′ and 48° 40′ and between north latitude 29° 55′ and 30° 25′. Its altitude is about one to three metres above sea level. It is surrounded by the Shatt-al-Arab on the west, the Persian Gulf on the south, the Bahmanshir on the east and the Haffar (the connection between the Karun river and Shatt-al-Arab) on the north (fig. 50). The area of the island is about 40,000 hectares. The topography is flat. The soils are silty clay. Salty groundwater is under the area at depths ranging from about two metres in the highest parts of the Abadan or northern end to only 30 centimetres in parts of the Gosheh area in the southern end of the island.

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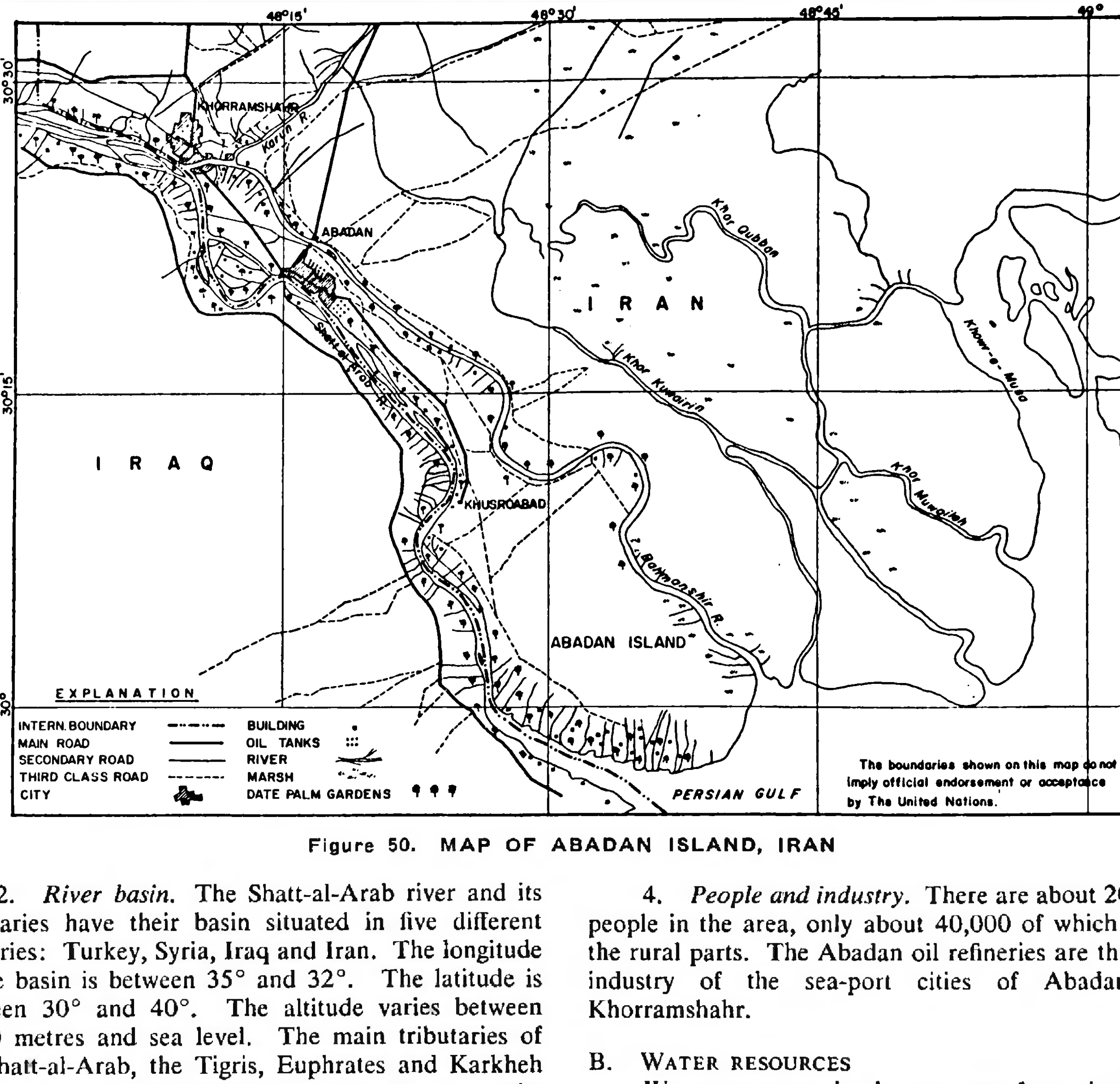

Figure 50. MAP OF ABADAN ISLAND, IRAN

2. *River basin.* The Shatt-al-Arab river and its tributaries have their basin situated in five different countries: Turkey, Syria, Iraq and Iran. The longitude of the basin is between 35° and 32°. The latitude is between 30° and 40°. The altitude varies between 5,000 metres and sea level. The main tributaries of the Shatt-al-Arab, the Tigris, Euphrates and Karkheh rivers, empty into Saida and Hammar lakes and the Hor-al-Azim marsh land. This spreading of the discharges of these rivers over wide areas causes very heavy water losses from evaporation. Part of the Karun water flows through the Bahmanshir to the Persian Gulf, but the greater and increasing part of it flows through the shorter Haffar branch to the Shatt-al-Arab at Khorramshahr (fig. 51).

3. *Agricultural production.* The principal agricultural production of the area is from date palms which are grown on lands along both sides of all the rivers. The total area covered by the approximately 6,000,000 trees is about 25,000 hectares. In addition to the date palms, there are some other fruit trees in the northern part of the area. Grape vineyards, apricots, pomegranates, figs and a few bananas are all represented in decreasing numbers. Also, in the small open areas between the palm trees some vegetables (tomatoes, cucumbers, cabbages etc.) are cultivated. Some alfalfa is grown for feeding cattle.

4. *People and industry.* There are about 200,000 people in the area, only about 40,000 of which are in the rural parts. The Abadan oil refineries are the main industry of the sea-port cities of Abadan and Khorramshahr.

B. Water resources

Water resources in the area are from the Karun and Shatt-al-Arab rivers.

1. *The Karun river.* Seasonal variation in the river is due to the conditions of the catchment area: severe winters with snow on the mountains, and long dry summers. The melting of snow on the main part of the upper catchment area, combined with spring rainfall, results in a flood period from March to June. The first rains usually come at the end of October or during November. The minimum flow normally occurs in the latter half of October. During the period 1934 to 1959, the mean monthly discharge ranged from 1,760 cubic metres per second to 240 cubic metres per second. The absolute minimum was 155 cubic metres per second.

A development programme for the Karun basin has been initiated by the Plan Organization. It includes regulation of the summer flow of the Karun by construction of nine storage dams, two of which are on the Dez river and one of which is already completed. The Mohammad Resa Shah Dam is for irrigation, for

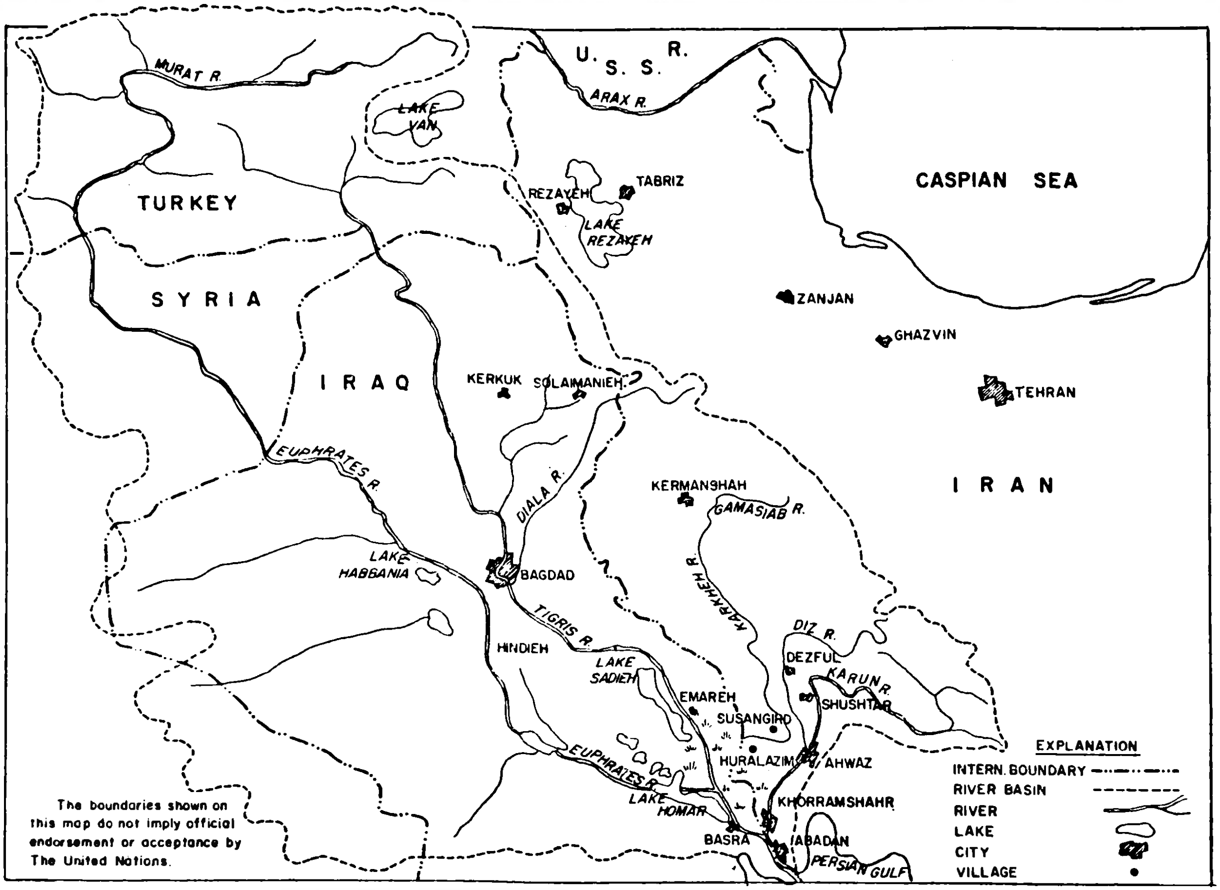

Figure 51. MAP OF SHATT-AL-ARAB RIVER BASIN

generating hydroelectric power and for flood control. A minimum regulated summer flow of 190 cubic metres per second in the Dez and 430 cubic metres per second in Karun will be available when the entire system is completed. It is anticipated that one-third of this amount, including return flow, will reach the Abadan area. It is the Karun river water that appears to offer the greatest possibilities in the Abadan area.

2. *The Shatt-al-Arab river.* This river is fed by the inland delta of the Euphrates, Tigris and Karkheh rivers, through a vast area of rice fields, marsh lands and lakes.

The water supply from these three rivers is summarised approximately in the following figures from ILACO, Consulting Engineers, in cubic metres per second flow:—

	Euphrates	*Tigris*	*Karkheh*
(a) Average annual discharge before diversions	855	1,465	150
(b) Diversion for irrigation	215	465	50
(c) Losses in rice area ...	170	—	—
(d) Supply to marshes ..	470	1,000	100
(e) Total supply to marshes		1,570	
(f) Evaporated in marshes		900	

(g) Average flow into the Shatt-al-Arab 670 cu. m. per second.

C. Soils resources.

The soils of the area are from mixed alluvial sediments, the finest of which have settled in this area nearest to the Persian Gulf. Tidal effects are also obvious in the soils, especially in the subsoils. The subsoils are grey and range in colour from grey to olive. They contain much remains of marine life, including shells and fish bones. The top soils are shallow and range in texture from silty clay loam in the northern part of the area to silty clay in the southern part. The top soils as well as the sub-soils are rich in soluble salts. Their very fine textures facilitate capillary movement of brakish water.

The soils are classed as saline and saline-alkali types. Relief is level. Drainage is poor. Run-off is very slow, and permeability is slow.

II. PRESENT IRRIGATION METHODS

A. Surface water with tides

According to historical documents, about 1,500 years ago, at the time of the Sasanian dynasty in Persia the method of irrigation by tides was adopted in this delta area.

The tides of the Persian Gulf rise about four metres twice a day at high tide. The back water rises with the tides throughout the lengths of Bahmanshir and Haffar estuaries and about 30 kilometres upstream in the Karun proper. In the Shatt-al-Arab, the tides reach the Basra area. This back water pushes the fresh water flowing in the rivers up into the canals and laterals that have been dug in the banks on both sides of the streams.

The distribution system is composed of the main canals which are at right angles to the direction of the streams. Laterals are at right angles to the main canals, secondary laterals etc. The date palms are located along the banks of the end laterals. The irrigation is by infiltration. There is a tendency to not submerge the cultivated areas, for preventing concentration of salt on the soil surface by capillarity. Where the land is submerged, the farmers cut the capillary tubes by tillage. During low tide the water in the ditches, laterals, and main canals flows back to the river. During the six hours of low tide an automatic leaching takes place in the system.

B. Underground movement

The saline groundwater under the area is highest near the source of supply of water, commonly ranging from 30 to 60 cm, and slopes gradually deeper towards the centre of the island, where it is most saline. There is thus apparently a slight gradual movement of groundwater inland, with no arrangement for leaching past the ends of the last lateral ditches. This situation for gradual accumulation of salt near the end laterals may account for the gradual abandonment of the lands near the end laterals as may be best observed from aerial photographs.

III. DIFFICULTIES FROM INCREASED SALINITY

A. Reasons for increased salinity

1. *Water.* From figures 52 and 53 it may be seen that the variation of salt content in the rivers has been periodic according to seasons and total supplies. The problem of increased salinity of water has become critical only in periods of low flow in the series of recent dry years.

The two main reasons for the increasing salinity of water are:—

(a) The decreased discharge of the rivers during the series of dry years from 1957 to 1962, after increased use of water in irrigation upstream, and the increasing salt content in the river water in return flow from drainage.

(b) The increased mixture of sea water with river water in the delta area during high tide, when the rivers become lower, and the creation of back flow of highly saline water (in some places mostly sea water) in the rivers, especially in the Bahmanshir and the lower part of the Shatt-al-Arab.

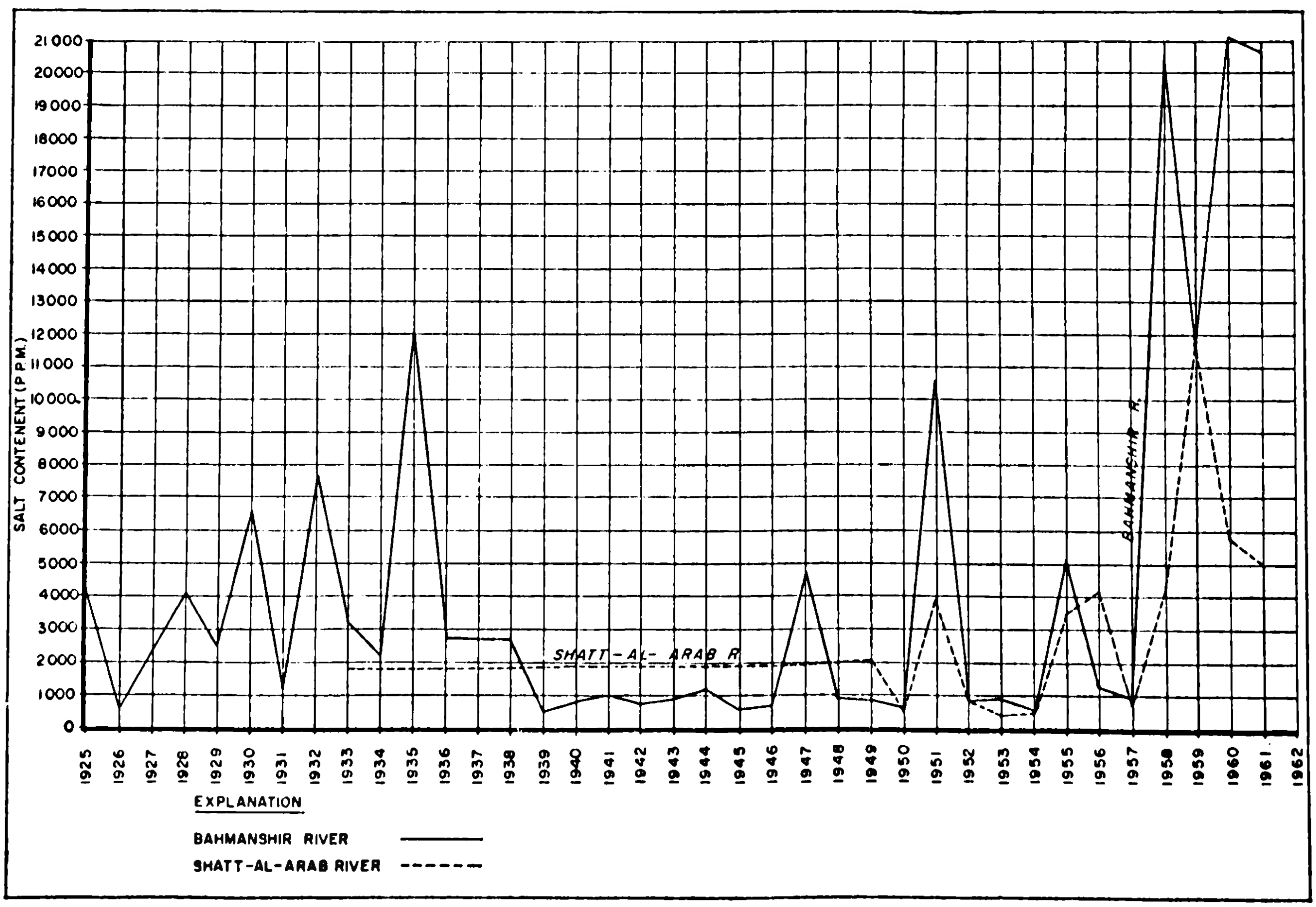

Figure 52. SALT CONTENT IN SHATT-AL-ARAB

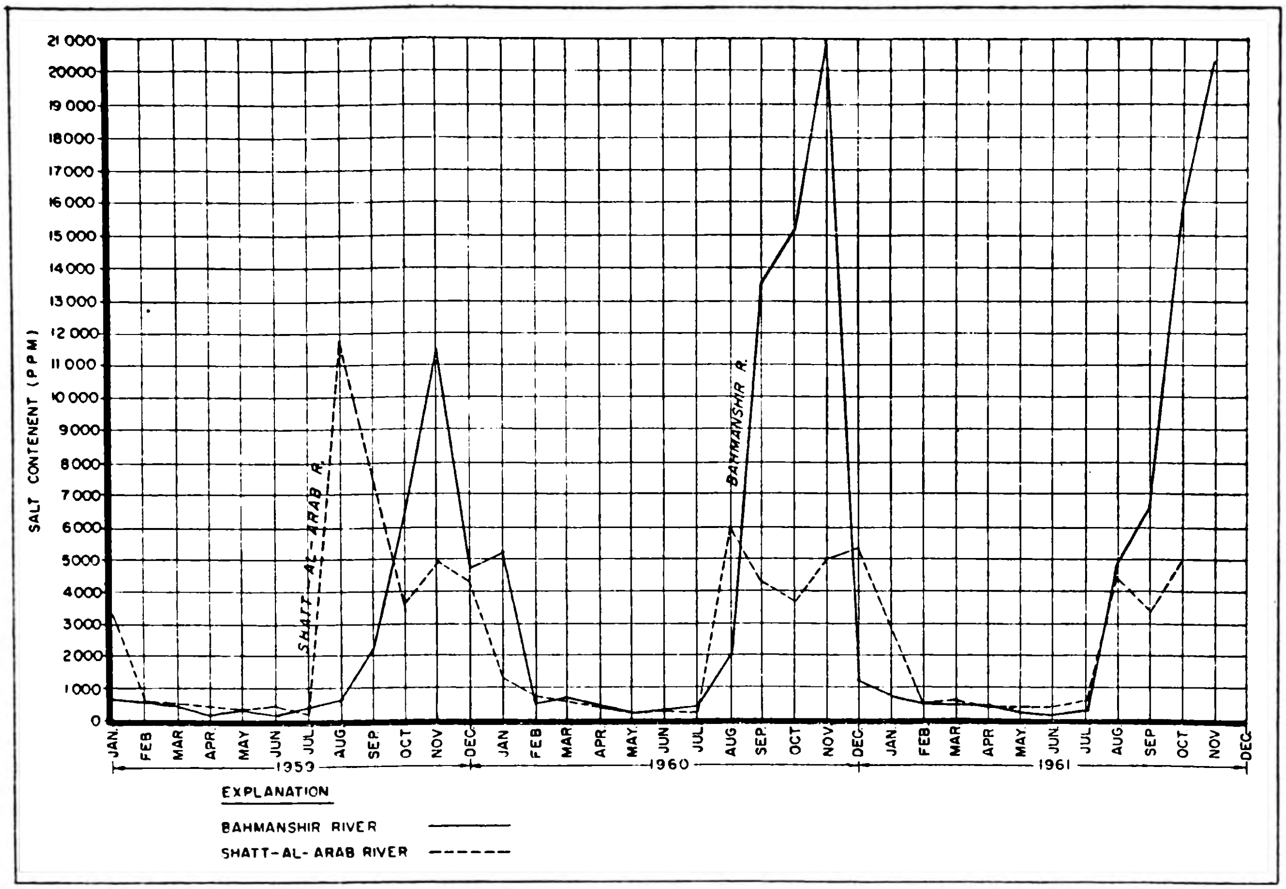

Figure 53. MONTHLY MAXIMUM SALT VARIATION IN SHATT-AL-ARAB AND BAHMANSHIR RIVERS

2. *Soils.* The use of saline water in irrigation, especially on the heavy and poorly drained soils, in the hot dry climate of the area is the major factor in the increased salinity of the soils.

B. Effects of increased salinity

The increasing salinity of water has had many social and economic effects in the region. In the southern part of the island, most of the fruit trees—apricots, pomegranates, figs and vineyards — disappeared. The yield of date trees decreased from 25 kilos per tree to 2.5 kilos. The quality became too low for human consumption. Many of the date trees are dead, and the others are being attacked by diseases and insects.

The social and economic effects of this decreased yield and lowered quality of dates was abandonment by the farmers. There is no market for the low-quality product from the lower part of the area. Most of the farmers are trying to get jobs in industry. They rent their houses and leave the gardens to others who continue to live in this part of the area.

IV. POSSIBILITIES AND PROBLEMS IN IMPROVEMENT

A. Fresh water from the Karun River

The actual fresh water resources in the Abadan area are:—

The Karun

The Shatt-al-Arab

But the influence of the tides and the intrusion of salt from the sea water in the Bahmanshir and Shatt-al-Arab has changed the quality of water in the delta area. Yearly variations of salt content are shown in graph No. 3 for the Bahmanshir and Shatt-al-Arab from 1925 to 1962, and monthly variations are indicated in graph No. 4 from 1959 to 1962. It is evident that the use of this kind of water for irrigation will increase the salt content of the soil. Fresh water may be obtained from upstream in the Karun and Shatt-al-Arab, where the tide and salt intrusion have no effect. Or, it may be obtained for the northern and eastern side of Abadan Island and for pumping and carrying to other parts by regulating the division of Karun river water between the Haffar and the Bahmanshir, so as to maintain a constant pressure against the sea water in the Bahmanshir.

For the Shatt-al-Arab the Government of Iraq has a large scale plan to use monthly all the water in the irrigation season. The return flow from irrigation of the salt lands of Mesopotamia will contain a high degree of salinity. In the Ruka canal the return flow contains 22,000 parts per million total salts.

The high evaporation in the Hammar and Sardia lakes and in the marshlands in the internal delta of the tributaries of the Shatt-al-Arab causes the increase in salinity. The following table shows ILACO's forecast of the discharge and salinity of the Shatt-al-Arab for 50 years from 1960 to 2010:—

Year	*Average annual discharge in billion m^3*		*NaCl per year in million tons*	*Salinity & occurrence in days per year*					
				Average		*High*		*Low*	
	River	*Drains*		*ppm*	*days*	*ppm*	*days*	*ppm*	*days*
1960	21	—	—	200	182	—	—	—	—
1970	18	0.25	7	590	182	960	120	370	345
1980	15	0.60	17.5	1,320	182	2,500	120	670	345
2010	8.5	0.50	70	6,600	182	7,600	155	2,400	345

In the Karun river after building all nine storage dams, regulating the flow and using all water for irrigation, the salt content of the return flow will be about 700 p.p.m. in 1980 and 900 p.p.m. in 2010.

The table below shows the comparison of the two rivers:—

Years	*Rivers*	*Mean annual discharge cu. m./sec.*	*Salt %*
1980	Shatt-al-Arab	500	0.25
2010	" "	300	0.76
1980	Karun	150	0.07
2010	"	80	0.09

In addition to the difficulties caused by the salinity of water, there are other technical and political problems involved in taking water from the Shatt-al-Arab:—

— Very high costs of structures on so wide a river
— Agreement of the Iraqi Government
— Interference with the large amount of navigation in the International Waterway.

These reasons all support the conclusion that fresh water for the area must come from the Karun river.

1. *Gravity diversion.* Nine different possibilities and alternatives were proposed in the preliminary report, most of them based on gravity diversion. According to the recent topographic survey, the general slope of Abadan Island is about one metre in 50 kilometres. This situation exposes the major difficulties for gravity diversion. These difficulties may be reduced or further complicated by other data being obtained in the studies which are now underway.

2. *Regulating the division of flow of the Karun between the Bahmanshir and the Haffar during periods of lowest flow.*

By re-establishing the balance of flow in the two branches of the Karun (along the east side and along the north end of the island), it should be possible to maintain a constant pressure of fresh water flowing to the sea. The tides should then continue to push fresh water into the canals on both sides of the Bahmanshir and the Haffer.

This partial solution would require at least some obstruction in the Haffer at Khorramshahr, which would interfere with navigation up the Karun during the entire period of lowest flow. The only advantage for the date palms along the Shatt-al-Arab would be a constant supply of Karun river water for pumping.

3. *Pumping.* If gravity diversion is not feasible, it will be necessary to lift water by pumping and send it by gravity through lined canals to the existing date palm gardens, as far as this is physically, economically and otherwise feasible. This alternative may not be feasible from the economic view, due to permanent expenses of lifting water especially for the more distant and less productive parts of the area. Nevertheless, it will probably be found politically or otherwise feasible to use considerable amounts of electric power produced at the Mohammad Reza Shah dam, or in the Abadan Oil Refinery. Certainly, the better and more conveniently located parts of the area will need to be continued in production one way or another.

B. Limiting supplies during periods of high salinity

Experience in some existing date palm gardens shows that the control of supplies during periods of high salinity prevents the increase and concentration of salinity in the soil, but it is evident that the plants need water during that period. Some selected experimental farms will be checked during the summer as part of the current studies and the decrease of yields due to controlling supplies will be observed. Of course, the salts in the available soil moisture become more concentrated as the moisture becomes less during extremely dry periods.

V. STUDIES UNDERWAY

For completing the investigations, the following studies were started on them in March 1963. It is hoped to complete them in 16 months.

A. Hydrology and hydraulics

Collection of the basic data on the quantity and quality of water resources and observations on tides and their effects are being made.

Measurements and computations are being made of the flows, back-flows and back-water during the high tide and low tide.

B. Topography

Measurements are being made and maps prepared showing elevations, across sections of rivers and traces of proposed main canals and laterals.

C. Soils and drainage

Soil survey, land classification and groundwater studies are being made to determine suitability and methods for irrigation and drainage.

D. Agriculture and economy

These studies are for collecting agricultural data, land use and crop patterns, agrohydrologic data, water requirements, size and shape of farm units, parcellment and costs and benefits in the production area. Social factors are included.

E. Designs and cost estimates

Designs will be prepared after data in the other fields show what solutions are possible. Cost estimates will then be prepared for the various alternatives.

F. Feasibility

In this phase of the studies, results from all the other parts will be brought together for analyses and determination of a proposed line of action in development.

VI. TENTATIVE CONCLUSIONS INDICATED

This paper sets out to describe the situation created by increased salinity of water and to outline the problems of saving as many as is feasible of the six million date trees of the area, thus keeping to a minimum the decrease of production in this 25,000 hectare irrigated deltaic area.

Final conclusions about solutions must await results from the studies underway, but it appears possible to draw enough tentative conclusions to indicate some rather strong probabilities for the future of the area.

A. Additional water from the Mohammad Reza Shah (Dez) reservoir may for several years prevent recurrence of extremely low flow as recorded in the Haffar and Bahmanshir during the past few years.

B. Designs may have to be made ready for enough obstruction in the Haffar to maintain some outward flow in the Bahmanshir during lowest flow.

C. The Shatt-al-Arab will probably continue to be too saline for irrigation below the Khosrowabad area. In the future, the area of saline water will probably extend gradually farther up the Shatt-al-Arab.

D. It will be necessary to abandon tidal irrigation in the lowest parts along the Shatt-al-Arab and to provide fresh water for as much of this part as is feasible by pumping from the Haffar and Bahmanshir and carrying by gravity flow.

E. It may be possible to continue using the tides to push fresh water by gravity into canals along the Haffar and Bahmanshir.

F. The studies underway will indicate the best technical and economic solutions. Other factors also will probably be included in the final determinations.

Paper No. 7

PROBLEMS IN THE IMPROVEMENT OF DELTAIC WATER-LOGGED PADDY FIELD WITH SPECIAL REFERENCE TO IRRIGATION AND UNDERGROUND DRAINAGE*

1. CHANGES IN SOIL PROPERTIES AND THE EFFECT OF INTRODUCING DRAINAGE TO WATER-LOGGED PADDY FIELDS

Throughout the year the groundwater level is high in water-logged paddy fields, sometimes reaching surface water level with practically no downward water movement. Change in the quality of organic material in the soil is a reductive action and the organic material in the soil tends to accumulate. By lowering the groundwater level, the soil can be dried, thus producing decomposable organic material. Bacteria unable to bear to dryness can be destroyed but the stronger bacteria remain. Then, with the application of moisture, living bacteria begin to work actively causing the decomposition of decomposable organic materials and of dead bacteria, thus producing a large amount of ammonia type nitrogen which in turn becomes a fertilizer for the crops.

Furthermore, downward percolation, which did not exist during the water-logged period, starts with the lowering of the groundwater level by drainage and this water flow launches the movement of various bases and leaching away of fine soil particles into sub-soil layer. As a result, acidization of soil is expedited. Besides, the aggregation of soil is also expedited, the increase in aero-hydraulic conductivity becomes salient and the soil permeability increases considerably due to hair cracks and other causes created by dryness.

The results of various researches and experiments indicate the fact that increase in soil permeability and in the bearing power of the soil reach as much as 30-50 per cent, the percentage becoming larger in proportion to the increase in the content of clay and silt in soil.

By lowering the groundwater level it is possible: (1) to facilitate higher utilization of paddy fields through the introduction of second crop, thus converting paddy field to upland, (2) to increase labour productivity by strengthening the bearing power of the soil and (3) to increase the paddy yield by the improvement of the physico-chemical properties of soil.

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2. PROBLEMS IN PLANNING ON UNDER-DRAINAGE SYSTEM

Of course, the completion of a surface drainage system is a prerequisite for the complete under-drainage. It is necessary that the water level of a drainage ditch should be at least one metre below the paddy field surface and the capacity of ditch has to be comparatively larger than when only surface drainage is the object. To introduce heavy machinery, large tracts of land are required; open ditches may cause a bottleneck to its operation, so it is necessary to consider the construction of sub-drainage installations. In such case, possible damage to pipes by the pressure of large machines must be considered. Thus, depth and material of installation become problems. Of course, the scale and arrangement of the drainage system are subject to the natural condition of soil.

Furthermore, in a case where the surrounding water level is higher than the planned area, pump drainage becomes necessary. In such cases, the suction water level should be lower than when flood drainage is the sole object. For this purpose, it is economical to separate pumping for flood drainage and pumping for lowering the groundwater level.

Needless to say, the capacity of the drainage canal should be such that it takes account of seepage through the embankment from the higher water level of the surrounding area besides floods caused by rainfall.

As an ideal drainage system for the future, repeated use of water should be carefully considered in order to insure a rational method of irrigation, such as by carrying seepage water to the drainage ditch by a small pump.

3. THE OPTIMUM WATER REQUIREMENT FOR RICE CULTIVATION UNDER FLOOD IRRIGATION

a. *The water requirement to insure a higher yield*

Statistics on the average values of paddy yield and daily water requirements in Japan show that, for the maximum paddy yield of 7.5 ton/ha, the daily water requirement is 20-25 mm. (The same values are not applicable to other countries where sunshine hours and evaporation are different from those of Japan).

b. *The theoratical water requirement*

The processes by which water is consumed in flood irrigation can be classified into evaporation, transpiration and percolation below the root system.

Evaporation is completely subject to weather conditions; in Japan it is 2.5 mm/day on an average;

Percolation is around an average of 5 mm for the control of soil and water temperature and to dispose of harmful substances appearing in soil;

Transpiration has a direct influence on the paddy yield and is also subject to weather conditions.

As the result of various experiments in Japan, the required transpiration for the production of 1 ton husked rice per hectare is found to be about 140 mm. If the husked rice yield is to be assumed as 4.5 ton/ha., then the transpiration requirement is 630 mm. If the irrigation period during rice cultivation is 100 days, then the daily average is 6.3 mm and the daily average for 10 days during a peak water requirement period reaches 10-13 mm maximum.

From the above three factors, it will be seen that the minimum water requirement for paddy growth, upon the assumptions of transpiration at 12 mm/day, evaporation at 2.5 mm/day, absorption loss caused by rice at 2 mm and percolation at 4 mm, is about 20 mm, which practically coincides with the actual case.

If the paddy yield is to be increased, based upon the above three factors it is necessary to assume a large amount of transpiration.

4. IRRIGATION AND DRAINAGE CONTROL IN WATER-LOGGED PADDY FIELDS

In swampy paddy fields the groundwater level is usually high with practically no vertical movement of water and, in most cases, the water requirement is below the optimum water requirement stated above. Hence, it becomes necessary to provide a water requirement appropriate to ideal paddy rice growth by controlling the water level in the drainage ditch and thus controlling the hydraulic gradient. The findings from various experiments clearly indicate that to increase paddy yield in the case of transplanted rice, it is better to restrict percolation up to the maximum stooling stage in the early half of the rice-growing period and to apply an appropriate percolation later on.

Because of the drying out of soil during dry season, the permeability increases and the puddling at the early irrigation period requires a larger volume of water. One of the methods of restricting this increase is to raise the water level in the drainage ditch before the end of the second crop and utilize the underdrain reversely for sub-irrigation, thus preventing the soil from excessive drying out. Care should be taken, however, not to raise the water level too high as to jeopardize the second crop. This same method can also be applied to the swamp paddy field.

One problem which should be remembered in the control of groundwater by drainage system is the difference between the water level in the system and groundwater level, and time lag before both reach th balanced levels, i.e., even if the water level of the drainage system is lowered, it requires considerable time before the groundwater level of the paddy field will be fully affected — normally from 50 to 100 hours. This time lag is influenced by the intensity of drainage channels. However, from the economic standpoint, the construction of excessive drainage installations should be avoided and the drainage should be carried out in relation to the intensity of planted crops, kind of crops and the methods of cultivation.

Paper No. 8

MULTIPURPOSE UTILIZATION OF LAND AND WATER RESOURCES IN THE VOLGA-AKHTUBA FLOOD PLAIN AND VOLGA DELTA*

Abstract

The paper gives a short description of the natural conditions and present state of agriculture, fishery, forestry, navigation; it also gives the characteristics of the Volga-Akhtuba flood-plain and Volga delta, as well as power utilization of the Volga river. The paper describes the measures on the flow regulation in the flood-plain and delta to supply water to spawning areas and on application of simplest methods of irrigation for haylands, forests and areas which are under cane in conformity with the hydropower utilization of the lower section of the Volga.

The paper also describes the measures on the protection and improvement of fish reserves and prospects of agricultural development, as well as the programme of hydraulic construction in this zone.

This project of multipurpose utilization of land and water resources within the Volga-Akhtuba flood-plain and Volga delta is an evidence of much attention paid by the Soviet Government to the problems of reasonable and effective utilization of abundant water resources available in the USSR.

INTRODUCTION

Much attention is constantly paid by the Soviet Government to the problems of efficient utilization of the country's natural resources and particularly to the problem of reasonable and most effective use of abundant water resources.

The programme of communist construction in the USSR includes a comprehensive plan of multipurpose and most efficient use and conservation of water resources.

To solve the problems of water development and to utilize fully the water resources along with the development of all the branches of national economy, at present a general scheme is being worked out for the multipurpose utilization of water resources of the country and their conservation in the long run. Schemes of utilization and conservation of water resources for the Union Republics and for individual important river basins are also under design.

Such primary problems of hydraulic development include multipurpose utilization of land and water resources within the Volga-Akhtuba flood-plain and Volga delta.

The Volga-Akhtuba flood-plain and Volga delta cover a remarkable region where the natural conditions are quite favourable for the development of agriculture, animal husbandry, fishery, pulp-and-paper industry as well as for hydropower development and improvement of navigation.

Effective utilization of natural resources of this zone is possible only under multipurpose development of the rich water and land resources as this should meet the requirements of various branches of the national economy.

The project provides for the construction of the Nizhne-Volzhsky hydroelectric station together with the large-scale irrigation construction and development of agriculture, erection of structures for the controlled watering of the meadows, pastures, cane areas, construction of a large longitudinal levee protecting the Volga-Akhtuba flood-plain from inundation, arranging of fishery establishments, etc.

Generation of power is to be accompanied by the prevention of inundations over the vast areas within the flood-plain and delta caused by floods, and by radical improvement of utilization of land and water resources and by the conversion of these regions into the zones of highly intensive agriculture. All these measures will permit to produce vegetables, rice, melon crops, fruit, livestock products, to breed waterfowl, to develop fishery and ensuring a sharp increase of

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reproduction of fish reserves, to grow cane to cover the raw demands of the pulp-and-cardboard mill already in operation.

The lands within the Volga-Akhtuba flood-plain and Volga delta are highly valuable due to the fine combination of fertile flood-plain soils and favourable climatic conditions. The period free from frost lasts here 180-200 days a year. There is abundant water, sunlight and heat. The productivity of the flooded soils exceeds 5-6 times that of the steppe and semidesert soils.

The combination of riverside semidesert pastures and flooded meadows favours the further broad development of animal husbandry, fine-wooled sheep breeding in particular.

The lower reaches of the Volga and the northern part of the Caspian Sea are the main fishery regions for the entire Caspian Sea. The Volga-Caspian region is the most important fishery region in the Soviet Union due to the rich resources of valuable kinds of fish, geographical location, availability of fishing fleet and fish-processing industry.

All the above favourable natural and climatic conditions of the Volga-Akhtuba flood-plain and Volga delta create the necessary prerequisites for the implementation of the proposed developments aiming at the increase of economic efficiency of all the branches of the national economy in this zone.

The capital investments are evaluated to be 1.6 billion roubles.

The paper presents the summary of the project of multipurpose utilization of land and water resources within the Volga-Akhtuba flood-plain and Volga delta.

NATURAL CONDITIONS

Location and relief

Below Volgograd the Volga and its main branch Akhtuba form the Volga-Akhtuba flood-plain, this is a strip 10-35 km wide and over 400 km long. The flood-plain covers the area of 775 thousand ha. Fifty km to the north of Astrakhan the flood-plain turns into a fan-shaped delta. The delta area is 1,102 thousand ha.

More than one thousand watercourses cut the delta thus forming islands. The flood-plain is also cut with numerous watercourses and old river channels functioning, as a rule, only when the high water occurs, while during the low-flow period these channels drain the adjoining lands.

On the west there is a peculiar area adjacent to the delta. This area is known as the western ilmeni[1] covering 500 thousand ha. The ilmeni neighbour upon the steppes. A lot of hills 5-20m high and 200m-5 km long are met here. The hills cover 40 per cent of the area, while the rest of the area is under ilmeni inundated with the Volga water during floods.

Semidesert areas bordering upon the flood-plain, delta and ilmeni form one economic unit known as the Volga-Akhtuba zone.

Climate and hydrology

The climate of the zone is typically arid. During 50-80 days in summer, dry winds occur creating the temperature +40°C. Mean annual precipitation varies from 170 mm (near Astrakhan) to 320 mm (near Volgograd).

The Volga is the largest river in Europe. Its catchment area is 1,380 thousand sq km, its length from the source to the Caspian Sea junction is 3,700 km. Mean annual runoff is 251 km^3, the floor water volume is about 151 km^3. The maximum discharge during the flood occurred in 1926 was 59 thousand m^3/sec.

The life and formation of the flood-plain and delta are closely connected with the annual Volga overflows. Inundation of the flood-plain and delta begins with the discharges of 16-18 thousand m^3/sec. The main areas are inundated with the discharge of 25 thousand m^3/sec.

Long duration (up to 50-60 days) and late floods spreading over the flood-plain and delta during the growing period hinder the intensive land utilization. The agricultural land should be protected with levees.

Soils and vegetation

The soils of the flood-plain and delta are composed of century-old fertile silt deposits brought from year to year by flood waters. Shallow occurrence of groundwater table was and is very important for soil formation processes.

The soils composing the flood-plain and delta are extremely different by their composition. All kinds of soil varieties from the young alluvial deposits not affected by the soil formation processes to the meadowy chernozem-like soils with considerable range of solonchak varieties can be found here. The soil texture varies greatly, from sand to heavy clay.

In the flood-plain and delta, meadow vegetation prevails creating fodder reserves for the local livestock. The elevated places within the flood-plain, usually the ridges, are covered with forests. The riverside strip of the delta is grown with cane.

The light-chestnut and brown soils together with saline and alkaline soils are typical of the adjacent areas. The vegetation grown here belongs to wormwood-and-grass family and to saltwort (Chenopodiaceae).

[1] Ilmeni -pl. Russ., lake-shaped depressions in the Volga delta.

PRESENT STATE OF NATIONAL ECONOMY IN VOLGA-AKHTUBA ZONE

Fishery

The Volga and its delta play the main part in the reproduction of sturgeon and carp kinds of fish. During flood periods, carp (sazan), bream, pike perch, vobla (Caspian roach), etc. spawn in the Volga delta.

The Northern-Caspian area (the Volga delta is included) is one of the main fishery regions in the Soviet Union.

The great economic significance of the fishery in the northern part of the Caspian Sea is evaluated not by the quantity of the fish caught but rather by its high quality and valuable species.

The level in the Caspian Sea has lowered by 2.5 m as compared with 1929. This changes the conditions of reproduction, the fattening and winter inhabit of some valuable food-fish. The further fall of the Caspian Sea level is expected.

Agriculture

Agriculture of the Volga-Akhtuba zone is greatly influenced by the almost yearly inundations of the main areas within the flood-plain and delta as well as by the availability of vast semidesert pastures in the riverside regions. The conditions favour cattle growing.

The flood-plain haylands are considered to be the main source of getting coarse fodder for stabling periods thus providing the cattle with the pasture fodder during the periods of fodder deficit in the steppe. Out of the total hayland area, the flooded haylands make up 87 per cent. Productivity of the latter is reliable enough, the fodder obtained there is the cheapest.

The main branches of agriculture are vegetable raising and melon production. Tomatoes and watermelons are mainly grown. The yields obtained by the farms in the Volga-Akhtuba zone are the highest in the Russian Soviet Federative Socialist Republic. Excellent gustatory qualities of watermelons and tomatoes has made the area very popular. Many of the local kinds of apple, quince and table grape are well known.

Almost all agricultural crops require irrigation because of the arid climate of the Volga-Akhtuba zone. Experience has shown that dry agriculture in the zone is not effective and often is even unprofitable.

In the Volga-Akhtuba zone the area under irrigation approximates 60 thousand ha or 15 per cent of the entire sown and planted areas. In spite of the low percentage of the irrigated land it produce ¾ of all the marketable agricultural production.

All paddy fields, 89 per cent of vegetable plantations, 47 per cent of the fields under melon crops, 81 per cent of grain corn fields and 69 per cent of orchards and vineyards are in the irrigated areas.

The role of the Volga-Akhtuba zone is very important at present already as it supplies Volgograd and Astrakhan with food products, it is a reliable source of raw materials for the local vegetable and fruit canning industry.

Navigation

The Great Volga Way crosses the Volga-Akhtuba zone and in the delta it runs via the Caspian Sea. The navigation route to the Sea is through the Bakhtemir river, one of the branches starting below Astrakhan, and then it follows the Volga-Caspian canal for over 100 km long.

The water and transport network within the flood-plain and the delta in particular is heavily developed. Passenger and passenger-and-freight boats run along the navigation routes. At the point where the sea and riverways meet there is a large river and sea port of Astrakhan.

The construction of the White Sea-Baltic Sea canal, Moscow canal, V.I. Lenin Volga-Don navigation canal and the conversion of the Volga into the system of reservoirs have opened the waterway from the Caspian Sea to the White, Baltic, Asov and Black Seas and to Moscow, the capital of the USSR.

Forestry

Forests within the flood-plain and delta are met along the banks of the Volga and Akhtuba, fringe the islands and banks of the lakes and watercourses. The area under forests is over 117 thousand ha.

Forests decrease flow velocities during spring floods, prevent the banks, islands and levees from scouring.

Use of cane

The Astrakhan region has the richest resources of cane covering the area of 315 thousand ha. Annual yield reaches 2.5 million tons. Cane is used as a raw material for pulp-and-paper industry.

The 1st stage of the pulp-and-cardboard mill has been commissioned. The mill produces cardboard, fibrous slabs, nutrient yeast, etc.

Cane is used as a building material. In the delta there are mills producing cane sheets. A factory to manufacture prefabricated houses made of cane sheets is at present under construction.

HYDRAULIC AND POWER DEVELOPMENT ON THE VOLGA AND KAMA

The construction of the systems of hydroelectric stations on the Volga and Kama and the connection of the Volga with other rivers and seas solve many problems which are of importance for the Soviet national economy. The most important problems are: power utilization of the rivers, namely the Volga and its tributary Kama which are the largest in the European part of the USSR, and the creation of the system of main waterways. In the regions adjacent to the middle and lower Volga conditions become favourable for further development of agriculture with electrification of irrigation and water supply systems.

On the Volga and Kama the construction of the hydroelectric stations is completed at the village of Ivanjkovo and at the towns of Uglich, Rybinsk, Perm, Gorky. The most powerful stations in the world Volzhsky station named after V.I. Lenin near Kuibyshev and the Volzhsky station named after the XXII CPSU Congress near Volgograd are also commissioned. The installed capacity of the systems of hydroelectric stations on the Volga and Kama is now 6.2 million kW, and the power output for a mean water year is 17 billion kWh.

The Votkinsk station on the Kama and Saratov station on the Volga are being constructed, three stations more are under design. After the completion of construction of the systems the installed capacity of the stations will be 12.7 million kW with the mean annual power output of 45 billion kWh. The total storage capacity of the reservoirs will be 203 km^3.

Consideration is being given to increase the power generation at the hydroelectric stations on the Volga, to deliver irrigation water to the regions behind the Volga, to stabilize water levels in the Caspian sea and to the diversion of some portion of the flow of the Northern rivers, namely the Pechora and Vychegda to the Volga.

FLOW REGULATION IN THE FLOOD-PLAIN AND THE DELTA

Water supply of spawning areas within the delta

The areas to be irrigated in the flood-plain and the delta will be 375 thousand ha in which a considerable part will be natural meadows.

Utilization of the flood-plain and delta areas on an intensive scale will necessitate the construction of lift irrigation, levees, irrigation network of reinforced concrete flumes or pressure pipes, sprinklers, levelling of land and filling up of some streams and the establishment of specialized state farms. All the above works require considerable capital investments and time.

Therefore, it is very important to apply the simplest methods of irrigation in the haylands and pastures together with the irrigation of intensive crops, as the former does not require considerable capital investments and labour for irrigating.

The guaranteed irrigation of haylands, pastures, forests, cane areas and supply of spawning areas with water can be attained with relatively small amounts of water by means of the system of hydraulic structures. However their construction will require considerable capital investments and time. Thus sequences of construction should be planned.

The main part of the delta is inundated when the flood discharge is about 25 thousand m^3/sec, out of which 15.5 thousand m^3/sec enter the western part of the delta through the main channel. The remaining 9.5 thousand m^3/sec enter the eastern part of the delta through the Busan and Akhtuba rivers. In low-water years provision is made for the inundation of the eastern part of the delta by diverting there 9.5 thousand m^3/sec with the help of a special structure. The same result will be evidenced in the western part of the delta if the discharge of 15.5 thousand m^3/sec is delivered there. The spill of water from one part of the delta to the other can be prevented by the erection of a small longitudinal bund. The above stated was taken into consideration when constructing the regulator permitting to inundate one of the delta parts with comparatively small flood discharges.

Spawning areas are designed in the eastern part of the delta fishing ground and reclamation developments are being provided there. To control the water supply of this area regulator will be constructed on the Volga at the head of the delta. The regulator is projected as a dam of disassembling type with a total span of 1,100 m, and 4 m head. The dam will close the Volga channel below its branch, the Busan river. This structure in low-water years will discharge 9.5 thousand m^3/sec to the eastern part of the delta, while the discharge not less than 3 thousand m^3/sec will be let into the main channel to provide the navigation depths. The regulator has a fishpass and a lock for ships. When the water supply period lasting 60 days is over in the eastern part of the delta the dam is disassembled and the Volga channel is free.

The construction of the regulator will create the most favourable conditions for inundating the spawning areas in the eastern part of the delta over the area of about 600 thousand ha. The regulator will protect the cane and will make possible the simplest methods of irrigation for the haylands and pastures over the area of 180 thousand ha.

The construction of the regulator has been commenced.

Simplest methods of irrigation of haylands within the flood-plain

The construction of the regulator on the Volga will solve the problems of water supply of spawning areas and application of the simplest methods of irrigation of haylands and cane areas only in the eastern part of the delta.

To irrigate haylands, pastures, forests and cane areas in the flood-plain and western part of the delta it is planned to provide these areas in low-water years with guaranteed water releases of short duration. During low-water years, except the catastrophic ones, that is during 3 years out of 10, the Volzhsky hydroelectric station named after the XXII CPSU Congress will deliver as much as 125 thousand m^3/sec to the downstream in 12 days. In order to reduce the power losses the releasing of water should coincide with the period of spilling of the regulated peak. In low-water years the amount of water released will total 50 km^3, out of which as much as 10 km^3 will not pass through turbines.

Mean annual amounts of additional releases will make up 3.6 km^3, i.e. 2.5 per cent of the mean annual spring runoff. During catastrophic low-water years, to inundate the areas within the flood-plain it is necessary to provide additional spillings amounting to 20 km^3. During such years releases are considered to be undesirable. Water releases of short duration make it possible to introduce the simplest methods of irrigation over the area of about 700 thousand ha covering haylands, pastures and forests. It should be noted that each hectare gets additionally 5 thousand m^3 of water.

The total capital invested per 1 ha of the meadows and pastures irrigated by the simplest methods including the expenses to compensate for power losses approximates 30 roubles, the mean annual expenditure being about 4.5 roubles.

The water released will permit the inundation for a short period of the area of 150 thousand ha under cane in the western delta.

The water releases of short duration should be considered only as a temporary measure for the low-water years (3 years out of 10 years) during the period prior to the completion of reconstruction of the lower section of the Volga.

POWER UTILIZATION OF LOWER SECTION OF THE VOLGA

Nizhne-Volzhsky hydroelectric station

Reorganization of agriculture within the Volga-Akhtuba zone is connected with the introduction of lift irrigation over vast areas together with the electrification of the industrial plants such as the fertilizers plant and processing factories and for domestic uses. The ever growing demands for electric power can be met by the new hydroelectric station, known as the Nizhne-Volzhsky hydroelectric station to be constructed on the Volga below Volgograd.

The hydroelectric station is to be located at the section between Volgograd and Astrakhan. The Nizhne-Volzhsky hydroelectric station is the last stage of the system of hydroelectric stations on the Volga and Kama. It will operate with the flows which are regulated by the above created reservoirs. That is why the regulation reservoir of this station is not required. The capacity of the station will be 1.5 million kW and the power output will be about 6 billion kWh per year.

The pondage of this station will inundate the area within the right-bank flood-plain. To protect the lands which are within the left-bank flood-plain from inundation the levees 288 km long with the head up to 15 m will be erected along the left bank of the Volga on the stretch from the Volzhsky hydroelectric station named after the XXII CPSU Congress to the Nizhne-Volzhsky hydroelectric station. At the section from the hydroelectric station to the regulator the levees which are not high will be built to protect the downstream part of the left-bank flood-plain from the flood inundation.

The volume of earthwork of this hydroelectric station will be 262 million m^3, the volume of concrete and reinforced concrete placed will be 2.3 million m^3.

Application of simplest methods of irrigation of haylands after the construction of the Nizhne-Volzhsky hydroelectric station

To raise the productivity of natural meadows and pastures within the left-bank flood-plain and to preserve forest plantations it is designed to make use of the water releases for irrigation needs. The irrigation is to be applied two or three times per a vegetation season. The irrigation discharge of 2.3 thousand m^3/sec is to be delivered from the upstream of the Nizhne-Volzhsky hydroelectric station through a special structure. During the rest of the year this structure will release small discharges to the Akhtuba and to the system of watercourses connected with the Akhtuba. The releases are meant for navigation, water supply and also irrigation.

To exercise the simplest methods of irrigation over the haylands and pastures within the western part of the delta, the 2nd stage regulator on the Busan river will be constructed. The discharge delivered will be 16.5 thousand m^3/sec.

The regulator will give inundation to the western part of the delta (prior to spawning) first and then it will inundate the eastern part. The vice versa order of the inundation is also possible. With the regulator of this type the possibility of delivering fresh water to the northern part of the Caspian sea will be realized thus creating the best conditions for the fish fattening.

The area under irrigation of the simplest type within the flood-plain and delta will total 520 thousand ha. Capital investments per 1 ha of natural meadows and pastures under irrigation of this simplest type will be about 100 roubles.

Irrigation of the simplest type will prevent both the conversion of the lands into steppes and salinization of the flood-plain areas. These areas can be developed in any succession and at any rate in conformity with the planned agricultural development of the Volga-Akhtuba zone.

The areas under intensive irrigated crops should be protected from inundation by levees. The height of these levees in the flood-plain will be 1.5 m. Some areas are to be irrigated by gravity in which water is to be diverted from the upstream of the Nizhne-Volzhsky hydroelectric station. The height of the water lift for the right-bank irrigation systems will be decreased.

On the Volga from Volgograd to the site of the Nizhne-Volzhsky hydroelectric station the river will have the guaranteed navigation depth. The length of the transit navigation route will be reduced by 50 km. The volume of earth dredged will be reduced as well. The Akhtuba and main watercourses of the flood-plain will also become navigable.

It is planned to clear the Akhtuba and to arrange several artificial spawning areas for the sturgeon fishes.

PROTECTION AND IMPROVEMENT OF FISH RESERVES

The conservation of reliable reserves of the main food-fish in the Northern-Caspian area under the conditions of the regulated flow can be achieved by carrying out a number of fish-breeding and reclamation developments.

The reproduction of fish belonging to sturgeon family may be provided by artificial raising of fish at fish-farms of intensive type. Three fish farms meant for sturgeon reproduction have already been built.

The proper organization of an artifical sturgeon breeding will not only prevent damages caused by hydraulic construction, but will also permit the increase in reproduction of fishes. The food reserves of the Caspian sea do not limit the number of sturgeon fishes.

The research work is now being conducted to find out whether it is reasonable to use the Akhtuba channel for the natural spawning of the sturgeon fishes entering the Volga from the delta.

The commercial yields of carp, bream, pike perch and Caspian roach are kept at the designed level due to the water supply and reclamation of the natural spawning areas in the eastern part of the delta will as due to the creation of intensive spawning and fish breeding establishments.

To provide the sires with ways of entering the delta from the sea and to let them distribute uniformly over the flooded spawning areas as well as for the young fish to go down to the sea, drainage canals have been dug over the area and the main branches have been cleared and deepened.

The water supply for the improved natural spawning areas in the eastern part of the delta as well conform to the regime of the optimum years under the nonregulated flow.

In the western ilmeni adjoining the steppes, commercial fish farms have been planned for the raising of pond fishes (mostly carp).

PROSPECTS OF DEVELOPMENT OF AGRICULTURE

Development of farming

In the Volga-Akhtuba zone there are great possibilities for increasing the production of vegetables, rice, melon, fruits, meat and fine wool. The natural conditions of the Volga-Akhtuba zone call for irrigation agriculture.

The total area under irrigation in the Volga-Akhtuba zone will amount to 575 thousand ha, including 375 thousand ha in the flood-plain and delta.

In addition, the simplest methods of irrigation is proposed over 520 thousand ha of natural meadows and pastures.

Irrigation development will sharply increase the production output and will fully provide the population of Volgograd and Astrakhan with vegetables, melon, rice, fruits and partially with potatoes. The central regions of the country will be supplied with early vegetables (mainly tomatoes), watermelons and fruits. The raw material for canning industry will thus be created.

Animal husbandry

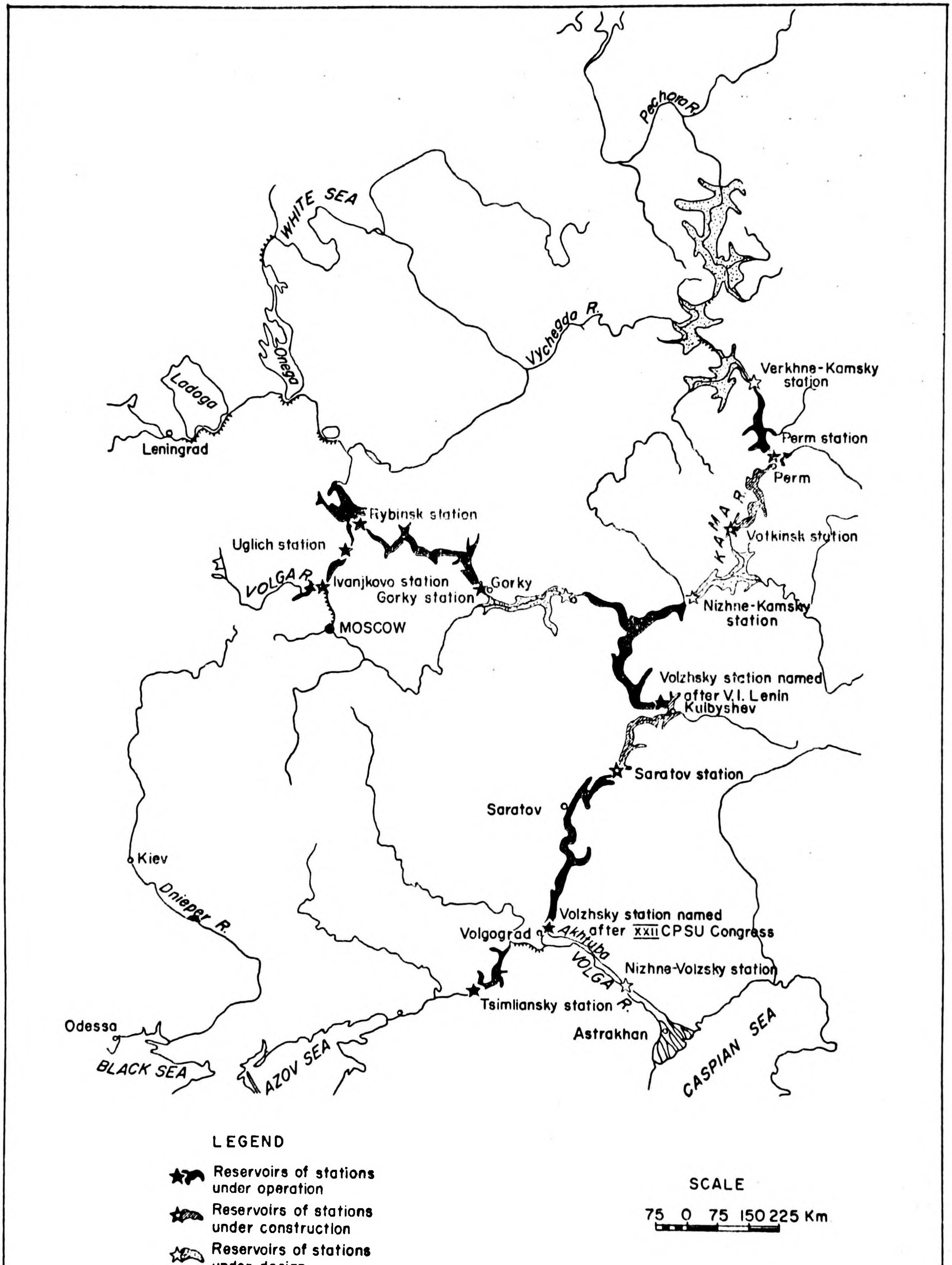
The increase of forage production, succulent fodder in particular, and the measures for improving the haylands and pastures will result in the threefold increase of forage reserves. With the forage production raised up to such a level, the forage deficiency now existing will come to an end. This will create the conditions favourable for the growth of cattle and poultry, mainly waterfowl.

For the purpose of waterfowl breeding in the flood-plain and the delta, about 15-20 thousand ha of reservoirs will be used to raise ducks.

The gross output of the livestock production will increase 3-4 times.

Irrigation and water supply

The areas under irrigation will increase from 60 thousand ha to 575 thousand ha, including as many as 375 thousand ha in the flood plain, delta and ilmeni. About 75 per cent of the irrigated lands in the flood-plain, delta and ilmeni are to be located behind the levees. Sprinkling is designed for 150 thousand ha, flood irrigation (rice systems) is planned for 120 thousand ha, furrow and strip irrigation is projected for 305 thousand ha.



Fiugre 54. HYDROPOWER DEVELOPMENT SCHEMES ON VOLGA AND KAMA RIVERS, USSR

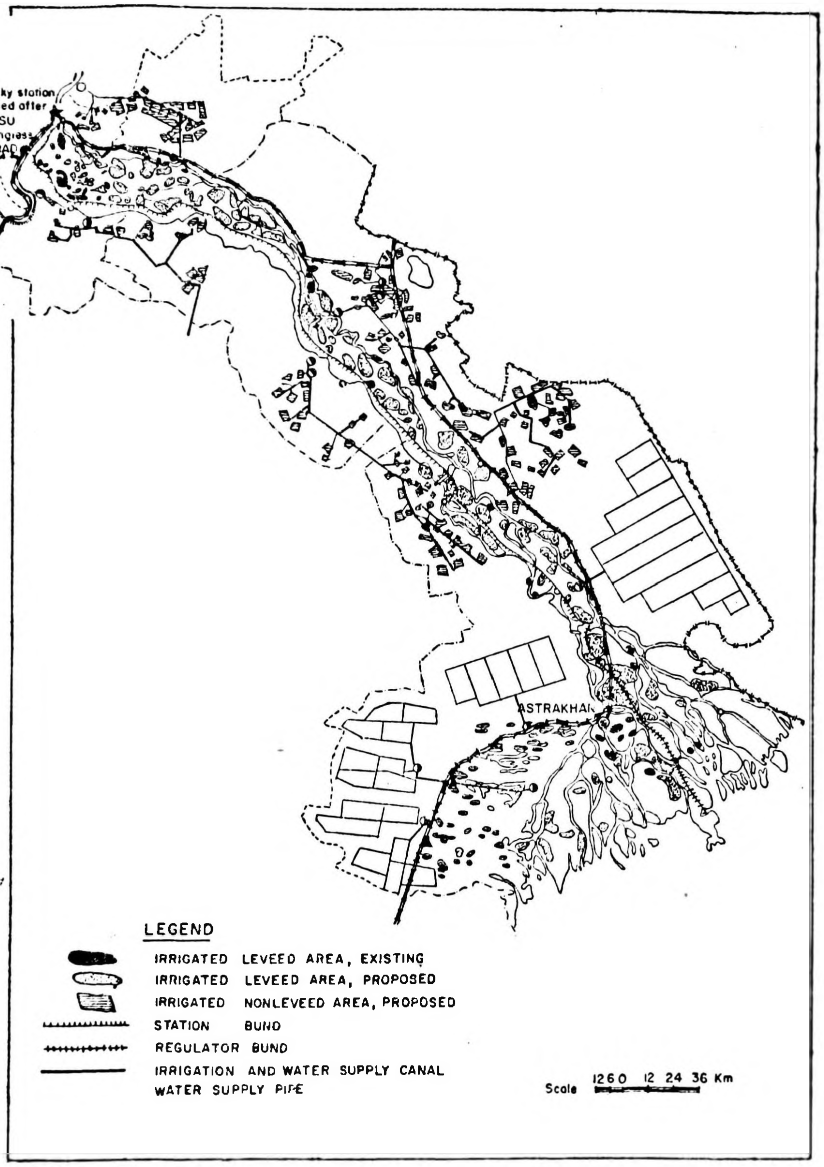


Figure 55. MULTIPURPOSE SCHEME OF LAND AND WATER RESOURCES UTILIZATION IN VOLGA-AKHTUBA FLOOD PLAIN AND VOLGA DELTA

The use will be made of flexible pipes over an area of 140 thousand ha. The inner-farm irrigation network is designed to be composed of flumes made of prestressed reinforced concrete.

Water to the irrigation systems will be delivered by pumping stations, the water lift being 10-20 m.

Electrified stationary and floating pumping stations will ensure irrigation over 500 thousand ha. The installed capacity will be 85 thousand kW with the power requirements of 125 million kWh per year. It is designed to irrigate the elevated areas, i.e. the areas located on the ridges, amounting to 60 thousand ha, with the help of floating pumping stations. The areas are to be irrigated when the flood is over. The capacity of floating thermal pumping stations will be 25 thousand h.p.

The water supply of the riverside semidesert pastures over the area of 2.3 million ha is designed to be made mainly from the network of irrigation and watering canals and asbestos-cement pipes, their total length being 928 km.

The total volume of water for irrigation and water supply will approximate 3 km^3.

Capital investment efficiency

In the course of construction of irrigation and water supply systems, which will take about 15 years, it is expected that the volume of earthwork will be 300 million m^3 and the volume of concrete and reinforced concrete placed will be 450 thousand m^3.

With the development of irrigable land resources of the Volga-Akhtuba zone and the hydraulic constructions, some measures to organize agriculture under new conditions will have to be made. It is planned to establish specialized farms.

The productivity of labour in state and collective farms within the zone will increase three times, the cost of production will decrease by over 40 per cent.

The capital expenditures required for the hydraulic constructions and the development of agriculture will be justified after 3-4 years.

The development of the Volga-Akhtuba zone is a matter of great national importance.

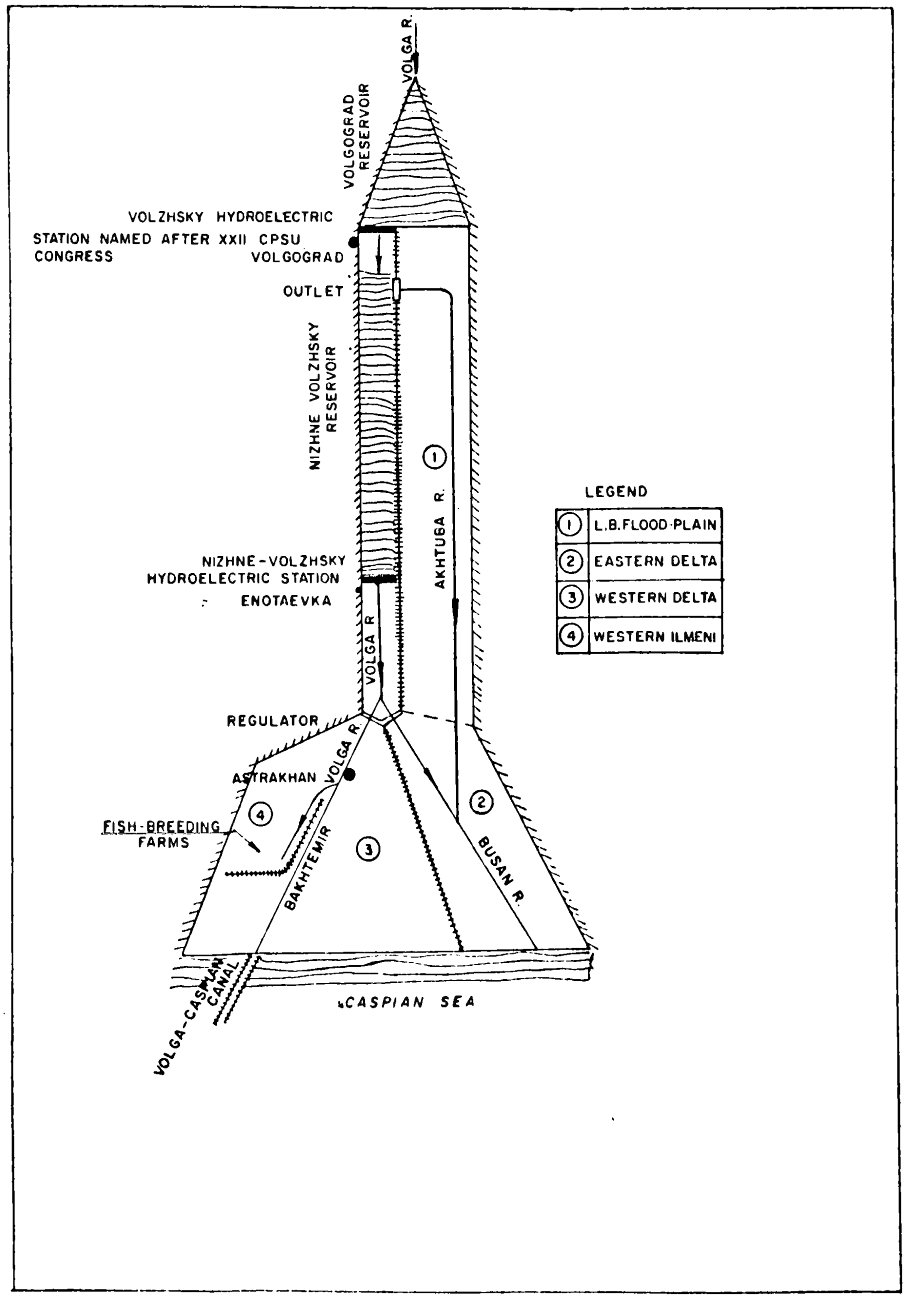


Figure 56. SCHEME OF IRRIGATION OF HAYLANDS, PASTURES, FORESTS, CANE AND SPAWNING AREAS IN VOLGA-AKHTUBA FLOOD PLAIN AND VOLGA DELTA

Paper No. 9

MAINTENANCE OF A RIVER MOUTH WHICH IS CONNECTED WITH A TIDAL BASIN*

The discharge through a channel which connects a reservoir or a basin with the sea is generally determined by the tidal curve of the sea. Besides, it depends on two factors, the hydraulic resistance of the channel and the capacity of the basin for a given tidal graph of the sea.

There may be three cases as follows, depending on the relative conditions between the above two factors.

(A) The discharge flowing in and out is to be dominated exclusively by the hydraulic resistance of the channel in the case of the basin with large water surface.

(B) The discharge is to be determined primarily by the capacity of the basin in the case of a basin with a small water surface.

(C) The discharge is influenced by both factors if the channel and the size of the basin are evenly balanced.

Let us consider the changes of the discharge at the estuary to varying conditions of the two factors for the above 3 cases, for a given tidal curve.

For case (A), a slight difference in the surface area of the basin occasions little change in the discharge, but a diminution of the hydraulic resistance of the channel brings a rather noticeable increase in the flowing in and out discharges.

In this case, the diminution of the hydraulic resistance by channel improvement works, such as short cut of waterway, enlargement of the channel section, increase of depth by dredging etc., will augment the discharge at the estuary for a given tidal condition and will have a good effect on the maintenance of the river mouth.

Nevertheless, much attention must be paid to preventing an enlargement of tidal amplitude and salt water intrusion into the basin.

Case (B) is just the reverse of case (A). Channel improvement works will cause little change in the discharge flowing in and out; on the contrary, the change of water surface area (for example, due to reclamation work) will cause a great change in the flow.

For case (C), a change of either factor will influence the discharge.

The influence which the close proximity of a basin to the estuary has on the maintenance of the river mouth may thus be ascertained from the above. Nevertheless, to ascertain this quantitatively, it is necessary to solve the equations of movement and continuity of the unsteady flow simultaneously under given boundary conditions (varied flow may be substituted by an unsteady flow in the case of a relatively short channel or in the permissible case of approximation).

For further discussion on general aspects of the problem, quantitative study is carried out under several assumptions.

Fig. 57 shows the general scheme of water bodies near the sea. Point A represents the lower reach of a tidal river and point B is the outlet of the lake of which the water stage represents that of the lake.

Let $H(t)$ and $h(t)$ represent the water stages at points A and B respectively. Head loss, h_l, of the flow between these two points is expressd as follows:

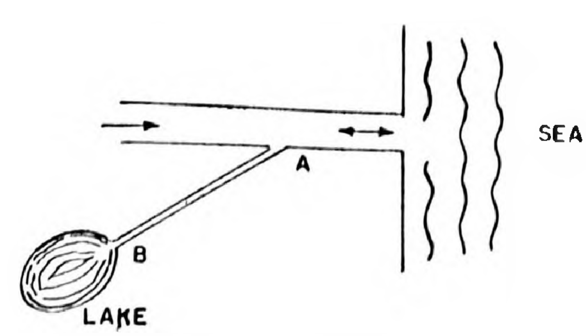


Figure 57. A LAKE CONNECTED WITH THE LOWER REACH OF A TIDAL RIVER

$$h_l = h(t) - H(t) \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Using Manning's formula,

$$h_l = \frac{n^2\, Q(t)\, Q(t)}{B^2 \cdot R^{10/3}} \qquad \ldots\ldots\ldots\ldots \quad (2)$$

Where n is roughness coefficient in Manning's formula, B is the width of the channel, R is the hydraulic radius, L is the distance between A and

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B and Q(t) denotes the discharge with + sign toward the sea and − sign from the sea.

The equation of continuity in the lake is:—

$$h(t) - h(o) = \frac{-1}{A} \int_o^t Q dt \quad \ldots\ldots\ldots\ldots\ (3)$$

In the above equation, h(o) is the water stage of point B at t=o and A is the water surface area of the lake.

The timely change of Q should be precisely obtained by solving simultaneously the equations of movement and continuity for unsteady flow with given boundary conditions. However, judging from many examples, the change of Q during the half period can be assumed as approximately linear. Thus equation (3) may be replaced by the following:—

$$h(t) - h(o) = \frac{-1}{2A} [Q(t) + Q(o)]\, t \quad \ldots\ldots\ (4)$$

From equations (1), (2) and (4), we obtain:

$$\frac{n^2 Q(t) Q(t)}{B^2 \cdot R^{10/3}} \cdot L = \frac{-1}{2A} [Q(t) + Q(o)]\, t + h(o) - H(t)$$

Replacing

$$\frac{n^2 L}{B^2 \cdot R^{10/3}} = K_1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (5)$$

and

$$\frac{t}{2A} = K_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (6)$$

the above equation becomes;

$$K_1 \cdot Q(t)Q(t) + K_2 \cdot Q(t) + H(t) - h(o) + K_2 Q(o) = O \quad \ldots\ldots\ldots\ldots\ (7)$$

K_1 expresses only the conditions of water channel, i.e., some constant coefficient of the roughness of the channel (strictly speaking, width and depth are variable with time) and K_2 is the constant expressing the relation between the behaviour of the lake and the tidal period, namely, a constant which represents the capacity of the lake.

For positive discharge equation (7) becomes;

$$Q(t) = \frac{-K_2 + \sqrt{K_2^2 + 4K_1[H(t) - h(o) + K_2 Q(o)]}}{2K_1} \quad (8)$$

and for negative discharge, it becomes:

$$Q(t) = \frac{-K_2 + \sqrt{K_2^2 + 4K_1[H(t) - h(o) + K_2 Q(o)]}}{-2K_1} \quad (9)$$

In the case of

$$K_2^2 \geqq 4K_1[H(t) - h(o) + K_2 Q(o)] \quad \ldots\ (10)$$

equations (8) and (9) can be reduced to

$$Q(t) = \frac{H(t) - h(o) + K_2 Q(o)}{K_2}$$

or

$$Q(t) = \frac{H(t) - h(o) + K_2 Q(o)}{-K_2} \quad \ldots\ldots\ (11)$$

This explains case (B) where the influence of K_1 disappears and the discharge is controlled only by the water surface area. Making the area smaller, K_2 becomes larger and the discharge decreases. At zero water surface, area K_2 becomes infinite and the discharge becomes zero.

The variation in the resistance term has little effect on the discharge in so far as the condition remains within the scope of equation (10).

When $$K_2^2 \leqq 4K_1[H(t) - h(o) + K_2 Q(o)] \quad \ldots\ (12)$$

Therefore $$Q(t) = \frac{\sqrt{-[H(t) - h(o) + K_2 Q(o)]}}{\sqrt{K_1}}$$

$$\text{or} = \frac{\sqrt{[H(t) - h(o) + K_2 Q(o)]}}{\sqrt{-K_1}} \quad \ldots (13)$$

This equation (13) is applicable to case (A) where the term of water surface area itself is much smaller (that is the water surface area itself is very large) than the terms of resistance and variation of water stages. In this case, the discharge is determined by the resistance term with no regard to the water surface area.

Although, in the case of equation (10), little change in the discharge is occasioned by the variation of resistance, in the case of equation (12), the discharge changes directly with variation of resistance and the rate of the change is reversely proportional to the square root of K_1.

An example of the river Naka in Ibaragi Prefecture is given hereunder.

Fig. 58 shows the estuary part of the Naka river which has a lake (the water surface area is 10 km²) connected with the estuary by the 9 km stretch of the river Hinuma.

Tidal ranges at Shimoishizaki, the outlet point of the lake, and Iwai-cho, at the mouth of the river Naka are shown in fig. 59. The distance between the two points is 9.2 km.

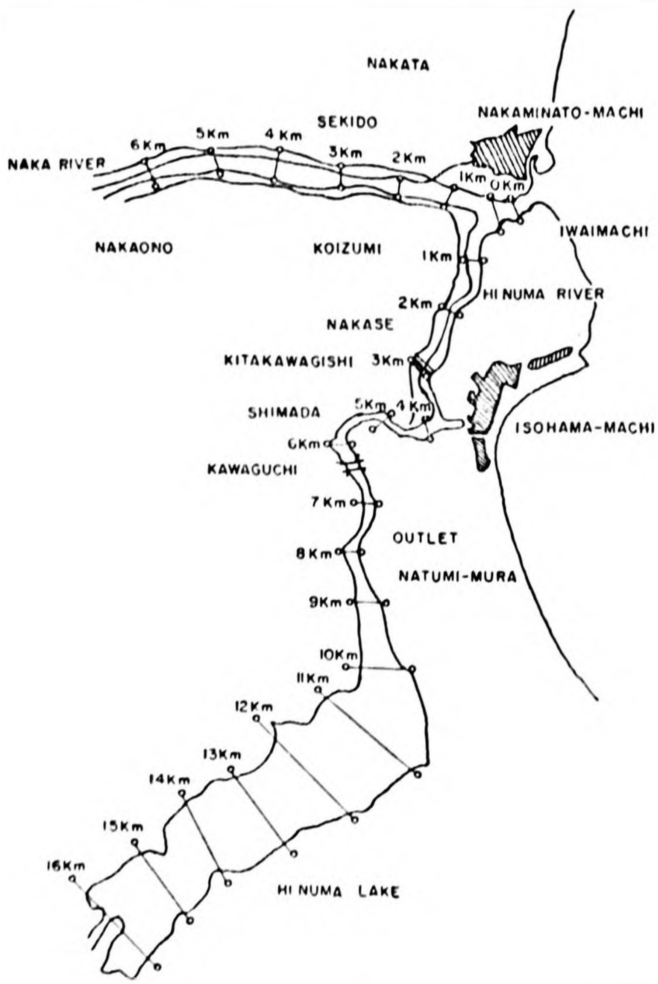

Figure 58. MAP SHOWING THE ESTUARY PART OF NAKA RIVER, JAPAN

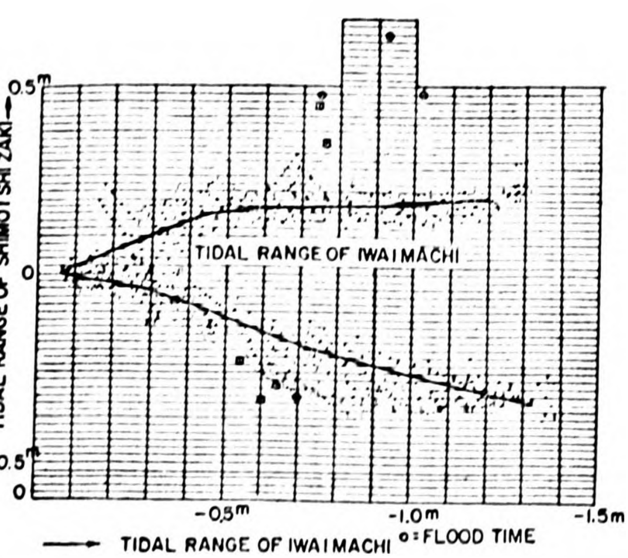

Figure 59. RELATION OF TIDAL RANGE BETWEEN NAKA RIVER AND HINUMA LAKE, JAPAN

From fig. 59, a large diminution of tidal range due to the resistance of the Hinuma river is seen, namely, the tidal range of 1.35 m at the mouth of the main river is reduced to 0.34 m at Hinuma lake outlet.

A close investigation of water stages along the main river, Hinuma lake and the Hinuma river shows almost the same tidal curves.

In fig. 60, a one and a half hour time-lag of ebb tide for Hinuma-bashi and a four and a half hour time-lag for Shimoisizaki are shown, as well as the maximum stage difference of 1.1 m between Shimoishizaki and Iwaicho. At the maximum difference in stages, the water moves rather fast and the measured velocity is about 2.0 m/sec.

Thus the present hydraulic resistance of the river Hinuma seems rather large. To make the resistance smaller would mean more storage effect to the lake, which would give better results in the maintenance of the estuary.

At present, there is a time lag between the discharge hydrographs of the Hinuma river and the main river. At the estuary, the discharges of these two rivers often run against each other in opposite directions. The reduction of hydraulic resistance will tend to create the coincidence of phase of discharge hydrographs of both rivers, thus the storage effect of Hinuma lake will be greatly increased.

Thus, the treatment of Hinuma river may be an important key to the problem of maintenance of the river mouth of Naka.

As an example, the character of this water scheme is analysed by the above mentioned equations and the measured values, as follows.

From measured data (see fig. 60 and 61) on the 5th of May 1954, (starting $Q=0$ at $t=0$) we obtain;

$$t = 14{,}400 \text{ sec}$$
$$H(t) = 0.72 \text{ m}$$
$$h(t) = 0.2 \text{ m}$$
$$Q(t) = 180 \text{m}^3/\text{sec}$$
$$h(o) = 0.3 \text{ m}$$
$$Q(o) = 0$$

From equations (1), (2) and (5)

$$K_1 = \frac{n^2L}{B^2 \cdot R^{10/3}} = \frac{h(t)-H(t)}{Q(t) \cdot Q(t)} = \frac{0.92}{180^2}$$

A is given as 10×10^6 m², then

$$K_2 = \frac{1}{2}\,\frac{t}{A} = \frac{14{,}400}{2 \times 10{,}000{,}000} = 7.2 \times 10^{-4}$$

Therefore,

$$K_2^2 \leq -4K_1[H(t)-h(o)+K_2Q(o)];$$

which shows that this case should be in the category of the equation (12).

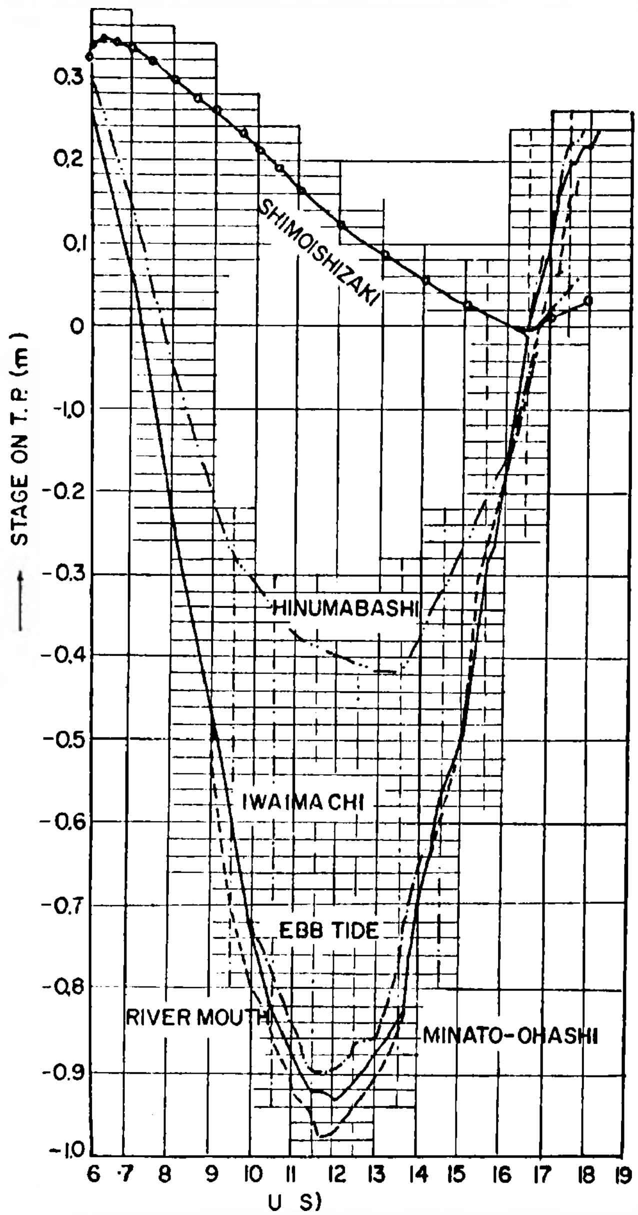

Figure 60. STAGE HYDROGRAPHS NEAR THE ESTUARY OF NAKA RIVER

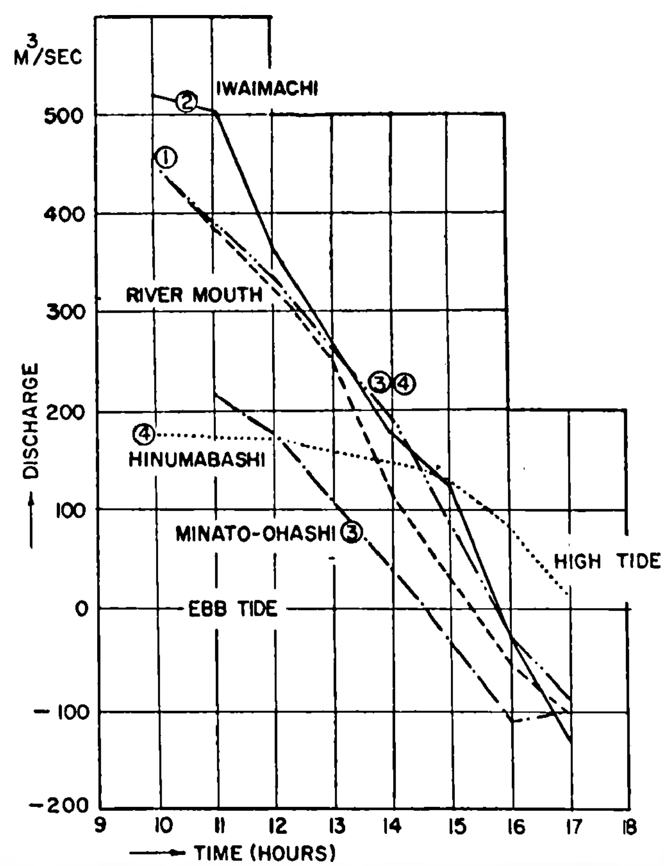

Figure 61. DISCHARGE HYDROGRAPHS MEASURED ON 5 MAY 1954 NEAR THE ESTUARY OF NAKA RIVER

Paper No. 10

EFFECT OF CLOSURE OF KOJIMA BAY ON THE TIDE AND FLOOD WATER LEVELS AT THE MOUTH OF ASAHI RIVER*

Abstract

This study is to determine the hydraulic characteristic of a river at various points along the tidal reach and to investigate the effect of closing a part of Kojima bay near the mouth of Asahi river and forming it into a fresh water reservoir.

The method employed in this study incorporates the resistance of fluid motion in the calculation. It solves the characteristics of the condition in the bay which is subjected to forced oscillation at its mouth. The method may also be applied to the case of a bay having in-or outflow and to tidal rivers.

The method described is by no mean complete. It has to be further developed to take care of more details of the problem, and the complicated and labourious computation involved in the calculation has still to be simplified.

I. INTRODUCTION

Kojima bay is a part of the Seto inland sea. It lies to the south of Okayama city. Natural silt deposition is progressing in the bay.

The land along the bay has moderate temperature and ample sunshine. It also has fertile soil and good transport facilities. All these attracted the interest of the authorities concerned with land reclamation. The first reclamation project in this district was started by Fujitagumi in 1887.

With the increase in the area being reclaimed, the problems relating to the irrigation and drainage of the reclaimed land became more and more important. The scarcity of annual rainfall, which amounts to about 1,000 mm, caused a shortage of irrigation water. Farmers had to rely on water stored in ponds and the discharges of Asahi and Takahashi rivers. Apart from that, this district was subjected to poor drainage, salt water intrusion and frequent drought.

In order to solve these problems, the Ministry of Agriculture and Forestry decided to build dike across a part of the Kojima bay to form a fresh water reservoir and to construct drainage works for the reclaimed land. The work was started in 1950.

It was thought that the loss of the inner part of the bay might change the tidal characteristic, and that the flood stage at the mouth of Asahi river might rise due to the decrease in storage for flood. On the other hand, the decrease of tidal flow due to the closure might cause deposition of silt at the mouth of the river. These problems were considered important from the standpoint of maintenance and navigation of the Asahi river.

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II HYDRAULICS OF LONG NARROW BAY

(A) Fundamental equation and method of calculation.

The equation of motion of unsteady flow is given as follows;

$$\frac{\partial}{\partial x}\left(\frac{v^2}{2g}\right) + \frac{1}{g}\frac{\partial v}{\partial t} + fv^2 = -\frac{\partial \xi}{\partial x} \qquad (1)$$

where f is the coefficient of frictional resistance, which can be derived from $f = \frac{1}{C^2R}$ (Chezy's formula) or $f = n^2/R^{4/3}$ (Manning's formula), and ξ is the elevation of water surface from the datum.

The equation of continuity for unsteady flow is given by

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \qquad (2)$$

where A is the area of the flow section.

By taking ξ to denote the height of the water surface from mean sea level, and $A = A_0 + b\xi$ as the sectional area of the channel, we have $\frac{\partial A}{\partial t} = b\frac{\partial \xi}{\partial t}$ (3)

Substituting eq. (3) in (2), we have from (1)

$$-A\frac{\partial \xi}{\partial x} = A\frac{\partial}{\partial x}\left(\frac{v^2}{2g}\right) + \frac{1}{g}\left(\frac{\partial Q}{\partial t} + v\frac{\partial Q}{\partial x}\right) + Afv^2$$

Neglecting the term $\frac{\partial}{\partial x}(\frac{v^2}{2g})$ and differentiating

$$\frac{A}{b}g\frac{\partial^2 \xi}{\partial x^2}+\frac{g}{b}\frac{gA}{\partial x}\frac{\partial \xi}{\partial x}-\frac{\partial^2 \xi}{\partial t^2}+\frac{1}{b}\frac{\partial}{\partial x}$$

$$(v\frac{\partial Q}{\partial x})+\frac{g}{b}\frac{\partial}{\partial x}(Afv^2)=O \quad (4)$$

From eq. (2)

$$\frac{\partial Q}{\partial x}=-b\frac{\partial \xi}{\partial t} \quad (5)$$

By solving equations (1) and (5) or (4) and (5), we shall be able to solve the given problem.

As it is impossible to solve these equations analytically, we have to obtain their numerical solutions.

By changing ∂ into $\triangle$, equation (1) becomes:

$$\triangle\xi=-\frac{1}{2g}\triangle v^2-\frac{1}{g}\frac{\triangle v}{\triangle t}\triangle x-fv[v]\triangle x \quad (6)$$

When there is local inflow or outflow, equation of continuity (5) may be written as follows:

$$Q_2-Q_1=q=-b\triangle x\frac{\triangle\xi}{\triangle t}$$

where q is taken as positive for inflow, and negative for outflow. Taking $\triangle F$ to be the water surface area in section $\triangle x$ and b its average width, we have

$$\triangle F=b\triangle x$$

Therefore, the equation of continuity can be written as;

$$Q_2-Q_1-q=\triangle F\frac{\triangle\xi}{\triangle t} \quad (7)$$

Equations (6) and (7) are to be solved with the boundary conditions of $\xi=f(t)$ and $\frac{\delta\xi}{\delta t}=\phi(t)$ at the mouth of the bay and $Q=O$ at the upstream end of the bay.

(B) Practical method of calculation

The bay is divided into n sections which are denoted as $\triangle x_1$, $\triangle x_2$, ... $\triangle x_i$, ... $\triangle x_n$. By taking the co-ordinate axes as in fig. 62 and putting the coefficient of frictional resistance as $f=n^2/R^{4/3}$, the equations (6) and (7) for the respective section may be written as,

$$\xi_{i,t}=\xi_{i-1,t}+\xi_{i,t}$$

$$=\xi_{i-1,t}-\frac{1}{2g}(\triangle v^2)_{i,t}-\frac{1}{g}$$

$$(\frac{\triangle v}{\triangle t})_{i,t}\triangle x_i-(\frac{v^2}{R^{4/3}}v[v])_{i,t}\triangle x_i \quad (8)$$

$$Q_{i,t}=Q_{i-1,t}+q_{i,t}-(\frac{\triangle\xi}{\triangle t})_{i,t}\triangle F_{i,t} \quad (9)$$

As the value of ξ is known from the boundary condition at the mouth of the bay, we shall take it as the origin of x-axis and the direction towards the head of the bay as the positive direction of the x-axis.

The terms $\xi_{i,t}$, $Q_{i,t}$, $v_{i,t}$, $A_{i,t}$, $R_{i,t}$, etc., in equations (8) and (9) denote the water level, discharge, velocity, flow area, hydraulic radius etc. For x=i and t=t, $(\triangle v^2)_{i,t}$ becomes the variation of velocity head in section i at t=t and may be obtained from $v^2_{i-t}-v^2_{i,1,t}$.

$(\frac{\triangle v}{\triangle t})_{i,t}$, $(\frac{v^2}{R^{4/3}}v|v|)_{i,t}$, $(\frac{\triangle\xi}{\triangle t})_{i,t}$ are values in section i at t=t and if ξ for section i is determined, then A and R can be obtained and v calculated. Therefore, the problem is to know the value of ξ, which will represent the water level in section i. From the fact that the difference between ξ_{i-1} and ξ_i is insignificant, it may be assumed that the required value is represented approximately by ξ_{i-1}. (If the difference is not small enough, the section must be subdivided.)

(C) Method of numerical computation

(1) Assumption of Q-t at the mouth of the bay

For numerical computation, Q-t at the mouth of the bay must first be assumed. Q at the mouth of the bay is actually measured or calculated for the case without the local inflow, and to this value the local inflow q-t is added with due consideration of its arrival time at the mouth of the bay.

(2) Computation of equations (8) and (9) from the mouth towards the head of the bay

$\xi_{o,t}$ $(\frac{\triangle\xi}{\triangle t})_{o,t}$, $q_{i,t}$ are given and $Q_{o,t}$ is assumed in (1).

(a) Computation of $Q_{1,t}$ and $v_{1,t}$

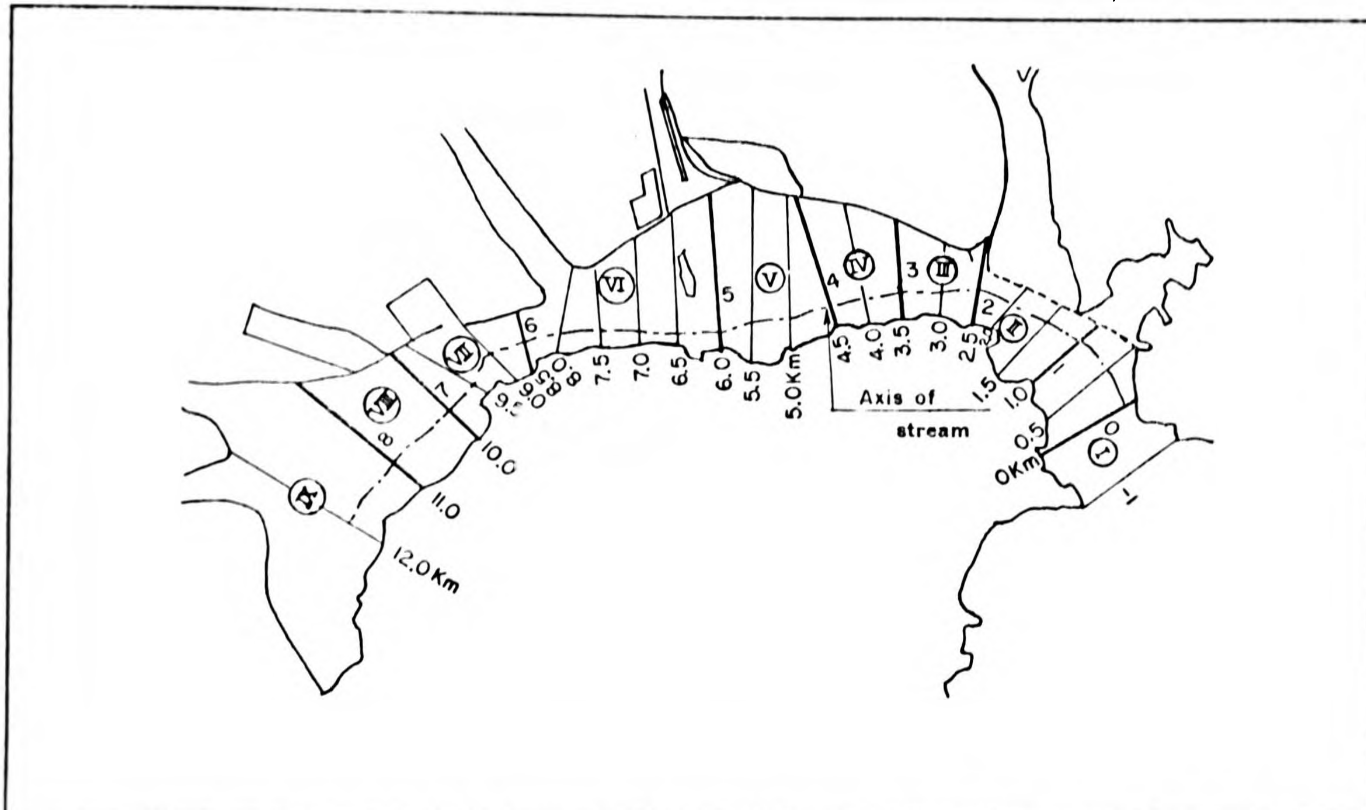
Equation (9) for computation of $x=_o$ to $x=_1$ becomes,

$$Q_{1,t}=Q_{o,t}-(\frac{\triangle\xi}{\triangle t})_{1,t}\triangle F_{1,t}+q_{1,t}$$

In this equation ξ is to be substituted by $\xi_{o,t}$ for section I as stated above, so we obtain $\triangle F_{1,t}$.

Substituting $(\frac{\triangle\xi}{\triangle t})_{o,t}$ for $\frac{\triangle\xi}{\triangle t}$ in section 1, we obtain the values of $Q_{o,t}$ and $Q_{1,t}$ for any required time.

Figure 62. SECTIONS OF KOJIMA BAY USED IN THE COMPUTATION, JAPAN



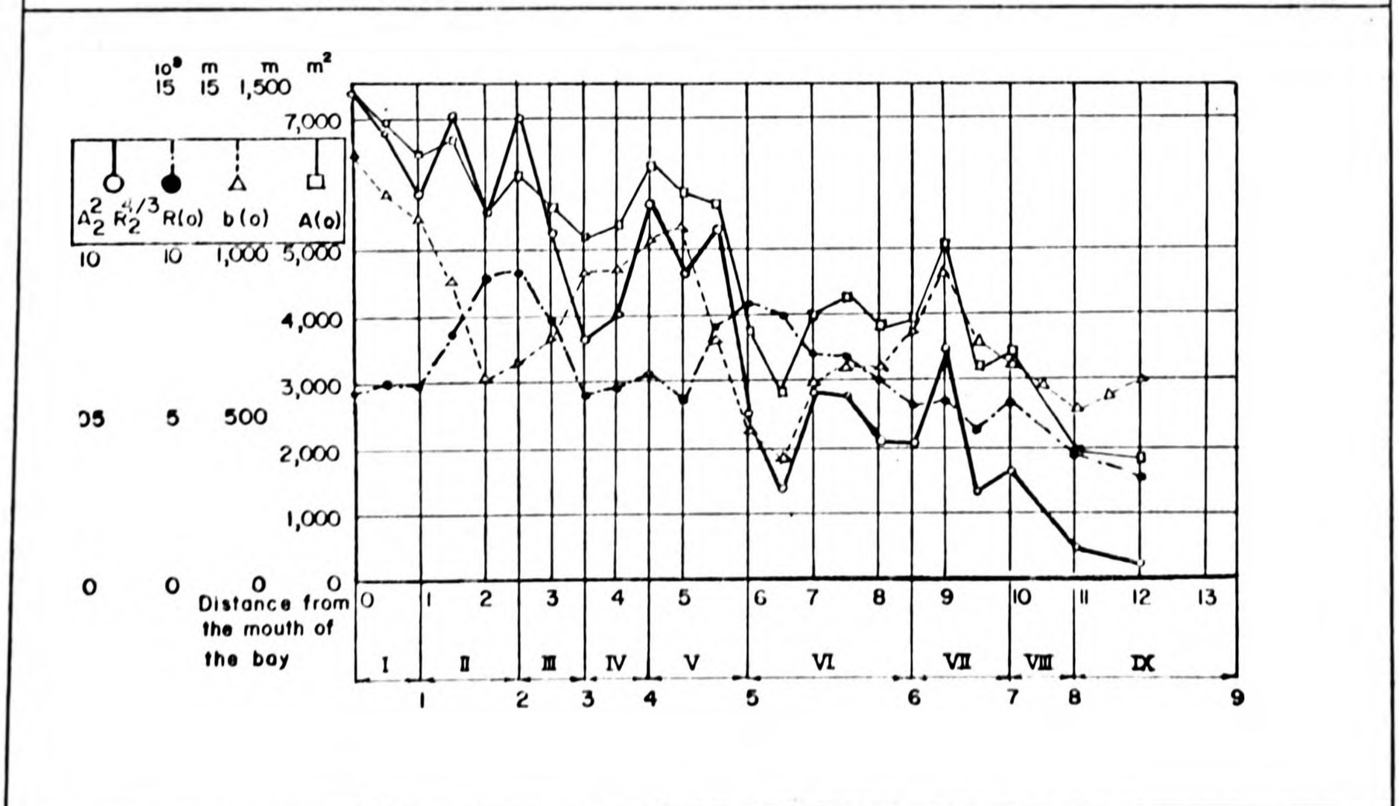


Figure 63. EFFECTIVE AREA, WIDTH AND HYDRAULIC RADIUS OF KOJIMA BAY

By taking $A_{o,t}$ and $A_{1,t}$ corresponding to $\xi_{o,t}$, we obtain $v_{o,t}$ and $v_{1,t}$ for given t from
$v_{o,t} = Q_{1,t}/A_{o,t}$ and $v_{1,t} = Q_{1,t}/A_{1,t}$.

(b) Computation of $\xi_{1,t}$

When $v_{o,t}$ and $v_{1,t}$ are determined as above, $(\Delta v^2)_{1,t}$ can be computed using the following formula;

$$(\Delta v^2)_{1,t} = v^2_{1,t} - v^2_{o,t}$$

To obtain $(\frac{\Delta v}{\Delta t})_{1,t}$ for section 1, we put

$$\overline{v_{1,t}} = \frac{1}{2}(v_{o,t} + v_{1,t})$$

and draw diagrams of $\overline{v_{1,t}}$ for t, or it may be computed from

$$(\frac{\Delta v}{\Delta t})_{1,t} = (\overline{v_{1,t+1}} - \overline{v_{1,t-1}})/2\Delta t$$

$(\frac{n^2}{R^{4/3}} . v[v])_{1,t}$ is computed by obtaining $R_{o,t}$ and $R_{1,t}$ corresponding to $\xi_{o,t}$ and taking

$$\overline{R_{1,t}} = \frac{1}{2}(R_{o,t} + R_{1,t})$$

By carrying out these computations for each time interval, $\xi_{1,t}$ can be obtained from following equation:—

$$\xi_{1,t} = \xi_{o,t} - \frac{1}{2g}(\Delta v^2)_{1,t} - \frac{1}{g}(\frac{\Delta \bar{v}}{\Delta t})_{1,t}\Delta x$$

$$(\frac{v^2}{R^{4/3}} v\,|\,v\,|\,)_{1,t}\Delta x \qquad (9)$$

The procedures stated in (a) and (b) are repeated to obtain the values $\xi_{o,t}, \ldots . \xi_{n-1,t}$, where $\xi_{n-1,t}$ is the value just one section before the head section of the bay.

(3) Computation of $Q_{o,t}$ at the mouth of the bay

$Q_{o,t}$ at the mouth of the bay may be computed as the summation of equation of continuity for each section, and can be written as follows:—

$$o = Q_{n-1,t} - (\frac{\Delta \xi}{\Delta t})_{n-1,t}\Delta F_{n,t} + q_{n,t}$$

$$Q_{n-1,t} = Q_{n-2,t} - (\frac{\Delta \xi}{\Delta t})_{n-2,t}\Delta F_{n-1,t} + q_{n-1,t}$$

$$Q_{1,t} = O_{o,t} - (\frac{\Delta \xi}{\Delta t})_{o,t}\Delta F_{1,t} + q_{1,t}$$

$$Q_{o,t} = \sum_{i=1}^{n}(\frac{\Delta \xi}{\Delta t})_{i-1,t}\Delta F_{i,t} - \sum_{i=1}^{n} q_{i,t} \qquad (10)$$

III. *Actual computation and boundary conditions*

The computation was made according to the method explained in II for Kojima Bay, taking the datum for the water level at zero point of the water gauge at Akuura (T.P.—1,185m). This elevation corresponds to approximately the lowest water level of Kojima Bay.

(A) Determination of sections for computation

The distance 13.5km measured along the longitudinal axis of the bay from its mouth to Komesaki was divided into 24 sections at intervals of 500m (fig. 62). Fig. 63 shows the effective area A(0), width b(0) and the hydraulic radius R(0) which was calculated for each section at water level T.P. 0.00m.

The frictional resistance entered into the computation in the form of $\frac{A^2, R^{4/3}}{v^2\ Q^2}$ which varies with water level. However, in this case, the difference due to the change of water level was insignificant because the depth variation was so small compared to the total depth, therefore the value of $A_2^2 R_2^{4/3}$ corresponding to water level of 2m was taken for computation. This value is illustrated in fig. 63.

The sections for computation were determined by taking into consideration such factors as the location of the mouths of Yoshii river, Hyakken river and Asahi river, the alignment of closing dike and the degree of variations of cross sections. The sections thus determined are shown in figs. 62 and 63.

The relation between tide and flood discharge curves at the mouth of the bay was determined as shown in fig. 64 from the available data. The roughness coefficient of the channel was taken as n=0.025 and was assumed to remain constant throughout the channel.

The time interval was taken as 30 min in the computation. The highest tide level at the mouth of the bay occurred at t=35 and the computation carried out from t=O to t=49, approximately a whole day.

The water level at Komezaki, section 0, near the mouth of bay was assumed to be the level as given by the tidal curve at the mouth of the bay and to remain unchanged by flood discharge. There was some doubt concerning the validity of this assumption. But the fact that the result of the computation taking the water level at section — 1 as remaining constant during flood time, showed only minor difference in the water levels within the bay, as compared to the result obtained when section — O was taken was constant. This gave assurance that the assumption in question was valid.

The computation in this paper is based upon the assumption that section — O was the mouth of the bay.

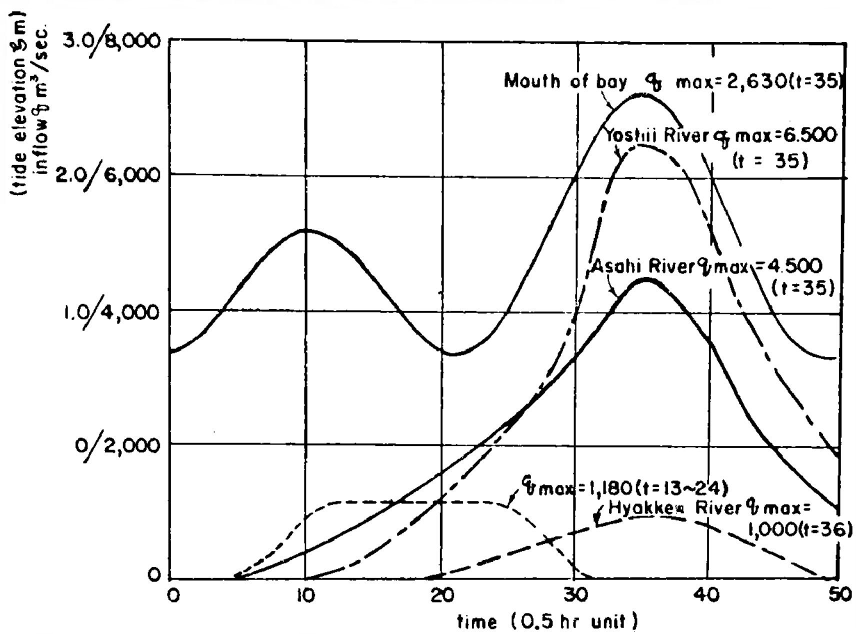
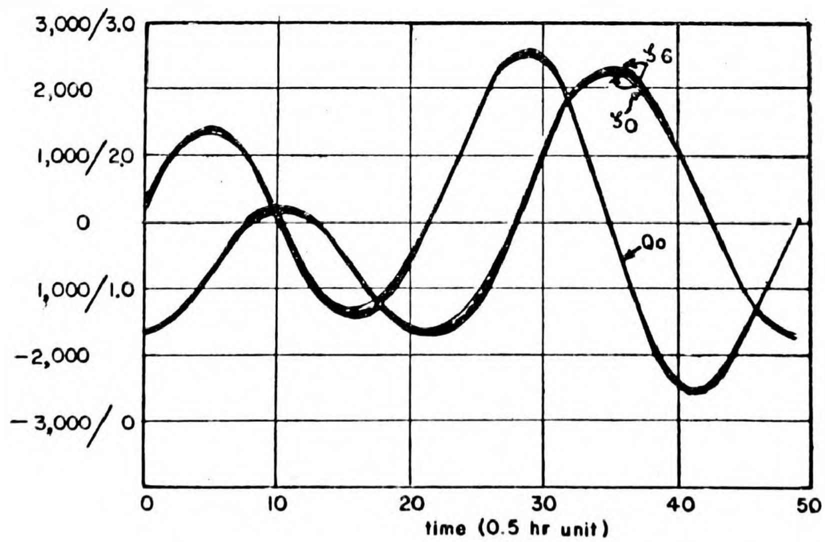


Figure 64 RELATION BETWEEN TIDE AND FLOOD DISCHARGE CURVES AT THE MOUTH OF KOJIMA BAY



LEGEND

Qo
- ASSUMPTION FOR 1st STAGE CALCULATION
- CALCULATED BY 1st STAGE CALCULATION
- CALCULATED BY 2nd STAGE CALCULATION

ζ
- WATER LEVEL AT THE MOUTH OF BAY ζ_0
- WATER LEVEL AT THE MOUTH OF ASAHI RIVER BY 1st STAGE CALCULATION ζ_6
- WATER LEVEL AT THE MOUTH OF ASAHI RIVER BY 2nd STAGE CALCULATION ζ_6

Figure 65 RATE OF FLOW AT THE MOUTH OF KOJIMA BAY AND THE WATER LEVEL AT THE MOUTH OF ASAHI RIVER PRIOR TO CLOSURE

At ordinary flow of the river, its discharge may be neglected as being negligibly small compared with the quantity of tidal inflow and outflow at its mouth. But in the case of tidal flow in the channel in the vicinity of the mouth of the river, this tidal flow could not be neglected. Therefore, the areas of the water surface of the tidal compartment of the river were taken into consideration in order to introduce the effect of the above stated tidal flow in the calculation. The area of tidal compartment was also considered in the calculation for flood flow, which may be said to be a reasonable procedure because no reservoir action of the channel at the mouth of the river was taken into account at flood discharge.

IV. *Tidal level at the mouth of Asahi river before and after the closure of the bay.*

The result of actual observation showed that the propagation time of the tide into the head of the bay was short and that the water level curve did not differ greatly at various places in the bay. The Q-t curve primarily assumed for the mouth of the bay was obtained solely by solving the equations of continuity with the assumption that the inner bay was oscillating simultaneously with the tide at its mouth Using the Q-t curve thus obtained, ξ_8 and ξ_0, the values for before and after the closure were computed as explained in III by the equation of continuity and motion for each section towards the interior of the bay corresponding to t=O to t=49. After this calculation, the Q-t at the mouth of the bay was computed using the values of water level, just obtained. Up to this point the calculation was only at the first stage. Using the Q-t curve determined by the first stage calculation, the same procedure was repeated for second stage calculation. Comparsion between the Q-t curves at the mouth of the bay initially assumed for calculation and that determined as the result of the first stage calculation, showed differences of 2% to 9% with an average of 6% before the closure and 1% to 4% with an average of 2% after the closure.

These differences became 0 to 3% with an average of 1%, and 0 to 3% and an average of 1%, for respective cases in the second stage calculation. This fact indicates that the calculation had quite high convergence. The reason for such favourable convergence should be attributed to the existence of only minor variations at the time-stage curve at any points in the bay. If the channel were shallower which would mean higher frictional resistance or if the length of the channel were longer, thus necessitating longer propagation time for the tide, the calculation would not have shown such favourable convergence. In such cases calculations of third or fourth stages would be required.

The results of the calculation are given in fig. 65 and fig. 66. Comparing the tidal stages at section 6 near the mouth of Asahi river prior and after the closure obtained by second stage calculation, we see that for t=35 or high tide, the water level ξ_0 is 2.67m before and 2.64m after the closure, which means there is a drop of 3cm. in the water level at high tide after the closure. (Fig. 67)

V. *Water level at the mouth of Asahi river at flood, prior and after the closure.*

The estimated Q-t at the mouth of the bay was obtained by adding the river discharge as determined in III to the rate of flow at the mouth of the bay as assumed in the first stage calculation for normal flow, with due consideration to the time of arrival of the flood peak at the point. The flood discharge from the catchment basin of the fresh water reservoir after the closure is equal to the drain discharge from the sluice gate of the closure dyke, so it was necessary to know the value of the water level on the outside of the dyke to determine its quantity. In the present calculation this water level ξ_0 was assumed equal to that at the mouth of the bay.

This procedure was repeated as in IV twice, to determine the required quantities. The water level at the mouth of the bay was taken as the inherent water level of the tide. By comparing Q-t initially estimated for the first stage calculation with that obtained from the results of the calculation, we found differences of 2% to 15% with an average of 7%, for before the closure, and 2% to 12% and an average of 7% for after the closure.

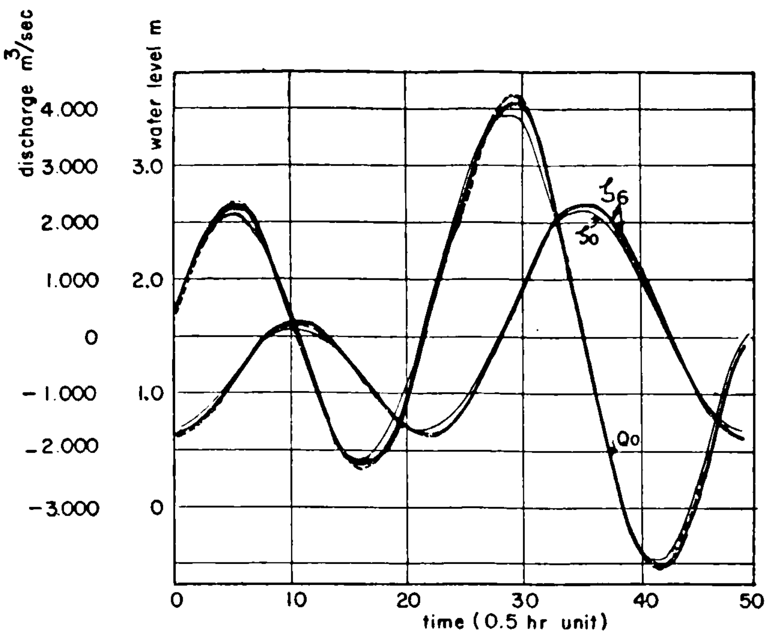
These differences became 1% to 3% — average 2%, and 0 to 2% — average 1% for the respective cases in the second sage calculation.

Here also we see quite good convergence. The results of the calculation are shown in fig. 68 and fig. 69. From the comparison of values of ξ_0, the flood water level at section 6 in the vicinity of the mouth of the Asahi river, we obtained the highest water level 2.88m at t=35.9 before the closure and 2.875m at t=35.4 after the closure. Both cases showed a retrogression as compared to t=35 of the high tide, and the peak after the closure was computed to be 15 min earlier than that before the closure. No significant difference in highest water level was expected to occur at flood by the closure.

VI. *Discussion of ten results of calculation*

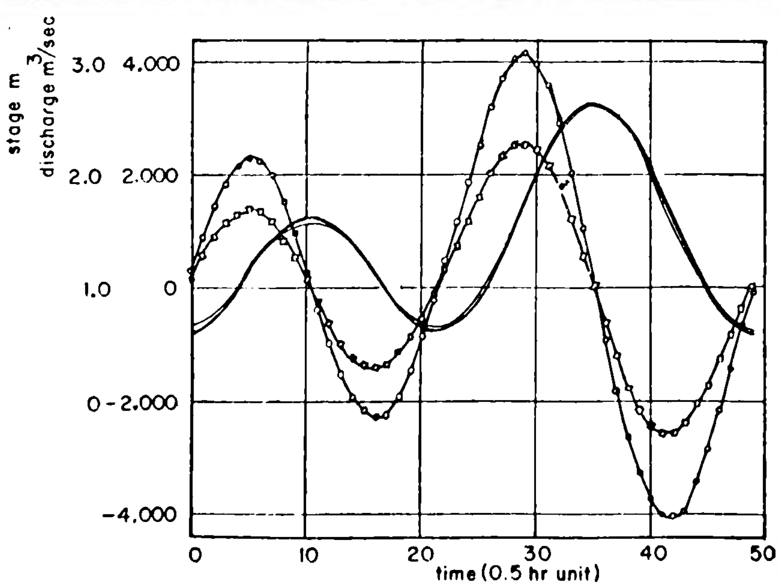
(1) Flow mechanism during normal river flow

In fig. 67 we see that there is almost no tidal current at high and low tides, and that the discharge and velocity reach their maximum values at about mean tide. During flood tide, the velocity becomes maximum first and the discharge follows it; at ebb tide, this phenomenon is reversed. The time variation of the water level is acute at mean tide and of the velocity at high and low tides. The rate of tidal flow decreases towards the interior of the bay, to become zero at its innermost part. By comparing the



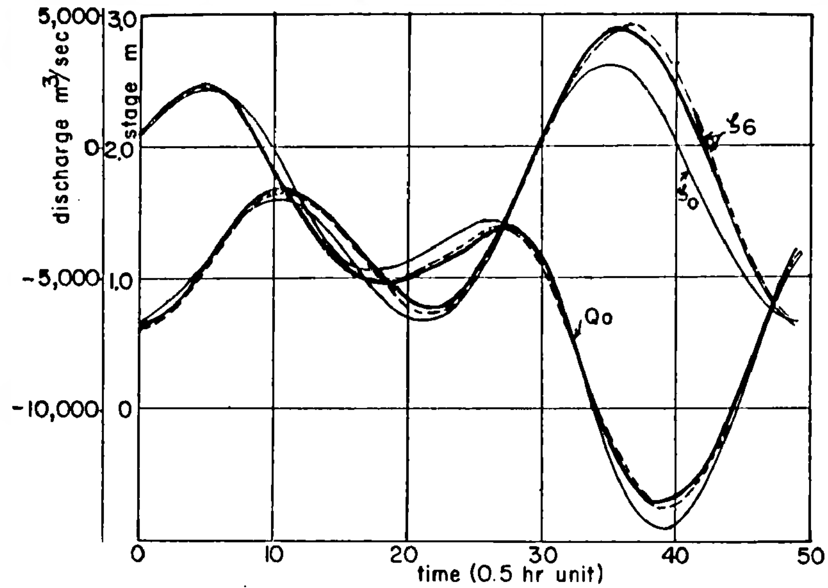
assumption for 1st-stage calculation
calculated by 1st-stage calculation
calculated by 2nd-stage calculation
water level at the mouth of Bay ζ0
water level at the mouth of Asahi River by 1st-stage calculation ζ6
water level at the mouth of Asahi River by 2nd-stage calculation ζ6

Figure 66 RATE OF FLOW AT THE MOUTH OF KOJIMA BAY AND THE WATER LEVEL AT THE MOUTH OF ASAHI RIVER, AFTER CLOSURE



tidal stage at the mouth of Asahi R. before the closure
tidal stage at the mouth of Asahi R. after the closure
rate of flow at the mouth of the Bay before the closure
rate of flow at the mouth of the Bay after the closure

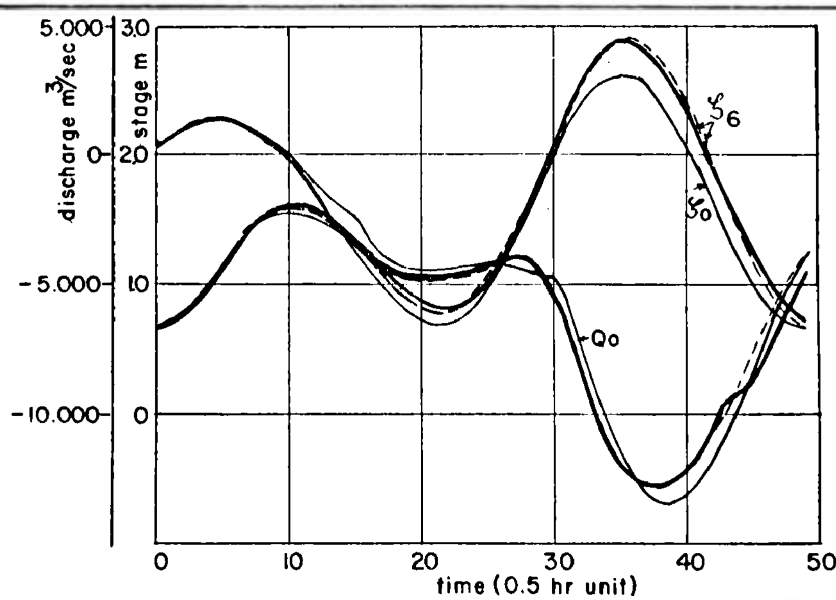
Figure 67. COMPARISON OF RATE OF FLOW AT THE MOUTH OF KOJIMA BAY AND THE TIDAL RANGE AT THE MOUTH OF ASAHI RIVER, PRIOR TO AND AFTER CLOSURE



Qo
- assumed rate of flow at the mouth of the Bay for 1st-stage calculation
- calculated rate of flow at the mouth of the Bay for 1st-stage calculation
- calculated rate of flow at the mouth of the Bay for 2nd-stage calculation

ζ
- water level at the mouth of the Bay ζ_o
- water level at the mouth of Asahi R. by 1st-stage calculation ζ_6
- water level at the mouth of Asahi R. by 2nd-stage calculation ζ_6

Figure 68 RATE OF FLOW AT THE MOUTH OF KOJIMA BAY AND THE WATER LEVEL AT THE MOUTH OF ASAHI RIVER DURING FLOOD, PRIOR TO CLOSURE



Qo
- assumed rate of flow at the mouth of the Bay for 1st-stage calculation
- calculated rate of flow at the mouth of the Bay for 1st-stage calculation
- calculated rate of flow at the mouth of the Bay for 2nd-stage calculation

ζ
- water level at the mouth of the Bay ζ_o
- water level at the mouth of Asahi R. by 1st-stage calculation
- water level at the mouth of Asahi R. by 2nd-stage calculation

Figure 69 RATE OF FLOW AT THE MOUTH OF KOJIMA BAY AND THE WATER LEVEL AT THE MOUTH OF ASAHI RIVER DURING FLOOD, AFTER CLOSURE

time — stage curves at the mouth of the bay and Asahi river, it will be seen that the amplitudes of the wave increase towards the interior of the bay and that the propagation of wave from the mouth to the innermost part requires less than 30 minutes.

The water level in the bay which is low at low tide begins to rise with the inflow of tide, and at 1 to 2 hours before high tide the difference in water level will be almost equalized.

The water level in the interior of the bay will become higher due to the change of tide. At ebb tide, the water level will be equalized at 1 to 2 hours before low tide, but the tidal current continues to flow towards the mouth of the bay not withstanding lower water level in its interior.

In order to explain this phenomenon, we analysed the difference in water levels at the mouth of Asahi river and innermost part of the bay, $\sum_{1}^{6} \sum_{v,w,f} \triangle\xi$ or the surface slope $\bar{I}$ and arrived at the following elements; $\sum_{1}^{6} \triangle \xi v$ or I_v relating to difference in velocity head, $\sum_{1}^{6} \triangle \xi_w$ or I_w relating to property of wave and $\sum_{1}^{6} \triangle \xi_f$ or I_f relating to frictional resistance. Fig. 70 illustrates the characteristic before closure. Studying this figure we arrive at the following conclusions:—

(a) At slack water of high and low tides, the term relating to I_w dominates thus rendering the effects of other terms negligible. The amplitude in the bay interior is being aggravated by I_w. Therefore the problem concerning tidal stages at high and low tide may be considered as a problem of waves without much error.

(b) At mean tide when the velocity is at its maximum, the term I_f becomes dominant.

(c) $|I_v|$ is large, when $|I_f|$ is large, $|I_v|$ is small, when $|I_f|$ is small and $|I_v|$ has a value of less than 20% of $|I_f|$.

(d) By comparing $|\bar{I}_f|$ max. and $|\bar{I}_w|$ max, we find that $|\bar{I}_w|$ max. is larger when the tidal range is small, whereas $|\bar{I}_f|$ max. becomes greater when the tidal range is large. This phenomenon is considered to be due to the decrease of tidal in-and outflows, which causes reduction of maximum velocity at mean tide without any significant decrease in time variation of velocity at high and low tides. This fact may also explain the phenomenon stated in (e).

(e) After the closure, $|I_w|$ max. and $|I_f|$ max. become 50% and 25% of their pre-closure values respectively, which means the closure of the bay or the decrease of the rate of tidal in-and outflows will indicate greater effect on $|\bar{I}_f|$ than $|\bar{I}_w|$.

(f) $|\bar{I}|$ max. after the closure appears earlier than before the closure, and approaches the time for $|\bar{I}_w|$ max.

(2) Flow mechanism at flood

The discharge of the rivers that flow into the bay causes the water level in the bay to rise. The discharge is influenced by the tide at the mouth of the bay. A part of the discharge is stored up in the bay during flood tide, which at ebb tide flows down towards the mouth of the bay together with the discharge from the rivers. Therefore, the flow during flood is an unsteady flow effected by the tidal oscillation at the mouth of the bay and the flood discharge of the rivers into the bay.

The difference in water levels or the surface slope was analysed; the results of which are shown in fig. 71.

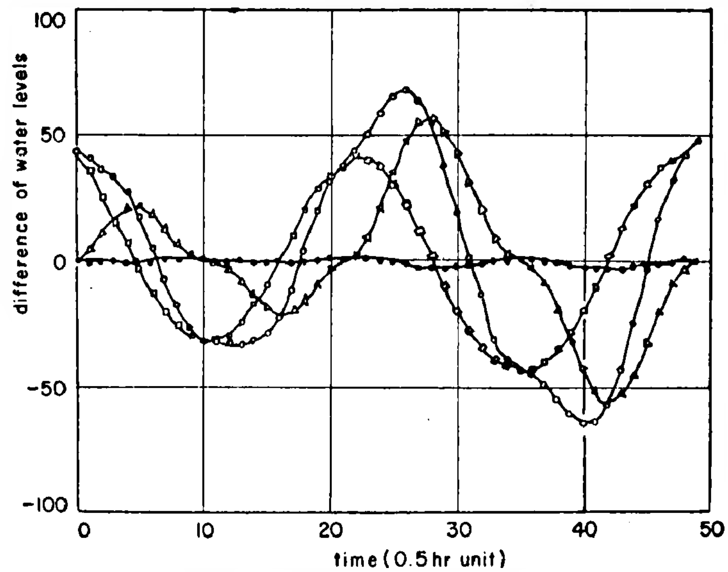
From the result of the analysis, we draw the following conclusions:

(a) The surface slopes for both high and low tides are governed by the term $|\bar{I}|$ in normal flow, but the effect of the term $|\bar{I}_f|$ becomes gradually more and more dominant with the increase of flood discharge.

Before the closure, at high and low tides corresponding to t=11, 22 and 36, when the rates of flow at the mouth of the bay were 1,800, 4,600 and 12,320 m^3/sec, the values of $|I_w|$ were 220, 30 or 26% of $|\bar{I}_f|$.

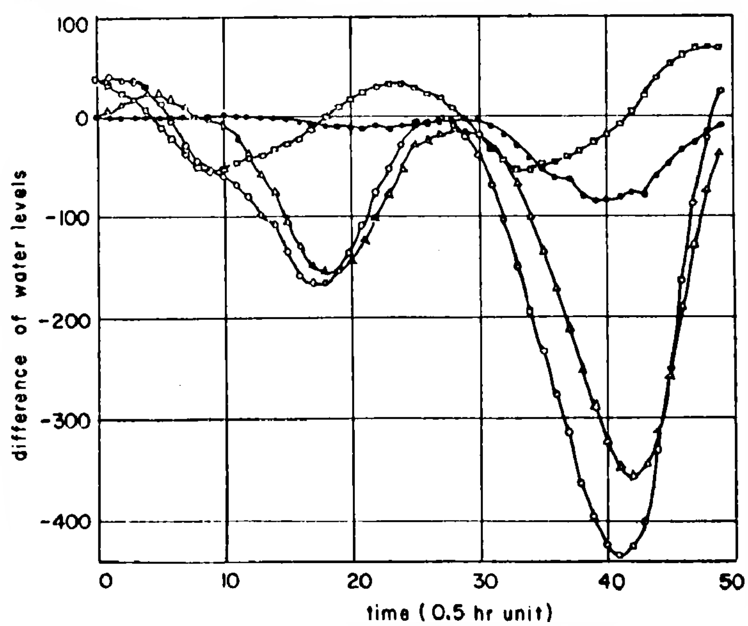
After the closure, at low and high tides corresponding to t=22 and 35, when the rates of flow at the mouth were 4,700 and 11,800 m^3/sec, the values of $|\bar{I}_w|$ were 9% and 15% of $|\bar{I}_f|$.

The reason for having smaller percentage after the closure, as compared to pre-closure, may be explained by the decrease in time variation of velocity caused by the closure of the inner bay.



—○— Difference of water levels at the mouth of the Bay and Asahi R. So–S6
—●— Difference of water levels relating to velocity head
—□— " " to wave
—△— " " to frictional resistance

Figure. 70 ANALYSIS OF DIFFERENCE OF TIDAL LEVELS AT THE MOUTH OF KOJIMA BAY AND ASAHI RIVER, AT NORMAL FLOW, BEFORE CLOSURE



—○— Difference of water levels at the mouth of the Bay and Asahi R. So–S6
—●— Difference of water levels relating to velosity head
—□— " " to wave
—△— " " to frictional resistance

Figure 71 ANALYSIS OF DIFFERENCE OF WATER LEVELS AT THE MOUTH OF KOJIMA BAY AND ASAHI RIVER DURING FLOOD, AFTER CLOSURE

(b) At the time when $|I_f|$ becomes maximum, the variation of velocity is generally insignificant and $|\bar{I}_w|$ may be ignored.

(c) There is a relation between $|\bar{I}_v|$ and $|\bar{I}_f|$. When $|\bar{I}_f|$ is large then $|\bar{I}_v|$ is large, and when $|\bar{I}_f|$ is small then $|\bar{I}_v|$ is also small.

By the analysis described above, it is found that the elements constituting the surface slope of the bay in flood are effected by the combinations of tide and flood waves, hydrographs of flood discharge, and tidal curves.

(3) Retarding mechanism of the inner bay

Fig. 72 illustrates the comparison of flood water stages at the mouth of Asahi river, before and after the closure. This diagram shows that the closure of the bay has caused almost no change in the water levels at the highest water level, which means that the closure of the bay will have no significant effect on the flood stage at the mouth of Asahi river.

The flood stage at the mouth of Asahi river may generally be considered to reach its maximum when the peak of flood wave coincides with the high tide. Under this condition, the closure of the bay will have the function of regulating the flood discharge from the catchment basin of the reservoir, and will be effective in lowering the flood stage at the mouth of Asahi river.

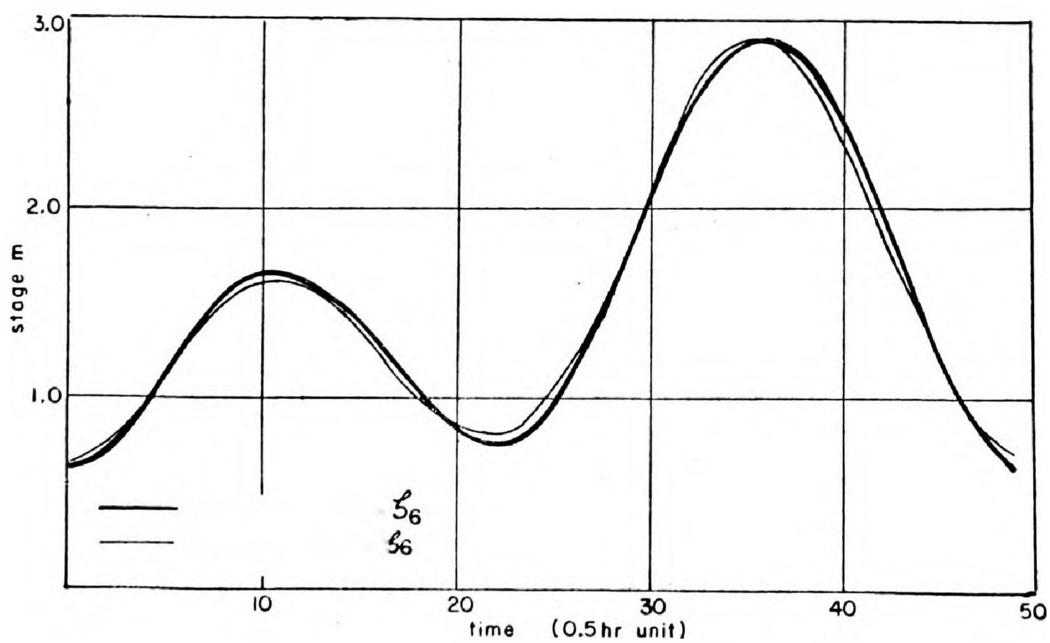


Figure 72. COMPARISON OF FLOOD WATER LEVELS AT ASAHI RIVER MOUTH, BEFORE AND AFTER CLOSURE

Paper No. 11

RECLAMATION SCHEMES IN THE MEKONG DELTA IN VIET-NAM*

I. GENERAL ENVIRONMENTAL AND AGRICULTURAL CONDITIONS

The delta area in the south part of Viet-Nam generally covers the Mekong delta and the delta areas of the two Vicao rivers and the Saigon river, as there are many channels in existence linking one river to the other. In all, the delta covers an area of about 46,200 km^2, of which some 19,000 km^2 is cultivated. Of the cultivated land, 92 per cent is planted with rice and, due to the shortage of proper irrigation, only one crop of rice is raised each year during the wet season from May to November (with a possible short drought in August or September). As the entire delta is extremely flat, drainage is a common problem. In the north part of the delta, the Mekong spills over its banks every year, usually inundating an area as vast as 20,000 km^2. A part of the flood flow even runs into the Gulf of Thailand. It is in this region that floating rice and two kinds of transplanting rice are planted. Also due to the flood, a great part of the land is highly acid, with pH value ranging from 3.5 to 4.5. Along the coast, as the land is low and the tide range is high, salt water intrusion is very serious. Although many large and small channels mostly perpendicular to the rivers have been opened in the past for navigation, irrigation and drainage, the advantage for irrigation and drainage is very small. The reason is that the water level in these channels is not under control due to the lack of an overall plan. However, the unit yield of paddy rice in the delta is the highest of the whole country.

II. SOME REMARKS ON ITS FUTURE DEVELOPMENT

The delta, as its land surface slopes very gently, may be more scientifically divided into three zones in relation to the effect of flood and tide.

(A)—*Zone affected principally by flood (An-Giang, Kiên-Phong etc.)*

In this zone, once the flood comes, the rice fields are covered constantly with deep water until the flood begins to recede in November. Drainage of soil remains poor throughout the year. During the dry and low river flow period, land is not productive if irrigation is not available.

(B)—*Zone affected by flood and tide (Phong-Dinh, Vinh-Long, upper part of Vinh-Binh, Kiên-Hoa, Dinh-Tuong, etc.)*

The flood water in this zone is not as deep as that in the floating rice area. The river water level varies greatly in a day due to the oscillation of the tide water of the sea. In the lower stretch of this zone, the flood water level many go somewhat below the ground surface at low tide period. Soil drainage of the whole zone, however, is still poor the whole year round.

(C)—*Zone affected by tide only (Ba-Xnyên, lower part Vinh-Binh, Kiên-Hoa, Dinh-Toung etc.)*

This zone is subject constantly to salt water intrusion at high tide. The drainage of this zone is also poor at present for lack of a proper drainage system; but, basically, it will be easier to improve when a drainage system is installed, as the low tide level is about 2 metres below the mean sea level and is therefore considerably lower than the ground surface. This zone, however, is remote from the source of fresh water and lacks a year-round fresh water supply for irrigation.

Judging from this general description, it is very true that the reclamation work in the Mekong delta area in Viet-Nam is multiple-phased as it covers irrigation, drainage, flood control and the prevention of the intrusion of salt water.

It is the opinion of the writer that the reclamation work in the Mekong delta in Viet-Nam should be grouped into the following two categories with different guiding principles:

(a) In the zone affected principally by flood, the control of the Mekong river floods is the principal task to be done. In general, the control of the Mekong river depends solely on the construction of reservoirs on the river and its tributaries, although dikes and polders might be considered for certain places. In planning irrigation projects in this zone principally affected by the floods of the Mekong, it should be kept as the main aim to raise one more diversified crop during the dry season. With such an irrigation capacity principally by pumping, there will be sufficient water for the supplementary irrigation needed by rice planted during the wet season. However, this

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* By Ywan Hsi Djang, Irrigation Engineer, Food and Agriculture Organisation of the United Nations.

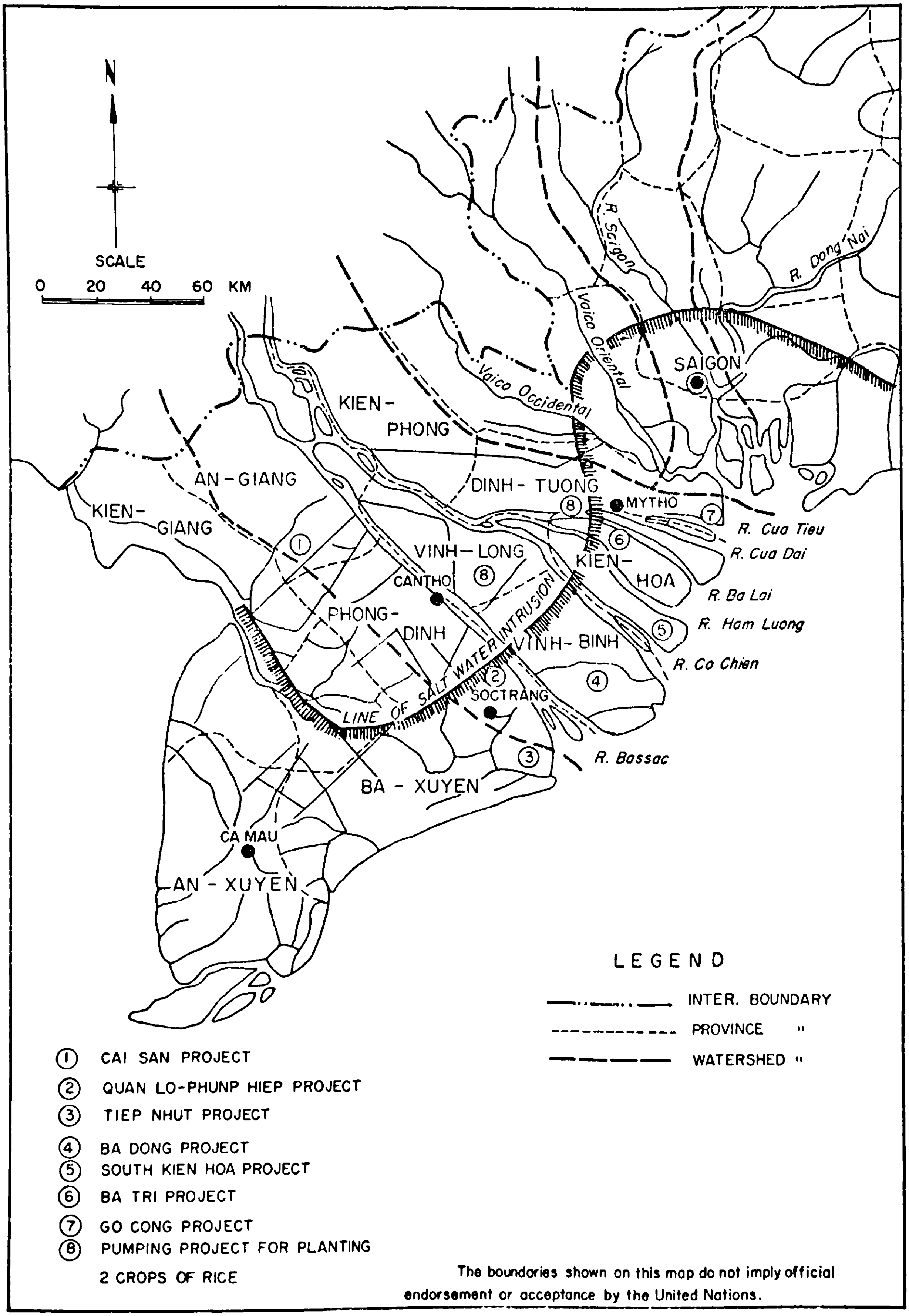

Figure 73. MEKONG DELTAIC AREA IN VIET-NAM

pumping capacity will be too small to serve as a drainage facility, especially in the floating rice area where regular rice is to be raised in substitute in an attempt to obtain higher yields. For the area with soils of high acidity, it is believed that the most important work is to select some fitting crops and to breed acid tolerant varieties.

(b) The improvement for the zones affected by flood and tide or by tide only can be obtained with some well-co-ordinated programmes. As advocated by the writer before, through digging more channels in the north-south direction generally in parallel with the principal rivers, the reaches to the south of salt water intrusion line will have better supply of fresh water and the drainage problem of the area to the north of the salt water intrusion line will also be greatly improved. Each sub-project will have (a) dikes and structures preventing the flood flow and the salt water, (b) drainage systems, (c) irrigation systems and (d) facilities provided for navigation.

III. MAJOR EXISTING AND PROPOSED RECLAMATION SCHEMES

(A)—*Cai San project*

The Cai San area lies about 190 km southwest of Saigon in the provinces of An-Giang and Kiên-Giang in the extreme western part of the Mekong delta. It covers an area of about 60,000 ha on both sides of the Rach Soi canal which runs from the Bassac to the Bay of Thailand. It is located in the zone principally affected by the floods of the Mekong river.

In this area, the construction of new canals and new dikes has been intensively carried out, as it has been selected by the government for the settlement of refugees from North Viet-Nam and landless farmers from more crowded areas. However, this development anticipates only a single wet-season crop of rice. As the flood flows of the Bassao reach the sea overland through this area, floating rice is usually planted.

Under the new proposed Cai San project, 25 electrically operated pumping plants will be built to irrigate 50,000 ha of land lying in a strip five kilometres wide on each side of the Rach Soi canal, approximately 50 kilometres long during the dry season and to pump excess flood waters from the land during the rainy season to permit easier land preparation and weed control, as well as harvesting on dry land. It has been assumed that electric energy will be available at Saigon from the Da-Nhim or other sources. It is proposed that a pumping station be located in the centre of each 2,000 hectares block. Each pumping station would have a capacity of two cubic metres per second, pumping against a maximum head of three metres. It is estimated that the pumps would operate 40 per cent of the time during the four-month irrigation and four-month drainage periods. The total energy consumed would be 5 million kilowatt-hours per year as estimated.

(B)—*Quan Lo — Phung Hiêp project*

This project is located in Ba-Xuyên and Phong-Dinh provinces in the southwestern section of the Mekong delta. The projected area is bounded by the Bassac river on the northeast; the Rach Dua Tho and Rach Bac Liêu on the south; and the canal Quan-Lo — Ho-Phong on the southwest; and the Song Trem and Song Xa No on the northwest. The area embraces 600,000 hectares in a strip 60 kilometres wide, running southwesterly from the Bassac river to the vicinity of Quan-Long (Ca-Mau).

The problems in the area at present are: lack of enough drainage channels to drain out the excessive rainfall during the rainy season; intrusion of salt water through the drainage channels; and lack of fresh water for irrigation during the dry season.

A project to improve this area consists of constructing many pumping plants, irrigation canals, dikes and tide gates, all of them large scale works. When the flood control works on the main stem of the Mekong river proposed by ECAFE are implemented, they will reduce the critical flood heights to be considered and will increase the low water flow and force the dry-season salt water intrusion boundary downstream. It seems more advisable to delay this big-scale project until the flow of the Mekong river is regulated, as the construction cost of this project will thus be greatly curtailed.

The Government of the Republic of Viet-Nam is employing a consultant firm to make intensive studies in the My-Phouc area; the design for the development of this area totalling 10,000 hectares will be ready soon. It is a pilot project in nature.

(C)—*Tiêp-Nhut project*

This project is located in Ba-Xuyên province. It is bounded on the east by the river Bassac, on the southeast by the sea, on the southwest by the river My-Thanh and on the northwest by the river Tong-Cang. This area totalling 34,000 hectares is entirely in the zone affected principally by the tide. The land is quite flat. As this area is heavily affected by the intrusion of salt water, only one crop of rice could be produced if the rain comes at the right time and the amount of which is sufficient to keep the salt water out until harvesting period.

The main features of this project consist of the construction of sea dikes 62 kilometres, 4 major drainage outlets and 31 minor drainage outlet works.

This project was initiated about 25 years ago. The construction of 3 major outlet works was started in 1937. All of the sea dikes, all minor outlets and one major outlet were realized during 1958-1962. There are still many drainage channels to be excavated and one of the major drainage outlets has to be rebuilt.

(D)—*Ba-Dong project*

The Ba-Dong project in Vinh-Binh province is bounded on the northeast by river Co-Chiên, an arm of the Mekong; on the southeast and south by the sea; on the southwest by the Bassac; and on the northwest by the Rach Cai-Chong, Kinh Ba-Tiên and Kinh Tra-Vinh. This area is also affected principally by tide.

A strip five to seven kilometres wide along the sea coast is largely a mangrove swamp at sea level. Excluding the mangrove swamps, the area contains 110,000 hectares. Most of this area has hitherto produced one crop of rice a year. The area is generally about two metres above mean sea level with isolated spots rising up to 12 metres elevation on old seashore sand dunes. There is a series of old foreshores more or less parallel to the present coast, which are higher than the general land level and are used for village and building sites. Under the proposed project, dikes will be built around the perimeter of the project with necessary tide gates. Two pumping stations and irrigation canals will be built also. Several local projects forming part of this project area have been initiated and completed since 1941.

(E)—*South Kiên-Hoa project*

This project covers the area bounded by river Co-Chiên and river Hàm-Luông in Kiên-Hoa province. As the northern part of this area is in the zone affected by flood and tide and the southern part is in the zone principally affected by tide, it is the opinion of the writer of this report that this area be developed in accordance with the principles as described before under section II.

In accordance with his suggestion, this project area has been divided into three districts. The area covered by the respective districts will be 29,820 ha in District A, 14,650 ha in District B and 21,970 ha in District C. District A is located along the most downstream reach of river Ham-Luong and is bordering with the sea. Inland from District A is the District B and then District C.

The topography of District A is very much like the Ba-Dong area as it has also a series of old foreshores more or less parallel to the present coast. It is also the writer's opinion that District A should be further divided into a number of polders. These polders will be enclosed by polder dikes. Earth dams will be used to close the mouths of the existing rivers. Tidal gates with controlling devices are to be provided to check the salt water and to drain off the storm runoff. Water stored in the existing river channels will be pumped up for irrigation. Supplementary supply will be obtained from the other two districts through opening a new irrigation canal when the construction of the district project is started.

In dealing with the district development, attention is called to the following points:

1. Main structures: structures including surrounding dikes, closing dikes, tidal gates, ship locks and irrigation canal will be built.
2. Irrigation system: each district is to be provided with a main irrigation canal taking water from the artificial canal on the north of the respective district. Each adjacent two of these main canals are again to be connected with one another by a syphon. This arrangement permits fresh water from the most northern district flowing down to the most downstream district, in case the salt water in the river moving upstream.
3. Navigation: After the districts are enclosed by surrounding dikes, some rivers will become non-navigable. For transportation purposes, different types of gates and shiplock structures will have to be well planned in advance.

   Up to date, the designs for building two polders in District A each about 1,000 hectares in area have been completed.

(F)—*Ba-Tri project*

Ba-Tri in Kiên-Hoa province lies between two deltaic branches, river Hàm-Luông on the south and river Ba-Lai on the north. The project area is bordered by the sea on the east and the Song Ben-Tre and the Canal de Chetsay on the west. The land is very flat, ranging in elevation from a narrow belt of sea-level mangrove swamps to a maximum of four metres above sea level. Excluding the seacoast belt of sand dunes and mangrove swamps, the area covers 37,300 hectares.

The most serious problem in this area is the intrusion of salt water, particularly during the dry season. In almost the entire area only one crop a year can be obtained.

The proposed Ba-Tri project consists of a perimeter dike, tide gates, one or more pumping plants and irrigation canals.

(G)—*Go-Cong project*

Go-Cong area in Dinh-Tuong province is bounded on the east by the sea and the Cua Soirap; on the south by the river Cua Tiêu, one of the arms of the Mekong; and on the north by the river Viaco. The western boundary has been tentatively selected as the Canal de Cho-Cao. As estimated this area is about 50,000 ha. The area, like the whole delta, is uniformly flat. During the dry season the entire region is affected by salt water intrusion and during the monsoon season it is inundated by flood water.

The attempt to control the inflow of salt water was started in 1930. A new project is under consideration which is a multiple-phased one aiming to prevent salt water intrusion, provide fresh water for irrigation during the dry season, control flooding and permit drainage and navigation. As suggested by the Parsons Co., to get enough water, a new canal 40 kilometres long will have to be built and it will require crossing and other structures. It is expected that the necessary surveys, investigations and detailed plans will be undertaken soon.

(H)—*Major pumping projects for planting 2 crops of rice*

In November 1959, a report was prepared by the writer concerning his studies made on the available rainfall data, the probable effective rainfall and the water requirement of rice in the delta area of South Viet-Nam. In that report he advocated that 2 crops of rice could be successfully planted during the wet period, if suitable rice varieties are selected.

In June, 1962, he wrote another report concerning the same subject. He further stressed his aforementioned idea with following statements:

(a) Based upon the rice cultural calendar in 9 provinces in South Viet-Nam, the transplanting and growing period of rice is generally within the period from the late part of July to the middle part of December. Although not very often, short droughts might happen in August or September. This means that even a single crop is planted each year, some supplementary irrigation, if available, is still needed to ensure a better yield.

(b) If the period from May to November is taken for growing 2 crops of rice as recommended, the demand of supplementary irrigation may not be too much higher than the demand of supplementary irrigation for single crop of rice yearly.

(c) It is true that a suitable supplementary irrigation rate for planting two crops of rice in South Viet-Nam can only be obtained through making experiments and tests. However, it seems that a supplementary irrigation as low as 5mm/day (equivalent to 0.5787 litres/ha/sec. or 50 m^3/ha/day; excluding conveyancy losses) might solve the water shortage problem entirely or at least to a great extent as (1) the mean monthly rainfall between May and October has been usually higher than 200 mm, while 350 mm is already deemed quite sufficient for rice growth in a clayey-soiled area as South Viet-Nam (2) although the mean monthly rainfall in November at some places and those in August and November at other places are lower than 200 mm, some carrying-over water from the previous months could be expected.

(d) With an available irrigation at 5mm./day (equivalent to 0.5787 litres/ha/sec. or 50 m^3/ha/day), during the dry season, diversified crops can be planted either for the whole area at the same time or by rotation. A supplementary irrigation at 5 mm/day will provide 450-600 mm of water to a crop with a growing period of 3 to 4 months. This amount usually is sufficient for one dry crop.

(e) In view of the fact that (a) the rate of supplementary irrigation needed in South Viet-Nam is not high and that (b) the pumping head is very low, besides engine or motor driven pumps, attention should be paid to the utilization of pumps either operated by manpower or by buffaloes.

(f) Since the harvesting period of the first crop of rice is within the wet period, attention should also be paid to the paddy-drying problems. Since 1963, the Government of the Republic of Viet-Nam has paid great attention to this matter. At the time of writing this report, three pumping projects totalling 1,500 ha in Vinh-Long province and six projects totalling 13,000 ha in Dinh-Tuong province are under intensive investigation. These projects [illegible] all in the zone affected by flood and [illegible] and have fresh water supply year round. It is hoped that these areas will produce one more crop of rice in the wet period and one dry crop in the dry period after the needed pumping stations and proper irrigation distribution system are implemented.

IV. REFERENCE

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