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AND THE NATIONAL GOVERNMENT OF CHINA

REPORT BY THE COMMITTEE OF EXPERTS
ON
HYDRAULIC AND ROAD QUESTIONS
IN CHINA

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CONTENTS.

	Page
I. PREFACE	5
II. THE YELLOW RIVER (HWANG HO)	7
III. PROBLEMS OF THE HYDRAULIC SYSTEM OF SHENSI	55
IV. IRRIGATION PROBLEMS IN SUIYUAN	103
V. SHANSI: FEN HO	120
VI. HSIAOCHING HO—PROPOSED IMPROVEMENTS	123
VII. NORTH CHINA RIVERS	124
VIII. THE KUANG TING RESERVOIR ON THE YUNG TING HO (HOPEI)	127
IX. HWAI RIVER: IMPROVEMENT WORKS	138
X. OBSERVATIONS CONCERNING CERTAIN PROBLEMS OF THE YANGTSE KIANG	140
XI. THE ROAD PROBLEM—ROAD COMMUNICATIONS IN CHINA	143
<i>Annex: Hwang Ho: Inspection of the Golden Dyke on the Left Bank of the River</i>	<i>212</i>

I.

PREFACE.

The Chinese Government having expressed the desire to obtain, through the Communications and Transit Organisation of the League of Nations, an opinion on important questions of special concern to it relating, on the one hand, to hydraulic works and road building and upkeep and, on the other, to transport by road, the Chairman of the Advisory and Technical Committee for Communications and Transit appointed a group of experts to proceed to China and study there the problems referred to them by the Chinese Government.

This group of experts consisted of :

Mr. A. T. COODE, of Messrs. Coode, Wilson, Mitchell & Vaughan-Lee, London, Consulting Engineers to the Crown Agents for the Colonies, Member of the Committee of Experts on Hydraulic Questions sent to China by the Communications and Transit Organisation in 1932 ;

M. L. COURSIN, Chief Engineer of Roads and Bridges ; Director of Public Works in Madagascar ;

M. G. P. NIJHOFF, Consulting Engineer, Rapporteur to the Committee of Enquiry on Questions relating to Public Works and National Technical Equipment of the Communications and Transit Organisation ;

M. A. OMODEO, Consulting Engineer, Rapporteur to the Committee of Enquiry on Questions relating to Public Works and National Technical Equipment of the Communications and Transit Organisation.

The above experts visited China in December 1934 and the early months of 1935. The Chairman of the Advisory and Technical Committee also appointed to be a member of this Committee of Experts :

M. P. H. WATIER, Counsellor of State, Director of Navigable Waterways and Seaports at the French Ministry of Public Works,

who, though unable to visit China himself, co-operated with the other experts both in framing the present report and in making the preliminary studies undertaken prior to the experts' departure for China, which consisted in examining the data placed at the experts' disposal, deciding what questions they should first study on the spot, always subject to any wishes expressed by the Chinese Government, and, lastly, giving instructions for carrying out the investigation on the spot.

The Committee has drawn up its general report on the basis of the drafts prepared for the various problems examined by the experts especially entrusted with their study on the spot—namely :

Mr. Coode :

Improvement works on the Hwai River ; North China rivers ; works on the Fen Ho ; improvements proposed on the Hsiaoching Ho ;

M. Coursin :

The road problem : Road communications in China ;

M. Nijhoff and Mr. Coode :

Improvement of the Yellow River ;

M. Nijhoff :

Problems of the Yangtse Kiang ;

M. Omodeo :

The Kuang Ting reservoir on the Yung Ting Ho ; problems of the hydraulic System of Shensi ; irrigation problems in Suiyuan.

At the suggestion of his colleagues, M. Watier presided over the Committee's discussions.

* * *

Before giving an account of the result of its work on the various questions referred to it, the Committee desires to thank the Chinese authorities and technical departments for the courtesy shown and the welcome accorded to the experts and for the willingness to facilitate their work and supply them with all available information. At the present stage reached in the observations and investigations made in the various basins, however, the technical information on certain points is not yet sufficiently complete, detailed or even concordant.

The opinions, therefore, which the Committee is able to give on the various questions referred to it are necessarily based only on that information.

The Committee accordingly feels that it should before all draw the special attention of the Chinese Government and technical departments to the basic importance of local observations, studies and investigations, as these form the essential preliminary steps in the study of any technical problem.

In matters of waterway hydraulics in particular, the only basis that can be taken as at all reliable consists in observations systematically conducted, carefully checked and spread over a very large number of years.

* * *

Appended to this report is a note on an inspection of the Golden Dyke on the Yellow River, drawn up by Mr. Coode and M. Nijhoff during their visit to China.

* * *

In submitting this report, the Committee feels that it has discharged the mission entrusted to it by the Chairman of the Advisory and Technical Committee for Communications and Transit.

II.

THE YELLOW RIVER (HWANG HO).

CONTENTS.

	Page
<i>Introduction</i>	8
<i>Chapter I. — Some Characteristics of the Yellow River :</i>	
1. General, Development, Levels and Fall	10
2. Loess	11
3. The Great Changes in the Course of the Yellow River	12
4. River System : Discharges	13
<i>Chapter II. — Improvement of the Defences in the Plain :</i>	
1. Harmful Influence of the Yellow River	15
2. Process by which Inundations occur	17
3. The Various Causes of Breaches of Dykes	18
4. Breaches by Over-topping	19
5. Breaches by Under-cutting	29
6. Breach by Infiltration from the Effect of Waves	35
7. Breach by Human Agency	35
8. Considerations on the Improvement of the Dyke System	36
<i>Chapter III. — Other Proposals for improving the Conditions of the River :</i>	
1. The Different Means for improving the System of the Yellow River	39
2. Alleviation of Floods by means of Reservoirs constructed above the Plain	40
3. Limitation of the Masses of Loess carried down by the River	42
4. Limitation of Deposits of Loess in the River Bed	44
<i>Chapter IV. — Combination of Different Methods for improving the General Conditions of the Hwang Ho :</i>	
1. Introduction	46
2. Combination of Methods of dealing with Floods	47
3. Combination of Methods : Agriculture	47
4. Combination of Methods : Navigation	48
5. Relationship between Irrigation and Navigation	50
<i>Chapter V. — The Delta of the Hwang Ho and its Outlet to the Sea</i>	50
<i>Chapter VI. — Summary and Conclusions :</i>	
1. The Improvement of the Yellow River	51
2. Conclusions	53

INTRODUCTION.

As regards the area of its basin, the Yellow River is the second largest river in China, the largest being the Yangtse Kiang.

The basin comprises very extensive and important parts of China. The river flows through several provinces and some 140 million persons live alongside it or in its vicinity.

After a very long course, during which it makes frequent and wide changes of direction, the Yellow River, swollen by its main tributary, the Wei Ho, enters the alluvial plain of China at a distance of about 700 kilometres from the sea.

This plain, which is extraordinarily flat, forms a regular "cone of evacuation", which is gradually advancing into the Yellow Sea on both sides of the Shantung Peninsula.

The inhabitants of this plain have for centuries striven to prevent the destructive deviations of the river and the submersion caused by the flood waters by controlling the latter through a system of parallel dykes.

The construction and upkeep of these defences against inundation have led, as everywhere else in similar circumstances, to a ceaseless struggle between the river and man, in which man has not always been successful.

When the dykes held back the floods, the inhabitants of the plain were able to till the soil, gather in the harvests and multiply.

The defence works have frequently been broken down, however, when the river water has reached levels beyond their capacity to withstand. Inundations which became regular catastrophes, chiefly owing to the density of the population and the slow and gradual elevation of the bed above the plain, followed periods of relative security. As a result of poor organisation, lack of money and the feeble authority of the central Government, the river has not been forced, by the renewal of the dykes, to return to its original bed after the flood, but has formed a new bed which completely changed the geography and the hydraulic, agricultural and economic conditions of a large part of the plain of North China.

This struggle between man and the river has lasted for thousands of years and is far from ended now.

To find a remedy for this evil, which costs thousands of lives, does damage to the value of millions of dollars and prevents any rational agricultural development throughout a large part of the country, has been the constant aim of Chinese Governments and engineers for more than a hundred generations.

No decisive victory can be gained by man. He does not build for eternity, while in the river he has an adversary both eternal and powerful. Yet it would be an invaluable achievement to improve the situation even for a comparatively short space of time, for a single generation or for a few generations.

Accordingly, the Committee has undertaken, within the limits of human capacity, the study of the crucial problem—namely, the improvement of the defence of the plain against floods.

The present report therefore deals chiefly with the problem of security; the question of irrigation and the less important problem of navigation have been studied in their relationship with the main problem.

Even when restricted to the problem of security, the improvement of the Hwang Ho is one of the most formidable and difficult tasks with which engineers have ever been confronted in ancient or modern times.

The Committee has accordingly studied this question as thoroughly as the time at its members' disposal permitted.

In the early months of 1935, the members of the Committee who visited China inspected the Fen Ho and Wei Ho tributaries above Tungkwan and examined the dykes and dangerous points below that locality for a distance of some 1,000 kilometres on both banks of the river.

In addition to these inspections, as complete a study as possible was made of the various documents and the lengthy reports supplied to the Committee and of the most recent data regarding the maximum volume of water carried by the river. According to the data, this volume is very much above the figures hitherto accepted, and consequently the nature of the problem is entirely transformed.

The members of the Committee were able to interview the Government and provincial authorities and the river and reconstruction Boards and also a large number of engineers, from all of whom it received the most courteous and prompt assistance.

Before submitting the result of its work, the Committee must enter certain preliminary reservations regarding its study of the subject.

The theory and technique of river hydraulics in the West are based on a whole series of observations, experiments, studies and experience systematically and uninterruptedly acquired in the course of several generations on a very large number of rivers and streams throughout the world, with the most diverse characteristics.

There have thus been established a number of rules for the improvement of rivers and streams with characteristics that do not vary widely from the extremes of experience on which the general theories and rules of river hydraulics are based.

The Hwang Ho and other rivers of North China present hydraulic phenomena which, in intensity and size, go beyond—frequently far beyond—anything of the same kind observed on Western rivers.

Further, and more particularly, Chinese rivers present special phenomena, not observed on Western rivers, which may make the current rules of river hydraulics inapplicable to the Hwang Ho and other Chinese rivers.

The problem lies not so much in the volume of water discharged as in the immense amount of solid matter, consisting mainly of loess, carried down by the flood waters of the tributaries, and of the main river on a quite exceptional scale, and particularly in the peculiar way in which the loess, attaining on some tributaries as much as 50% in weight, is carried along and deposited, as a result of the changes in speed and the action on friable soil and earthworks of water so heavily laden with solid matter.

These phenomena have been studied for some time past, both in Europe and in China; but no one has yet reached sufficiently definite conclusions to be able to affirm that, in the special case of the Hwang Ho floods, the usual rules of river hydraulics can be applied *without modifications*.

In the present report, the Committee has expressed opinions based on current hydraulic experience, singling out those regarding which reservations must be made so long as no final conclusions can be drawn from the study of the deposit of loess by Chinese rivers.

Chapter I.

SOME CHARACTERISTICS OF THE YELLOW RIVER.

I. GENERAL, DEVELOPMENT, LEVELS AND FALL.

The Hwang Ho or Yellow River rises in the province of Ts'ing Hai, in Tibet. Leaving Tibet, it flows through the province of Kansu, forms the boundary between Ninghsia on the west and Suiyuan on the east, turns northward and enters the Ordos desert and Inner Mongolia. Having thus flowed northward from Lanchow at 36° as far as 41° N. latitude, it takes a general easterly direction for more than 2° of longitude. The Hwang Ho then describes a wide curve and flows southward, descending 6° of latitude.

Near Tungkwan, where its waters join those of its principal tributary, the Wei Ho, it again sharply changes its course and follows the general direction of the Wei Ho from west to east.

After traversing rather less than 2° of longitude, it enters the plain, which it crosses to the sea between two unbroken lines of dykes or natural elevations.

Near Lanfeng, it again changes direction, and since 1853 has followed a winding course generally from south-west to north-east, entering the sea at the end of the Gulf of Chihli, north of Shantung.

In consequence of these various changes of direction, the Hwang Ho, therefore, follows an exceptionally long course from its sources to the sea. Owing to the very different climatic and geological regions it traverses, its character and regime undergo great changes on the way. After joining the Wei Ho, it is difficult to say whether it is the Wei Ho or the Hwang Ho whose influence preponderates below that point.

The Hwang Ho is about 4,700 kilometres long and its basin, covering 1,260,000 square kilometres, has a population of 140 millions.

Below the bridge of the Peiping-Hankow Railway in Honan, the river is almost continuously banked in and receives no tributaries until it reaches the foothills of the Shantung mountains. Consequently, the drainage area of the Yellow River is substantially smaller than the figure stated above, and, from the standpoint of conservancy proper, should be reduced to about 754,000 square kilometres.

The following table provides a comparison of the principal rivers of the world (the figures are approximate) :

	Length in kilometres	Basin in square kilometres
Yellow River	4,700	1,260,000
Danube	2,800	800,000
Ganges	2,400	1,000,000
Mississippi	7,250	3,200,000
Yangtse Kiang	5,150	1,950,000

In the province of Kansu, the river has a width of 50 to 100 metres and is of a torrential character and very difficult for boats to cross.

Through the Ordos desert, and as far as the frontiers of Shansi, it carries flat-bottomed boats and rafts made from skin sacks, by which means a certain amount of goods transport can be carried on.

In this section, there are several systems of irrigation.

Cataracts and waterfalls make navigation impossible on the greater part of the course from north to south between Shansi and Shensi.

Below Tungkwan, where the river turns eastward, small wooden junks can be navigated.

Tributaries.

The principal tributaries of the Hwang Ho are : the Tao Ho in Kansu, the Wuting Ho, the Yen Shui, the Wei Ho, the northern Lo Ho and the King Ho in Shensi, the Fen Ho and the Tsin Ho in Shansi and the Lo Ho and the I Ho in Honan.

In the last 700 kilometres across the plain, the Hwang Ho does not receive any tributary, except a small part of the flow which at flood periods is discharged between the Grand Canal at Kiang Kow and Shantung.

Levels and Distances.

As regards the levels and distances of various points in the upper course of the river, little exact surveying or topographical work has yet been done. Slightly more is known of the plain, but the data are not yet sufficiently detailed.

The sources of the river at Ao Ling Hai and Ching Hai are about 4,120 metres above sea-level.

The river falls to 2,440 metres at Kueite, Ching Hai, 1,580 metres at Lanchow, 914 metres at Paotow and 320 metres at Tungkwan.

The following table gives particulars according to the most recent maps of distances, levels and general fall in the various sections :

Section of river	Distance in kilometres	Difference of level	Approximate fall
Ao Ling Hai-Kueite	—	1,680	—
Kueite-Lanchow	242.0	855	0.00353
Lanchow-Paotow	1,326.0 (990)	670	0.000506
Paotow-Tungkwan	600.0 (830)	594	0.000990
Tungkwan-Shanchow	73.8	30.7	0.000416
Shanchow-Kunghsien	230.0	183.6	0.000800
Kunghsien-Jao Chi Ying	42.1	11.76	0.000265
Jao Chi Ying-Haikow	742.5	94.84	0.000122

These data are only approximate, even as regards the plain.

2. LOESS.

The Yellow River carries down enormous quantities of loess, so that, in the lower part of its course, it is yellow in colour, whence its name.

This loess is a brownish-yellow earth, almost invisibly fine, with a tendency to fracture vertically either when drying up or when absorbing moisture. Consequently, when the river makes its way through such soil, it forms vertical cliffs sometimes several hundred feet high. These cliffs are rapidly undermined at flood time by the waters below. The loess breaks off in vertical slices which may be of immense size, and large amounts of solid matter are carried down by the current.

The resulting sediment constitutes the greater part of the immense plain of the Yellow River and accounts for the shallowness of the Gulf of Chihli and the Yellow Sea.

The distribution of loess in the basin of the Hwang Ho, according to the estimate of M. W. H. Weng, Director of the Chinese Geological Service, is as follows (reproduced with all reserves, particularly as regards the King Ho) :

Upper plateau :	Square kilometres
Lanchow	60,000
Lanchow-Ninghsia section	55,000
Wei Ho valley	26,000
King Ho valley	2,000
Northern Lo Ho valley	16,000
Fen Ho valley	11,000
Siankwan Yingtang section	1,000
Lo Ho valley (Honan)	2,000
Unspecified	<u>15,000</u>
Total	188,000

M. Weng, moreover, considers that this estimate is probably too low.

About a quarter of the total area of the Yellow River basin consists of loess.

During the winter season—about November 15th to March 15th—during which there is little precipitation, the river rarely carries down more than 0.5 to 0.6% of solid matter. During the coldest period, this percentage may even fall as low as 1 per thousand.

In spring-time, when the flow increases, there is a substantial rise in the proportion of solid matter. In a few hours, the weight of the solid matter carried increases by *several units* per cent.

Subsequently, this proportion never falls to the winter minimum. Generally, the water at that time contains more than 1%, but if the spring is dry, and if the flow remains for a fairly long period below 500 cubic metres in the lower course, the percentage of solid matter may become less.

During the summer high-water levels and the corresponding heavy floods, the proportion of solid matter transported reaches figures which are not attained elsewhere in the world, except on some other Chinese rivers; in the case of certain tributaries of the Yellow River, it may amount to about 50% in weight.

The solid matter carried down by the Hwang Ho consists almost entirely of mineral products, from extremely fine sand to impalpable clay.

These matters are generally carried off by the heavy summer rains from the large deposits of loess and tertiary clay in its basin and that of its tributaries. They come chiefly from the provinces of Shensi, Shansi and Kansu.

The matter from the provinces of Honan, Suiyuan, Ninghsia and Ts'ing Hai represents a relatively small percentage of the total solid discharge. The provinces of Hopei and Shantung receive more loess than they evacuate.

Generally speaking, it is the basin of the Wei Ho which is the principal source of the solid matter carried down by the Hwang Ho below Tungkwan.

3. THE GREAT CHANGES IN THE COURSE OF THE YELLOW RIVER.

The Yellow River has several times changed its course across the plain during the long period in which man has attempted to keep it in place by means of dykes.

All these changes have taken place below Meng Tsin in the cone of alluvial evacuation. The first mentioned in Chinese annals dates from 2279 B.C. At that time,

the Emperor Yu, China's greatest hydraulic engineer, succeeded in forcing the river back into its old bed. The mouth was near Tientsin.

In 602 B.C., 1,677 years later, the river burst through its dykes at Su Shu Kow, in Honan; the new course was almost parallel with that of the Wei Ho.

The river changed its course, 613 years later, at Wei Chun and flowed through Tsinan, in Shantung, to Chien Cheng (now Litsin).

In 1048—that is to say, 1,037 years after the previous change—the river changed its course at Shang Hu (now Pu Yang). The mouth was near Tientsin, and afterwards changed to Haifeng.

In 1194, 146 years later, the river broke through the dykes at Yang Wu and turned towards Liang Shan Lo, in Sowchang, where it divided into two branches, one of which was very near the present bed, while the other flowed into the Hwai Ho.

In 1493—*i.e.*, 299 years later—the dyke of Taihang was constructed and the river flowed through Hsuchow to the sea at Yuti Kwan.

Finally, in 1853, 362 years after the last change, the river adopted its present course as a result of breaches of the dykes at Tungwasiang, near Lanfeng.

Just as the long and glorious history of China tells of a number of changes of dynasty, it also enumerates the changes in the course of the Hwang Ho across the plain. As the history of each dynasty comprised a number of Emperors, so the history of the Yellow River recalls several very great catastrophes during each period of its course, and an endless number of more or less serious ones, which nevertheless would be recorded as truly calamitous in the annals of any other part of the world.

4. RIVER SYSTEM: DISCHARGES.

The Yellow River has very pronounced periods of flood and low water.

The flood season generally begins more or less abruptly towards the end of June or the beginning of July and is characterised by a few floods, each lasting only a few days.

Between these series of floods, which pass quickly, the level remains decidedly above that of low water.

The floods become less numerous and less considerable in September and October.

From the middle of November, the low-water season commences.

Dangerous floods may, nevertheless, appear even at the beginning of October, as was observed in 1934, when a flow of 10,000 cubic metres per second ($m^3/sec.$) occurred.

During the winter months, particularly during frost, the flow reaches the minimum for the year.

The flow increases again after the thaw.

In the spring, there are sometimes smaller floods than in summer, but, in general, the level falls between these flood waves. It is not exceptional for the river to reach a new minimum in May or June, which, however, is not so low as that of the winter.

The basin of the Wei Ho, the largest tributary of the Hwang Ho, is in the centre of the river basin as a whole and is encircled on the west, north and east by the course of the Hwang Ho. This peculiarity is one of the reasons why the flow of the Hwang Ho in the plain is generally small in comparison with the size of its basin, and generally remains during flood periods below 10,000 $m^3/sec.$ and rarely exceeds 20,000 $m^3/sec.$

At flood time, the Yangtse Kiang, with a basin not much larger than that of the Hwang Ho, has, above Ichang, a flow which is rarely below 30,000 $m^3/sec.$ and may attain as much as 70,000 $m^3/sec.$

The low-water flow of the Yangtse Kiang is about 3,000 m³/sec. at Ichang and that of the Yellow River about 300 at Shenchow, except in the period of frost, when the flow falls lower.

The difference in the low-water flows between the Hwang Ho and Yangtse Kiang is certainly due to the less abundant rains in the basin of the Hwang Ho. As regards the high-water flow, it appears that the rainfall in the basin of the Yellow River is at times as large as in the basin of the Yangtse Kiang.

The rainfall is not the sole cause of the great difference in the flows of the larger Chinese rivers.

The low-water flow of the Hwang Ho is specially small during the winter, owing to the severe climate, which, in turn, is the result of the continental situation of the upper basin.

The question of the coincidence of the floods on the Wei Ho and the Yellow River is of importance only for the part of the river below Paotowchen.

The floods above Lenchow are very serious. Observations show, however, that they become appreciably lower over the section of about 1,000 kilometres between Ninghsia and Suiyuan.

At Paotowchen the floods are moderate, with slow variations. As they carry down comparatively little solid matter, they have a very favourable effect on the lower course, when the latter receives the flood waters of the Wei Ho, which are heavily laden with solid matter.

Low River Discharges.

At the upper end of the dyked section, a discharge of less than 400 m³/sec. is not unusual. The greater part of this discharge appears to come from the section about Lanchow. At Shenchow, it has been observed that the discharge during periods of frost has been less than 150 m³/sec. At Lokow, in Shantung, the discharge during these periods has been less than 100 m³/sec. and is liable to fall to less than 50 m³/sec.

In the spring, moderate floods may appear which raise the discharge for one or two days up to 2,000 or 3,000 m³/sec. If the spring rains are abundant, the discharge does not fall below 1,000 m³/sec. after mid-May.

Flood Discharges.

The floods of the Yellow River are more remarkable for their abruptness than for their volume. This is especially true of the section above the railway bridge of the Peiping-Hankow line. When the flood passes downstream along the embanked bed, the crest of the flood wave is flattened, because part of the discharge spreads over the flood channel, and perhaps also to a lesser degree because the river loses water by infiltration through the dykes. In the province of Shantung, the flood discharge is much smaller than in Honan. The dykes in Shantung, however, have never had to bear the pressure of the high floods, because, when these occurred, dykes had always burst higher up, and inundations have taken place which diminished the flood discharge in the Shantung area.

With the existing dyke system and river bed, the whole of a major flood can never get as far as the sea. A flood of more than 13,000 or 14,000 m³/sec. does not reach much further downstream than the frontier between Honan and Hopei without breaching dykes. Fortunately, floods of this extent do not occur every year. To the right of the railway bridge on the Peiping-Hankow line, they do not as a rule exceed 10,000 m³/sec., and in that case their discharge does not attain 8,000 m³/sec. when they enter the Shantung area, even if they have not burst the dykes higher up.

On the other hand, observations made at the time of the 1933 flood showed that it had exceeded 23,000 m³/sec.

Hydraulic engineers were surprised at this figure, because in all previous theories and studies the discharge during flood periods had been assumed to be less than half that quantity.

All recent information on the flood discharge of the tributaries of the Yellow River and the Wei Ho unanimously corroborate this figure of 23,000 m³/sec.

Thus a flood discharge measured on the King Ho, a tributary of the Wei Ho, showed a figure of 12,000 m³/sec.

An approximate analysis of the 1933 flood of the Yellow River shows that, at Shenchow, the discharge rose on August 7th, 1933, from 2,500 to 5,200 m³/sec., and twenty-four hours later reached 16,000 m³/sec. Next day, the discharge measured 22,200 m³/sec., and reached its maximum of 23,000 m³/sec. in the night of August 10th.

Twenty-four hours later, however, the discharge had fallen to 10,000 m³/sec., and on August 11th to 8,000. After an increase on August 12th up to 9,800 m³/sec., the discharge fell to 5,000 m³/sec. on August 14th.

The contribution of the Wei Ho and its tributaries to this discharge was very large, amounting to about 16,000 m³/sec. out of a total of 23,000 at the peak level.

The Yellow River itself gave the further considerable discharge of 4,000 m³/sec. when the peak of the flood was already past.

It may be asked whether the maxima of the Wei Ho and the Yellow River can coincide.

An analysis of the flood of 1934, which was much smaller than that of 1933, has shown that such coincidence actually occurred.

On August 10th, 1934, the Wei Ho and the Yellow River simultaneously reached their maximum, at that time nearly the same amount—viz., 5,000 m³/sec. each—thus forming together a maximum discharge of over 11,000 m³/sec.

The probability of the maximum discharges of the two rivers coinciding is small, but such an occurrence is certainly not impossible. For this reason, it appears wise to reckon in future on floods having a discharge much greater than 23,000 m³/sec.—for example, 30,000 m³/sec. or even more.

These figures suffice to show that the earlier studies must be resumed on these new bases.

Chapter II.

IMPROVEMENT OF THE DEFENCES IN THE PLAIN.

I. HARMFUL INFLUENCE OF THE YELLOW RIVER.

The floods of the Hwang Ho are a continual danger to the lives of the numerous population of the plain to the north of the Yangtse Kiang.

The harmful influence of the Yellow River shows itself in two different but both typical ways.

In the first place, the history of the Hwang Ho records a large number of breaches of dykes, followed by serious inundations.

The passage of a great summer flood almost without exception causes several breaches, which sometimes take place in groups of three or four, and sometimes in larger numbers.

The gravity of the inundations following such breaches depends on several factors.

Some of these are of a local character: the height of the bed of the river above the neighbouring land, the existence of a second line of defence, and means of diverting the waters, the density of the population and its distribution.

Other factors depend on the river itself, and the characteristics of the flood, the discharge of the river after the breach, and the duration of the flood, the portion of the volume of water discharged through the breaches, the proportion of solid matter carried by the water, and so on.

In every case, however, the breach of a dyke is a catastrophe invariably entailing material losses, both direct (loss of houses and property, destruction of harvests) and indirect (period of non-productivity), usually accompanied by much loss of life, either immediate or indirect, through famine or disease following the flood.

The extent of the catastrophe varies widely. From the loss of some dozens of lives and material damage of some hundreds of thousands of dollars, it may rise to hundreds of millions of dollars and the loss of hundreds of thousands of lives.

The material losses caused by the river may be placed at more than ten times as much as the cost of maintaining and restoring the system of defence.

The other harmful influence of the Yellow River is of a different nature, but is even more serious.

The greater part of the waters coming from the fluvial basins of China is drained by river systems crossing the Chinese plain formed by their deposits and flowing into the Yellow Sea or the East China Sea or its gulfs to the north-east or south-east.

The plain, although broken by mountain systems, as in Shantung, is quite flat and forms a whole which is not divided into well-defined natural basins. The danger of breaches of dykes and human action in the chaotic hydraulic conditions of this perfectly flat alluvial plain have more or less closely and effectively defined the basins of the different rivers.

Thus, at the north of the lower course of the Yellow River is the basin of the Hai Ho, which flows into the gulf of Chihli, near Tientsin, carrying to the sea water from an area of about 68,000 square kilometres.

To the south, between the Hwang Ho and the enormous basin of the Yangtse Kiang, is the Hwai Ho, the waters of which are drawn from an area of 270,000 square kilometres.

The hydraulic conditions of the different rivers the courses of which are by nature not very stable, on account of the very slight slope of the plain and the mobility of the alluvial deposits of which it is formed, are seriously complicated by the Grand Canal. This gigantic work, connecting the south of China with the north, crosses the basins of the Yangtse, the Hwai Ho, the Yellow River and the Hai Ho. Its dykes form an obstacle to the direct outflow of several rivers into the sea and bar the plain between the great watercourses.

Of these, the Yellow River occupies the central position. It forms the key to the hydraulic system of the Chinese plain north of the Yangtse.

Every change in its course causes a radical disturbance of hydraulic conditions in one or more neighbouring river basins; and these disturbances, attended by dreadful catastrophes, either destroy or completely change the lives of millions of men and revolutionise conditions of habitability in the country for years.

Such catastrophes, the last of which took place only eighty years ago, are liable to occur in any year.

In the present conditions of defence, any great summer flood may cause radical changes in the Chinese plain. It is, however, impossible to predict with any certainty in what direction or in what manner such disturbances will take place, and what will be their consequences.

What is certain is that the consequences of a displacement of the river-bed involving a revolution in the hydraulic conditions in a considerable part of this over-populated plain are far more serious than those caused by local inundations, which take place frequently but vary in extent.

These various characteristics of the Yellow River are known and feared by the whole population of the plain. A change in the course of the Hwang Ho may produce catastrophes even hundreds of kilometres away from the existing river-bed, by changing the hydraulic conditions obtaining on other watercourses.

The effect of this situation on the lives of tens, or maybe hundreds, of millions of men is much greater and much more harmful than is generally known.

The fear of inundations prevents any effort to improve hydraulic conditions in the plain. Yet there is no lack of schemes of draining, irrigation, warping and embanking requiring only reasonable effort and expenditure, which would be really remunerative and would largely increase the value and productivity of extensive areas; but for the uncertainty due to the menace of the Yellow River.

The Yellow River exercises its harmful influence on the life of the Chinese plain in two different ways. One is direct, by causing every year loss of life and destruction of wealth and by giving rise to heavy expenditure in the repair of breaches in the defences. The other influence is indirect; it renders impossible, or at least too uncertain, the realisation in the plain of substantial improvements of an hydraulic and agricultural character, which would permit of the creation of new wealth necessary to raise the standard of life of a large part of the population.

Accordingly, the improvement of the hydraulic conditions of the Hwang Ho must be classed among reconstruction works of the first order, not only directly, by the avoidance of catastrophe, but also indirectly, as adding to the value of large extents of territory and encouraging improvement undertakings by increased security.

2. PROCESS BY WHICH INUNDATIONS OCCUR.

Inundations are caused by the formation of one or more breaches in one of the defensive dykes. The breaches rapidly widen and allow part of the flow of the river to discharge into the plain, which is generally lower than the river-bed, and the water thus submerges vast areas of the plain.

Such breaches are produced on all rivers in the same manner, but the presence of loess may be an additional cause for the breach of dykes on the Chinese rivers, as will be seen later in this report.

The consequences of the breach of dykes in the low-lying plain crossed by the Yellow River are particularly disastrous on account of a number of very special local circumstances unconnected with the dykes themselves.

When the breach is made in a place where the river-bed is considerably higher than the neighbouring land, as is the case over a large part of the course of the river, it tends to widen and, especially, to deepen excessively, while its flow quickly increases until it absorbs a large part of the total flow of the river.

This phenomenon is aggravated by the torrential character of the floods of the Hwang Ho.

The flow increases very rapidly up to the maximum, and, in unfavourable cases, may, in the course of a few days, become twenty times as great as at the beginning of the flood. During the flood period and even when the water is subsiding, the water contains a very high percentage of solid matter, principally loess.

On the other hand, the part of the flood channel between the dykes consists of soil of the same composition as the alluvia brought down by the river—most frequently a mixture of loess and very fine sand, very liable to erosion. The current which overflows through the breach on to the plain creates, by enlarging the breach and detaching itself from the former channel of the river, a new bed, the dimensions and capacity of which increase very rapidly and in which, the fall being greater through the breach than along the normal course, an increasingly large volume of water passes.

At the same time, owing to the reduced flow in the original bed below the breach, the speed decreases and a considerable part of the loess and sand carried down by the river is deposited and reduces the capacity of the original channel, thus facilitating still further the flow through the breaches.

In the plain, channels are formed where the current is strongest and *alluvial deposits appear where the speed of the current lessens and the loess is precipitated en masse.*

The result is the formation of a new bed for the river, and the water sooner or later leaves the old bed, since the diversion towards the plain, which lies lower than the old bed, represents the greater fall for the water. This process may be interrupted in three ways :

In the first place, by the subsidence of the river before a permanent deviation has been completed. The great floods of the Hwang Ho, though violent, are usually of short duration. This is the principal reason why so many serious breaches in the defences have not caused still worse devastation.

In the second place, a state of equilibrium tends to occur when the resistance to the deviation increases at the same time as the resistance to the flow of water diminishes in the normal bed. This may happen for different reasons : either because the water encounters obstacles below the inundated land, such as dykes or higher ground, which cause the level of the water outside the breach to rise, or because, as a result of the special qualities of the loess, with which the Committee will deal later, abundant alluvial deposits are formed hindering a flow through the breaches, or else because dykes above or below the former breach render the situation less tense near the particular breach.

In the third place, it is the intervention of man which, after a flood, puts an end to a dangerous situation by closing the breaches and ensuring the continuity of the defences, thus fixing the traditional course.

Hence the direct causes of catastrophes of the Hwang Ho are breaches of the dykes which confine the flood channel. But the very special characteristics of the Yellow River and the plain through which it runs make the consequences of these breaches particularly disastrous.

3. THE VARIOUS CAUSES OF BREACHES OF DYKES.

The protecting dykes of the Yellow River are made of soil excavated in the immediate vicinity of the place where it is used.

In the course of centuries, this soil has not always been selected and tamped with all the necessary care.

Breaches may be produced by five different actions or by combinations of those actions.

(1) The breach may be formed when the water in the river rises to such a level that it overflows the crest of the dyke. As this is constructed of loose earth and is not lined or faced, even by a simple covering of turf, it is rapidly eroded on the crest and along the outer bank. As a result of the erosion, the height of the crest and the thickness of the dyke diminish, while the volume of the water and the speed increase, and the destruction is accelerated in geometrical progression. A complete break is soon produced.

(2) A breach may also be formed when the inner side of the dyke, and especially its base, is directly attacked by the current of the river, generally in the concave parts. The inner bank gradually gives way, the thickness of the dyke decreases, and a breach is rapidly formed. The current passing through the breach is then at once greatly

reinforced by the river, especially if the foot of the dyke has been eroded, since in that case the breach is particularly deep as soon as it is formed. Consequently, such breaches generally allow an immense outflow of water.

(3) A breach may also be produced when the body of the dyke is saturated with water, either by direct infiltration from the side of the river or by indirect infiltration through the more permeable layers at the bases of the dyke. The cohesive capacity of the earth is reduced, while at the same time hydraulic pressure, accompanied by the oozing out of water, takes place. Its effect is felt when the base of the inner side of the dyke collapses. The dyke itself is thus weakened, and a breach may result.

This case arises especially when the high water lasts a long time or the dyke is of inadequate construction or composition.

(4) The fourth way in which a dyke may be ruined is when the inner bank is directly attacked by the lapping of the water during floods.

(5) Finally, during a period of flood a dyke may be cut by human agency, in order to reduce the level of the water and relieve the neighbouring dykes.

Breaches may arise in any of these five ways on the Hwang Ho. These five phenomena are not, however, equally likely to occur.

Dykes are not very likely to be breached on the Hwang Ho by the direct attack of waves; for this to occur, a violent storm would have to arise just at the brief period of high floods and from such a direction that the weak points of the works would be attacked.

A breach by infiltration caused by the collapse of the outer side of the dyke arises, as a rule, only after high water of sufficient duration to saturate the body of the dyke.

This case is rare on the Hwang Ho, where the risings and inundations of the flood channel are of short duration and where, generally, the main dykes are exposed to the pressure of the water for only a few days in succession.

Moreover, for the most part, the main dykes, although often composed of poor material such as loess more or less mixed with fine sand, not faced with a layer of impermeable clay on the river-side or covered with turf, are of large dimensions and withstand the pressure of the water quite well for some time.

The situation is quite different, however, when, after the breach of the main dykes, the water remains for a long period in a cavity and is retained by reserve dykes. This happens often and for long periods. The reserve dykes are generally of smaller dimensions or constructed of earth of poor quality, are badly maintained and are poorly provided with defensive materials.

In this case, a breach by infiltration may arise and may have the worst consequences during the period, which is usually prolonged, when the breaches of the main dyke which cause the flood remain unclosed.

Breaches by over-topping and by under-cutting by the current are by far the most frequent in the history of the Hwang Ho. No reliable statistics exist, however, whereby the frequency of the two principal kinds of breach can be estimated.

It would appear, however, from the records that breaches by over-topping are the most numerous.

On the other hand, it appears to the Committee that breaches by erosion of the lower part of the dyke have the most serious consequences.

4. BREACHES BY OVER-TOPPING.

To avoid breaches by over-topping, it would be necessary, and it would also be sufficient, for the dykes of the Hwang Ho to be raised at each point above the highest possible flood-level.

In theory, therefore, the solution would be extremely simple. In practice, however, the problem is extremely complicated by reason of the character of the river.

Indeed, the probable high-water level cannot at present be determined with sufficient accuracy at the various points along the course of the river.

First of all, the maximum possible discharge is not known. In order to attain sufficient probability in the matter, accurate observations taken over at least a century would be required.

Since the time of the last radical diversion in 1852 (when the river, which used to flow into the Yellow Sea south of Shantung, passed north of the peninsula and flowed into the Gulf of Chihli), its course has constantly changed.

When taking the direction south-west-north-east, instead of west-east, the river, on a large part of its new course, has followed the course of a lesser river, which, however, was composed of clear water, and the level of which was lower than that of the neighbouring plains. This means that from the time immediately after the breach there was a sudden change of level, fall and speed as between the part of the old bed, which was still traversed by the river, and the new bed in the plain downstream.

The river, full of solid matter, especially in time of flood, and flowing through a plain formed of recent and very mobile sediment, has constantly been trying to alter its bed, so as to reduce the abrupt changes in and to regularise its own longitudinal section.

After the great breach, the old bed above the breach became deeper, while below, by its successive deposits, the river has continually been raising its bed downstream.

This natural correction of the longitudinal section of the river, assisted by the dykes, is now in course of completion; the dyked part of the river-bed has approximately the same fall throughout its whole length. As regards the situation near the breach of 1852, it would require very little to make the Hwang Ho resume the course it followed before that time.

The floods of the summer of 1935 have indeed given proof of this at a time when, as a result of breaches of dykes on the right bank of the river downstream from the great breach of 1852, a large part of the water discharged through the lakes to the eastward towards the former river-bed.

During the last eighty years, the level of the bed has thus undergone continual change, which, however, has not been the same in different sections, and has only recently attained a certain general equilibrium.

It would not therefore have been possible during that time to take the mean height of the bed as the basis from which to deduce the probable level of the highest floods in the future. In the case of the Yellow River, there is a third characteristic factor of uncertainty in respect of the level of the highest possible floods.

A considerable length of the present course of the river in the lower part of the plain has never had the volume of water of a large flood passing through it, since, in such cases, there are always breaches upstream through which part of the discharge flows; the river has thus lost part of its volume before reaching the lower parts of its course.

Thus, over a length of more than 200 kilometres in the Shantung Province, where the dykes are fairly close together, the discharge of the river has probably never exceeded 8,000 to 10,000 m³/sec., while higher up, in the section of the old bed, the highest floods have probably attained 25,000 to 30,000 m³/sec.

In any case, there is an immense disparity between the discharge of the river at flood periods in the plain of Shantung and that higher up, which disparity is due to the breaches of the dykes in the upstream region.

A fourth cause of uncertainty as to the probable level of the highest waters is the general and permanent rise of the river-bed. This is the phenomenon which, in modern times, has most engaged the attention of engineers who have studied the Yellow River.

This phenomenon of the rise of the river-bed is a very complex one and is governed by factors which sometimes are mutually incompatible.

The discharge of solid matter deposited in the plain downstream from Shenchow is divided and deposited in three distinct zones.

One part—much the least in size—is deposited in the river-bed by reason of various circumstances. The most important of these is the change of fall noted at the downstream end of the closely dyked part of the river, extending from Tungkwan to Shenchow, where the river, following a very general law, endeavours to adjust the longitudinal section of its bed.

The surplus is deposited partly in the sea and partly in the plain.

The sediment carried down into the sea causes a protrusion of the coastline. As a result, the course of the river is lengthened and the fall reduced, with a consequent gradual rise in the river-bed, while the sea is constantly being silted up over a vast area by reason of the tenuity of the particles, which are thus carried far out to sea.

Under the influence of the movement of the sea and of the sea currents, slight though they may be, the sedimentation of the sea is very regular.

Alluvial matter is deposited in the plain wherever breaches of dykes brought about by a flood enable part of the discharge to spread outside the dyked channel. In this case, however, the thickness of deposits produced by each flood is very irregular. *Ceteris paribus*, it depends on local reductions in speed.

These deposits are quite large, since the flood waters are, as a rule, heavily charged with solid matter; at certain points after an inundation, local deposits several metres in thickness have been observed, the total volume of which would run into tens and even, in the case of exceptional floods, into hundreds of millions of cubic metres.

If the dyke system fulfilled the theoretical condition of absolute watertightness, all alluvium would be deposited in the river-bed or in the sea.

Hence the advance of the coastline would be accelerated, and there would be a further rise in the river-bed through the lengthening of its course and the consequent reduction in the fall.

The real means of estimating with sufficient accuracy the three final categories of alluvia—namely: (1) volume of matter raising the river-bed, (2) volume of matter deposited on the plain, and (3) volume of matter advancing the coastline and of sediment in the sea—would be to compare the hydrographic surveys and the contour-line plans, both being correct and taken at sufficient intervals of time (several periods of ten years at least), and to compare the results thus obtained with direct observation of sediments in test borings made in suitable places alongside the successive courses of the river, and by taking core samples in the marshy parts of the delta and in the sea.

It would seem that the general rise of the river-bed during recent centuries has been comparatively slow—on an average, about 1.5 metre per century.

This conclusion has been arrived at as a result of the observation of the rises which have taken place in the region upstream from the plain, between the railway bridge of the Peiping-Hankow railway and the town of Lanfeng. The observation is supported by inferences which are ingenious but somewhat conjectural.

The Committee points out that this probable increase of 1.5 metre should be taken as an average figure covering several centuries and applying to the river-bed as a whole; local unimportant and much more rapid rises of the bed, possibly followed by falls corresponding to periods of erosion, have inevitably taken place over certain parts of the river-bed as the result of local circumstances.

The general rise of the bed may be arrived at by another and more reliable method based on the rate at which the coastline advances.

A comparison of maps shows that the delta through which the Hwang Ho flowed into the Yellow Sea during a period of some seven centuries had lengthened up to

1852 from 50 to 70 kilometres—that is to say, an average of 7 to 10 kilometres a century. (This advance would appear to be less rapid in the case of the new delta and not to exceed 3 or 4 kilometres during eighty years; this is probably due to the vast deposits in the plain above the breach of 1852.)

On the cone of evacuation of the Hwang Ho, there is a general fall of the river, due to the absence of deposit and erosion, resulting from the combination of various characteristics of the river, nature of alluvia, shape of the main river-bed, liquid discharge, etc. If the fall becomes less, the current slows down and the river deposits solid matter in order to regain its general fall. If the fall increases beyond the normal, the current is accentuated and the river erodes a bed for itself and so reverts to the normal fall.

Hence, as the river-mouth advances into the sea and the length of its course increases, the river raises its bed and so recovers its normal fall. If an advance of 7 to 10 kilometres per century is accepted, and the fall be taken at 1/5000 to 1/6000, we arrive at a general rise of 1.16 metre to 2 metres—that is to say, an average of about 1.6 metre per century, which fully coincides with the results obtained by using the first method.

In the case of the Hwang Ho, we may therefore allow for a general rise of the river-bed *in the past* of about 1.5 metre per century.

The fall of the river below the narrows between Tungkwan and Shenchow is not uniform. There is a sharp decrease in the fall at the exit from the narrows, which causes a marked reduction in speed of flow, with considerable deposit of alluvia. This transition zone extends over about 100 kilometres to the upstream beginning of the cone of evacuation, which will be found near the railway bridge of the Peiping-Hankow line. It is from that point that opportunities arise for the considerable deviations which have brought the course of the river from the south to the north of the Shantung Peninsula; and, reciprocally, this head of the cone of evacuation constitutes an actual articulation of the river-bed.

The Committee has clearly demonstrated that the general rise of the river-bed in the past averaged 1.5 metre. It is desirable to consider to what extent the prevention of breaches of dykes may affect the rate at which the bed rises.

The Committee takes the most unfavourable hypothesis—that is to say, that none of the measures recommended hereinafter in the present report for the purpose of reducing the carrying of loess and lessening the floods are taken.

Should there be no more breaches of the dykes, the total alluvial matter, minus the volume corresponding to the rise of the bed, would be carried to sea and would cause the coastline to advance more rapidly than in the past.

This more rapid advance of the estuary would result in a lengthening of the course of the river and a reduction of its fall, followed by a corresponding rise in the bed as a whole.

The rate at which the delta advances is governed by the two following factors—first, the greater volume of alluvial matter carried by the river, and, secondly, the natural features of the coastline, slope of the foreshore, conditions at sea (tide, current, winds), etc. The Committee takes this last factor first.

When a delta is formed on a straight coastline with a submarine beach having a gentle but regular slope, the rate at which the delta advances, should there be no shore current, will gradually decrease, since each extension of equal length in the sea will involve a greater volume of alluvial matter.

The conditions in the successive deltas of the Hwang Ho are different from this standard case, since the river, where it runs into the sea north or south of the Shantung Peninsula, ends in a gulf which is sheltered and not very deep, a fact which facilitates the advance of the coastline. From this point of view, the conditions in the present estuary are less favourable than those in the old one, since the Gulf of Chihli is more silted up and more sheltered than the Yellow Sea.

However, *ceteris paribus*, the estuary should thus advance at least as fast in the Gulf of Chihli as in the Yellow Sea.

In order to estimate the influence of the other factor—the increase in the volume of alluvial matter carried to sea as a result of prevention of breaching of dykes—it would be necessary to know the proportion of the volumes of alluvial matter deposited outside the river-bed during and after floods in relation to the total solid discharge of the river.

With the scanty information available on this subject, it is only possible to make a few general remarks.

The discharge of the river results from the discharges of its main tributaries, whose solid content varies quite considerably by reason of the geological composition of their respective basins. Since the height of the floods on the Hwang Ho is determined sometimes by one tributary and sometimes by another and sometimes by the Hwang Ho itself, the great floods are seldom similar, and their content of solid matter varies even more considerably, so that floods with the same total liquid discharge do not carry the same volume of solid matter.

On the other hand, in the course of centuries, inundations and, *a fortiori*, disastrous floods have not taken place every year. Thus from 1552 to 1852 (that is to say, up to the last great change of the river-bed), ninety-eight floods are on record, caused by breaches of dykes, of which thirteen are regarded as having caused particularly serious damage.

These ninety-eight floods took place during eighty-three years out of the 300 years of this period (in some years, there were two or more floods). During the 217 years in which there were no breaches of dykes, all the alluvial matter was carried down to the sea, with the exception of deposits corresponding to the general rise of the river-bed.

The hydraulic experts who have studied the Yellow River have estimated the average amount of alluvial matter carried down during the years in which there were no breaches of dykes at figures varying from 300 to 600 million cubic metres.

For its calculations, the Committee takes the average figure of 450 million cubic metres.

If we take account of the rise of the river-bed, which on an average receives about 75 million cubic metres yearly, the volume of matter reaching the sea yearly would, on an average, be about 375 million cubic metres—that is to say, a volume of 81 milliard cubic metres—during these 217 years.

During the thirteen floods which can be regarded as real catastrophes, we can take it that the greater part of the alluvial matter went out through the breaches of the dykes and was deposited in the plain.

The maximum discharge of floods which did not breach the dykes hardly exceeds 8,000 m³/sec.

The maximum discharge of the very serious floods may increase, as has been said above, up to 25,000 or 30,000 m³/sec.

Reckoning in respect of the thirteen disastrous floods an average discharge of 16,000 m³/sec., which is the mean between the highest point of floods not leading to breaches in dykes and the *maximum maximorum*, and taking account of the fact that the content of solid matter increases, *ceteris paribus*, much more speedily than the liquid discharge (some authors have accepted a proportion equivalent to the fourth power of the depth), the Committee thinks that it can adopt a figure arrived at, failing fuller information, by estimating the volume of alluvial matter carried down by each of these thirteen great floods at 1,350 million cubic metres.

In the case of the seventy years during which less serious floods occurred, the figure taken for the discharge of solid matter may be half-way between the two previous ones—that is to say, 900 million cubic metres.

Failing more adequate information, the Committee is prepared to assume that all the alluvial matter carried down during the thirteen years of very serious floods (a deduction being made for the rise of the river-bed) and that half the alluvial matter carried down during the seventy years of floods (a deduction being made for the rise in the river-bed) would be deposited in the plains.

The conclusion is that, during the three centuries up to 1852, the volume of sediment deposited in the sea amounted to 110 milliard cubic metres, whereas the volume of alluvial matter deposited in the plain was 45 milliards cubic meters, and the rise in the bed absorbed 2,250 million cubic metres.

These figures are not mathematically exact; they can only give a rough idea of the proportions, and it should be noted that the estimate for deposits in the plain is probably a conservative one.

Hence the volume of alluvial matter deposited in the plain during these three centuries may be taken as varying between 40% and 100% of the sediment carried down to the sea, so that the prevention of breaches in the dykes would increase the rate of the rise in the river-bed by 40% to 100% of the rise observed. That is to say, that it would rise from two to three metres per century.

The fourth point which is difficult to determine is the probable extent of the highest flood.

The observations taken during recent years are inadequate and do not extend over a sufficient length of time.

They show, however, that the discharge during the great floods may be much greater than was formerly believed.

Thus, the maximum discharge of the great flood of 1933 has been estimated at about 23,000 m³/sec., while formerly the maximum was believed to be 10,000 to 12,000 m³/sec.

In 1933, however, all the conditions favourable to a record discharge did not coincide. Thus the height of the flood on the Wei Ho and its tributaries was passed when that of the Yellow River itself arrived at the point of junction.

A coincidence of high waters on the Wei Ho and Hwang Ho may take place, however, as was shown by the flood of 1934, although the latter was of smaller dimensions than that of the preceding year.

It would seem wise, therefore, to assume that the discharge of the great floods of the Hwang Ho may exceed that of 1933, amounting to 25,000 or 30,000 m³/sec., and that very occasionally even those figures might be exceeded.

The Committee desires urgently to draw the attention of the readers of this report to the remarks made above with regard to the size of the maximum floods.

Experience indeed shows that in other parts of the world, where exact observations taken over several centuries are available, exceptional floods, exceeding all those previously recorded, still occur unexpectedly from time to time.

The various elements mentioned being now known, the question arises whether it would seem possible in the future to obviate the breaching of dykes by over-topping.

This brings us back to the conditions of the existing dyke system and the possibility of increasing the volume of water they can withstand.

On the north side, the Hwang Ho has an uninterrupted chain of dykes, 601.9 kilometres in length. On the south side, the dykes commence further east, near the railway bridge of the Peiping-Hankow line, continue for 350 kilometres up to the Shantung hills, and then continue below the latter for 27.5 kilometres.

These dykes are not all of the same age or of the same dimensions or quality. Over certain distances, they form a single line of defence, though often provided with directly supporting dykes, and in some regions duplicated by a line of reserve dykes further from the river; while elsewhere the system is supplemented by lines of dykes

which, in case of breaches upstream, are intended to bring the water back to the river lower down.

In fact, the Chinese dyke system is provided with the same defensive features as are found in Europe, particularly in the Netherlands.

The weakness of the Chinese system is due to four—or, rather, five—principal causes :

- (1) The very great length of the line of defence ;
- (2) The variations in the quality of the dykes in the different sections ;
- (3) The lack of a central directing authority capable of exercising power in the various provinces, in order to co-ordinate hydraulic defence in accordance with a carefully considered and well-planned scheme ;
- (4) Lack of funds ;
- (5) And lastly, certain phenomena connected with alluvion which are peculiar to the Hwang Ho and its tributaries when the water is carrying an excessive amount of loess.

The Committee considered this *last factor* first.

This is a well-known phenomenon which has for some time been systematically studied in laboratories. Indeed, the same features have been noted in other countries where loess is prevalent (irrigation work in Sovietic Turkestan)—that is to say, water containing a large amount of loess is considerably affected by slight variations of speed, any reduction in speed leading to considerable deposit of solid matter, and even, within certain saturation limits, to very considerable deposits.

Thus, at certain points on the Hwang Ho it seems to have been noted that, during floods, even when there was no breaching of dykes involving a sudden change of speed in the river-bed, the slight local reductions in speed produced in a very short time a rise of several metres in the mean-water channel, the inference being that these obstacles in the main channel might lead to a correspondingly great increase in the level of the flood, causing over-topping and thus breaching of dykes.

Similar phenomena occur on other rivers, but on a smaller scale. The rise of shoals during floods, followed by their lowering during the fall of water, occurs on all rivers with a mobile bed ; but, from the point of view of discharge of water, it is compensated by the erosion of deeps during the course of the flood, which are filled up again during the subsidence of the water.

During frosts, a sudden rise in the water-level occurs in places where the free current of a river is sharply held up or retarded by a barrage of ice.

Conditions on the bed of the Hwang Ho tend to reduce the discharge sections of the dyked bed through the deposit of loess by reason of the existence of many obstacles—villages, plantations of trees or shrubs, sudden changes in the width of the bed, etc.—which lead to changes in speed and eddies ; they are also caused by the slope of the general flood current as compared with the mean-water bed occupied by the river at periods of mean and low water.

While admitting that the Chinese have good reason to call the Hwang Ho “capricious”, and that the phenomena on this river are remarkable for their abruptness and for the large scale on which they occur, the Committee considers it not impossible to remedy the disasters resulting from them.

The situation would in some respects be improved by a certain adjustment of the main river-bed—a task that is gigantic, like all things connected with the Hwang Ho—in order to ensure as far as possible the concurrence of flood currents and of mean- and low-water currents. In addition, there should be an increase in the height of dykes amply sufficient to protect them against the highest floods, in order to prevent

their over-topping in the zones where large deposits of loess in the mean-water bed lead to a rise of the flood-level, and to enable such deposits to be subsequently removed through the increase of local current speed due to the raising of the dykes.

The Committee's conclusions would not be so optimistic if it were clear that the phenomena of the discharge of loess accompanying the reduction in speed of the water—which is full of sediment of a special character on a wholly exceptional scale—are dependent upon characteristics peculiar to this substance when carried down in large masses by flood water.

Evidence collected by the Committee shows that the levels of the Hwang Ho, and of several of its tributaries which carry a large amount of loess, may rise like boiling milk, and the consequence would be over-topping of dykes.

Without accepting such an extraordinary explanation, this phenomenon may easily be explained by the discharging action referred to and by the fact that on the Hwang Ho and its tributaries these phenomena are exceptionally prominent by reason of the very nature of the loess and of conditions on the river.

Until observations of the phenomena and the study of the laws governing the carrying-down of loess by water are sufficiently advanced, the conclusions arrived at with regard to the Yellow River must be treated with the greatest reserve.

This does not mean that nothing can be done until the laws regulating the phenomena connected with the suspension and discharge of loess are fully known.

In whatever manner loess in suspension acts, the raising of the dykes to a height giving them an adequate margin over the probable level of exceptional floods will provide a considerably greater measure of security.

Improvement work on the mean-water channel involving the fixing of concave banks will similarly have a most salutary influence, particularly since it will prevent the breaching of dykes by the erosion of their inner bank.

The enormous length of the defensive dykes certainly increases the probability of breaches, and the characteristic conditions of the Chinese plain undoubtedly add to the disastrous consequences following upon a breach of the dykes.

The efficiency of the system of defence is lessened by its lack of uniformity.

Knowing that certain sections are inadequately protected by the dykes, the population and governing authorities in other sections are led to hope that, during a flood, breaches will be produced in the inadequately protected section, which will lower the level of the river for a certain distance above the breach and over its whole extent below, and so ease the situation in the other sections.

One of the unfortunate consequences of this state of things is that in some provinces the possibility of breaches of dykes at certain places comes to be regarded as a fortunate circumstance.

The strengthening and maintenance of the dykes on other sections are neglected. When the population of the most exposed section attempts to improve its dykes, the neighbouring populations try to prevent it from doing so and may even cut the dyke in time of flood. This means a deliberate disorganisation of the general system of dykes such as has often been recorded in history, and not in that of China alone.

Mention must be made of another disastrous consequence in the case of the Hwang Ho. As a result of repeated breaches in the same section, the authorities are now inclined not to intervene in time to close breaches, owing to the cost, duration and difficulty of these closing operations, and to allow a dangerous situation to continue. Thus the deviation of the river through the dykes becomes an accepted fact. Not only may the deviation become the principal course of the river, but the reserve dykes or those of other rivers, with which the new course of the river is now in constant contact and which form the last line of defence of the dyke system, are in serious danger of being breached in their turn. Such an event at the time of a heavy flood may dislocate the whole hydraulic system of the Chinese plain.

In China, the closing of breaches of dykes is in fact a delicate, difficult, lengthy and very costly undertaking.

By reason of its general conception, and above all by reason of the minute details, the traditional Chinese technique is extremely ingenious and arouses great admiration among Western experts who, like certain members of the Committee, have had an opportunity of studying it on the spot. We found there a remarkable fund of experience accumulated throughout centuries, intelligent utilisation of material of poor quality, extraordinary understanding on the part of small farmers, who, at a moment's notice, become skilled hydraulic workers, and who are past masters in the art of using fascines, and a public works organisation enabling admirable use to be made of the thousands of labourers working over a limited area—all of which is rightly regarded as one of the glories of Chinese tradition. Above all we must not destroy what already exists, this treasure of human activity, which should play an essential part in any future improvement of the system of protection against floods.

Certain mistaken practices should, however, be modified and the corresponding technical methods perfected.

Whereas, in the Netherlands, the procedure is to begin by protecting the base of the breach in order that it should *not become deeper*, and gradually to decrease its discharge capacity by reducing the depth, *which is a logical and sure method*, in China the *width of the breach* is gradually reduced. This necessitates a continuous deepening of the breach, which may become so deep that the fascine works built on each side of the breach cease to touch the bottom and float on the surface.

Hence at the end of the work, when the main closing barrier has been put in place between the two "heads" and the breach seems closed, there are actually strong currents of water running under the conservancy works, making it impossible for the breach to be really closed.

Another serious defect in the method is that the placing in position of the main closing barrier is such a delicate operation that it often proves unsuccessful and the barrier is carried away by the current. The preparation of this barrier and of all the machinery for putting it in place involves so much work and time that generally it is not possible to complete it during the low-water season, the only period favourable for the work of closing breaches.

This method is therefore in itself a very risky one and it endangers the whole dyke system, since breaches cannot be closed soon enough or with any certainty.

In the best interests of the riparian populations the method should be changed, either by merely adopting the Dutch method, which consists in using fascine mattresses laid one on top of another, which is a rational, speedy and safe method, or by combining this Dutch method (preliminary protection of the base of the breach by fascine mattresses) with the Chinese method, which would seem, *a priori*, preferable, since it would enable use to be made of the Chinese technique and the unrivalled aptitude of the hydraulic workers among the peasants of the northern plain.

Should this reform be fully considered, well prepared and suitably applied, the consequences of breaches of dykes could in most cases be limited to merely local occurrences.

In order to avoid breaches by over-topping, the crest of the dykes will have to be raised throughout the course of the river to a sufficient height above the highest probable flood level, on the most unfavourable hypotheses—that is to say, (a) that there is no breach of dykes upstream lowering the level of water, (b) that, during the years to come, there is a general and continual rise in the height of the river-bed amounting to about three metres per century, and (c) that there may be considerable local rises in the water-level through deposits of loess, which should be reducible by suitable conservancy work in the mean-water bed.

These conditions imply an appreciable rise—up to two metres or even more—in several sections in the provinces of Honan, Hopei and Shantung, especially along the course which the Hwang Ho has followed since 1852.

The merits of this scheme will be discussed in a subsequent section, but a few words should be said here as regards the probable scale of such an operation.

It would necessitate for *the first great section*, as it has been studied by the Yellow River Commission, an aggregate of embankment work of about 8 million cubic metres in the province of Honan, 12 millions in Hopei, and 20 millions in Shantung; or about 40 million cubic metres in all.

The preliminary operation involved here is fundamentally simple and would not in any way require the application of a complicated technique. The scale of the operation alone calls for some reflections.

At the first glance, the quantity of 40 million cubic metres appears enormous. It will seem much less so when it is considered that the work will have to be carried out over a length of nearly 1,000 kilometres in the most thickly populated part of the world. Among the riparian population of tens of millions, abundant skilled and cheap labour is available, particularly during the winter periods, when the agricultural workers are unoccupied and the river, being at low water, is in a suitable condition for conservancy work.

Accordingly, at the price per cubic metre estimated by the Yellow River Commission of \$0.12 to \$0.20, the operation would cost only about 8 million Mexican dollars. The whole of this sum would remain in circulation among the riparian population, and China would not suffer from any export of capital.

Thus the undertaking would in no way exceed the resources which China has available, while the expenditure it would involve is not excessive.

This would still be true so far as the financial aspect is concerned if the first stage of the work were followed later by other stages, bringing the total volume up to 80 or 100 million cubic metres or even more, or if for any reason the price per unit were to rise.

Something should also be said with regard to the weak administration and organisation of the system of defence.

The past history of the hydraulic administrative organisation in China is unknown, at least to Westerners; nor is there any comparative survey of the Chinese hydraulic administration and organisation with reference to other and similar organisations in the West, particularly in the Netherlands, the country which has the most points in common with the plain of Northern China. It is therefore impossible to formulate detailed and final conclusions. Nevertheless, our limited knowledge of the Chinese organisation enables us to establish certain facts which, combined with the results of experience in other countries, enable us to make some technical suggestions.

When, during their investigation in China of the defence of the plain against floods, the experts stressed the necessity for any measure—for police or technical regulation, for a closer or more centralised organisation—it was very aptly replied that all that already exists or, at least, that it had once existed.

In its thousand-year-old history of hydraulic control, China has tried nearly every system and every form of administration and organisation of hydraulic control. Certain regulations have fallen into disuse; however, they are no longer observed or it is no longer possible to observe them.

The second fact demonstrated by the experts' enquiry is that, during the periods when order and authority were maintained, when there was peace, when the central authority was strong and active, hydraulic conditions in the plain were far more satisfactory than in times of internal and external unrest.

This, indeed, is only logical: the success of defensive measures against floods requires co-operation on a large scale, prepared, encouraged, strongly organised and wisely directed.

Failing a strong and energetic central power, the provinces and regions misuse their autonomy by protecting only their own most immediate interest, regardless of what is happening up the river or down the river, and the outcome is sometimes really alarming.

In order to put matters in general on a satisfactory footing, what is required is not so much instructions and regulations—these already exist or have existed—as sound and effective co-operation between the provinces under the authority and direction of the central power.

This was realised in ancient China under certain dynasties : a viceroy was appointed as director of the hydraulic services of the Empire. His rank was equal to that of the viceroys governing the provinces, but he ranked above them in respect of hydraulic administration.

Another conclusion to be drawn is that in China, as elsewhere so far as hydraulic matters are concerned, excessive centralisation is dangerous when there is a crisis affecting the central power. Should the central power alone be responsible for defending riparian populations against the menace of floods, those very populations are unfitted to defend themselves alone at times when the central power is weak ; and this, particularly in China, may lead to most disastrous results. Finally, the Chinese riparian population has always been very ready to understand that its own interest lay in working for its defence as soon as the main lines of the work to be done and the results to be expected from it were explained, and when it felt itself supported by the force of a local and immediate authority which was not too remote.

A happy mean must be found between absolute centralisation and extreme decentralisation, as the wise Chinese in the past contrived to do.

The fourth reason for the ineffectiveness of the system of defence against floods is *lack of funds*. In China, particularly as regards improvement work on the Hwang Ho, lack of funds is not an insuperable difficulty. Indeed, as will be explained later, improvement work on the Hwang Ho may be combined with improvement work on riparian land. This would enable the value of such land to be increased and would thus compensate for the cost of improving the system of defence. Furthermore, it should be possible to have such defence work carried out by the riparian population, which would thereby obtain a greater measure of safety and would only need to be paid low wages.

Conclusions. — It would not appear beyond the bounds of human possibility to reduce very considerably the frequency of breaches of dykes by over-topping by raising the embankments to a sufficient height, more particularly in the provinces of Hopei and Shantung, but also in the province of Honan.

This operation does not, in itself, present any technical difficulties once it has been possible to determine with sufficient accuracy the probable level of the great floods.

Although the undertaking is a large-scale one, it will call for only such expenditure as is possible and will not lead to any export of capital ; it in no way exceeds the technical capacities of the riparian populations of the river.

In order to limit the harmful results of breaches of the dykes, to expedite the stoppage of such breaches and to reduce the risk and cost of these operations, it would be advisable to improve Chinese technique by providing first for the defence of the base of the breach by the use of fascine mattresses according to the Dutch method, which might easily be adapted by the Chinese technical experts and workers.

5. BREACHES BY UNDER-CUTTING.

There are, in principle, two methods of defence against breaches of dykes through the erosion of the inner slope or of the base of the work—namely, the direct and passive method and the indirect and preventive method.

The former method was best suited to the Chinese mentality and to local conditions, and has been chiefly followed in China.

This method consists in providing, with the help of labour recruited among the riparian peasants and with perishable materials, a more or less ingenious local protection for the sections attacked.

The indirect and preventive method of defence requires boldness backed with profound knowledge, not only of the dykes but also of the river-bed, technical organisation covering the whole river, at least in the plain, and an authority extending over both banks of the river. Although such an organisation existed in China under several dynasties, it lacked the indispensable spirit of enterprise.

The direct method of defence followed in China makes use especially of two technical elements: the defensive mattress and the groyne. Chinese technical knowledge has from very early times included familiarity with almost all the hydraulic appliances which the Dutch have employed in very similar circumstances.

The Chinese have for centuries carried to a high point of refinement the technique of these measures, adapting them to the materials of the country and employing abundant, inexpensive and resourceful labour. In one direction only, Chinese hydraulic technique has not been developed—namely, as regards defence and prevention *below water-level*.

The conception of means of defence stopped more or less at low-water level. Consequently, the defence of the banks and of the dykes also stopped short at that level, except for the deposit of stone and bags filled with earth—methods which are employed chiefly at times of emergency during the floods and which, over most of the course of the Hwang Ho, are very costly owing to transport difficulties.

The groynes employed are generally raised above high flood-level. They are very wide, a circumstance due to the fact that they were originally constructed of kaoliang and ropes. As a rule, they are sharply inclined downstream. This entails the serious disadvantage—which, moreover, is very general—that the bank below the groynes is violently attacked, with the result that new defences are required.

For this reason alone, this method of defence is not very effective.

These groynes, moreover, end in a vertical section that does not go down any appreciable distance below low-water level. In consequence, the most vulnerable part, the foot of the dyke, is not defended at all, and accordingly there is nothing to stop the action of the current, which erodes the base of the outer end.

Lastly, the application of defence appliances is limited on the horizontal plane. Protection is provided only at places that are threatened, because the defence works are costly, because, being made of perishable materials, they last for only a short time, and because, for the sake of economy, there is reluctance to apply them in advance at places where they may perhaps never be required.

In the sections where dykes are far apart, however, thus allowing of wide deviations of the mean channel, the river may, in a short time, threaten a section of dyke that is entirely different from that which was defended. Such changes may even take place during a single flood, and, in that event, the attack by the current on a dyke, the defence of which there has been no time to organise, occurs in very unfavourable circumstances.

The unforeseen element in the conduct of the river gives the Chinese method of defence a provisional and uncertain character which prevents the undertaking in advance of large-scale construction and the employment of durable but expensive materials where less durable but cheaper means will suffice for a time.

In order to obviate breaches of dykes by erosion caused by the current, there are, in theory, two means: (*a*) to improve the defence on the spot, and (*b*) to force the current to remove or remain at such a distance from the dykes that the latter are no longer exposed to direct attack.

In principle, both methods are applicable to the Hwang Ho.

By means of fascine mattresses, corbels, artificial aprons and other methods employed in Western Europe, more particularly in the Netherlands, a dyke may be very effectively protected against under-cutting, even below water-level and even with Chinese materials.

Owing, however, to the depth of water which often exists at the foot of the dyke and to the length of dykes to be protected, this method of defence is more costly than that at present employed in China.

Once such a defence has been carried out, there always remains the uncertainty whether, at the next flood season, the operation will not be rendered useless by reason of a new deviation of the bed, causing the river to attack another section of dyke which is not protected. *A direct defence would therefore be entirely effective only if both dykes of the river were protected along the whole course*—a procedure that would be very costly—or if the river were prevented from deviating—a procedure that would necessitate a supplementary operation of an entirely different character not directly connected with defence on the spot.

The second method—the removal of the current from the foot of the dykes—is fundamentally more effective than defence on the spot, because it attacks the danger at its actual source.

The resources required, however, are greater than those at present employed, whilst there is always the possibility that the river may deviate beyond the heads of the groynes and come to flow along the base of a section of the dyke that is not defended by groynes. As in the previous case, therefore, the necessity has to be faced either of organising the defence over a greater area than that directly attacked or of *making it impossible for the river to deviate*.

It has been proposed to prevent deviations of the channel by bringing the dykes nearer together. In this case the dykes would naturally have to be higher. A deeper flood-channel would thus be created, deposits in the river would be reduced and, consequently, the rise of the bed would be retarded.

If the dykes were brought nearer together, the extent of the deviations of the river would naturally be reduced and the formation of sharp bends would be impeded. It is impossible, however, to fix the mean channel solely by bringing the dykes close together. The dykes would, moreover, require to be stoutly defended, owing to the increase in the speed of the current.

From the point of view of a breach of the dykes by under-cutting, this proposal has only one advantage—namely, that the length and therefore the cost of the groynes for preventing the river from deviating between the dykes would be less. On the other hand, at least one or two new dykes would have to be built.

A study of the plan of the Hwang Ho and its dyke system shows that the mean channel impinges alternately on the two dykes which enclose the flood channel and passes from one to the other, following an oblique course, the length of which, measured parallel to the general direction of the dyke, depends on the general fall of the bed, the hydraulic regime of the river, the distance between the dykes and the nature of the materials of which the bed is composed.

To prevent breaches of dykes by undermining, the current should be kept away from the slopes of the dykes and the mean channel should not be allowed to impinge on the base of their inner slopes.

This result may be achieved by means of a system of sloping groynes starting from points sufficiently high up on the inner slope of the dyke and *directed upstream*, so as to bring the flow of the river, which tends to cross these groynes at right angles, back to the axis of the dyke. These groynes should be sufficiently close to each other to ensure that the main deep-water channel between two successive groynes starting from the same dyke has no time to bend and form a tangent to the base of either dyke.

The slope of these groynes in the flood channel should be as gentle as possible, so that, as far as is practicable, they may be effectively defended by simple turfing and the use of stone revetment may be reduced to the minimum.

The heads of the groynes springing from the two dykes must be placed opposite one another in reference to the deep-water channel, so as to make an actual chevron across the flood channel.

These heads must be strongly defended by appropriate appliances—fascines and pitching—so as to be completely protected from erosion.

By this means, the position of the mean channel will be fixed, the formation of secondary channels within the flood channel, between the dykes and the mean channel, will be prevented, and the loess brought down by the floods will tend to be deposited in the spaces between the groynes, the slopes of the dykes being thereby strengthened.

In determining the height to which the dykes should be raised in reference to the greatest floods, account must be taken of the groynes in the flood channel, which, from the hydraulic standpoint, have the effect of reducing the cross-section of flow.

With such a system of groynes, the "regularisation" of the river, involving the complete adaptation of the mean channel so as to give regular cross-sections and a regular course with a depth as constant and as large as possible on the successive shoals, is not indispensable to the actual security of the dykes.

Such a regularisation, which implies the calibration of the mean channel and of the low-water channel by means of many kinds of works—longitudinal dykes, groynes and depth sills at very frequent intervals—would be very costly.

In the case of the Hwang Ho, regularisation works—which are indispensable only from the standpoint of navigation—could not seriously be urged as against the formation of secondary arms in the parts of the plain which are enclosed between each dyke and the mean channel and which correspond to the so-called "chantiers" zone in the Loire valley.

In the case of most European rivers, unlike that of the Hwang Ho, it is usually sufficient to undertake the regularisation of the bed, because the regime of the river and the consistency of the "chantiers" zone are such that there is no danger of the formation of ravines or of secondary arms in that zone at times of flood.

On the Hwang Ho, the flow increases in a few hours from a few hundred m³/sec. to several thousand, perhaps 30,000 or more.

During these floods, the amount of solid matter brought down is very great.

The "chantiers" zone, formed of loess and very fine sand, is generally in a state of tillage. Its soil is therefore very mobile, so that, during a single flood, the shape of the whole surface enclosed between the two dykes may be entirely changed.

This instability of the flood channel as a whole makes it necessary to construct transverse works to consolidate these "chantiers" and, consequently, to fix the mean channel by concentrating the current within the deep-water channel and preventing the formation of secondary arms at the foot of the dykes.

Two remarks of a very general character should be made at this point.

The construction of a permanent dyke system for the Yellow River, comprising dykes high enough to escape submersion, must necessarily be started from upstream at the apex of the vast cone of deposits constituted by the alluvial soil.

It would indeed be useless to construct in Shantung a system of dykes capable of withstanding the greatest floods of the river, if the dyke in the neighbourhood of the 1852 breach were maintained in its present state and exposed to breaches that might cause the Hwang Ho to return to its 1852 channel and discharge its waters once more into the Yellow Sea south of Shantung.

In the event of fresh breaches in the neighbourhood of the 1852 breach allowing the course of the river to return to its channel flowing directly eastwards, any dykes

constructed downstream capable of withstanding the great floods would become useless and the expenditure incurred on them would be entirely lost.

The position is quite different in regard to works designed to fix the mean channel and to keep the current away from the inner slope of the dykes.

When, through the execution of appropriate transverse works (sloping groynes directed upstream), the river has been successfully kept away from a dyke at the foot of which it had established its mean channel, this change will necessarily result, over a fairly great distance downstream, in wide changes in the course followed by that mean channel, the final position of which cannot be determined in advance.

The operation of clearing the base of a dyke of the flood channel, so as to keep the currents away from it and to protect the dyke from erosion, should be undertaken only when it is absolutely certain that measures can be taken to cope downstream with the changes that will certainly occur in the course of the mean channel.

Such operations should therefore be started from downstream and should proceed upstream. It is not essential, however, to start from the sea ; it is possible to find between the mountains and the sea a number of compulsory passage points to determine the position of the mean channel.

It is therefore possible to begin fixing the mean channel by proceeding upstream from each of these compulsory passage points.

Where the width of the flood channel between the dykes is very great, the construction of sloping groynes long enough to prevent any deviation of the flood channel would be costly.

In these sections, it may be possible at the outset simply to construct relatively short groynes directed upstream, which would keep the current away from the inner slopes of the dyke and would suffice to prevent the breach of the dykes through erosion.

In these sections, the river is thus left at liberty to deviate between the lines connecting the ends of the groynes ; but these deviations, being thus limited, would not seriously affect the dykes.

In sections where a displacement of the mean channel would constitute too ambitious an operation, action must be confined to perpetuating the present situation, by a strong defence of the dykes and the foot of their slopes at places where they are actually touched by the mean channel, more particularly in concave bends.

The groynes must start from high enough up on the inner slope of the dykes. This obviates costly defence of the slopes and, at the same time, appreciably reduces the force of the current along the dykes. The reduction in the cross-section of flow of the flood channel is usually not very considerable when these groynes are short by comparison with the width of the flood channel.

In order to preserve the greatest cross-section of flow, it is essential that the sloping groynes should be totally submersible during the floods.

Transverse works that were not submersible would excessively reduce the cross-sections, particularly in parts of the river where the dykes of the flood channel are close together.

It is impossible in this report to give more definite rules on this subject, since the details of the scheme of improvement must be determined by local conditions in the different sections.

In the construction of groynes, allowance must be made for the action of the river on a submerged dyke, which is quite different from its action on a transverse dyke raised above the highest river-level. Special care is required to guard against the results of secondary currents flowing round the groynes, the ends of which must be very strongly built and based on ample fascine mattresses sufficiently flexible to withstand without difficulty any local deepening of the mean channel.

It is harder than in the case of the raising of the dykes to estimate the scale of the operation required in order to eliminate, by means of groynes, the danger

of breaches by under-cutting. No general scheme is, in fact, available, whilst it is difficult to estimate the cost that would be incurred once the supply of materials and labour were well organised.

Submerged works may be constructed partly of earth, especially if they are long and well turfed, while a certain quantity of fascines and stonework will always be needed to protect them, especially at the heads.

The aggregate cost of a sloping groyne of average dimensions would thus be comparatively high; but, if an operation on this scale were undertaken, the systematic organisation of the supply and transport of materials would be essential. Willows, the branches of which provide good fascines, are already very plentiful in the main channel of the river. Their cultivation would have to be extended—outside the dykes, as much as possible, since plantations of trees and shrubs in the dyked channel would interfere with the flow of water and raise the flood-level.

The supply and transport of stone presents greater difficulties. The quarries are situated away from the plain, and therefore at a distance from most of the river dykes. Transport by junks is slow and costly, and their capacity is very limited, owing to the insufficiency of draught at low-water periods.

The improvement of the river for navigation cannot be undertaken until the dykes have been consolidated and strengthened and the deviations of the mean channel have been eliminated by sloping groynes.

If, on the other hand, the quarries are well organised, and linked up with the dykes by macadamised roads carried as far as possible along the top of the dykes, quicker and cheaper transport than is to-day available can undoubtedly be provided. This would at the same time allow of an improvement in ordinary transport along the river, which is certainly just as necessary at flood periods as at low-water periods.

While the cost of stonework can undoubtedly be reduced by sound organisation, it will still remain sufficiently high to make it desirable to use stone sparingly and find methods of construction limiting the use of stone to what is strictly necessary. Systematic use should thus be made of other materials—earth, fascines, and bricks—and labour should be largely employed, as it is abundant, skilled, and cheap.

In the plain of the Yellow River, the situation from the hydraulic standpoint very much resembles that of the Netherlands some centuries ago, where it was also necessary to make shift with local materials—earth, fascines and bricks—stone being at that time too dear for hydraulic constructions.

The prevention of breaches of embankments by under-cutting is a more difficult operation technically, more delicate in execution, and more ambitious, than the raising of the embankment to prevent breaches by over-topping.

None the less, what was said in Section 4 in regard to this latter operation is equally true of the former. The necessary money for the improvement will remain within the Chinese economic system and will be spent almost entirely on labour, employed either directly in the execution of the work or indirectly in quarries, in willow-plantations, and in the transport of material.

The operation can be carried out in successive stages, each comprising a definite section.

The scale of the undertaking does not exceed that of river works carried out in other countries, and China is certainly capable of achieving it.

In this connection, the results obtained by the Americans on the Mississippi are particularly encouraging. The density of the population of the North China plain and the skill of the labourers can, of course, make up for the difference in financial resources and mechanical equipment between China and the United States.

6. BREACH BY INFILTRATION FROM THE EFFECT OF WAVES.

It has been seen in Section 3 that breaches of dykes by infiltration cannot be frequent on the Yellow River in the present state of the defence system. This kind of breach may occur when the dykes have been exposed for a long time to the high waters of the river, and when the dyke has been weakly constructed of poor quality earth, or where the foundation soil readily allows infiltration into the body of the work.

On the Hwang Ho, the principal dykes are hardly ever required for long to hold in the high waters of the river, because the floods pass off quickly.

The composition and construction of the dykes are often inferior to those of European countries, though the dykes themselves are generally of larger dimensions. Lastly, the foundation of the dykes, except for sections in which the raised bed consists chiefly of very fine sand, is formed of loess or a mixture of loess and fine sand, which is not very permeable.

There is, however, some possibility of breach by infiltration on the Hwang Ho.

After an inundation, a dyke in the second line of defence may be exposed for a long period to the pressure of the water. This second line is generally the last line of defence. Once it is destroyed, the river may, in the case of a considerable rise, deviate into the basins of the neighbouring rivers and throw the Chinese plain and its hydrography into confusion.

Where this second line of defence is of great value, either because it forms the ultimate defence, or by reason of its position in the defence scheme, *its establishment requires all possible care in order to prevent a breach by infiltration as well as by over-topping or under-cutting*. The weak sections of the dyke must be examined and a choice made between two means of defence: either the inner bank (facing the river) must be protected with a good layer of mixed and puddled clay and sand covered with grass turfing, which must be kept in good condition, or else the dimensions of the outer side of the dyke (facing the plain) must be so enlarged that the water penetrating the body or the foundation of the dyke cannot destroy the outer bank, and that, even after the banking collapses, the body of the dyke remains strong enough to withstand the pressure of the water.

Of these two remedies, the latter appears to be the more suitable for the Hwang Ho, because the dykes cannot be kept sufficiently well turfed to cover the layer of earth to be protected.

It is impossible to foresee the points where the dykes might be attacked by waves during a period of flood. For defence, mobile devices should be used, such as bags of sand and weighted kaoliang, which should usually be sufficient.

The two causes of bursting of dykes mentioned in this section are neither as frequent nor as serious on the Yellow River as over-topping and under-cutting, and a remedy for them should easily be found.

7. BREACH BY HUMAN AGENCY.

From time immemorial, in all countries where a system of dykes has been used for preventing a water-course from inundating the adjacent land, disputes have been known, which have even developed into armed conflicts, on the subject of floods and the danger caused by the defence dykes themselves. The breach of a dyke and the flooding of a neighbour's land often means one's own safety.

This anarchical state of affairs prevails *especially* where the riparian population knows that the system of dykes is inadequate to ensure their safety. They then mistrust the efficacy of defensive measures, fear overcomes them and their thoughts

turn to sabotaging at their neighbours' expense, in order to save their own lives and property.

The first essential for preventing people from breaching dykes is a well-organised scheme of protection from floods, so that the riverside populations trust to the system of defence and are not tempted to destroy the dyke of one bank in order to relieve the strain on that of the opposite bank.

The second essential is to prevent acts of sabotage by a well-organised police system at the vital points of the river before and during flood period.

8. CONSIDERATIONS ON THE IMPROVEMENT OF THE DYKE SYSTEM.

There are certain points in the above programme which require special explanation.

The *first point* is the *raising of the river bed*. Even if the system of defence is improved and breaches of dykes are reduced to a minimum, the river will still continue to raise its bed, and, in fact, this process will be appreciably accelerated; the improvement is therefore not permanent.

At the beginning of this report, it was calculated that, assuming a system of dykes theoretically efficient enough to prevent breaches and consequently all deposits outside the river-bed, the general rise of the latter per century would be about three metres.

If the dykes are well built and kept in good repair, there is no reason why they could not be gradually raised concurrently with the general rise in the bed for a long period. It would not seem impossible to keep the bed three or four metres higher above the plain than it is at present, when it is already in some places eight or nine metres above the riverside fields.

The conditions which dykes must fulfil in both these cases are absolutely identical, and the gradual raising and reinforcing of the dykes nowhere presents insuperable difficulties.

On the assumption that the present conditions obtaining on the river do not improve, but remain nearly the same, its present course and defence system may conceivably, by appropriate defensive devices, last for a long time with reasonable prospects of success.

Any improvement in the general condition of the Yellow River in the direction either of diminishing the liquid flood discharge or the amount of solid matter carried down would also have the effect of prolonging the life of the system and increasing the chances of such dykes proving successful.

The same would hold true of any devices that might be introduced into the dyke system with a view to systematically warping the plain outside the dykes and thus retarding the process of raising the river-bed.

The *second point* is the increased volume of floods below the area in which breaches now occur.

If breaches are prevented, the dykes downstream will be in a much less favourable position than at present. The fact that every large or even average flood causes bursts in the dykes and inundations favours the sections downstream, where the dykes are relieved of the whole volume of water discharged through the breaches higher up.

A great deal of the *embanking has never yet had to retain the whole mass of the flood waters*.

An improvement in the defensive system tending to make breaches much less frequent will certainly produce on the corresponding section of the river and further down an appreciable rise in the water-level. The dykes will thus have to carry a bigger load.

Two favourable considerations, however, supervene here.

The first is that the dykes can quite easily be strengthened and raised. The cost of this work in China need not be prohibitive, and if carried out on scientific principles would engender confidence.

The second favourable circumstance is a decrease in the volume of floods by means of reservoirs in the plain.

The dyke system of the Hwang Ho has often been criticised on the ground that the flood channel appears to be excessively wide in several sections.

This criticism has been based mainly on a pessimistic estimate of the extent to which the bed will rise, or by undue fear of the consequences of that process, and further by a comparison with other dyked rivers where the dimensions of the flood channel are much smaller than those of the Yellow River.

But, contrary to what happens on many other rivers, on the Hwang Ho it is the floods which are the dominating factor, not the low or medium waters. *The flood channel must therefore be suitably large.* To this it is rejoined that the flood channel in several sections is bigger than is necessary for the discharge of the floods, and that an excessively wide bed is injurious because it conduces to deposits of loess and therefore to a rise of the bed, thus reducing the area of protected land cultivable by the peasants.

A smaller flood channel certainly might, in theory, be sufficient for the discharge of floods. Generally speaking, too, the deposits in the very wide sections are greater than in the narrow sections, though they can never exceed certain limits. The remark that the area of cultivable land is limited is, however, very much open to question. In several districts, the land situated between the dykes is much more productive than that outside.

This argument, however, overlooks the fact that the flood channel in sections regarded as too wide does not serve merely for the discharge of the flood waters, but plays the highly valuable part of a regulating reservoir.

Two considerations may give an idea of the value of this function.

The 130-kilometre section of the Hwang Ho between the railway bridge on the Peiping-Hankow line, where the right-hand dyke begins in the plain—though a dyke already exists higher up on the left bank—and the place where the river changed its course in 1853 has a capacity of about 2,500 million cubic metres at high flood time—that is to say, it could take a 36-hours' discharge of the heaviest flood known.

Below this section, as far as Shihlipu, for a distance of 190 kilometres, the flood channel between the dykes on the right bank and the "People's Dyke" on the left bank has nearly the same capacity. This capacity would be increased if the dykes were raised.

Above Shihlipu, therefore, the Hwang Ho at present possesses lateral reservoirs capable of holding several thousand million cubic metres, or the discharge of a flood of 20,000 m³/sec. for more than three days. These reservoirs could easily be made bigger, and this will, in fact, be done if the dykes along this part of the course are reinforced and raised.

Shihlipu is situated above that part of the Shantung district where the dykes are much closer together and where some parts even of the flood channel are very narrow.

The wide sections of the flood channel on the Hwang Ho act as regulators. When a high flood reaches the plain, much of the water spreads over the wide sections, while only a part of the original flood discharge passes through the narrow channel formed by the Shantung dykes, which it would be very advisable to put wider apart, while at the same time strengthening and reinforcing the dykes upstream.

Thus the regulating reservoirs formed by the dykes tend to attenuate an excessive rise in the level of the downstream floods.

The lateral reservoirs formed by the wide sections of the dykes are quite capacious—in fact it would be a mistake to enlarge them—and are very adaptable from the

hydraulic point of view. They halve the flood discharge downstream and at the same time space it out in time by doubling its duration in the Shantung section, where the dykes are close together.

The most serious objection is that the reservoirs would quickly lose part of their capacity because they tend to become silted up ; in other words, even if the capacity is increased by raising the banks of the reservoirs, or by taking in land to serve for the same purpose, the period of service would be limited to an unknown number of years.

Hence, the Committee concludes, other means must be found to provide a more lasting solution to serve at the end of this period of duration of the reservoirs in the plain, or these regulators must be made to serve for a longer time. There are several ways of securing this result ; these will be studied below.

In the meantime, while these reservoirs in the plain are maintained, the present dyke system might be accepted for the immediate future, without having recourse to major supplementary works in the plain for reducing flood discharge, such as opening a second arm of the river towards the sea, selecting a new course outside the existing dyke system, or employing the mountain reservoirs which will be discussed later in this report.

The *third point* relates to *the general system of dykes at present in use.*

If by the means described in the preceding sections the various causes of breaches of embankments are eliminated as far as is humanly possible, would it then be necessary to maintain or even to improve the reserve dyke lines ?

The length of the active line of defence on the left (north) bank is 600 kilometres, and that on the right bank, 377.5 kilometres.

In other words, both, and especially the north one, extend for a great distance.

Even if the improvement works are executed with the greatest possible efficiency, and if the highest level which the river may attain throughout its whole length is correctly calculated everywhere, and an adequate margin of safety is allowed, unforeseen contingencies may still occur to endanger one of the two great lines of defence, perhaps even both simultaneously.

A flood may prove to be greater than could have been foreseen. For some reason or other, a section may not have been kept in good repair, or during a war one of the dykes may have been deliberately destroyed.

An improved system of first-line defence increases security as far as this is possible. The reserve system serves to limit inundations due to breaches in the first line of dykes and to localise their harmful consequences.

Systems exist of second-line dykes already mostly of ancient and even very ancient date. Their conception generally reveals a sound understanding of hydraulic strategy.

Taken together, however, they are not complete ; should any one of several serious eventualities occur, there is no second line of defence to avert flood and widespread disaster.

Again, several of these second lines have not been kept in repair or have even been levelled by peasants needing soil.

It is of very great importance that these second-line dykes should be restored. This would not be very expensive and might be of invaluable service at times of inundation. For this purpose, the task must be clearly defined, all eventualities must be studied and analysed, and *a suitably located second line of defence must be decided on for every case.* The Hwang Ho floods can thus be limited.

By improving the first line of defence, the breaching of dykes—the sole direct cause of catastrophes—would be obviated *as far as is humanly possible.* If, nevertheless, an inundation should occur, it will be limited by the reserve line, which will make a complete change in the course of the river more difficult and will localise disasters.

The execution of this complete scheme of dyke construction will have to be spread over a considerable number of years, during which time the safety of the inhabitants

will gradually increase only to the extent to which the works are completed ; it will therefore still remain precarious for a rather long time, unless an immediate palliative is found which can be speedily and easily put into execution.

It would seem that a practical method of protecting human lives could quickly be found by erecting small local dykes solely to protect the inhabited centres, which would become regular islands at flood periods and thus save the population from drowning.

Further, to ensure a food supply for the population after the floods, it is essential that the growing crops should not be destroyed by the floods.

The floods, however, occur in the summer during July and August, and less frequently in September.

The Committee, therefore, draws attention to the primary importance of considering the introduction into the northern plain of very quick-growing crops, particularly cereals, such as rye, selected wheat, potatoes, etc., which would probably be harvested before the floods.

If the produce were thus stored in good time inside the local dykes protecting the inhabited centres, they would escape destruction and make it possible to avoid or at any rate attenuate the serious famines which follow large-scale floods.

Chapter III.

OTHER PROPOSALS FOR IMPROVING THE CONDITIONS OF THE RIVER.

I. THE DIFFERENT MEANS FOR IMPROVING THE SYSTEM OF THE YELLOW RIVER.

It is from its violent floods, carrying down vast masses of loess, that the Hwang Ho has gained its evil reputation.

Accordingly means have been sought to diminish the violence of the floods and the quantity of loess carried down, so as to reduce the extent of the immense deposits of solid matter, which raise the general level of the river-bed, to the detriment of the neighbouring plain.

Efforts have been made in the most varied directions : sometimes there has been a very limited objective—for example, the reduction of the flood discharge or the diminution of the quantity of loess carried down ; sometimes the object has been the general improvement of the system, with fortunate effects as regards both the violence of the floods and the quantity of solid matter.

Thus it has been proposed to construct great *reservoirs* along the middle course of the river and its tributaries, to retain part of the flood water and lessen the maximum flow.

It has been proposed to achieve the same result by utilising reservoirs intended primarily for irrigation and subsidiarily for the production of electric power.

It has been proposed to return to the *ancient Chinese system of "ditches"*, which consists of retaining, in ditches dug in the fields themselves, the water necessary for agriculture as well as the solid matter which, but for this precaution, would be carried away by the water as it drains. This method, employed on a large scale along the upper and middle course of the river, would effectively counteract the impoverishment of the soil by the drainage waters.

At the same time, a considerable part of the rain waters would be retained above the plains and would be of great value in improving the productivity of the soil by enabling it to be watered. Applied in the plains, this system would help to improve agriculture by watering.

Other methods are *reafforestation* and *vegetation*.

Reafforestation would have the further advantage of supplying the country in the future with the timber of which it is in need. Carried out on a sufficiently large scale, it would serve to attenuate abrupt changes in the rainfall, would help to retain a considerable proportion of the rain in the upper catchment basin, and acting as an obstacle to drainage would protect the soil from erosion.

Vegetation, which is often possible when reafforestation is not, produces similar results, but in a lesser degree; and these results can be obtained in a short period, whereas reafforestation requires a long time to produce its effect, owing to the slow growth of the trees.

A considerable part of the loess loosened and carried away by the river and its tributaries comes, not merely from definite regions, but more particularly from specific points. The processes—few in number—by which much of the loess is washed down by the floods are known.

The logical course is then to seek to reduce the quantity of loess thus carried down by employing technical means for the conservation of those regions from which the largest quantities of solid matter are derived.

This method differs from those mentioned above—reservoirs, reafforestation and vegetation—in that it does not act upon the flood discharge.

The methods which are intended to reduce the flood discharge help, by means of this result itself, to reduce the quantity of loess carried down, whenever there is an appreciable decline in the flood discharge in the zones where the water carries down loess.

Lastly, measures have been proposed for diminishing the deposits of solid matter in the bed of the river, so as to retard the partial or general rise of the latter. In order to obtain this result, three different methods are generally proposed: (1) the fixing of the mean river-bed in the plain; (2) the calibration of the dyked flood channel; and (3) systematic warping in the lower parts of the plain.

All these methods have their merits and defects, but, from their very nature, few of them are capable of improving the river system to the extent of preventing inundations.

2. ALLEVIATION OF FLOODS BY MEANS OF RESERVOIRS CONSTRUCTED ABOVE THE PLAIN.

If a large quantity of water at times of flood were retained along the middle course of the river and its tributaries, and if such waters were subsequently returned to the river, the high waters would be reduced and the floods would be less extensive. At the same time, the reservoirs would play their part in the process of transport of loess.

Reservoirs constructed for the sole purpose of reducing floods must be of such a capacity, and the reduction in the level of the great floods must be such, that part of the defensive works in the plain becomes superfluous, so that the saving thus effected will cover an appreciable part of the cost of building reservoirs, the same security being obtained by a combination of the two kinds of works.

On the Hwang Ho, a considerable saving in the works in the plain is realisable only if the discharge of the main floods can be brought below 6,000 to 8,000 m³/sec.

In order to achieve this object, it would be necessary, during the great floods, estimated at 25,000 m³/sec. or even more, to have reservoirs with a capacity of 4 to 5 milliard cubic metres.

As there is no means of constructing a single great reservoir or a series of great reservoirs on the river *below the junction of the Hwang Ho with its principal tributary the Wei Ho*, the capacity required would have to be distributed among several reservoirs situated on the principal tributaries.

The floods of the Yellow River do not always occur in the same manner, and it is impossible to know in advance what part each tributary will play. The total capacity of the different reservoirs must therefore exceed the capacity theoretically necessary to reduce the flood below the junction of the last important tributary.

Accordingly, it would not be sufficient to construct a single reservoir of adequate capacity on the Yellow River itself—for example, in the gorges—because such a reservoir would not affect the floods on the Wei Ho, nor would a single reservoir on the Wei Ho in any way lessen the floods on the middle course of the Hwang Ho.

Hence the cost of this operation would be much higher than if it could be carried out by means of a single reservoir installed below the last tributary.

But what saving would it be possible to effect in the dyking work in the plain, following on the construction of a series of reservoirs of an adequate total capacity?

If the flood discharge is limited in future to 6,000 or 8,000 m³/sec., the dykes along the river would still have to be put in good condition and be kept in good repair. The danger of breach by under-cutting would be reduced, but it would not disappear entirely, so that the fixing of the middle bed would still have to be progressively undertaken.

Consequently, the same works would be necessary in the plain, except as regards the strengthening and raising of the dykes, which might be on a smaller scale.

Suppose, however, that all the natural conditions were favourable for the construction of these large reservoirs, the expense involved would far exceed the cost of the programme of defence by dyking described in the preceding chapter, while the construction of reservoirs would not save half the cost of that programme.

Accordingly, the construction of reservoirs as a means of reducing the floods does not appear to be advantageous from a financial standpoint.

A reservoir is the best means for separating the solid matter carried down by the flood waters.

The flood water held in the reservoirs would have ample time to deposit in them a very large part of the loess and sand with which it is charged.

From this point of view, storage reservoirs closed by a barrage wall are much more effective than the great lateral reservoirs constituted by sections of the dyked flood channel in the plain, mentioned in the preceding chapter.

When these lateral reservoirs are filled by a flood, the quantity of water sufficiently slowed down to enable a large proportion of the solid matter to separate out is far less than in the storage reservoirs closed by a barrage wall.

Thus very much larger deposits will collect in the latter than in the lateral reservoirs formed between the dykes in the plain.

These storage reservoirs will therefore lose their capacity more quickly than those of the plain, and the life of these works would necessarily be limited.

The lateral reservoirs in the plain will also ultimately become choked, but not nearly so quickly, and they possess the great advantage that their capacity can be increased by simply raising the embankments or continuing them further back, an operation which can be carried out at a comparatively low cost. On the other hand, no extension of a storage reservoir closed by a barrage is possible except under certain well-defined conditions which are not always present in practice.

Lastly, such an operation, even when possible, is always delicate and costly.

A full investigation might show that the creation of great storage reservoirs of sufficient capacity would be technically possible along the middle course of the Hwang Ho and its tributaries; nevertheless, according to the foregoing observations, such

an operation, *designed only to reduce the volume of the floods in the plain*, would be onerous, and would prove less successful than the programme of defence in the plain consisting of dyking the flood channel and fixing the mean channel.

Another proposal is that of reservoirs with a number of uses, serving at the same time for irrigation, for the limitation of floods and for the production of motive power.

Each case must be studied and judged separately on its merits, and accordingly the Committee can only make a few general observations here on the limitation of floods.

The period during which the soil needs a supplementary supply of water is that during which there is no rain, or not enough rain, in the river basin. The Hwang Ho and its tributaries are rain-water rivers, in which the rate of flow at its lowest is not maintained either by lakes acting as regulators or by the melting of glaciers. The period of irrigation therefore coincides with that of low water, the volume of which must accordingly be increased in order to extend the area of irrigation.

If great reservoirs were constructed for irrigation, they would be out of use during the flood periods, and that is why it is proposed to use them to limit the flood discharge.

Here two observations have to be made.

During the floods, certain confluents carry down per cubic metre of water fifty times more solid matter than during the long period of mean flow or low water.

Generally speaking, the capacity of the reservoirs, particularly of those including vast valley extensions, diminishes more rapidly by silting if they are filled during the floods than if they are filled during the periods of mean flow or low water. Irrigation is best served when there is provision for the filling of such reservoirs by water containing a low percentage of solid matter. The filling of reservoirs at times of flood by waters charged with a high percentage of silt is thus, in many cases, contrary to the interests of irrigation.

But the necessities of irrigation and of defence against floods are not always incompatible, and it is possible to find sites suitable for the construction of reservoirs to be used both for irrigation and for defence against floods. In each particular case, as suggested by the Committee for the Shensi rivers, attempts must be made to reconcile these two objects and to adopt suitable rules of operation.

The second observation concerns the capacity of irrigation reservoirs as compared with the capacity necessary for the reduction of floods.

If the feeding of an irrigation system calls for the construction of a number of reservoirs capable of supplying 150 m³/sec. for a period of three months—which would be a remarkable achievement—the total capacity of such reservoirs would be about *one-fifth* or *one-sixth* of that necessary for lowering the maximum volume of the flood waters below 6,000 to 8,000 m³/sec. If, therefore, these reservoirs were used for reducing the flood waters, they would not have sufficient effect to enable a reduction to be made in the dyking work to be carried out in the plain in order to prevent disasters, and would therefore not entail any appreciable economy on that score.

The construction of reservoirs along the middle course of the Hwang Ho and its tributaries must therefore be judged on the merits of the irrigation schemes. Their financing must accordingly be justified from this point of view alone, and they do not contribute substantially to an increase of security in the plain.

3. LIMITATION OF THE MASSES OF LOESS CARRIED DOWN BY THE RIVER.

There are several ways of diminishing the quantity of loess carried down by the river.

The *first category* of stabilisation processes consists of all the measures designed to retain the soil by some kind of vegetation. If such action is seriously pursued on

suitable lines, the amount of loess carried down by the river would undoubtedly be reduced.

This method, however, is not applicable either on ranges where the slopes are too steep to allow of their remaining covered with vegetation or on those which are likely to subside owing to the erosion of their bases by the currents.

Soil conservancy thus requires the application of the methods widely and quite successfully employed in the Alps and other mountain systems of Europe.

Cheap though labour is, however, the cost of applying these methods would be prohibitive, owing to the enormous size of the areas to be protected.

Further, in contrast with the plantations of grass, bushes and trees, the only result of such works would be purely and simply the conservancy of the soil; there would be no other advantage. Except for some special cases where, circumstances being favourable, simple and cheap means could be employed to prevent large masses from being carried away by the river, this method is not to be commended in China.

The masses of loess carried down by the river at flood time towards the plain might also be reduced by deviating the flood water at suitable points.

The construction of sets of weirs¹ not more than a few metres high across rivers or torrents at suitable spots would provide a whole system of small reservoirs which quickly fill up with solid matter.

This method has several advantages. It concentrates the fall in certain points and slows down the current over most of the course, thus reducing direct erosion by the current. Part of the solid matter is retained in the district itself and does not reach the plain. By the gradual raising of the bed, the ravines and canyons become shallower, and the field of attack is thus limited.

The problem of the loess removed and carried away by the river is particularly difficult.

When the floods do not result in the dykes bursting, almost all the solid matter is carried down to the sea, the shore of which is constantly advancing.

The great drawback of these deposits in the sea is that they increase the length of the river's course across the plain. The river has consequently to raise its bed in order to keep sufficient fall for the discharge of its volume of water and solid matter.

The amount of alluvia carried down by the river is so great that only *very extensive measures*, or small but very intensive measures *applied on a huge scale*, can perceptibly affect the process of raising the bed or thrusting the river delta into the sea.

The areas subject to erosion from which the Hwang Ho and its tributaries carry away solid matters are so extensive that if it were sought to combat erosion by technical systems and works which would be costly and yet would give no indirect benefits in return, the expenditure would far exceed that necessary for defending the plain against inundations by improvements in the plain itself.

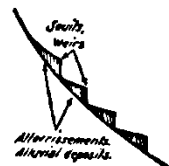
Consequently, only effective action resulting in indirect advantages can be employed on a large scale for combating erosion on the middle and upper courses.

Such measures are the following :

Vegetation and reforestation; small barrages or weirs for decreasing the local fall and, lastly, the Chinese system of "ditches".

All these measures are very effective and *their various effects reinforce one another.*

Thus, vegetation and reforestation serve, in the first place, to retain part of the



¹ Italian *briglie*.

rainfall in the district and thereby limit, to a certain extent, the quantity of water flowing off. The flood discharge, accordingly, falls while the low-water discharge rises.

Erosion is lessened by this fall in the flood discharge, because the quantity of loess carried away rises rapidly with the discharge of torrents, brooks, streams and rivers.

At the same time, the covering formed by vegetation, if well applied, is a first-class factor in preventing erosion due to running water.

Apart from the fact that they are very effective, these measures are of direct advantage, as they enable vegetable products to be grown.

Small barrages and weirs constructed in torrents and small streams are also of positive value. They retain some of the flood water and thereby reduce erosion downstream; the deposits which they tend to form are easily cultivated and irrigated.

The system of "ditches" is perhaps the most useful and the most profitable from the Chinese point of view.

Its principle is that part—in olden days, one-ninth—of every field cultivated by a peasant is devoted to storing the rainfall.

The system costs nothing but the family labour available; its drawback is that the part used as a "reservoir" is lost to cultivation. But the rest of the land, with the reserves of water thus formed, usually produces a much more abundant crop than would ordinarily be grown over the whole area if none of the rainfall were stored.

This system, if well organised, could improve agricultural production; and it also has a very favourable effect on the general hydraulic conditions of the river basin.

If this system could again be applied on a very large scale, much of the rainfall would be retained, the floods would be reduced and the quantities of loess carried down to the plain would thereby be limited. Further, the loess that would be eroded by the water which, but for these reservoirs, would have seeped away, stays in its place.

In other words, while the "ditch" system reduces the amount of loess removed by seepage, it also reduces the erosion of loess elsewhere—in ravines, canyons beside torrents and streams where the system itself cannot be introduced—by its attenuating effect on floods in the upper sections of the tributaries.

The system is not applicable everywhere, and its introduction in the regions of the middle courses of rivers on such a scale as to be effective would be a slow and rather difficult process.

To reduce erosion effectively and decrease the flood discharge, however, this method, together with vegetation, reafforestation and the construction of weirs or barrages to prevent erosion by torrents, constitutes one of the most economical and effective measures.

4. LIMITATION OF DEPOSITS OF LOESS IN THE RIVER-BED.

The general effect of the erosion and carrying-down of enormous quantities of loess by the Yellow River and its tributaries is that, apart from floods breaching dykes, most of these masses are carried down to the sea, where they form new land, while the portion deposited in the bed of the river, and so raising it, is much smaller.

This process is changed when dykes burst and floods occur. During a flood, the water, loaded with solid matter, leaves the bed *through the gaps* and deposits in the plain, *at any rate during major floods, almost the whole volume of solid matter* which, in normal circumstances, would have reached the sea. By improving the system of defence dykes and avoiding breaches, these deposits in the plain would be eliminated.

Observations and calculations show that one or two major floods of short duration bring down more than half of the whole mass of solid matter displaced by the river during a whole year.

Thus it has been calculated that, out of a total quantity estimated at about 560 million cubic metres of solid matter carried down by the Hwang Ho in a single year,

nearly 90% was carried during the three months of July, August and September, and nearly 60% of the whole during the month of August alone.

Thus, if the solid matter carried down is taken alone, it shows the preponderance of the floods as even greater than if the water discharged is considered. When a very heavy flood occurs, it may account for 50%, or even more, of the total mass of solid matter carried down during the whole year.

Hence the floods, and especially the major floods, are the dominant factors in the changes which occur in the plain and particularly in the raising of the bed and the advance of the delta into the sea.

As explained in the previous chapter, the average elevation of the bed at any point depends on the distance from that point to the mouth of the river and on the general fall of the bed, which in the case of the Hwang Ho and some other rivers in north China is not quite 1 in 6,000. There are only three ways of limiting the deposits in a dyked bed and, *eo ipso*, its rise : to shorten the distance to the sea, to reduce the fall or to retard the advance of the delta by decreasing the amount of sediment brought down to the sea.

Unless the river's course is changed, the first operation can be carried out in only one way—by allowing the tide to come farther upstream, so that the point where the river meets the sea is moved higher up. This cannot be done in the case of the Hwang Ho, as has been explained in the chapter dealing with the delta.

Another way—to decrease the fall—has been proposed for the Yellow River.

By continuous observation and exhaustive investigations, it is proposed to find an ideal bed offering less resistance to the discharge of water than the present bed.

For this purpose, it has been proposed, *inter alia*, to narrow the flood channel by constructing two new lines of dykes closer together.

The inevitable result of bringing the dykes closer together would be a very substantial rise in the flood level, which would increase the risks of breaches by infiltration and submersion.

Moreover, these dykes would have to be protected from under-cutting over long distances and the mean-water channel would have to be kept in place by submersible transverse works, so that this operation would be much more costly than simply improving the present system of dykes.

On the other hand, the ultimate outcome of this operation might quite possibly be a substantial deepening of the bed, and the flood levels would hardly be lowered later, because a general deepening of the mean-water channel would be offset by the higher floods, due to the narrower width of the flood channel.

Furthermore, the narrowing of the river-bed would mean the loss of the advantages of the present system from the standpoint of elasticity of *storage capacity*. *The preponderant part which the flood channel plays as a lateral regulator would be disregarded.* A single mistake in the observations or calculations, or an unforeseen occurrence during the formation of the floods, might destroy the whole system.

If, moreover, the results which would be obtained by such a costly, uncertain and dangerous operation are compared with the efforts it requires, the flagrant disparity between the two is apparent.

The flood channel, which is very wide in certain sections, is indispensable as a regulating reservoir, so long as the hydraulic conditions at present determining the formation of floods do not change.

This conclusion does not preclude the improvement of the current during floods and the fixing of a mean-water channel.

By these means, the movement of solid matter towards the sea can undoubtedly be facilitated, the deposits in the bed reduced and the raising of the bed thus retarded.

So long, however, as the delta is moving seawards and wide sections remain necessary, the formation of deposits in the dyked bed cannot be seriously prevented.

The third way of retarding the raising of the bed is to restrain the advance of the delta by systematically holding back and keeping in the plain part of the solid matter carried down by the river.

To achieve this result, even with dykes which are no longer subject to bursts, the dyke system will have to be provided with two kinds of special works :

(1) *Spillways* permitting the discharge in the lowest sections of the surrounding plain, acting as lateral reservoirs, of a large proportion of the flood water, which can thus—at any rate, to some extent—be drained off. These spillways should, as far as possible, be erected immediately above the narrow sections, as this would have the additional advantage of moderating the tendency of the latter to raise the water-level.

(2) *Feeder-weirs* placed, where possible, above the widened sections, bringing back to the river the drained-off water after it has passed through the depressions acting as lateral reservoirs ; this would have the advantage of reducing the silt content downstream and, consequently, of reducing or eliminating deposits in the bed, perhaps even of producing at least local scouring therein.

The result of the operation of such a device would be, not only to retard the advance of the delta and the concomitant rise in the bed, but also to raise the lower sections of the plain and improve the situation of the dykes by lowering the height of the bed as compared with the plain.

This spillway and feeder system might therefore be particularly successful and deserves to be fully studied ; for this purpose, it will be necessary to have an exact contour map of the Hwang Ho plain.

The size of spillways and feeders must be proportionate to that of the river, so that the volumes of water deviated would represent a rather large proportion of the instantaneous flood discharge.

Chapter IV.

COMBINATION OF DIFFERENT METHODS FOR IMPROVING THE GENERAL CONDITIONS OF THE HWANG HO.

I. INTRODUCTION.

Among the many problems of the Hwang Ho, that of protecting the plain against inundation takes precedence of all others : irrigation and drainage, improvement of navigation and the possible utilisation of hydraulic power. All the wealth created over a long period by toil and human intelligence is liable to be destroyed by the floods of the Hwang Ho in a few hours.

Any systematic action to exploit the sources of wealth which the river-valley possesses will remain sterile so long as the forces of destruction of the Hwang Ho are not overcome.

It must always be remembered, however, that the Yellow River can never become a source of wealth instead of a source of disaster to China, unless, after adequate security has been attained, the necessary steps have been taken to exploit this source of wealth. The schemes aiming at the prevention of inundations must take into account future developments in irrigation, drainage and navigation.

A programme for the improvement of the Hwang Ho must therefore enable the cost of the dykes to be recovered through agricultural improvements by means of irrigation and drainage, and improvements in transport by the regularisation of the river.

2. COMBINATION OF METHODS OF DEALING WITH FLOODS.

It has been observed above that, in the case of the Hwang Ho, there is only one practical method of defence against catastrophes which gives results in a short period ; that is, the increased restoration of the dyke system, together with the fixing of the mean-water channel. The effectiveness of this method may be prolonged, should no steps be taken to reduce the transport of loess, if the bed of the river continues to rise above the plain. This method may therefore improve the position for some generations.

The simplicity of this method makes the measures for reducing the floods and for diminishing the solid masses carried by the river of secondary importance ; nevertheless, it would be unwise to abandon all attempts to obtain these results.

The first line of defence against high waters in the plain is of considerable length (about 1,000 kilometres on both banks of the river together).

The effectiveness of the protective dykes made of such materials as earth, kaoliang, willow branches, hemp roping and a little stone depends primarily on the technical conception of the hydraulic defence and its details, and, in the second place, on the organisation and discipline of the men maintaining and defending them when the waters rise.

As a result, the method of improving and strengthening the existing dykes, like every work of man, has its weaknesses, due less to the materials employed than to the energy of man and to the strength of the central authority.

There is only one *technical means* of partially remedying these weaknesses, and that is to limit as much as possible the effect of the original causes of catastrophes—in other words, the maximum discharge at times of flood.

By reducing floods, the system of defence of the plain is placed in a more favourable position, and by carrying out work both in the regions where erosion takes place and in the plain by warping obtained by means of the system of spillways and feeders, the mass of loess carried down by the water is reduced and the advance of the river-mouth and the rise of the river-bed are retarded.

The extent of the advantages obtained depends both on the effectiveness of the means employed and on the scale on which those means are applied. The scale must be enormous on account of the dimensions of the river-bed. Systematically organised, however, these means may greatly improve the general conditions obtaining on the Yellow River.

All these measures should be studied and compared. They cannot replace the system of defence in the plain. If, however, action is well organised and is carried on for a sufficient period, they will, as a whole, provide extensive advantages, which will render the defence in the plain less difficult and less costly, as the floods will not be so high and the river-bed will rise more slowly.

3. COMBINATION OF METHODS : AGRICULTURE.

The construction of large reservoirs designed solely to reduce the flood waters was studied in Chapter III and was considered inadvisable.

The idea of employing irrigation reservoirs for reducing floods entails various disadvantages—already mentioned—on account of which they can only be considered in certain circumstances.

The case is different as regards low weirs on the higher course of the tributaries, and these might effect an improvement of the general conditions, though only a small one.

In the plain, the water of the Hwang Ho might benefit agriculture in two ways : it might be employed for irrigating the land in the vicinity of the bed and for improving the quality of the soil along the river, which is often very poor, by covering it with a layer of loess taken from the river. These two measures might be combined, but would have to be supplemented by drainage for removing the salts from the surface and also the superfluous water.

A number of schemes have been discussed—and some have been carried into effect—for installing siphons along the Yellow River, especially in the province of Shantung, with a view to fertilising the sandy and alkaline soil along the dykes by the deposit of a layer of silt carried down by the river.

Provided the sites chosen for these installations are at places where the course of the river is stabilised, the results may be very advantageous and may be obtained at little cost. It is indispensable, however, that the distribution channels should have a fall sufficient to avoid excessive deposits of silt in these channels, and that the configuration of the irrigated area should enable a warping system to be constructed. The object of such a system is to supplement the irrigation works—an essential step—and to aim at reducing the level of the water in the subsoil sufficiently to prevent the alkaline substances from rising to the surface of the soil.

The Committee draws the special attention of the engineers to the *importance of a good warping system*.

However extensively these siphon installations are employed, they will have no effect on the flood waters, on account of the size of the river.

These combinations of irrigation, warping and drainage would have only a negligible effect on the general condition of the river. Applied on a large scale, when the results of the first experiments are better known, they might very greatly benefit the population by improving agricultural conditions and productivity in large areas of land beside the river.

The improvement of the defence against floods has an influence of the first importance on agriculture in the plain, since it increases the security without which any considerable effort to improve agriculture must be vain. Independently of this dominant influence, the defensive works, when they include the fixing of the mean-water channel, are useful for arranging irrigation intakes.

4. COMBINATION OF METHODS : NAVIGATION.

On the dyked part of the Hwang Ho there is very little navigation—far less than is needed to meet the requirements of the country.

The principal causes of this are the shallowness of the river during the greater part of the year and the changes in its bed.

If the Hwang Ho and its tributary the Wei Ho were more suitable for navigation by junks and larger vessels, noteworthy results would be obtained. The provinces of Honan, Shansi and Shensi would then be connected to the great network of inland navigation the principal branches of which are formed by the Yangtse and the Grand Canal, and which is supplemented by innumerable streams and canals.

Inland navigation, which in China is essential for all transport that is to be effected on any great scale and at reasonable rates, would receive a new impulse from this development. Cheap transport would bring into direct relations with each other parts of China which at present are closed to the exchange of many products by reason of the heavy cost and difficulty of transport.

The improvement of the navigation of the Hwang Ho is therefore of primary importance to national equipment.

In its present state, the Hwang Ho between its dykes represents the perfect type of the untamed river in the technical sense of the word.

Better conditions of navigation can be obtained only by providing a single channel with shallows established henceforward at an almost uniform depth throughout the period of low water.

If these conditions are to be fulfilled, however, the floods must not destroy the low-water channel once it is fixed. The mean-water channel must therefore be fixed before the regularisation of the low-water channel is begun, or simultaneously with it. Otherwise the high waters might erode, by the side of the regularised low-water channel, a second and perhaps a third channel, which will weaken and destroy the first.

A programme for the improvement of the navigability of the Yellow River would thus comprise two different operations: the fixing of the flood currents in the mean-water channel and the fixing and regularisation of the low-water channel within the mean-water channel, which has already been fixed. The second of these operations cannot be carried out until the first is completed.

In this respect, the improvement of navigability depends on the previous execution of schemes for preventing inundations caused by the breach of dykes.

If the destruction of dykes is not obviated, if at any moment during periods of flood dykes are likely to burst and the river to overflow into the plain, obstructing and displacing the mean-water channel of the river, nothing can be done to regularise the river for purposes of navigation.

The improvement of the systems of defence by dykes must therefore precede regularisation for purposes of navigation.

The question arises whether the same works can be used both for preventing the breach of dykes and for improving the navigability of the river.

If this were possible, a navigable channel could be provided and its completion could be speeded up.

In this respect, the two programmes—that of defence against floods and that of navigation—closely coincide.

It was stated in Chapter II that under-cutting of dykes, one of the most serious causes of catastrophes, could be combated in different ways: either by the improvement and modernisation of the defence on the spot in force in China or by active and offensive defence by confining the current in the flood channel at a sufficient distance from the dykes.

This solution might in certain cases, in the very wide sections, have the disadvantage that the works confining the bed would prove very costly on account of their excessive length. In other cases, with a view to preventing the breach of dykes, there might be an advantage in having recourse to the first method—that is to say, the improvement of the defence of the dykes and their foundation soil on the spot, where a displacement of the channel appears either too expensive at the outset, or too easily damaged in the sections above or below.

If, however, not only security but also navigability is aimed at, the problem assumes a different aspect.

From the point of view of security alone, it might be sufficient in certain sections to have dykes protected from the currents by rather short sloping groynes and to allow the mean-water channel to shift its course between the lines joining the heads of the groynes.

But if navigability is to be improved, much more is required.

The bed must be so fixed throughout its course that it can be regularised to obtain the maximum possible depth over the shallows at low water.

On the other hand, works fixing the low-water channel with a view to navigation will promote defence and prevent the river from shifting its course.

To sum up, apart from the raising of the dykes—an urgently necessary operation if breaches of dykes by over-topping are to be prevented—the mean-water channel must be gradually fixed along the whole dyked course of the Hwang Ho. This operation would not only prevent breaches of dykes by under-cutting, but would be the first step towards the fixing of the low-water channel, which is the second operation necessary for making the Hwang Ho navigable.

It is more than probable that the operation of fixing the current and eliminating the formation of a number of parallel channels or beds will in itself appreciably increase navigability. Navigation will also benefit by the fact that such fixing of the current would enable landing-stages and equipment to be established for transshipment, thus forming the nucleus of future river-ports.

On the results obtained by this fixing must depend the second operation to improve navigability for vessels of larger tonnage—that is to say, the regularisation of the low-water channel, the cost of which would need to be counterbalanced by the advantages afforded by better navigation.

The result of fixing the mean-water channel will undoubtedly show, if a comprehensive economic study is made of the possible trade and probable transport, whether this second operation of regularising the low-water channel appears to be justified.

5. RELATIONSHIP BETWEEN IRRIGATION AND NAVIGATION.

If the navigability of the dyked part of the Hwang Ho is contemplated, the discharge at the time of low water becomes a matter of the first importance.

In the preceding sections, it has been pointed out that the Hwang Ho is a rain-water river. Irrigation water is taken from it for agricultural purposes during the period when the discharge is at a minimum.

On the middle course and also in the plain, the quantities of water taken for irrigation will undoubtedly increase much more.

In years of drought, however, the flow of the Hwang Ho is very slight.

Irrigation on the middle course and in the plain will take away a large part of this water and render navigation, during the period of low water, if not impossible, at any rate precarious.

Periods of interruption of river navigation occur on many rivers, and they will not prove intolerable in China, where water transport is slow.

The disadvantages of reducing the discharge in time of low water, however, require to be mentioned; they necessitate strict economy in the use of water for irrigation.

Chapter V.

THE DELTA OF THE HWANG HO AND ITS OUTLET TO THE SEA.

The problems raised by the Hwang Ho delta are important from the threefold point of view of the raising of the river-bed in the plain, the conditioning of newly formed land and navigation.

The available information regarding the delta of the Yellow River and its outlets to the sea is very scanty as regards both topography and natural conditions, and even the few particulars supplied to the Committee are, in some respects, contradictory.

The protective dykes have not been carried beyond a point about 60 kilometres from the coast slightly above the apex of the delta. Below that point, the current is so slow and the alluvial deposits so abundant that the river has no clearly defined course and the distribution of the discharge between the various arms is subject to frequent and very considerable changes.

The average fall of the river at high water throughout the delta is 1 in 6,000. According to the British Admiralty chart, spring tides rise 10½ft. (3.2 metres) in the estuary ; but, in consequence of the river's sharper fall in the last 20 kilometres of its course, these have little or no influence on the general condition of the river outside the delta itself.

It is stated that the channels of the delta show a tendency to discharge to the north. This is probably due to the coastal current, which is given a northerly direction by the south winds prevailing during the summer months, when the river overflows its banks and forms new arms. If confirmed, this information would have an important bearing upon the schemes for the improvement of the mouth of the Siaoqingho, which lies to the south, the purpose of these schemes being to make that stream suitable for coastal traffic as far as Tsinanfu.

The delta has an area of 4 million mu (500,000 acres). It is sparsely populated and is not cultivated to any considerable extent. There is therefore no great reason to fear damage from inundations in this area.

The Shantung provincial authorities propose to extend the dykes below Litsin, but their alignment and spacing, and above all the question whether they should be extended below the upper tidal limit, will require very careful consideration.

It is unquestionably desirable that the course of the Yellow River should be regularised throughout the delta ; on account, however, of the difficult and constantly changing conditions of the estuary, which are due to the enormous quantities of alluvium brought down by the river and which, moreover, will grow increasingly serious as the bursting of dykes becomes rarer, and also on account of the shallowness of the sea at the river mouth and the mobility of the shifting mud lying at the bottom, the cost of effective works would necessarily be considerable, and all idea of establishing a port at the mouth of the river must be abandoned.

Everything points to the conclusion that the improvement of the delta and the river mouth is secondary in importance to the urgency of protective works and regularisation on the upper reaches, and can therefore conveniently be postponed.

Later on, before specific recommendations are put forward, a thorough study will have to be made of the delta and coast. The results of such a study will perhaps make it possible to work out a scheme giving due weight to the problems raised by the peculiar regime of the Yellow River, together with the additional complications due to the natural conditions of the Gulf of Chihli.

Chapter VI.

SUMMARY AND CONCLUSIONS.

I. THE IMPROVEMENT OF THE YELLOW RIVER.

The annual expenditure entailed by the conservancy of the Hwang Ho is not very great, but the damage caused by the bursting of dykes and the resultant catastrophes may amount to hundreds of millions.

The inundations lead to the loss of many lives and plunge tens of millions of human beings into destitution. Such are the dangers by which agriculture is constantly threatened that it is impossible to improve methods or increase production.

In the preceding chapters, the direct and indirect causes of catastrophes on the Hwang Ho have been analysed. The efficacy, advantages and disadvantages of the various possible remedies for each of these causes have also been considered and compared.

This study points to the conclusion that it is certainly possible to limit the floods and reduce their frequency very greatly, and that the best and most expeditious means to this end would be the improvement of the defensive dykes in the plain. It has further been shown that, for the purpose of carrying out this great undertaking, China possesses abundant skilled labour and the necessary material. The sums spent in financing these works would remain almost entirely in circulation within the Chinese national economy and would primarily benefit the riparian population, from which the workers would be recruited.

In spite of its magnitude, this operation could be carried out in a relatively short time. Like all other works of man, however, it would have its weaknesses and imperfections, and would therefore have to be completed by more protracted operations, the preliminary investigations for which have scarcely been begun. These operations would be designed to improve the regime of the Hwang Ho by appropriate works and measures on the middle and upper reaches of the river and its tributaries for the purpose of checking the violence of the floods and reducing the volume of alluvium brought down by the river.

It is difficult to estimate the scale of costs for the improvement of dykes in the plain, as this would be governed by several factors, such as the type and extent of the works, the nature and amount of the materials employed and the organisation of labour.

Nevertheless, the undertaking would not appear incommensurate with all the various resources at the Chinese Government's disposal.

In the most unfavourable hypothesis—that is to say, if the funds were obtained through a loan instead of by budgetary means, the annual payments in respect of such a loan would probably be offset by the reduction in the losses and damage of all kinds caused by floods.

The undertaking takes on an even more promising aspect if account is taken of the new wealth which could be created and the resultant appreciation in the value of the land protected from floods.

Detailed information on this point is lacking, but it is nevertheless possible to form a general idea of the probable extent of such appreciation.

In this connection, it must be borne in mind that, by the execution of the programme of defence works necessitating the fixing of the mean-water channel, the first stage in the programme of navigability would be completed. This would immediately lead to an initial improvement in conditions of navigation and would facilitate the subsequent improvement of the low-water channel.

While the great value to China's economic life of the improvement in navigating conditions would be indirect, the increase in agricultural production would, on the other hand, be of direct importance.

The security created by better defence against floods on the Hwang Ho and the consequent fixing of the bed would enable irrigation, warping and drainage to be introduced on a large scale alongside the embankments. If the schemes are carefully studied and prepared, and if they are carried out by the employment of peasant labour, well organised and directed at the period most suitable for such works, the results obtained should certainly exceed the expenditure incurred.

Along the Hwang Ho the inhabitants are merely awaiting security, together with adequate technical organisation, to take in hand the improvement of their land as soon as the necessary incentive is forthcoming.

There can be no doubt that irrigation, warping and drainage along the Hwang Ho would prepare the way for heavier crops and would enormously increase the value of large tracts of land representing an area of thousands of hectares, with a corresponding improvement in the lot of the people.

The improvement of the Hwang Ho would thus seem to be an undertaking the cost of which will be covered in the first place by the decrease in the damage done by floods, and even more so by the resultant appreciation in land values. It would thus seem as if it ought to develop into a paying undertaking.

The vast tracts of land along the dyked part of the river could be made more productive and more valuable by irrigation and warping by means of water and loess taken from the river.

It would be only right that the owners of such land should return to the community a part of the increment in the value of their land in the form either of monetary contributions or personal service. The resources thus obtained would enable the anti-flood defence works to be continued and improved.

2. CONCLUSIONS.

I. Among the problems of the Yellow River, that of the prevention of inundations due to flood waters is the most important and the most urgent.

II. Whenever the dykes give way, there are inundations in the plain ; as a general rule, these are rendered more serious by the fact that the river-bed is raised above the level of the surrounding land, and cause immense loss of life and property.

On several occasions, this has given rise to a complete change in the course of the river and, as a result, to irreparable disaster to tens of millions of people.

III. The direct cause of inundations is the bursting of the dykes. This may occur in five different ways.

The most frequent and the most dangerous are breaches by over-topping and by under-cutting. The first may be prevented by raising the dykes sufficiently, the second by diverting the current from the dykes and fixing the mean-water channel, or, where this method cannot be followed, by strengthening the local defence system.

IV. Subject to the reserves entered more especially in the introduction to this report, and in view of the uncertainty still prevailing as to the behaviour of the loess in suspension in the water, the improvement of the general system of defence in the plain is the only one which, in the case of the Hwang Ho, can be counted upon to give satisfactory results in a short period, by measures and at a cost not beyond China's means and capacities.

The construction of special reservoirs along the middle course of the river and its tributaries, with the sole or at least the principal object of moderating the floods, is not to be commended, because, though the capacity of the reservoirs would be very large and the expenditure enormous, the defence system in the plain would still have to be improved, while the value of these reservoirs would be limited in time by the huge deposits of solid matter, which would rapidly reduce their capacity.

The use of irrigation reservoirs for the same purpose of moderating floods is not, as a general rule, advisable. It would frequently be prejudicial to the interests of irrigation, the storage of silt-bearing water accelerating the accumulation of deposits ; moreover, the effect of such reservoirs on the floods would be small. This method can only be used in special cases, when local circumstances are favourable.

The other known measures are "minor measures", often very useful, but having no real effect on the regime of the river, except after rather a long period and only if applied *on an enormous scale*.

Among these are vegetation, reforestation, the reintroduction of the system of "ditches", small barrages and sills to prevent erosion, and other works to prevent the destruction of mountain lands.

Several of these measures may have a marked effect on the regime of the river, but, on the whole, are beneficial in China only in so far as they are remunerative.

Such measures for improving the regime of the river should be applied as soon as more security has been obtained by strengthening the defence works in the plain, or—better still—from the outset of those works.

They cannot, however, take the place of dyke construction in the plain.

V. The carrying-down of enormous quantities of loess has two very serious drawbacks: (1) the formation in the flood channel of very large local deposits as soon as the speed falls, thus reducing the discharge sections and raising the flood level, and (2) the continual raising of the bed.

The latter is not a source of insuperable danger, so long as the dykes are high enough and strong enough and their upkeep is properly ensured. It involves a corresponding elevation of the dykes, which seems feasible and would entail reasonable expenditure. This rise could probably be retarded and combated through the general application of warping on the lower sections of the plain by means of a system of overflow and feeder-weirs.

VI. The security of the population can be increased by the construction of local endykements of communities and by the organisation of flood-warning services, though indeed these last were inaugurated on the Hwang Ho in 1934.

VII. The programme of defence against floods by dykes in the plain involves stabilising the mean-water channel and thus facilitating irrigation. This stabilising process is at the same time the first stage in a programme of navigability, the second stage of which is the regularisation of the low-water channel, always provided that the volume of navigation justifies such an effort.

VIII. The limitation of floods by a defence system in the plain is a very ambitious undertaking, but it does not seem to be beyond the financial resources or working capacity of the population. It does not require the introduction of materials or products from abroad. It requires plenty of the industrious and skilled labourers who are so numerous in China.

Combined with irrigation and large-scale warping along the embanked Hwang Ho, the efforts and expenditure necessary for reducing insecurity would be compensated by the smaller expenditure for repair of damages and less loss of human life and property, to say nothing of the increase in the value of vast tracts of land along the river-banks.

If the programmes of dyke construction, irrigation and warping are well devised in every way — planning, use and supply of materials and labour — their execution would seem to be a remunerative undertaking for China.

III.

PROBLEMS OF THE HYDRAULIC SYSTEM OF SHENSL.

CONTENTS.

	Page
A. <i>Introductory</i>	57
B. <i>Utilisation of the King Ho for Irrigation:</i>	
I. General	60
1. Hydrological Notes	60
2. History of the Scheme	63
II. Description of the Irrigation System :	
1. Area irrigated and Irrigation Flow : Economic Advantages of Irrigation	63
2. Works of the First Stage executed before the Installation was put into Service (June 1932)	64
3. Results of the First Period of Operation (June 1932—Autumn 1933)	65
4. Repair and Completion of the Works from the Autumn of 1933 to the Summer of 1934	65
5. Cost of the Works of the First Stage and those of Repair and Completion	66
6. Results of the Working Period, 1934	66
III. Observations and Criticisms :	
1. General Criteria of Utilisation	67
2. Barrage and Intake Works	67
3. System of Distribution : Engineering Works	69
IV. Possible Réarrangement : Suggestions regarding the New Proposals	69
C. <i>Utilisation of the Lo Ho for Irrigation:</i>	
I. General	73
Hydrological Notes	73

	Page
C. <i>Utilisation of the Lo Ho for Irrigation (continued)</i> :	
II. Description of the Irrigation System :	
1. Irrigated Area : Crops and Irrigation Flow : Economic Advantages of Irrigation	74
2. Works contemplated under the Scheme	76
III. Observations and Criticisms :	
1. General Criteria of Utilisation	77
2. Barrage and Intake	77
3. Methods of Construction	79
IV. Possible Adaptations : Suggestions for New Proposals	80
D. <i>Utilisation of the Wei Ho for Irrigation</i> :	
I. General	81
Hydrological Notes	81
II. Notes on the Irrigation System contemplated	82
1. Area to be irrigated, Crops and Irrigation Discharges, Economic Advantages of Irrigation	82
2. Works included in the Scheme	83
III. Observations and Criticisms :	
1. General Principles of Utilisation	84
2. Barrage	84
3. Intake Works	86
IV. Suggested Alterations and Improvements	87
E. <i>Criteria for the Study of Intake Works for a Watercourse bringing down a Large Quantity of Silt</i>	88
F. <i>Some Important Supplementary Problems</i> :	
1. Gross and Net Supply for Irrigation : Operation of the System and Regulation of the Use of Water	89
2. Wells for Irrigation	90
3. Ordinary Works	91
4. Possibility of Hydro-electric Installations along the Canals	91
5. Reafforestation : Steppe and Desert Vegetation	91
G. <i>The Supply of Drinking-water and Electric Power for the City of Sianfu (Second Capital)</i>	92
H. <i>Available Water-Supplies in Shensi</i>	94
I. <i>The Reservoir Problem</i>	99
J. <i>Conclusions</i>	102

A. INTRODUCTORY.

From the geographical and climatic point of view, Shensi is divided into two clearly distinct parts by the high mountain-chain of Tsinling Shan, which lies mainly in an east - west direction, and also constitutes the watershed between the basin of the Yellow River to the north and that of the Blue River (Yangtse Kiang) to the south.

The *southern part* of Shensi, to the south of this chain, is constituted principally by the upper basin of the Han Ho (a tributary of the Yangtse Kiang), the valley of which is filled with alluvial deposits in which reddish, clayey soils predominate.

The climate, which is rather hot and damp, is not dissimilar to that of Southern China.

The rainfall, which is fairly abundant, with an annual average of 600 to 800 millimetres, is sufficient, in view of the natural fertility of the soil, for the regular development of a flourishing agriculture.

Immediately to the north of the Tsinling Shan lies *Central Shensi*,¹ constituted mainly by the lower valleys of the Wei Ho, King Ho and Lo Ho, which form widely extending plains, at the centre of which lies the capital, Sianfu.

These plains have enjoyed centuries of great prosperity and were the cradle of Chinese civilisation. The most glorious dynasties had their seat there, and the number and imposing character of the monuments scattered throughout the region and the remains of works on a vast scale, including extensive and complicated irrigation systems, bear witness to the splendour of the past.

North of the Tsinling Shan into Central Shensi, there begins the domain of the "yellow earth" (Huang Tu) or loess, the deposits of which here, as in a great part of Northern China, cover an area and have attained a depth (several hundred metres) unknown elsewhere. Loess, in fact, is the characteristic feature of the country and of local life and economy.

This radical change in physical conditions is attended by a change in the climate, which is becoming less hot and drier.

With the exception of the high northern slope of the mountains, where the rainfall is still heavy, the mean annual rainfall in the plain near Sianfu does not exceed 450 to 500 millimetres, while further north, on the terraced plateaux of loess on the left bank of the Wei Ho, the annual rainfall is only about 300 to 400 millimetres, or even less.

The rainfall varies widely from year to year, so that, while the annual maxima may reach 800 millimetres, the minima approach 100 millimetres.

Moreover, the rains are always concentrated into a few months; indeed, sometimes in the course of a few days the fall considerably exceeds that of an entire year.

These wide fluctuations in rainfall and the extensive formation of loess together explain the extraordinary vicissitudes of agricultural production—which, moreover, constitutes the whole production of the country—with their tragic repercussions on social life.

¹ Northern Shensi, which is mountainous and desert, is of much lesser ethnical and economic importance.

In fact, while the composition of loess produces an exceptional natural fertility, its physical structure, besides enabling the land to be easily tilled, allows the soil to absorb and retain the rainwater for a long time, thereby enabling the vegetation to derive the maximum benefit from it.

The gently sloping topographical conformation, both at the bottom of the valleys constituted by alluvial deposits and redeposited loess and along the declivities in which the original loess predominates in the form of broad terraces, favours admirable cultivation (the most minute and intensive that natural conditions will allow), in which the Chinese peasant is a past master.

Thus, once the rainfall attains even the average amounts above indicated, small though these are, agriculture may become so intensive as to encourage and support a dense population, attracted more especially by the frequent succession of years of abundance (for example, the years 1933 and 1934).

If, however, after the local agriculture has, for the reasons indicated, reached a high degree of prosperity—higher on account of the loess than could be reached elsewhere with similar climates—a year, or even a series of years, follows in which the rainfall is so scanty that the water sinking into the ground is not even sufficient to support the slightest vegetation, every form of agriculture, even the most elementary, is necessarily interrupted and the prime sources of life are cut off.

Hence the periodical catastrophes, in which the entire region is depopulated by death or by the departure of the inhabitants elsewhere.

Statistics, unreliable though they are, show that, as a result of the drought of 1928 and the following years, the population of Shensi fell from over 14,000,000 inhabitants to 7,000,000 and no less than 3,000,000 are believed to have died. In the valley of the Han Ho, which forms the southern part of the province above described, there were, in the years mentioned, harvests not greatly below the normal.

The significance of the figures quoted therefore becomes more tragic because the depopulation and high mortality are limited to the remainder of the territory of Shensi and especially to the central zone.

Even after seven years, the life of the region has not returned to the normal. Deserted villages may still be counted by the hundred, and empty houses by the thousand, and only the first beginnings of a slight recovery are perceptible.

From the time of the most remote dynasties down to the present day, efforts have been made to remedy such periodical disasters by irrigation. The agricultural population has dug innumerable wells, hundreds of thousands of which are to be found throughout the plain, the water being raised by manual or animal labour.

This method, however, partly because it was left to the unorganised and unsystematic efforts of the peasants (a very interesting study could be made of the course of the subterranean water-surfaces), partly because by its very nature it can only give very limited results, has produced benefits which, though very considerable, have been found absolutely inadequate.

An expedient frequently adopted has been to draw water from the main and secondary watercourses on the basis of irrigation schemes and systems far more ambitious than those in preparation to-day.

Yet these, too, after working for long periods, proved inadequate; even very extensive works were abandoned, and, to-day, no more than traces of them are to be found. Similar systems, constructed at equally remote periods, have existed for centuries in other regions of ancient civilisation, perpetuating and even increasing the wealth they once created.

The causes of the inevitable decay and consequent disappearance of even vast systems created time after time to meet the imperative needs of the country lie in the nature of the rivers or their conservancy, which latter depend in their turn on two

dominant factors : the vast formation of loess, which is quite peculiar to Northern China, and the disastrous variations in rainfall.

In order to explain the phenomenon more clearly and to show how serious it is, a few figures may be quoted by way of illustration.

The area of the King Ho basin at the point of the intake of the irrigation canal recently constructed is 40,000 square kilometres, one-seventieth as large as that of the Nile in Egypt (about 2,800,000 square kilometres).

Yet the maximum flow of the King Ho is higher than that of the Nile, while the minimum is a hundred times less.

Thus, while the ratio between maximum and minimum flow for the Nile is about 1 : 40, for the King Ho it is 1 : 10,000, or even less.

The effect of such immense volumes of water passing through a basin widely covered with loess and traversed by innumerable channels which cut deeply into the high terraces is that the *percentage* of solid matter carried down during floods is far higher than any of those noted elsewhere and may amount to as much as 50%.

The King Ho sometimes carries down more solid matter in a few hours than the Nile during a whole year.

For this reason, the great works repeatedly constructed in the past have often proved inadequate for their purpose, on account of frequent and prolonged periods of low water in the rivers, due to scanty rainfall. This lack of water, ruining agricultural production in the irrigated areas, has increased the general depression in the country in years of crisis, while even in normal years the periodical scarcity of water has rendered all irrigation precarious enough.

On the other hand, when the big floods occur, which they do with extraordinary suddenness, the water is so laden with matter as to resemble rather an avalanche of mud, and the old works (especially the intake works) are unable to withstand the strain ; they are carried away, or become obstructed, or are unable to prevent the long canals from becoming choked, sometimes to such an extent as to compel the abandonment of entire systems.

Thus in the course of centuries there has been a constant alternation of destruction, abandonment and reconstruction.

After the disastrous drought of 1928, and the terrible consequences to which it gave rise, various measures taken under the auspices of the National Economic Council have led to the recent initiatives which, based on the progress made in hydraulic technique, should overcome the hitherto insurmountable difficulties and constitute the beginning of a vast system of works calculated to effect a lasting change.

One irrigation installation is already in operation in Shensi, which diverts water from the King Ho for the irrigation of an area of 500,000 to 600,000 mu (31,000 to 38,000 hectares) in the plain of Wei Pei.

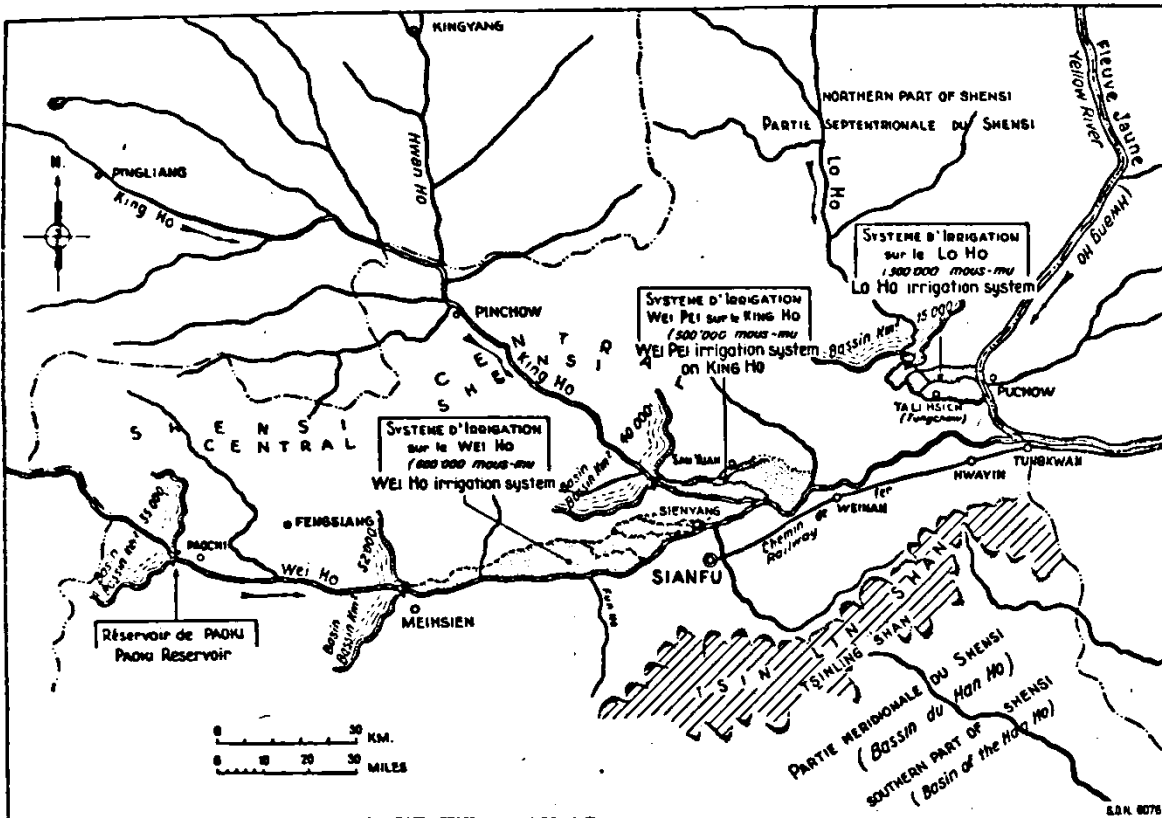
Another system of works, which has reached an advanced state of construction, will divert water from the Lo Ho to irrigate about 500,000 mu (31,000 hectares) in the low plain bounded to the south by the last section of the Lo Ho and to the east by the course of the Yellow River.

There is, further, a project for diverting water from the Wei Ho for the irrigation of about 600,000 mu (38,000 hectares) along the middle course of the latter river.

Another proposed hydraulic installation on the Fun Ho is of considerable importance, since it is intended for supplying drinking-water and electric power to the town of Sianfu.

These three major irrigation systems, drawing their waters from the Rivers King, Lo and Wei, occupied the chief attention of the Committee's expert during his visits and in the studies carried out by him in order to see *whether the systems themselves, and the works constructed or proposed in relation to them, fulfil the conditions necessary to ensure their permanency.*

IRRIGATION SYSTEMS IN SHENSI.



B. UTILISATION OF THE KING HO FOR IRRIGATION.

I. GENERAL.

In order to elucidate the problem of utilising the waters of the King Ho for irrigation, some general notes are given below on the natural hydrological situation and the history of the utilisation of the King Ho for irrigation.

1. *Hydrological Notes.*

The King Ho has its source in Kansu. It is fed by two main hydrographical systems which meet near the frontier between the provinces of Kansu and Shensi near the town of Changwu.

The eastern system is known by the name of Hwan Ho. Its basin consists primarily of a plateau of loess and tertiary clay cut by deep valleys. It is, perhaps, the part of China where such deposits are most uniform and the strongest. Rains, erosion by the water and not infrequent earthquakes cause extensive landslides, the debris of which obstructs the valleys and is afterwards carried away during floods. The waters of the Hwan Ho therefore have a very high content of silt. During the period of low water, the bed is almost dry.

The basin of the western hydrographical system, on the other hand, has been to a considerable extent denuded of deposits of loess and tertiary clay, and the waters of its streams are relatively clear. Even during the period of low water, the flow does not greatly fall.

Below the confluence of the two branches, eastern and western, the King Ho flows towards Pinchow. A few miles below this town, it enters a narrow, winding and steep gorge, 50 miles in length. At the end of this gorge, it flows out upon the plain of Wei Pei, the bed of a former salt lake.

The area of the basin is here about 40,000 square kilometres.

The river system is at present very imperfectly known.¹

The following table shows the maximum, minimum and average amounts in the various months of the discharge of the King Ho near the point of issue from the mountain valley (in the sections of Pei Tun and Changchia Shan).

The big floods on the King Ho, as on the other rivers in Shensi and the north of China, take place in July, August and September.

In the summer of 1931, a flood of 3,000 m³/sec. was observed, so rapid and unforeseen that, at the dam, the level of the water rose 10 metres in 10 minutes.

The flood of August 1933 was much more serious, however. On the 8th of that month, the *average daily* flow was estimated at 11,250 m³/sec., which would imply a much greater instantaneous maximum quantity. The proportion of alluvium on that day was almost 50% in weight.

In five days alone, 2,090 million cubic metres flowed through the section observed, carrying down some 550 million cubic metres of alluvium.

The flow is extremely irregular, and there is an exceptionally great difference between the flows at summer flood-periods and the very small flows at low water which last through the greater part of the year.²

¹ Although observations were begun several years ago, they are very incomplete (whole months and even years being missing), and it is, moreover, impossible to judge of the reliability of the data, which are often contradictory.

² The normal course of the floods in the winter and spring periods may be stated as follows, on the basis of the observations of the last few years :

After the summer flood, the flow gradually diminishes to some 20 m³/sec. towards the middle of December and to even smaller amounts towards the end of the year (average for December, 16 to 18 m³/sec.).

At the beginning of January, the freezing of the water in the rivers and on the surface of the ground gives rise for a few days to a diminution of the flow, which falls 5 to 7 m³/sec. It then increases again to 10 to 12 m³/sec. once the sheet of ice is formed.

In February and up to the middle of March, there is a slow increase up to 20 cubic metres, with occasional fluctuations of not more than about 5 cubic metres, due to cold or warmer periods. The thaw, towards the middle of March, is accompanied by a moderate spring flood, about 40 to 60 m³/sec., sometimes even 100 m³/sec. of short duration.

The flow then falls again to 16 to 20 m³/sec.

In April, May and June, the flow constantly decreases. The following monthly average quantities have been observed : in April, 11 m³/sec. ; in May, 15 m³/sec. ; in June, 12 m³/sec. At this period, small floods may occur, usually below 100 m³/sec. Floods of some hundreds of cubic metres per second with water heavily charged with alluvium are not improbable, however.

Flow of the King Ho in Cubic Metres per Second, in Pei Tun Section.

Year	Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
1922 Max.....	—	—	—	—	—	—	—	—	—	—	28.4	16.3
1922 Min.	—	—	—	—	—	—	—	—	—	—	26.5	14.6
1922 Av.....	—	—	—	—	—	—	—	—	—	—	27.4	15.5
1923 Max.	20.6	—	45.9	58.0	37.5	17.5	10.55	935.0	305.0	57.9	40.1	27.2
1923 Min.	13.2	—	28.7	23.3	15.6	10.0	12.50	21.9	31.5	36.4	26.0	8.2
1923 Av.....	17.0	16.0	36.8	33.0	24.1	13.8	—	347.5	62.9	42.2	29.4	20.8
1924 Max.	17.6	—	51.7	40.1	52.4	29.3	54.9	171.1	76.3	1,498.0	36.0	29.0
1924 Min.	11.4	—	27.4	16.3	15.8	10.7	9.0	12.9	14.5	21.7	18.3	16.6
1924 Av.....	13.4	—	36.5	24.8	28.2	16.9	22.9	69.0	28.6	56.2	28.0	21.1
1925 Max.....	—	—	—	—	—	—	—	—	—	—	—	—
1925 Min.	—	—	—	—	—	—	—	—	—	77.0	36.6	25.0
1925 Av.....	—	—	—	—	—	—	—	—	—	17.5	18.0	16.0
										31.0	24.5	19.0
1926 Max.	17.4	26.7	55.0	24.7	22.5	390.0	2,900.0	550.0	145.0	78.8	28.0	24.8
1926 Min.	6.8	11.4	16.9	12.5	8.7	8.0	9.0	13.5	15.0	18.5	21.5	9.0
1926 Av.....	12.0	16.0	31.0	16.3	10.8	36.5	81.0	31.9	31.9	25.6	24.2	17.6
1931 ¹ Max.	—	—	—	—	—	—	—	—	—	—	—	—
1931 ¹ Min.	6.0	12.0	18.0	13.0	9.50	9.50	10.0	10.0	15.0	18.0	22.0	9.50
1931 ¹ Av.....	—	—	—	—	—	—	—	—	—	—	—	—
1932 Max.	13.0	21.5	28.5	20.0	80.0	84.0	1,950.0	1,700.0	230.0	—	14.7	11.2
1932 Min.	4.9	12.3	12.5	11.5	9.6	5.0	3.1	7.0	8.0	—	8.0	2.8
1932 Av.....	9.0	16.1	21.3	14.9	30.4	11.8	478.2	220.9	—	—	10.7	6.8
1933 Max.	13.1	25.4	46.6	34.1	32.2	885.6	6,402.0	11,250.0	520.0	69.0	31.6	22.6
1933 Min.	6.2	9.3	12.4	16.0	11.8	11.4	17.5	16.0	17.5	28.0	20.0	11.8
1933 Av.....	9.9	16.1	26.8	21.2	18.1	71.4	15.8	958.7	56.5	37.4	24.4	16.5
1934 Max.....	16.9	39.4	42.4	28.1	30.1	317.3	1,081.0	1,080.0	58.8	331.0	50.4	—
1934 Min.	9.7	14.9	23.3	14.8	11.2	12.3	12.0	13.3	24.2	40.0	16.0	—
1934 Av.....	13.3	25.1	29.4	21.7	18.0	31.4	30.4	227.8	40.4	104.0	32.5	—

¹ These quantities have been deduced from a graph.

The alluvium carried down from the mountainous regions by the waters of the King Ho consists of clay, fine sand and mould ; it thus possesses considerable fertilising power.

2. *History of the Scheme.*

There are records of an installation, known as the Chang Kou system, constructed in 240 B.C., which diverted the waters of the King Ho, on emerging from the mountain gorge, into a canal which skirted the foot of the hill, collecting in its course the waters of minor torrents (Yeh, Tsing, Tsoh, Shechuan), and irrigated about 4,500,000 mu (280,000 hectares). The canal ended in the Lo Ho.

This irrigation system having fallen into ruin, a new and much smaller one was constructed about 100 B.C. to irrigate 450,000 mu (28,000 hectares).

Various vicissitudes—repair, ruin and abandonment—followed until about the middle of the eighteenth century. The experience of the past engendered *despair of ever succeeding in preventing the entrance of mud into the canals* and the consequent silting-up. It was therefore decided to abandon the utilisation of the waters of the King Ho and to close the inlet to the canal.

The latter accordingly had to confine itself to capturing the waters from the springs along its course. In this way, 70,000 mu were at first irrigated ; subsequently, owing to increasing losses along the canal, this area declined to 20,000 mu.

After the drought of 1921, with the object of preventing the repetition of such catastrophes, the China International Famine Relief Commission (C.I.F.R.C.) and the Government of the province of Shensi hurried on the preparation of new schemes. These were prepared, but the civil war caused their execution to be suspended.

After the droughts, even more serious and disastrous in their consequences, which marked the years 1928 to 1930, the problem was once more taken up and a scheme of M. H. Li was approved, which comprised the construction of a barrage, intake works and a short deflection tunnel, the adaptation of the ancient King Hui canal cut in the rock, the reconstruction and adaptation of the principal feeding canals and the system of distribution.

II. DESCRIPTION OF THE IRRIGATION SYSTEM.

1. *Area irrigated and Irrigation Flow : Economic Advantages of Irrigation.*

The plain to be irrigated is constituted by part of the bottom of an ancient salt lake subsequently filled up by fluvial and æolian deposits. It extends from the King Ho to the Lo Ho, with an area of about 3,000 square kilometres and is intersected by three minor watercourses (Yeh, Tsing and Shechuan).

The area which it was proposed to irrigate amounts to about 500,000 to 600,000 mu. The flow necessary for irrigation was assumed to be equal to 16 m³/sec., which corresponds to a unitary contribution of 0.51 to 0.43 litre per second per hectare.¹

As regards the increase in the value of the land as a result of the irrigation, the information available is sufficiently consistent.

The value of the land before irrigation is estimated at 5 to 6 Mexican dollars per mu (80 to 96 dollars per hectare) ; after irrigation, on the basis of the results observed in the district of Kingyang, at 30 to 40 Mexican dollars per mu (480 to 650 dollars per hectare).

According to information procured on the spot, the annual charge leviable per mu, with a more efficient administration and a more effective system of collection,

¹ This amount really appears to be somewhat small, in view of the inevitable losses along the canals.

would be sufficient, not only to cover the cost of operation, but also to allow of the completion and extension of the works, *provided, of course, the system of irrigation is put into working order so as to enable the farmers to derive the anticipated benefit from it.*

2. *Works of the First Stage executed before the Installation was put into Service (June 1932).*

The scheme provided for the execution of a first stage which would enable part of the system to be put into operation.

These works, which were for the most part constructed before June 1932, when the installation was inaugurated, are as follows :

(a) A *fixed overflow barrage* of concrete, of the gravity type, 9.2 metres in height, with a capping of 68 metres in length. The barrage dams a narrow gorge situated some hundreds of metres above Lao Lung Wang Miao, near the entrance to the old King Hui canal. The steep sides and the bottom consist principally of limestone. Below this emplacement is a rapid of about 2.5 metres.

The construction of the weir was begun in the spring of 1931 and completed in the summer of 1932.

During the construction, two sluiceways were left for the discharge of waters, which were subsequently closed with stop planks.

The scheme did not, in fact, provide for any permanent discharge sluiceways.

(b) The tunnel which runs from the inlet to the point of junction with the old King Hui canal has a length of 359 metres and a section of 14.8 square metres. This is preceded by a communication trench 25 metres in length.

The intake works are placed at the beginning of the tunnel and consequently stand well back from the current in order to prevent damage by heavy masses carried down by the current. The inlet is furnished with three gates 1.75 by 1.5 metres. The lifting apparatus is *situated 11 metres above the sill, so as to be above the maximum height of flood water estimated when the scheme was drawn up.*¹ The construction was completed in the middle of August 1931.

(c) A principal feeding *canal*, which begins at the outlet from the tunnel and follows the course of the old King Hui canal. Its section was planned to take a maximum flow of 16 m³/sec.²

After about 11.5 kilometres, the main canal is divided into two branches: the northern, with a flow of 5 m³/sec.; and the southern, with a flow of 11 m³/sec.

The annexed table, relating to the plan of the irrigation system, shows the lengths and discharges of the canals subsidiary to the principal canals and the areas irrigated by them in the summer season of 1934.

(d) *Various engineering works*—principally road-bridges and conduit-bridges for carrying over the flood waters from the valleys intersecting the hills and also for various purposes—gutters, falls over the canals, tertiary canal intakes, etc.

¹ During the exceptional flood of August 1933, however, the water overflowed the weir to a height of quite 14 metres, thus covering the lifting apparatus by 3 metres.

² The first section is excavated in the rock, and has a length of 1,620 metres and a slope of 1 : 2.133. Much of it had to be covered with masonry to reduce losses.

The second section is excavated in soil consisting of earth, gravel, large pebbles and conglomerate as far as the neighbourhood of Mu Su Won, and from there of ordinary earth. The part above for a length of 6,151 metres was constructed as far as the neighbourhood of Wang Chiao by the C.I.F.R.C.; the part below as far as the bifurcation of Liang Hui Chia by the Government of the province of Shensi.

It was intended to carry out in a second stage, after the installation had been put into service, a whole series of works for raising, consolidating and protecting the embankments towards the river, and facing the principal canal in order to reduce losses.

It was also proposed to construct for the flood reporting service a hydrometric station on the King Ho about 3 kilometres above the intake, with telephonic connection with the watch-house at the intake.

3. *Results of the First Period of Operation (June 1932-Autumn 1933).*

The installation was put into operation on June 20th, 1932.¹ Towards the middle of July, at the time of flood water, as it was not possible to close the gates at the mouth of the tunnel,² the water, which was extremely rich in mud (up to 48% in weight or about 27% in volume), silted up the principal and northern canals for a total distance of about 32 kilometres. The level of the water rose 5 metres above the top of the weir. The discharge of the King Ho was estimated at 2,000 m³/sec.

As a result of the silting-up, the discharge of the principal feeding canal decreased from 14 m³/sec. to 2 m³/sec.³

After the flood, the work of remodelling the canals was undertaken with promptitude and energy, secondary canals being taken first, in order to permit of at least a partial resumption of the distribution of water.

Owing, however, to the damage produced by the flood, and also to the limited extent and efficiency of the secondary canals, an area of only 50,000 mu (3,100 hectares) could be irrigated in the autumn of 1932. At the end of 1932, the works for repair and extension of the system which had been carried out enabled the irrigation to be extended 80,000 mu (5,000 hectares) under wheat.

In the spring of 1933, the further extensions and improvements introduced in the system of secondary canals and the greater experience acquired in the use of the water made it possible to irrigate about 100,000 mu sown with wheat, from which a satisfactory crop was obtained, and subsequently about 100,000 mu planted with cotton.

The flood of the summer of 1933, however, caused further serious damage to the works. After two severe storms, a flood wave⁴ occurred from August 7th to 11th, overflowing the weir to a height of 14 metres. The lifting apparatus of the gates at the intake was submerged for some four days.

The dykes enclosing the main canal at the outlet from the tunnel, and the northern branch of the canal itself over a course of about 9 kilometres, suffered very severe damage.

4. *Repair and Completion of the Works from the Autumn of 1933 to the Summer of 1934.*

The serious damage suffered by the works also during the flood of 1933 demonstrated the absolute and urgent necessity of carrying out the repairs and putting the works themselves into proper condition.

¹ By the bureau of the King Irrigation Works, to which the works described above were handed over on completion.

² Apparatus had been provided only for the lifting of the gates.

³ The southern branch of the main canal and the Chung Pei, by virtue of their sharp fall, were capable of carrying water laden with mud up to 20%.

⁴ The average daily discharge reached 11,250 m³/sec. (August 8th).

This work, which is described below, was executed for the most part during the period from the autumn of 1933 to the summer of 1934, together with the works for the completion of the system of canals.

(a) *Repair of the Weir.* — The pier dividing the two 4-metre sluiceways left in the weir near the left bank had been carried away by the flood.

At low water, owing to this breach in the weir, the levels of water upstream fell to a level insufficient to feed the canal. The breach was closed, a single aperture of 2 by 2 metres being left, *to allow evacuation in front of the intake.*

(b) *Construction of Locking and Discharge Works on the Principal Canal.* — About two kilometres below the end of the tunnel, at Yawuchiaio, a lock was erected comprising two regulating sluiceways with gates, and immediately above this, at the side of the canal discharge works, consisting of two sluiceways furnished with gates and a waste weir of a length of eight metres and with its top fifty centimetres below the top of the piers dividing the sluiceways.

The object of this arrangement, according to the authors of the scheme, was to enable surplus water to be returned to the river, and at the same time to prevent the muddy waters during floods, in case of failure to close the gates at the intake, from flowing downstream along the canal and producing deposits there.

(c) *Completion of the Canals branching from the Main Canal.* — Canals Nos. 1, 2, 4 and 5 starting from the northern branch of the main canal and No. 1 of the southern branch were completed in December 1933. At the same time, the engineering works (mouth for feeding the distributing canals, falls) were executed along these canals.

(d) *Works undertaken by the King Ho Irrigation Work Bureau.* — The installation of the irrigation system further required a series of works to complete the system of distribution and place the existing works on a permanent basis. These works were undertaken and are in course of execution by the King Ho Irrigation Work Bureau of the National Economic Council.

They comprise the repair of the facings of the weir, the reconstruction of the downstream apron with a suitable section, the construction of lock and discharge works at Chiaokiakou and at Tameitun, various repairs to the northern and southern branches of the main canal.

5. *Cost of the Works of the First Stage and those of Repair and Completion.*

The cost of the works executed in the first stage before the installation was put into service amounted to 715,658 Mexican dollars.

That of the works of repair and completion executed afterwards up to the summer season of 1934 was 920,534 Mexican dollars.

The expenditure from the beginning of the construction up to the period indicated above thus amounted to 1,636,192 Mexican dollars.

In January of the present year, however, the operations connected with the system of canals and with the works above indicated were still in course of execution.

6. *Results of the Working Period, 1934.*

Towards the end of 1933, on the completion of the works and the repair of those which had been seriously damaged, the irrigable area was increased to 400,000 mu.

The subsequent irrigation season showed, however, that the *effective discharges derivable from the King Ho were insufficient to meet requirements.*

Thus, in the month of June, in the principal irrigation period, the discharge fell below 13 m³/sec. and sometimes as low as 12 m³/sec. This confirmed the necessity of either appreciably reducing the areas under irrigation or regulating the flow by means of reservoirs.

Another circumstance, however, rendered the consequences of this technical deficiency still more serious. In fact, the unforeseen influx of water heavily charged with mud¹ made it necessary frequently to suspend distribution altogether, to avoid deposits in the canals by reason of the defective arrangement of the intake works.

III. OBSERVATIONS AND CRITICISMS.

I. *General Criteria of Utilisation.*

As already pointed out, a fundamental error, which detracts from and reduces the efficacy of this irrigation system, has been made in the estimate of the available water-supply, in relation to which the size of the works and the irrigable area are excessive.

In the preparation of the scheme of irrigation, account should have been taken of the hydraulic resources actually existing, with due reference to the possibility of future extension obtainable by the regulation of the flows.

As this criticism is applicable, not only to the installation on the King Ho, but also to those under construction or under consideration, the Committee will revert to the matter subsequently in each particular case; it can then indicate the means which, in its opinion, are alone suitable for solving the problem in a satisfactory way.²

2. *Barrage and Intake Works.*

The only effect produced by the fixed weir, despite its low height, has been, as might have been foreseen in view of the abundant solid matter carried down, to raise the bed of the river in the backwater.

The sluiceway of 2 by 2 metres left in the weir in order to remove solid matter from in front of the intake works was bound to be trifling in its effect,³ owing both to the absolutely inadequate dimensions of the sluiceway itself and to its remoteness from the intake works, and, lastly, to the arrangement of the latter. *Thus there is really no proper arrangement to remove such material.*

This is one of the causes of the difficulties observed during the few years of working.⁴ In such cases, the best course would be to construct a mobile weir, arranged in such a way as not to lead to silting in the bed, or at any rate to supply the fixed weir with sluiceways closed by gates large enough to clear away the silt when they are opened.

The general conception and design of the various works are defective.

¹ Water with a percentage of mud up to 30% in weight. Such unforeseen increases in turbidity, even in periods of low water, are probably due to *subsidence*s of the banks of the principal stream and its tributaries.

² See below the notes on "Available Water-supply in Shensi" and "The Reservoir Problem".

³ Besides the difficulty of working it.

⁴ The silting produced by the weir in the bed and upstream are not such as to compromise its stability. Nevertheless, the repairs recommended by the Hydraulic Bureau of the National Economic Council should be carried out.

They cannot be relied on to work satisfactorily, for the following reasons :

The apparatus for working the gates is not high enough and is thus liable to be submerged during floods. In August 1933, as already mentioned, it was under three metres of water for four days.

The working apparatus is not calculated to ensure the opening and closing of the gates in any eventuality, with due allowance for the strain placed on them and for the possible formation of deposits.

The arrangement adopted for the intake works does not effectively prevent the entrance of solid materials or allow for their removal, and this defect is especially serious because it leaves the system of canals exposed to the risks of damage by silting.

With a view to remedying the silting-up of the canals—a difficulty already realised, with the serious consequences related in the working of the installation—the locking and discharge works already described were constructed afterwards, on the proposal of the Hydraulic Bureau of the National Economic Council, about 2 kilometres below the outlet of the tunnel.

In this connection, the Committee has the following observations to make :

(a) Heavy floods spread so rapidly that the apparatus for closing the canal cannot be relied on to operate in time, unless there is an observation station a sufficient distance upstream which is permanently occupied and is in continuous touch by telegraph, telephone or wireless with the operators of the intake gates.

Owing to the position of the locking-works 2 kilometres below the intake, it would have been advisable to construct above and near these locking-works a discharge apparatus of sufficient capacity to return the muddy water to the river.

The waste weir constructed at the side of the locking-works previously mentioned, however, has an insufficient discharge capacity and cannot automatically limit flood waters in the downstream section.

It has, in fact, a sill barely 8 metres long, at an altitude of only 50 centimetres below that of adjoining pier's summit. *Its efficacy is therefore practically negligible.*

(b) The object in view¹ might have been attained at less expense, while avoiding the danger of silting-up even in the first 2 kilometres of canal, by *restoring the intake gates to working order*. It would have been sufficient for this purpose to arrange adequate working apparatus at a greater height (so as to prevent submersion) or, failing that, to adopt apparatus with remote control and capable of working even when submerged. It would also be worth considering making such apparatus automatic, since, as a general rule, the simplest solution is always the best.

As, moreover, it is in any case absolutely essential to have a locking apparatus at the upper end of the intake canal which can be relied upon to work in all circumstances, the lock-works constructed 2 kilometres downstream were unnecessary, particularly as their effect is very inadequate.²

The scheme of the work is defective. The sill of the regulating sluiceways is about at the same height as that of the discharge sluiceways, whereas it should have been appreciably higher. There is, accordingly, nothing to prevent the forward movement of solid materials on the bottom towards the canal, and any effective action for drawing the materials towards the river is also prevented.

¹ *I.e.*, to prevent the introduction of muddy water into the canal.

² If, indeed, it were found impossible to close the sluices in time during a very heavy flood, the volume of water discharging into the canal would be such as to cause a sharp rise in the water-level, an overflow towards the river over the canal dyke (which would thus be liable to be breached) and considerable silting-up of the apron floor.

Lastly, we think it desirable to make one comment which is none the less important for being self-evident.

In cases such as that of the King Ho, the intake works represent the *vital centre of the installation* and also *the most delicate point of the whole system*. If the system of distribution canals is not complete, or if defects are found in any part of it, the effect will only be to limit the irrigable area. To obviate the defects themselves, moreover, is not, as a rule, a really difficult matter and only involves a partial suspension of the irrigation operations.¹ *If, however, the intake is not in good working order, the whole system is paralysed.*

Once, therefore, the serious disadvantages due to the defective arrangement and planning of the intake works were observed (that is to say, immediately after the installation had been put into service), all action, whether of a technical or of a financial nature, should have been directed and concentrated on a *permanent and adequate regularisation of these works, the extension of the irrigation system being left to a second stage.*

3. *System of Distribution: Engineering Works.*

As regards the scheme of canals, it was evidently desired to make the maximum use of the existing former canalisations, adapting them to the new flows and the new requirements.

Nevertheless, the scheme is, as a whole, very rational and answers its purpose of covering the whole of the vast area to be irrigated, while, at the same time, reducing to a minimum (in view of the favourable topographical situation) the necessary drainage works.

Further, in spite of some initial delays, admirable skill was shown by the local agricultural population in digging the ditches and laying out the land, which involved altogether a great deal of intricate work.

On the other hand, we must draw attention to the necessity of solidly constructing the ordinary minor engineering works for the division and distribution of the irrigation water and of arranging them in a suitable manner, with the object of ensuring the efficiency of the system of distribution, the supervision of the use of the irrigation water, and generally securing a good irrigation service. The works have, in general, been designed and carried out too economically, to the detriment of security and satisfactory working. Furthermore, such works later entail excessive costs of maintenance and expensive repairs.

The putting into service of the installation has strikingly confirmed this conclusion.

IV. POSSIBLE REARRANGEMENT : SUGGESTIONS REGARDING THE NEW PROPOSALS.

I. The foregoing explanations have brought out what are the fundamental defects of the irrigation system on the King Ho, defects which seriously diminish the usefulness and jeopardise the life of the installation.

(a) The available supplies at periods of low water the very periods when irrigation is most necessary) are insufficient to satisfy the requirements of cultivation,² in view of the extent of the surface irrigated.

¹ Further, the topographical situation of the plain of the Wei Pei irrigated by the waters of the King Ho did not give rise to any special difficulties in the construction of the canal system.

² Over long periods, as has been seen, the supply falls *appreciably* below the 16 m³/sec. considered in the scheme, which figure itself appears insufficient to meet the real requirements.

(b) The intake works from the King Ho were defectively designed, regardless of the altogether special local situation,¹ which called for special measures, so that the efficiency of the installation is not ensured.

The insufficiency of the discharge at low water involves a general question with which we shall deal later. It may be said here, however, that the only way to improve the situation speedily is to construct reservoirs, if possible.

An adequate rearrangement of the intake works, however, is an absolutely necessary and urgent step.

The installation should, as soon as possible, be rendered capable of utilising the whole of the clear low-water discharge, in order to ensure irrigation as adequately as possible, even though only to a smaller extent than is contemplated in the *over-optimistic* estimates.

It cannot be too much emphasised that *the efficiency of the intake works is the indispensable condition for the working of any irrigation system.*

2. In order to obtain a satisfactory and rational rearrangement, there must, in our opinion, be a radical transformation of the intake works, comprising essentially : the restoration to working order of the intake sluices, so as to ensure their proper operation in all circumstances, the adaptation of a first underground section of canal as a sand filter by the construction of suitable works permitting of the locking of this section at the lower end and the discharge of excess deposits and silt into the river. In particular, the fall of the bed of this section should be increased and the section faced with masonry or concrete.

A detailed analysis of such works in the case of the King Ho need not be attempted here, for reasons explained below.

On the other hand, it seems necessary to make clear the principles which should underlie the study and planning of intake works in situations comparable to that of deflection from the King Ho, particularly as regards the transport of solid matter by means of an example quoted at the end of the present report, which relates to a *model arrangement* of intake works for irrigation on a very turbid watercourse.²

The modifications required by the particular circumstances should, of course, be arranged in each case. Thus for the installation on the King Ho, allowance should have been made for the exceptional size of the floods, rising to over 15 metres above low-water level in the deep gorge in which the intake is situated, and also for the fact reported to us that a large quantity of gravel and shingle is carried down on the bed.³

3. The expert was informed that the financial resources available did not permit of a *radical transformation of the intake works.*

For this reason, the Committee indicates the works of adaptation which, while utilising as far as possible what now exists and thereby limiting the expenses to be

¹ Chiefly by reason of the exceptional flow of solid matter, but also by reason of the great irregularity of the discharges.

² The following are the essential elements of the type of intake works quoted as an illustration :

A discharge apparatus introduced into the barrage works in proximity to the intake ;
Intake sluiceways with sill at a proper altitude and furnished with gates ;
A first section of canal faced and with a steep fall, serving as a sand- and mud-filter ;
Locking and regulation works arranged below the sand-filter section and the discharge works alongside the former comprising sluices, evacuating apparatus and syphons for the automatic adjustment of levels.

³ For this reason, it would be desirable to set the intake mouths back from the current of the river.

met as much as possible, might improve the present situation and remedy *the most serious defects* which now hinder the effective working of the installation.

These are, however, makeshift provisions, adaptations which cannot remove all the difficulties and will still be costly in upkeep.

They are to be considered not as definitive but rather as intended to enable the existing works to be immediately utilised in part, pending a future radical transformation, which will be *possible and indeed indispensable* when the development of agricultural production has increased the general prosperity of the region.

The modifications desirable in each group of works are as follows :

(a) *Barrage*. — The deflection is now carried out by a *weir fixed along its whole length*.

The existing sluiceway is useless ; in order to have any useful effect, it should be far larger and should possess locking appliances working easily and reliably.

Nevertheless, the defective arrangement of the sluices in relation to the weir would make any modification, short of a radical change, useless, and for this reason *we do not suggest any variation in the barrage works, notwithstanding the disadvantages of the present arrangements*.

(b) *Intake Works*. — The dimensions of the intake sluiceways and the altitudes of the sill should incidentally enable the entire available discharge of the river at low water to be deflected, within the limits of the maximum amount determined in advance.

The first of the modifications proposed here, which is the key to the whole system, has reference to *the restoration to working order of the lifting apparatus of the gates*. The lifting apparatus *must ensure the prompt opening or closing of the sluiceways in any eventuality*.

For this purpose, as already indicated, new lifting apparatus might be substituted¹ and placed out of reach of the floods, or remote-control apparatus, workable even when submerged, might be adopted.

The second of the modifications refers to *the arrangement of a discharge apparatus as far as possible automatic*, near the locking-works on the canal, which are situated about 2 kilometres below the outlet of the tunnel.

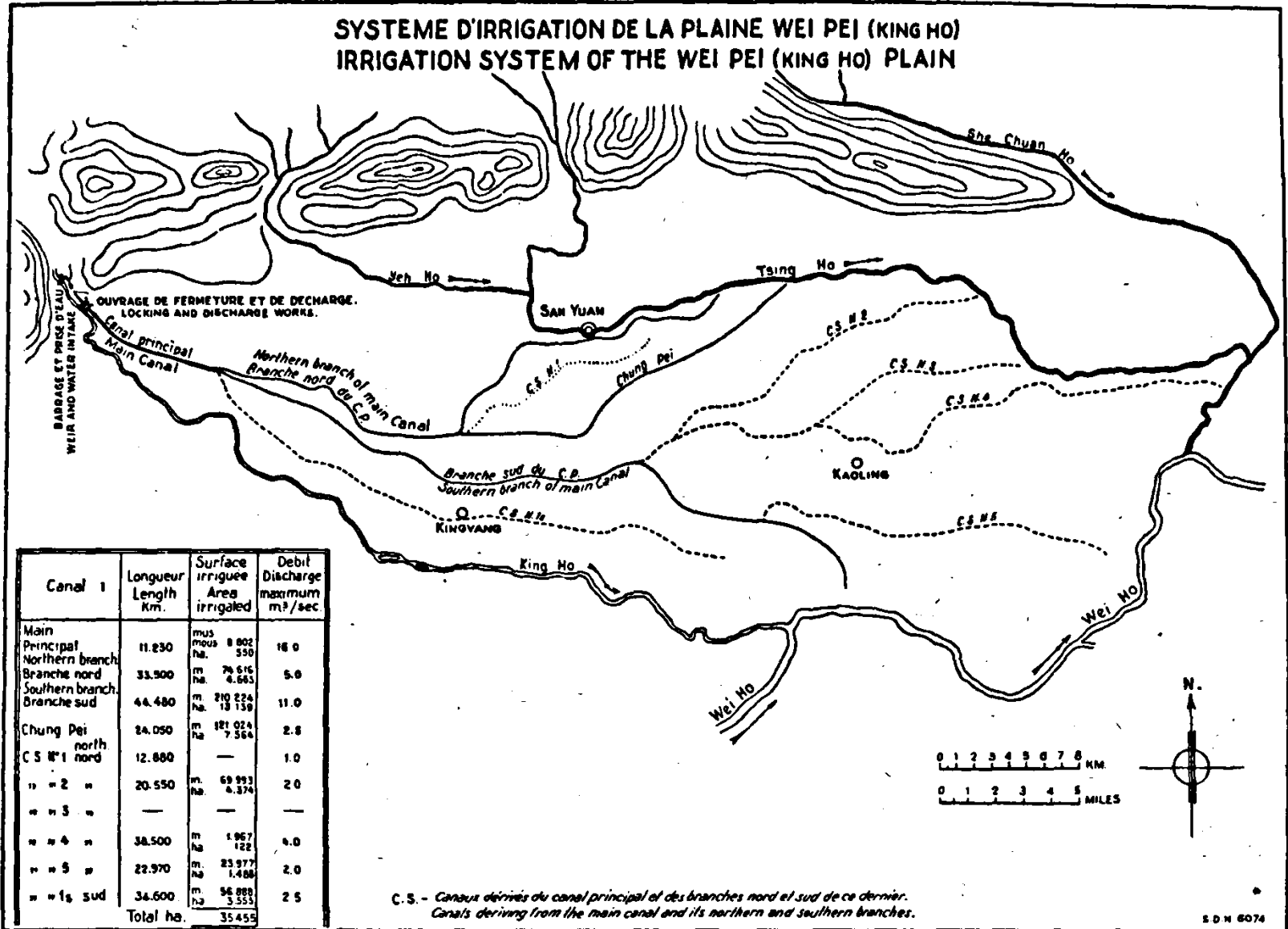
The absolute necessity of an *effective limitation* of the flood waters in the canal downstream has, in fact, already been affirmed, and the ineffectiveness for this purpose of the waste weir provided has, moreover, been made clear. A remedy must be found for this serious defect, and, at the same time, the expense involved in the construction of the works must be justified by enabling them to discharge their function, as far as is possible.

At the side of the canal, immediately above the locking-works, a set of auto-levelling syphons should be constructed.

These, coming into operation automatically as soon as the level in the canal rises above the admissible maximum, and being provided with a capacity sufficient for discharging into the river the highest discharges provided by the intake works, *will limit both the quantities of discharges and the quantities of mud in the downstream section of the main canal*. For this last object, the upstream mouth of the syphon must be established at a sufficient depth. A suitable form for auto-levelling syphons working as explained above is shown in the example of a model arrangement of intake works (see inset between pages 88 and 89).

¹ At present, it only provides for the opening of the sluiceways.

SYSTEME D'IRRIGATION DE LA PLAINE WEI PEI (KING HO) IRRIGATION SYSTEM OF THE WEI PEI (KING HO) PLAIN



Canal	Longueur Length Km.	Surface irriguée Area irrigated	Debit Discharge maximum m ³ /sec.
Main		mus m ²	
Principal	11.230	8 002	16.0
Northern branch		530	
Branche nord	33.300	76 616	5.0
Southern branch		4.683	
Branche sud	44.480	210 224	11.0
		13 139	
Chung Pei	24.050	121 021	2.8
north		7 564	
C.S. N°1 nord	12.680	—	1.0
" " 2 "	20.550	69 993	2.0
" " 3 "	—	4 374	—
" " 4 "	38.500	1 067	4.0
" " 5 "	22.970	122	—
" " 1 _s sud	34.600	23 977	2.0
		1 488	
		56 888	2.5
		3 533	
Total ha.		35 455	

C. S. - Canaux dérivés du canal principal et des branches nord et sud de ce dernier.
Canals deriving from the main canal and its northern and southern branches.

C. UTILISATION OF THE LO HO FOR IRRIGATION.

I. GENERAL.

Following the method employed in discussing the utilisation of the King Ho for irrigation, the Committee thinks it necessary to give here a few notes of a general character on the natural hydrological situation and the history of the utilisation of the Lo Ho for irrigation.

Hydrological Notes.

Much less is known of the regime of the discharge of the Lo Ho than of the King Ho.

As regards the latter, systematic observations had been made even before the putting into service of the installation, although there were some lacunæ. Moreover, the existence of the weir, by facilitating measurements and rendering them more certain, makes it possible to place greater reliance on the data.

As regards the Lo Ho, on the other hand, observations were only commenced in the summer of 1933. The data at our disposal extend over little more than a year and no definite opinion can be given on their accuracy.

The Lo Ho rises in the Paiyu Mountains in the north of Shensi. After a course of about 530 kilometres, it joins the Wei Ho immediately above the junction of the latter with the Yellow River. The basin of the Lo Ho has an area of about 15,000 square kilometres.

In its mountain course, the river runs through narrow and deep gorges, the bottom being covered with thick alluvial deposits. The fall is here in the neighbourhood of 1.2 in 1,000.

The fall of the bed then becomes gradually less on issuing from the gorges, while its width gradually increases.

Before reaching the plain, consisting of fine alluvial deposits, the river flows round the chain of the Tianlan Shan in a wide curve.

The numerous feeders of the Lo Ho descend from mountainous regions almost or completely devoid of vegetation as torrents liable to sudden spates and carrying large quantities of solid matter.

The maximum rise of the Lo Ho takes place about the same time as that of the King Ho—in the middle of summer, usually in July and August.

In August 1933, during the highest flood known for many years, the discharge reached a maximum of about 2,400 m³/sec. The proportion of solid matter then rose to 50% in weight (about 30% in volume).

A "catastrophic flood" discharge is estimated at about 3,500 m³/sec.¹

The regime of the river as regards discharge is extremely irregular. From the very high figures just indicated for the big floods, we fall to minimum flows of 5 to 6 m³/sec. or even less. In June 1934, for example, a minimum flow of 3.7 m³/sec. was recorded.

¹ This estimate is deduced from the maximum amount observed in 1933, of which it represents, so to speak, an extrapolation.

The fact that in the case of the King Ho also, for which a much longer period of observations is available, the flood of the summer of 1933 (over 11,000 m³/sec.) was *by far* the greatest on record (the flood of the summer of 1931 comes next with about 3,000 m³/sec.) increases the reliability of this estimate. Nevertheless, the shortness of the period covered by the observations makes it advisable to be very cautious in the matter of the estimates for the Lo Ho.

As to the probable duration of the lowest discharges—the only ones which are of importance, inasmuch as the channels of irrigation systems not provided with reservoirs can only rely on minimum discharges—the data so far collected do not permit of direct conclusions.

For lack of sufficient data, recourse can only be had to comparisons with the neighbouring basin of the King Ho. It would seem to be likely that the periods during which discharges are maintained near the minimum of 3.7 m³/sec. will be fairly long and fairly frequent, particularly in the late spring—that is, the period in which need for water is greatest.¹

The results thus obtained are very similar to the amounts of the discharges which are considered² to be “generally” available on the Lo Ho in the various periods of the year, amounts which there is reason to believe are obtained from the observations carried out during the last two years 1933 and 1934—a period in which water was undoubtedly plentiful. These are :

	m ³ /sec.
November, December, January, February, March	11
April	10
May	8
June	6
July, August and September	15

The expression “generally available” is too vague to allow of precise deductions. It will be sufficient, however, to observe that it is in any case not a matter of “continuously” available discharges, inasmuch as, in June 1934, as has been noted, the minimum fell to 3.7 m³/sec.

As regards the amount of *silt*, it appears from the observations made that in ordinary low-water periods this is inconsiderable,³ but that it increases rapidly with the increase in flow, attaining very high quantities of 40 to 50% in weight. In these circumstances, as in the case of the King Ho, we have a veritable river of mud during the floods.

II. DESCRIPTION OF THE IRRIGATION SYSTEM.

I. Irrigated Area: Crops and Irrigation Flow: Economic Advantages of Irrigation

On the proposal of M. H. Li, to whom the conception of the irrigation system was due, the work of surveying the area to be irrigated was commenced in 1933.

It consists of part of the plain of Yung Siang.⁴

Roughly triangular in form, it is bounded on the north by the chain of the Tianlan Shan, on the south by the Lo Ho, and on the east by the Yellow River. The eastern part of the plain, consisting of low-lying lands along the Yellow River, is liable to flooding and the irrigation of this area is not contemplated. Irrigation is confined to the higher lands, consisting of fine alluvial deposits bounded towards the west by the depressions mentioned, and stretching to the foot of the chain of the Tianlan Shan.⁵

¹ A more detailed study of the probable amount of the minimum discharges is indicated below in connection with the “Available Water-supply in Shensi”.

² In the report “General Description of Irrigation, Navigation and Reclamation Works in Shensi Province”, by the Conservancy Board of Shensi.

³ The water is described as “comparatively clear” at such periods.

⁴ This includes the principal district of Tali and those of Chaoyi and Pinmin.

⁵ The water-surface here is about 30 metres below the level of the fields. Irrigation is possible either by means of wells or by derivation channels from the Lo Ho.

The area of the lands to be irrigated is given sometimes as 31,000 hectares (about 500,000 mu), sometimes as 33,400 hectares.

The principal crops are cotton and cereals, especially wheat.

The following table shows the irrigation requirements of the crops mentioned as compared with the available water-supply of the Lo Ho.

Month	Net irrigation requirements in heights of water above the land (millimetres)			Thousands of mu			Net irrigation requirements in cubic metres (000's omitted) per agricultural year	Gross irrigation requirements (increased by 30% in cubic metres (000's omitted) per agricultural year	Discharges generally available in the Lo Ho (m ³ /sec.)	Total available discharge in the month in cubic metres (000's omitted)
	Cotton	Cereals other than wheat	Wheat	Cotton	Cereals other than wheat	Wheat				
January	—	—	—	—	—	—	—	—	11	28,900
February	—	—	—	—	—	—	—	—	11	28,900
March	100	—	—	150	—	—	9,230	12,000	11	28,900
April	—	100	100	—	100	250	21,530	28,000	10	26,220
May	—	—	100	—	—	250	15,540	20,000	8	21,000
June	80	100	—	150	100	—	13,650	17,750	6	15,730
July	100	100	—	150	200	—	21,530	26,000	15	39,530
August	100	100	—	150	200	—	21,530	28,000	15	39,330
September ...	100	—	100	150	—	250	24,600	31,900	15	39,330
October	—	—	—	—	—	—	—	—	15	39,330
November	—	—	100	—	—	250	15,400	20,000	11	28,900
December ...	—	—	—	—	—	—	—	—	11	28,900
Total	480	400	400							

According to the foregoing estimates of the flows, there would be shortages in April and June.

But these estimates seem to be *too optimistic*, partly because they presuppose a supply¹ larger than can actually be relied upon and partly because they fix the quantity of water required by the crops at too low a figure.

If, for purposes of comparison, we attempt to convert the quantities in the above-mentioned table into "continuously available discharge for each unit of land", or unit supply—litres per second per hectare—we shall obtain the following results :

In the periods of greatest abundance of water, a *gross* supply (that is, including the losses along the system of canals) of $\frac{15,000}{33,000} = 0.45$ litre per second per hectare, and a *net* supply (assuming the amount of losses as equivalent to 30%, in accordance with the indications given in the table) of $\frac{0.45}{1.30} = 0.35$ litre per second per hectare ;

In the periods of low water, in May and June : 0.24 and 0.18 litre per second per hectare respectively as *gross* unit supply, and 0.19 and 0.14 litre per second per hectare respectively as *net* unit supply.

¹ These are based on the undoubtedly high quantities, mentioned above, of "generally" available discharges, as observed in the period 1933-1934, when water was abundant.

A comparison with the supplies actually required (or, in any case, considered as *indispensable*) in irrigation systems, the conditions of which are comparable with the plain north of the Lo Ho as regards climate and the nature of the crops, shows that these amounts are *excessively low*.

As to the economic advantages of irrigation, it is to be observed that, assuming a crop-value of about 10 Mexican dollars per mu irrigated (160 Mexican dollars per hectare), the land would increase from the present value of about 5 Mexican dollars per mu to one several times greater.¹

2. *Works contemplated under the Scheme.*

The works contemplated in the scheme prepared by the Conservancy Board of Shensi in consultation with the National Economic Council,² which are at present in course of construction, are indicated below.

The most important works were begun in March 1934.

(a) *A fixed overflow weir* in cyclopean masonry, of the gravity type, 16.20 metres in height. It is in the form of an arch, with length of capping of about 150 metres. The width at the foot is 21 metres. The facings are covered with rubble.

This work bars the bed of the Lo Ho at Louchong, about 60 metres above a rapid of the river (the rapid of Lao Tsang), which has a fall of 7 to 8 metres. The banks and the bottom of the bed consist here of good limestone in thin horizontal strata.

The barrage works were designed on the basis of a "catastrophic flood" discharge of 3,500 m³/sec.

So far as we know, *no discharge sluiceway has been provided for in the weir.*

At the time of the expert's visit in January 1935, a cofferdam had been constructed above the works for the diversion of water into a temporary discharge canal while operations were in progress. The foundation had been prepared and about 2,000 cubic metres of masonry work (out of a total of 17,700) had already been carried out.

(b) *The principal canal and its eastern and western branches.* — The principal canal has a length of 21.4 kilometres. The section has been designed for a maximum flow of 15 m³/sec.

The inlet to the canal is situated immediately above the weir, and no provision has been made for regulation works.

The course first follows the left bank of the river, then leaves it and is carried through the Tianlan Shan chain in a long tunnel (3 kilometres), emerging upon the plain which is to be irrigated.

Here the principal canal is divided into three branches: one, called the Central Canal, constitutes practically a prolongation of the original canal; the second goes off in an easterly direction and the third in a westerly, with a length of 28.3 and 12.4 kilometres respectively.

¹ The amortisation of the expenditure on the construction of the works (estimated at about 1,480,000 Mexican dollars) should be effected in a few (about seven) years, on the assumption that it will be possible to collect an annual charge of 0.5 Mexican dollar per mu (thus making 250,000 Mexican dollars each year), and that the upkeep of the works will not cost more than 50,000 Mexican dollars per year.

² The scheme was originally (in 1932) prepared by the Conservancy Bureau of Shensi. On its being submitted for examination by the engineers of the National Economic Council, the latter suggested certain modifications relating, among other things, to an increase in the length of the crest of the weir, the adoption of a different profile for the downstream floor, etc. The inconsistent data regarding the scheme found in the various reports are probably attributable to this circumstance.

The sections of these last are designed for discharges of 9 m³/sec. and 6 m³/sec. respectively.

The central canal is itself divided into two branches going to the east and west respectively.

Along the principal canal, in addition to the tunnel already described, there are four smaller tunnels. The aggregate length of the five tunnels is 4,880 metres.

They are lined with rubble masonry.

At the time of the expert's visit, the four shorter tunnels along the principal canal had been almost entirely excavated (for about 1.5 kilometre) and the surfacing work was being carried out in them.

As regards the open canals, about 60% of the earthwork had been done.

(c) *The central canal and its eastern and western branches.* — It has a length of 6 kilometres and is capable of carrying off the maximum discharge of 15 m³/sec. The eastern and western branches have a length of 21 and 11 kilometres respectively and are capable of carrying a maximum discharge of 10 and 5 m³/sec. respectively.

(d) *Various constructive works.* — As has been mentioned, the inlet to the canal is not provided with intake works.

A regulator with discharge towards the river is situated about 250 metres¹ below the mouth of the canal.

In time of flood, the closing of the regulation sluiceways and the opening of the discharge sluiceways should permit of the return to the river of water carrying too much silt.

Other discharge sluiceways are arranged along the principal canal. Among the major constructive works may be mentioned, in addition to the ordinary road-bridges, three aqueduct-bridges of reinforced concrete, one of which over the Chuli Valley is 130 metres in length.

III. OBSERVATIONS AND CRITICISMS.

1. *General Criteria of Utilisation.*

One of the fundamental objections, similar in every way to that already expressed in regard to the irrigation system on the King Ho, has reference to the estimate of the available water-supply and relation between that supply and the works of deflection and distribution of water, and the irrigable area.

In the case of the Lo Ho, the *continuous* available water-supplies have been overestimated and, on the other hand, the actual irrigation requirements of the various crops have been underestimated.

2. *Barrage and Intake.*

As regards stability and safety, both the arrangements and the type of works might have been better chosen.

For example: the position of the weir and the rapid below it is defective. After the completion of the work, the floods entering it will cause more rapid erosion at the

¹ This measurement is deduced from a longitudinal section. In another place, a distance sometimes of 200 and sometimes of 100 metres is indicated.

foot of the rapid, the consequences of which may prove to be dangerous,¹ owing to the small distance between the rapid and the weir.

As regards the profile adopted for the downstream face of the weir, the foundation of the works and their abutments on the right bank, the hypotheses forming the basis of the calculations of stability² give rise to certain reservations.

The favourable natural geological situation, however, and also the good quality of the construction, may reduce the consequences of the inaccurate planning and the stability of the works does not seem to be threatened.

But in view of the exceptionally large quantity of solid matter conveyed by the stream and *the absence of any discharge sluiceway* through the weir, we are faced with an unfavourable situation very similar to that already pointed out in connection with the King Ho.

As an inevitable consequence of this situation, the basin above the weir will be rapidly silted up and the bed of the river will be raised.

As the sill of the barrage is 2 metres higher than the sill of the inlet to the canal, the section between the inlet and the proposed locking-works, 250 metres below, will be speedily obstructed by deposits.

If it is desired to prevent deposits in the system of canals, irrigation will have to be suspended, not only from time to time for the work of removing the deposits, but throughout periods of muddy water and therefore precisely at the periods when irrigation is most required.

As regards the canal, as we have already said, the absence of any means of locking and regulation at the inlet, in common with the absence of discharge sluiceways through the weir capable of keeping the inlet free from deposits, will mean that the first section *will be seriously exposed in times of flood* to being filled up, with the consequence that the deflection will be put out of service.³

The *regulation and discharge works* provided for about 250 metres below the inlet are capable of effectively protecting the canal system from the entrance of muddy water if the sluice-gates function in time.

The Committee must insist on the rule already enunciated that *this protection should be ensured by a discharge apparatus, as far as possible automatic and of sufficient capacity*, adapted to the maximum discharge capable of entering the canal.

No device has been introduced into the intake works for securing a partial *reduction of the turbidity* of the deflected waters.

Apart therefore from the interruptions in working caused by the obstruction of the inlet (or the necessary brief periods of suspension of operations when the discharge reaches its maximum amount), deflection could be carried out only when the proportion of solid matter falls below the admissible amount (10% according to estimates, though this appears somewhat high).

This means that, during the principal irrigation season, the system could be effectively worked only during very brief and intermittent periods, and consequently could not in any way fulfil the necessary function for which it is intended.

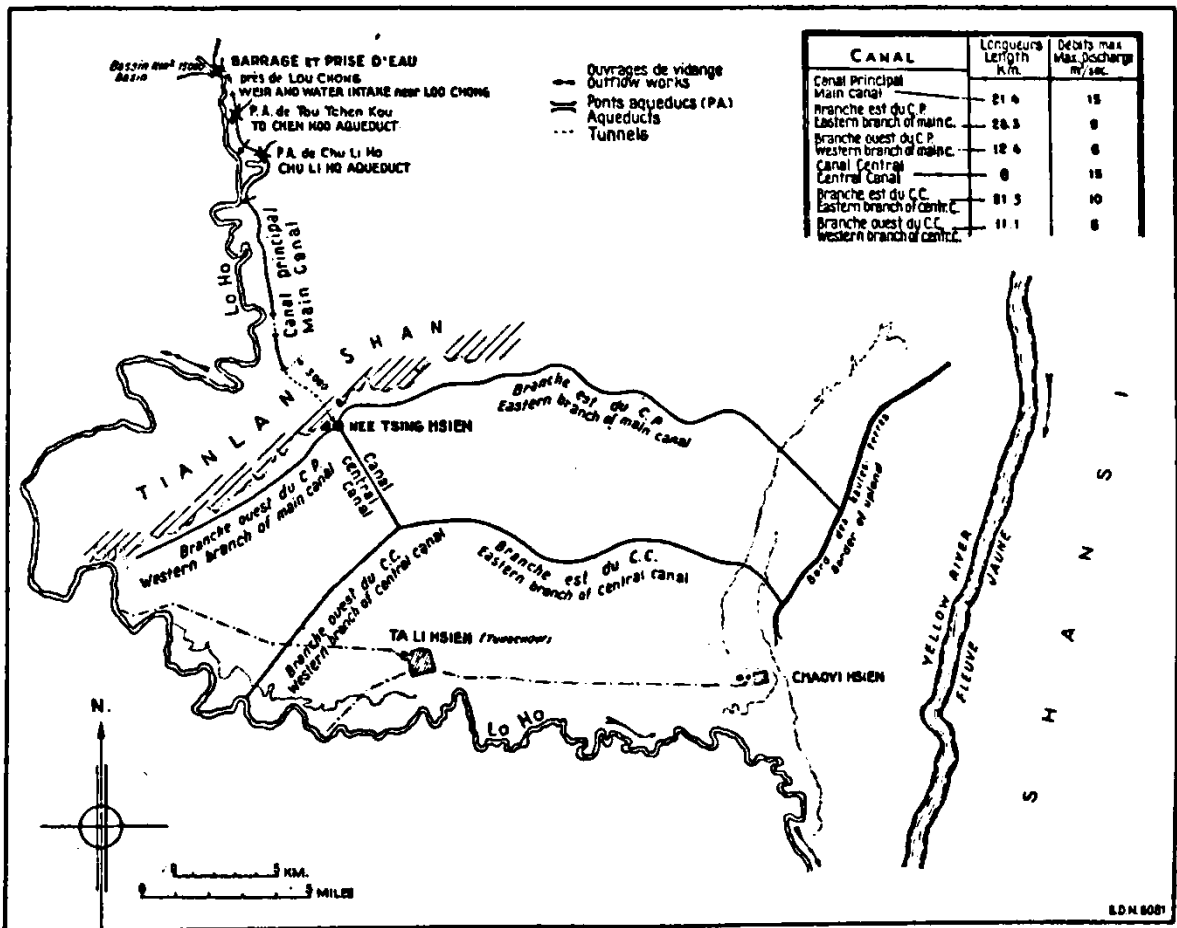
¹ Provision should therefore be made for suitable works for moderating the current and regulating the rapid.

² This is clear from the plans in our possession.

³ The absence of locking-works at the inlet has been justified on the ground that it was sufficient to adapt part of the canal dyke towards the river as an automatic waste weir, thereby increasing, with an equal height of water over the weir, the useful length of discharge of the barrage works. The absurdity of such a view is evident. It is a serious error; for, even if it were desired to attain the object mentioned, other devices should have been employed, and not that selected, the effect of which would be to prejudice most seriously the working of the intake and consequently of the entire installation.

To sum up, on the Lo Ho as on the King Ho, the intake which is "the vital centre of the installation", presents such grave defects as to compromise the working and effectiveness of the system.

IRRIGATION SYSTEM ON THE LO HO.



Area irrigated } 500,000 mu.
31,000 hectares.

3. Methods of Construction.

The topographical situation is favourable, and no particular difficulties have been encountered in preparing a rational series of works suitable for distributing water over the area to be irrigated.

Nevertheless, the organisation of the works was found to be deserving of praise from every point of view.

The works for the construction of the weir have been well carried out and well sheltered from the intense cold of the winter, and the same is the case with the works for the excavation and timbering of the tunnels, and the facing of the section in freestone. The other works, including the imposing *aqueduct-bridge* already mentioned, have also been carried out with care. With reference to the aqueduct-bridge, however, the expert was able to suggest, when visiting the works, a more reliable form of foundation.

The somewhat primitive and cheap types adopted for the works of the King Ho system have here been replaced by more expensive types. In some cases even (for example, the facing in freestone already mentioned), they might be described as luxurious.

But increased outlay has not always meant complete adjustment to local conditions, especially as regards arrangements to be adopted for construction in loess.

Thus, it appears that allowance has not been made for the different behaviour of loess according as it is found in its original position or in the form of alluvial deposits, wet or dry; that the respective sites were not, before the construction of the works and the surfacing of the canals, submerged in order to make them settle properly.

It appears, moreover, that the walls of the deep trench excavations are too steep and frequently lack interruptions in the form of ledges which would increase the solidity.¹

Next as regards the surfacings in freestone of the principal canal in the sections, in open trenches and in tunnels, these might be advised if it was expected by such means to obtain absolute impermeability. If not, a surfacing of a more economical type, with proper drainage, would have been more suitable.

Lastly, as with the King Ho system, we find a regrettable disproportion between the ample scale of works constructed for the principal distribution system and the inadequacy of the intake works. It cannot be too often repeated that these constitute the vital centre of the system, and that hence the greatest care should be devoted to them and money spent freely to make them efficient.

IV. POSSIBLE ADAPTATIONS : SUGGESTIONS FOR NEW PROPOSALS.

To sum up, the most serious defects revealed in the foregoing examination are, as for the King Ho :

(a) Insufficient discharge at periods of low water (*i.e.*, at the periods when irrigation is most necessary);

(b) Erroneous planning of the intake works without allowing for the fact that the very special natural situation also called for special arrangements.

The suggestions for improvement are therefore the same as those already described in regard to the improvement of the King Ho irrigation system, to which reference should be made.

At the same time, stress is laid on the following points :

(a) The necessity of reducing the irrigable area by limiting the development of the distribution system ;²

¹ It is also recommended that they should be protected by the steppe vegetation of which mention is made elsewhere.

² Until a possible regulation of the discharge (for which studies and research should be commenced without delay) provides a larger supply.

(b) The necessity of a *prompt and suitable* rearrangement of the intake works, which, if it is to be permanent and rational, should follow the fundamental principles applied in the standard example given at the end of the report.

If a transformation of the intake works¹ were speedily decided upon, the situation as regards the Lo Ho would be much more favourable than in the case of the King Ho. The works of the King Ho system are still in course of construction, and at least some of the changes required for a rational rearrangement can therefore be effected.

D. UTILISATION OF THE WEI HO FOR IRRIGATION.

I. GENERAL.

The studies in progress for the hydraulic regulation of the Wei Ho and the utilisation of its waters relate to the following questions :

(1) Derivation works for irrigation purposes near Meihsien (area to be irrigated 600,000 mu—that is, about 37,000 hectares) ; it was intended to start this work at the beginning of 1936 ;

(2) Construction of a regulating reservoir with a barrage on the river above Paoki, the reservoir to be used both for irrigation and for preventing floods. The construction of this reservoir must be considered as problematical, both its operation and its utility being at present subject to controversy.

For this reason, the Committee will confine itself to a detailed examination of the first scheme, as it appears from the information obtained and the observations made on the spot by the expert.

The question of the construction of the reservoir at Paoki will be dealt with at the same time as the more general question of reservoirs in Shensi.²

Hydrological Notes.

The Wei Ho has its source in Kansu. It enters the province of Shensi near Lungshien and flows through it for about 470 kilometres until its junction with the Yellow River near San Ho Kou. Below Lungshien and as far as the village of Taiyin (in the district of Paoki), the Wei Ho flows for more than 50 kilometres in steep gorges from 100 to 200 metres deep, at the end of which is the site of the proposed barrage for the creation of the great reservoir of Paoki.

The tributaries on the southern bank descend from the steep chain of the Tsinling Shan, which separates Central Shensi from Southern Shensi.³

Between the foot of the chain and the river, the valley is comparatively narrow and can be irrigated by the tributaries in question.

The terraced plateaux of loess and clay north of the Wei Ho, on the other hand, are very extensive and deeply furrowed by the principal tributaries, among which are the King Ho and the Lo Ho.

¹ Comprising essentially : the provision of discharge sluiceways in the barrage, the construction of regulation works at the inlet, the construction of locking and discharge works at the end of the first section of the canal devoted to the purposes of a sand filter, with its automatic discharge apparatus.

² Further data must be obtained before it is possible to express a final judgment.

³ Among these should be particularly noted the Fun Ho, the waters of which seem capable of utilisation for supplying drinking-water and electric power to the town of Sianfu.

The slope of the northern lands is greater than the fall of the river (the latter is about 1.2 in 1,000), and the bed, which is at first deeply sunken¹ (as much as 100 metres), gradually rises in relation to the land beside it, as it proceeds below Tainyin, until the terraces can easily be reached by a deflecting canal.

The observations on the system of flows of the Wei Ho only commenced recently, in May and October 1933 respectively, on the Taiyin and Sienyang sections, the latter being at a short distance from Sianfu, above the confluence with the King Ho.

Information on the subject is therefore extremely scanty.

As regards the extreme irregularity of the discharges and the quantity of solid matter carried down, however, the Wei Ho presents characteristics similar to those of the two principal tributaries, the King Ho and the Lo Ho, although to perhaps a somewhat lesser degree.

The maximum floods on the Wei Ho take place as a rule in the months of July and August.

During the great flood of August 1933 there were three successive "waves", on August 7th, 9th and 10th, with maximum discharges in the Tainyin section of 2,600, 2,100 and 4,100 m³/sec. respectively.² The differences between the maximum and minimum discharges are extremely great.

It is stated that, in ordinary years, the discharge falls to minimum quantities of 30 m³/sec. near the place of deflection. This figure appears to be contradicted by the results of the observations carried out at Sienyang³ in 1934, a year in which the volume of water was undoubtedly abundant. In July of the same year, in fact, a minimum discharge of 18.7 m³/sec. was observed, and in the previous January and February there had been minimum amounts of 27.5 and 26.5 m³/sec.⁴ Accordingly, the discharge must undoubtedly be even less in dry years.

As regards the alluvial content, the percentage falls in low-water periods to 1 to 2% in weight, but, during floods, it exceeds 30% in weight.

This alluvium consists mainly of loess and fine sand, and has a high fertilising value.

II. NOTES ON THE IRRIGATION SYSTEM CONTEMPLATED.

The results of the studies undertaken with a view to the preparation of a final scheme of works are not yet known. It is, however, possible to indicate here the fundamental characteristics of the system contemplated and to describe the types proposed for the works.

I. *Area to be irrigated, Crops and Irrigation Discharges, Economic Advantages of Irrigation.*

The area to be irrigated is situated along the north bank of the Wei Ho in the section Meih sien - Sienyang. It extends for a considerable part on the lowest terrace

¹ It is the river itself which has constantly been cutting a deeper and narrower bed in the friable loess.

² The information on the flood discharges observed on the various sections is confused and sometimes contradictory. Thus it is not clearly specified on what section the discharges above indicated were observed. The context, however, leads to the assumption that the Taiyin section is referred to (at the end of the Paoki gorges).

³ About 100 kilometres below the place of deflection.

⁴ There is also mention of a minimum discharge of 10 m³/sec. (for a short period) in the Paoki gorges.

of loess; then, as the foot of the bed approaches the level of the banks, it reaches the second and later the third terrace lower down. The aggregate area is 45,000 hectares, of which 37,000 (600,000 mu) are to be irrigated.

The possibility of later extending the area to be irrigated to the east, as far as the King Ho, is also under consideration.

The principal crops are cotton, wheat and other cereals. In present conditions, only one crop per year is obtained, but it is hoped that irrigation will allow of two crops per year.

The maximum discharge to be distributed on the land is assumed as equivalent to 30 m³/sec., and the deflection and canalisation works have been planned on this basis.

The corresponding gross "continuous unit supply" is $\frac{30,000}{37,000} = 0.81$ litre per second per hectare — that is to say, about double that for the King Ho system and considerably more than double that contemplated for the Lo Ho system.

The estimates of the continuous water supplies which can reasonably be relied upon appear to be again too optimistic, however. It has already been pointed out that the discharges of the Wei Ho, even in the spring and summer irrigation season, fall to quantities considerably below 30 m³/sec. and even to about half that amount. This was the case in the only year (1934) to which the observation data communicated to us extend—a year in which, it must be repeated, water was, in general, abundant. Until, by means of a regularisation of discharges, a supplement to the minimum discharges can be obtained, a most conservative estimate must be taken of the irrigable area, and all extension of the irrigation system will have to be postponed.

According to the programme prepared, 100,000 to 150,000 mu (6,000 to 9,000 hectares) should be placed under irrigation in 1936, in 1937 about 400,000 mu (25,000 hectares), and in 1938 the whole area of 600,000 mu (37,000 hectares).

The aggregate expenditure for the execution of the work is estimated at 2,050,000 Mexican dollars. The amortisation of this sum is expected to take about ten years, on the basis of an annual due of 0.5 Mexican dollar per mu.

The value of the annual crop per mu irrigated¹ is estimated to be the same as that already indicated in regard to the irrigation system on the Lo Ho — that is, 10 Mexican dollars per mu. The gross yield would therefore be about 6 million dollars per year

2. Works included in the Scheme.

As has been mentioned, the results of the final studies for the scheme are not yet known. From the reports and drawings, however, the types and location of the principal works appear to be already defined, and are as follows:

(a) A fixed overflow weir, 3.2 metres in height, intended to be submerged by the maximum floods to a depth of about 3.5 metres. The length of the crest will be above 500 metres.

The weir bars the river a little above Meih sien, where the bed at high water has a width of about 850 metres. It is prolonged on the right bank by an earthen dyke. The intake works are situated on the left bank.

For the removal of silt, the evacuation of deposits in front of the intake mouths, and also, in order to enable levels to be regulated during low water, a submerged metal sluiceway, measuring 2 by 2 metres, has been provided for near the abutment of the barrage on the left bank.

The bed of the river on the site of the barrage consists of a stratum of coarse gravel; the banks in the upper part are of loess.

Two alternatives have been indicated for the section of the barrage.

¹ On the assumption, of course, that the necessary quantity of water is available.

The first of these has a triangular profile with a slight fall. It might be constructed in stone masonry with horizontal courses in concrete.

This type of section is similar to that adopted for the Laguna barrage on the Colorado (United States of America).

The second alternative provides for a work of concrete and masonry with an ordinary overflow profile. The downstream foot is defended by a thick flooring ; the facings are of rubble masonry.

(b) *The intake works*, placed nearly perpendicularly to the barrage, consist of six sluiceways, measuring 1.75 by 2 metres, closed with metal gates.

About a kilometre downstream, along the main canal, provision has been made for the construction of regulation and discharge works of a type similar to that provided for the canal deflected from the Lo Ho, and comprising four regulation sluiceways and four discharge sluiceways with gates.

(c) *The main deflecting canal and its northern and southern branches.* — The length of the main canal, the course of which is roughly parallel with that of the river along the foot of the step separating the first loess terrace from the one above, is about 50 kilometres. The maximum discharge which the section is designed to take is 30 m³/sec.

This canal divides into two branches at the point where it leaves the first terrace of loess for the second. The southern branch, about 18.3 kilometres in length, flows down towards the river and the northern branch, 46.6 kilometres in length, continues the main canal.

III. OBSERVATIONS AND CRITICISMS.

1. *General Principles of Utilisation.*

We would repeat here what we have already had occasion to say in regard to the King Ho system—namely, *that the continuous water supplies available for irrigation are overestimated* (although to a less extent than for the King Ho).

2. *Barrage.*

An examination of the planimetry (which is too scanty for an extensive comparative study) and the observations made by the expert on the site of the barrage gave him the impression that the locality is suitable from a topographical and geological point of view but that the proposed design and arrangement are open to certain objections.

The oblique angle at which the axis of the weir would be placed to the current appears to be unnecessary, and is actually faulty in view of the position in which the intake would be placed as regards protection from silt in the river.

If the position were moved downstream and the axis of the weir¹ were turned, the conditions of deflection would be improved, as will be seen later.

Further, the dimensions assigned to the platform prolonging the barrage on the right bank are too large. A dyke of a normal type would fulfil the requirements, in view of the low level of the water in the reach ; but it should, for safety, be raised sufficiently high above the maximum high-water level.

The most serious defect, however, in the operation of the irrigation deflection consists in the *entirely inadequate dimensions of the discharge sluiceway* provided in the weir, which could not possibly work as required.

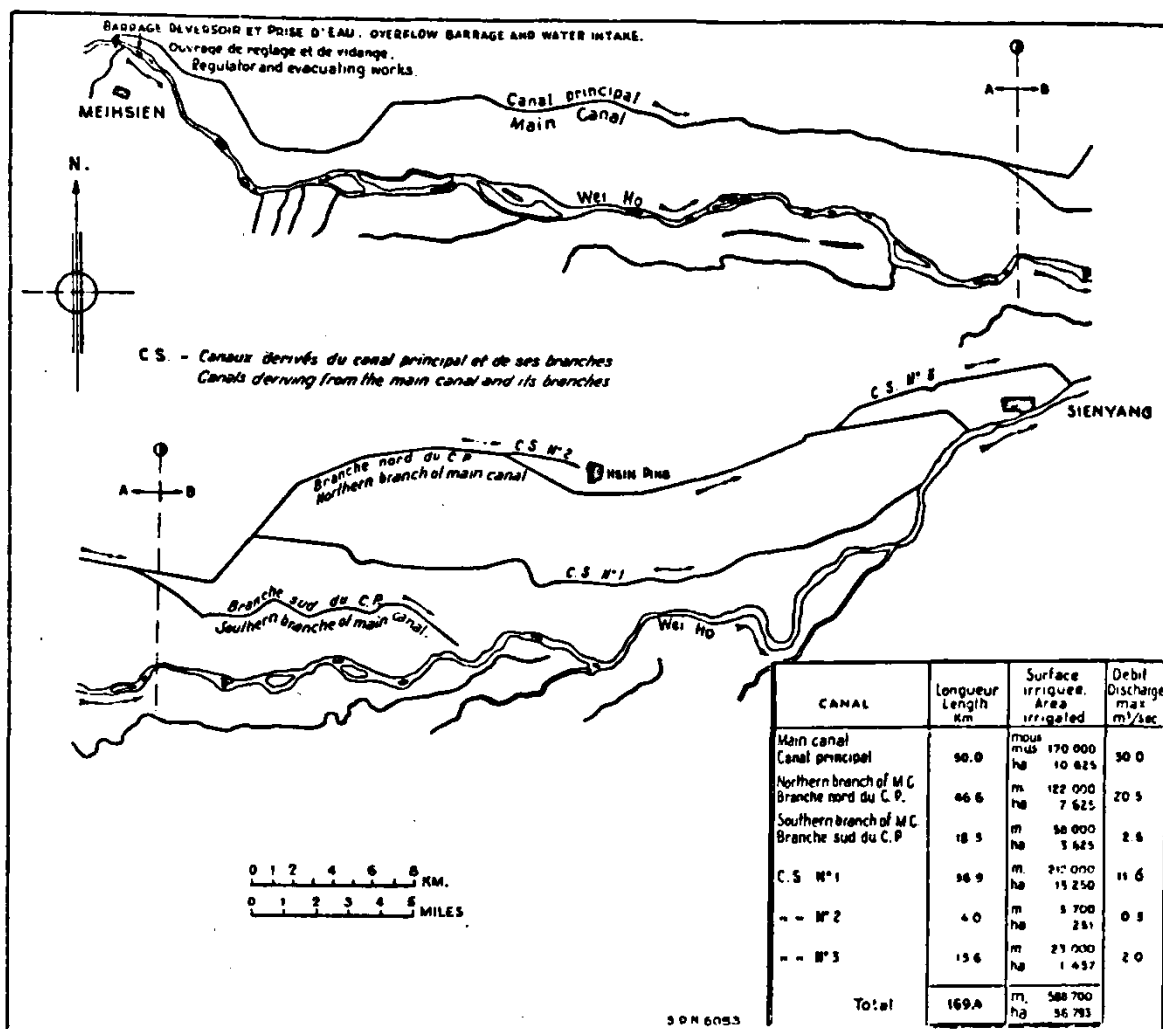
¹ See sketches reproduced on pages 85 and 86.

Again, another defective feature is the practical equality of height of the sills of the discharge mouth and of the intake mouths respectively.

As regards the section of the weir contemplated by the second alternative,¹ we are of opinion that :

The profile adopted for the downstream foot should be modified ; the form assigned to it does not appear best suited to check the force of the current and therefore to prevent erosions lower downstream ;

IRRIGATION SYSTEM ON THE WEI HO.



The fixing of sheet piles along the upstream and downstream feet is inadvisable, in view of the nature of the foundation ;

While the general type of the works should be maintained, they should be studied afresh on the basis of the most recent technical progress.

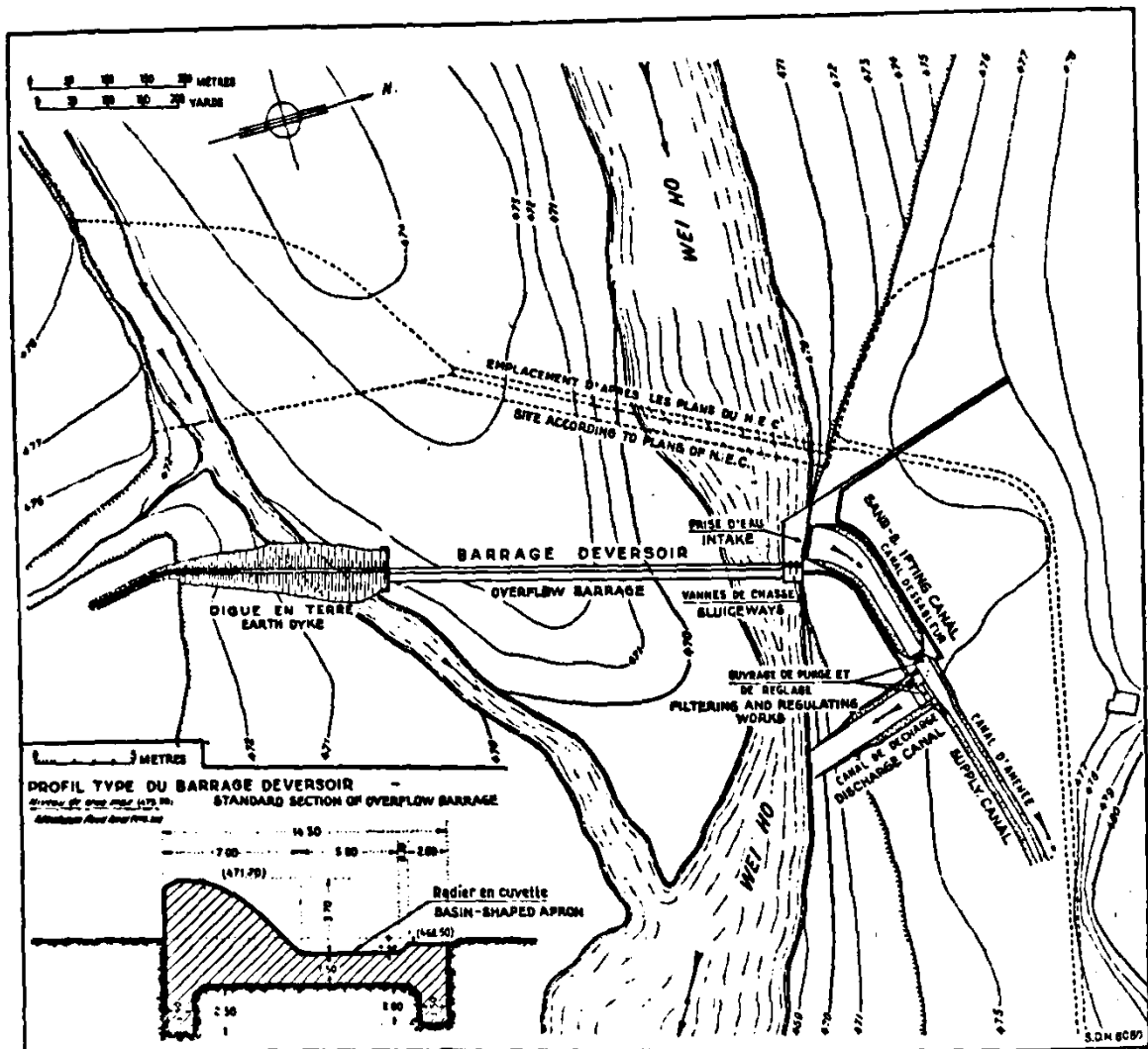
¹ We shall not consider the first alternative, since we think preference should be given to the second as being technically sounder.

3. Intake Works.

We have already had occasion to allude indirectly to the most serious defects of the intake works contemplated.

In the first place, they are not capable of removing silt and evacuating deposits in front of the intake holes, owing to the *entirely inadequate dimensions of the discharge sluiceway in the weir* and of the unsuitable arrangement in this respect both of the intake and the weir.

INTAKE FOR IRRIGATION ON THE WEI HO.



Further, the intake sill has been placed at the same height as the sill of the discharge sluiceway in the weir, whereas it should have been raised to prevent the entrance of solid matter into the canal and so as not to be partially obstructed by any deposit. This insufficient height of the intake sill greatly reduces the efficacy of the evacuating and dredging action of the discharge sluiceway.

Moreover, there is no *more or less automatic discharge* apparatus of sufficient capacity to ensure the protection of the canal system.

No provision has been made at the intake for a sand or mud-sifting apparatus making it possible in the ordinary times, and in particular during the irrigation period, to keep the deflection in operation.

Lastly, and incidentally, the proposed regulation and discharge works about a kilometre below the entrance to the canal have no useful effect upon the intake. They could serve only to section the canal, in case of emptying, or would afford security if the intake mouths were damaged.

IV. SUGGESTED ALTERATIONS AND IMPROVEMENTS.

As regards the necessity of adapting the irrigable area to the continuous supplies which can actually be relied upon, reference should be made to the observations already made on the subject, bearing in mind, however, that the situation is less serious in the case of the Wei Ho.

The fundamental criticisms raised by the plan relate, as has been indicated, to :

- The general arrangement of the derivation works (barrage and intake) ;
- The model to be adopted for the barrage, the whole series of intake works.

The principles on which the scheme should be prepared have been applied to the alternative proposed by the Committee, fully ensuring the efficient working of the intake.

The weir has been moved downstream and arranged nearly at right angles to the direction of the current.

In this way the working of the intake installation is considerably improved, both because it is placed at the end of the concave bank of a curve of the river ¹ and because it forms with the weir an angle nearly equal to that which experiment and observation on the spot have shown to be the most suitable for the regular feeding of the intake.

In the plan (see inset between pages 88 and 89), a rough section is shown for the barrage works, characterised by a suitable form for the apron at the downstream foot,² by the presence of two cut-offs above and below, to be pushed to a depth which will have to be deduced from the results of the geological researches in progress regarding the soil of the foundations and by a corrected design of the downstream overflow face.

Lastly, as regards the planning of the intake works, the following observations should be made :

More large discharge sluiceways³ should be provided through the left portion of the weir, immediately below the intake gates, and it is also advisable to construct a sill in front of the actual gates and below the discharge sluiceways, so as to facilitate the removal of deposits in front of the intake.

For reasons indicated above, the sill of the intake sluiceways should be placed sufficiently high in relation to that of the discharge sluiceways.

According to the criteria applied in the example of a model intake installation shown at the end of the present report, a first short section of canal is to be devoted to the purposes of a sand filter, the slope, and hence the height, being increased, the section faced, and regulation and filtering works provided at its termination — for example, auto-levelling syphons of sufficient capacity.

¹ In a place therefore where the action of the current itself tends to keep the bed free from deposits.

² A form suggested by experience both on models and on works actually executed.

³ In the plan (see inset between pages 88 and 89), these are three in number.

E. CRITERIA FOR THE STUDY OF INTAKE WORKS FOR A WATERCOURSE BRINGING DOWN A LARGE QUANTITY OF SILT.

We have pointed out on several occasions that, owing to the turbidity of the water due to the extensive and thick layer of loess on the river basins of Shensi, the position as regards intake works is altogether special and therefore calls for special measures.

Accordingly, the planning of the works cannot be based on standard criteria and standard types. These would be incapable, as bitter experience in the matter has shown, of meeting the special requirements and difficulties of the case.

In order to indicate clearly the principles on which, in our opinion, intake works should be constructed in such special cases, the best method will be to annex a plan of model works of this kind.

This plan is therefore intended purely as an *illustration* and *example*.

We have taken the hypothetical case of a watercourse which carries down a great deal of matter of the loess type, but of which the heavy material on the bottom is normal.

The stream is supposed to be tapped below the steepest and most deeply sunken mountain section, by means of an overflow weir, and the difference in water levels between low water and flood is assumed to be of average amount.

The case therefore roughly represents an average of those observed in the valleys of the Shensi watercourses at the level of the intakes for irrigation.

The types of works are clearly shown in the drawings; detailed description is thus superfluous.

The fundamental rules and principles applied in designing such works are as follows :

1. The intake works should be planned in such a way as to make it possible to isolate, with complete safety, and protect the system of canals during the short periods when the liquid discharge or the proportion of solid matter attain their maximum, or at any other time when this may be necessary.

(a) The possibility of isolation is ensured by the presence of a double system of locking (sluiceways furnished with gates), with adequate working apparatus, at the inlet to the canal and on a section of the latter in the immediate neighbourhood of this inlet (100 metres for example).

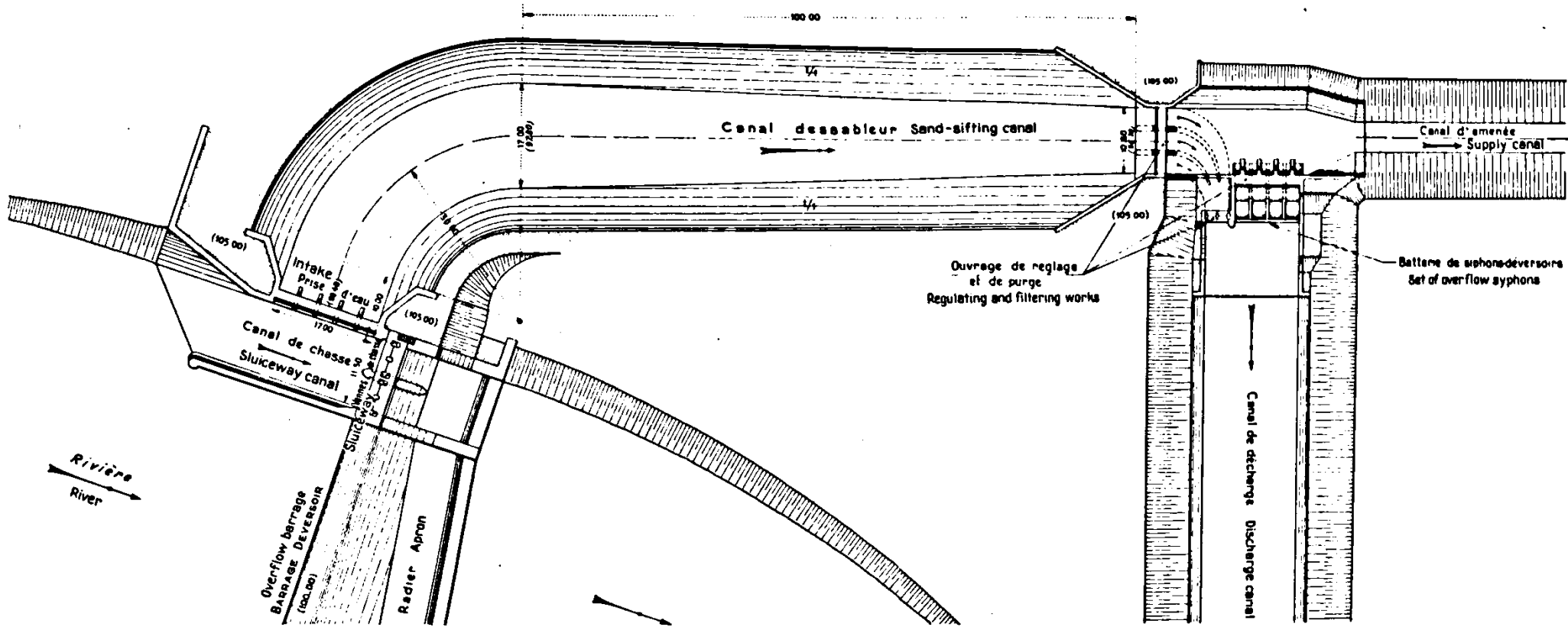
(b) As the protection of the canals must be ensured, even in the eventuality of its being impossible to close the locks in time or if, for any reason, the latter fail to work, an *automatic discharge apparatus* of sufficient capacity (set of auto-levelling syphons) is provided immediately below the second lock. This apparatus would function as soon as the water rose above a level decided upon beforehand. The type selected for the syphons will permit, without difficulty in working, of the discharge of very muddy water. For this purpose, *the mouth of the syphons is kept sufficiently low*.

2. The intake works should be such as to maintain the derivation channel in service during the longest possible period of the year. They should thus *reduce the turbidity of the diverted water* in the system of canals to such an extent that no difficulties in working will arise.

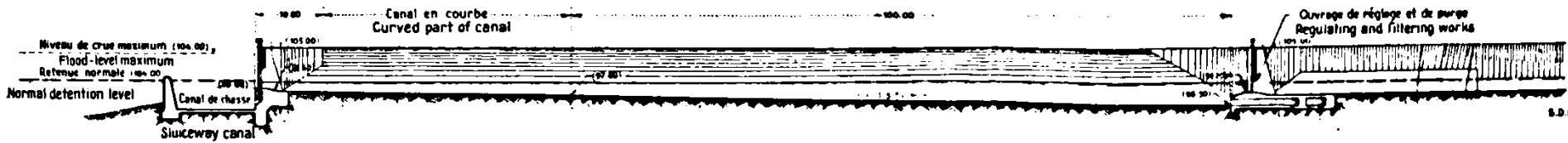
This can be effected either by facilitating the removal of mud from the intake mouths or by a preliminary filtering of the diverted water, in a section of the canal equipped as a mud filter, as explained in connection with the Lo Ho.

(a) In order to *prevent as far as possible the entrance of mud* into the intake mouths and to get rid of any deposits which may form in front of them, provision has been made

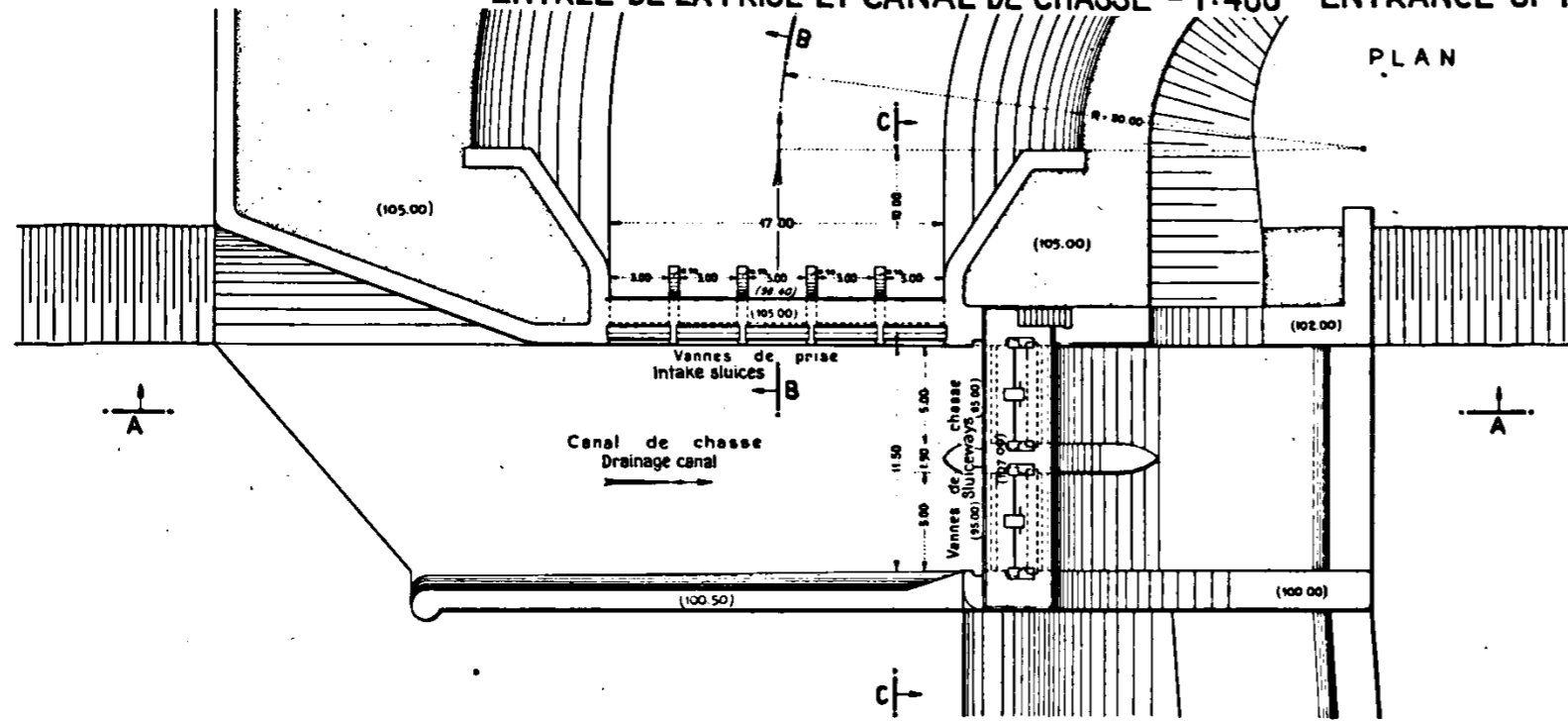
PLAN D'ENSEMBLE DES OUVRAGES DE PRISE - 1:1000 - GENERAL PLAN OF INTAKE WORKS
PLAN



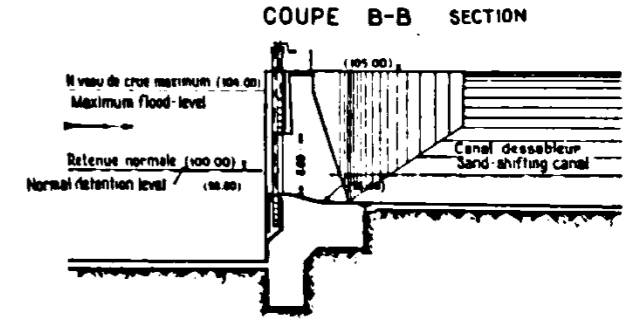
PROFIL EN LONG
LONGITUDINAL SECTION



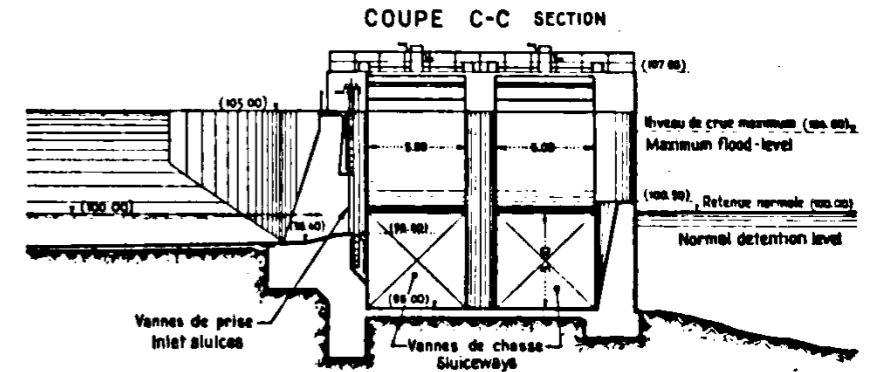
ENTREE DE LA PRISE ET CANAL DE CHASSE - 1:400 - ENTRANCE OF INLET AND SLUICWAYS CANAL



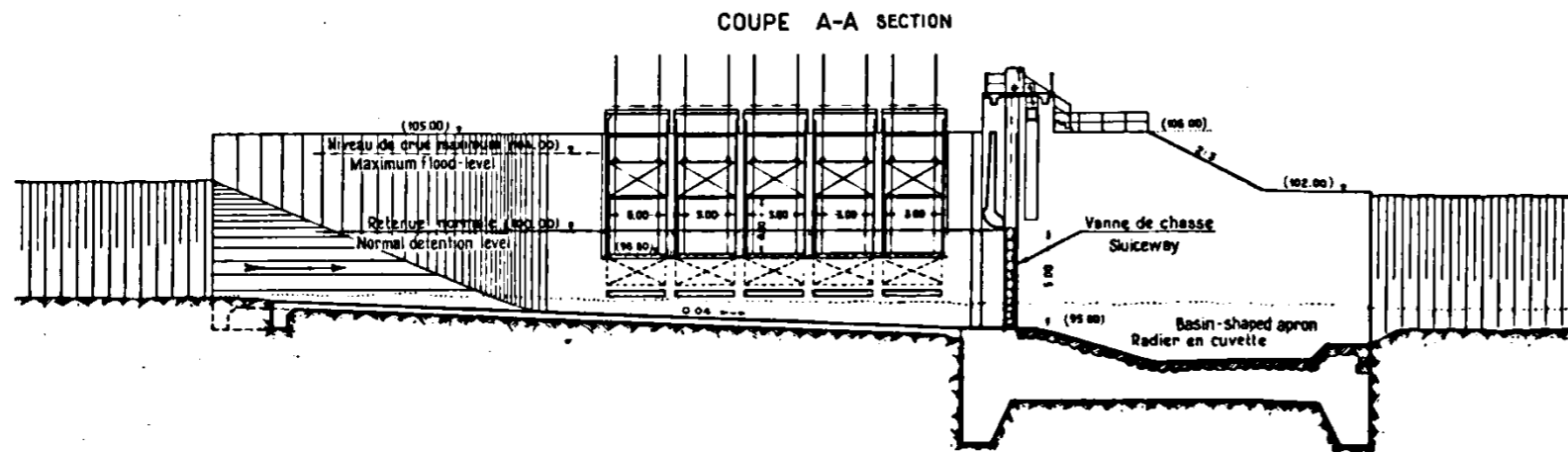
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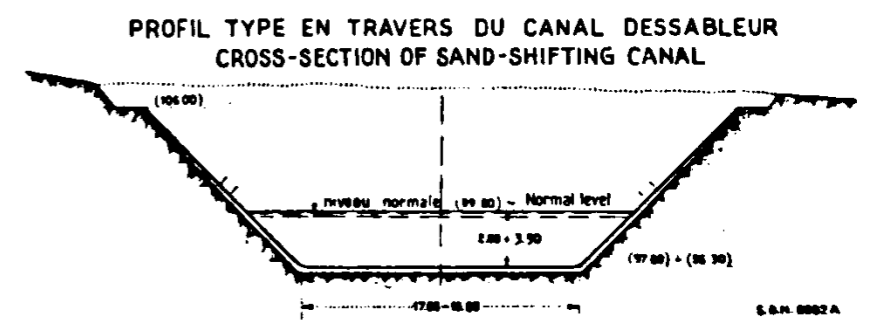
COUPE B-B SECTION



COUPE C-C SECTION

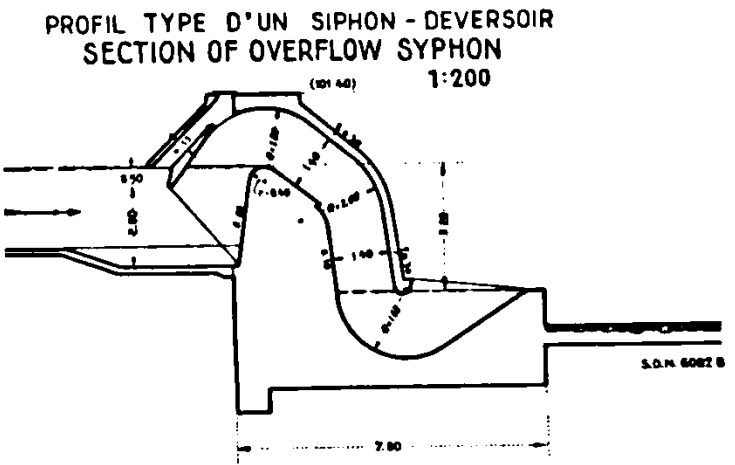
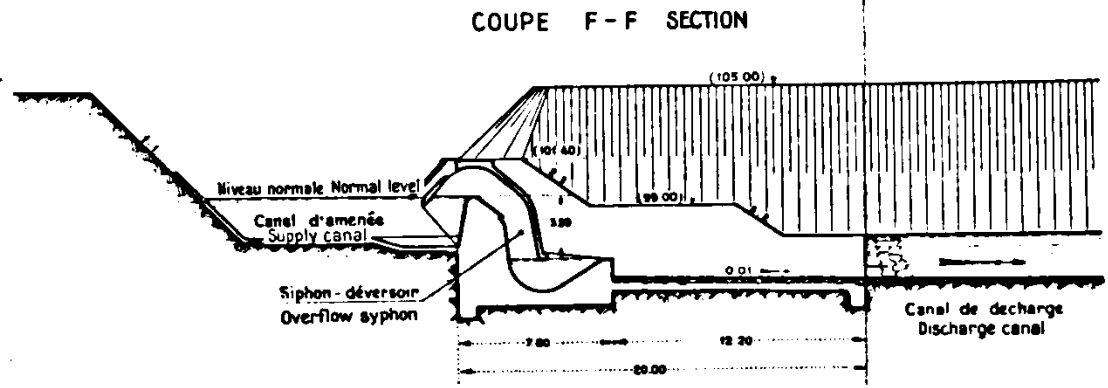
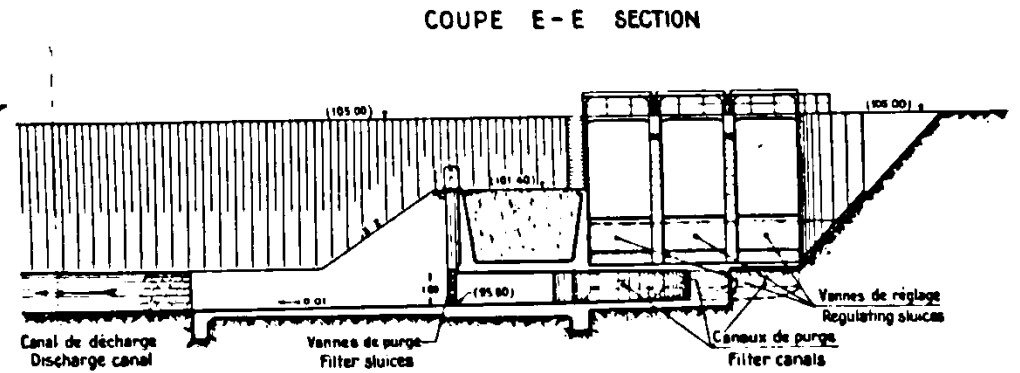
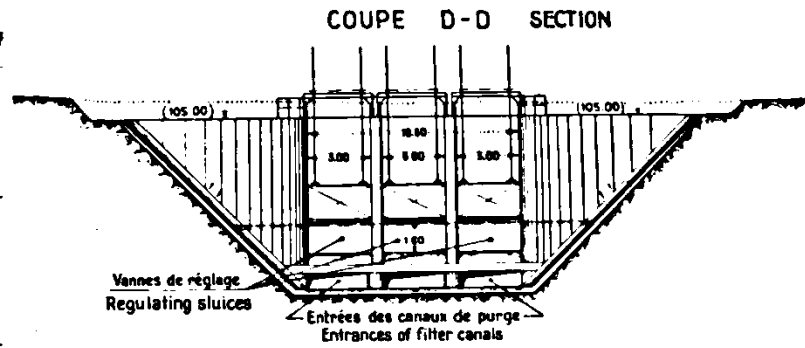
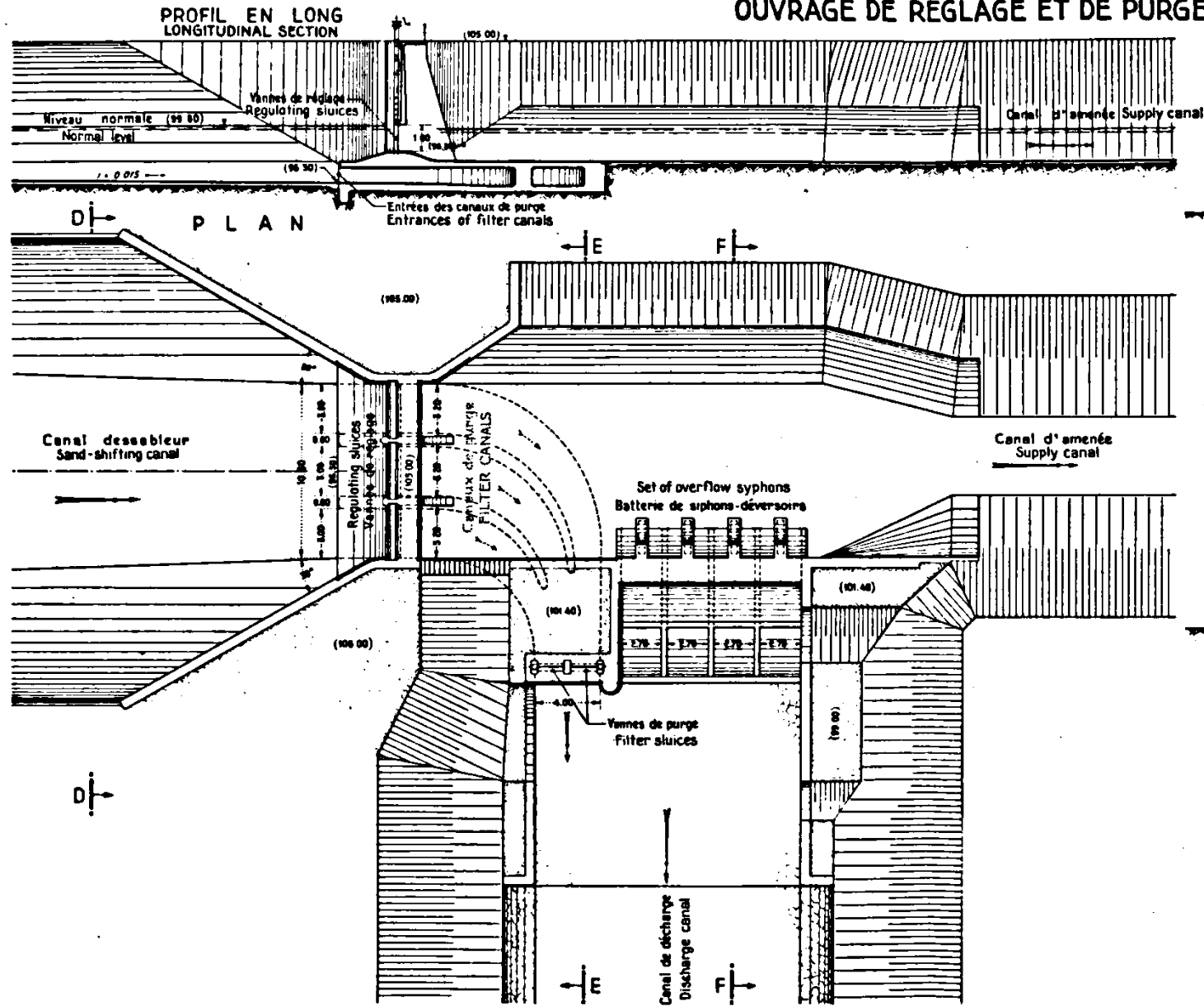


COUPE A-A SECTION



PROFIL TYPE EN TRAVERS DU CANAL DESSABLEUR
CROSS-SECTION OF SAND-SHIFTING CANAL

OUVRAGE DE REGLAGE ET DE PURGE - 1:400 - REGULATING AND FILTERING WORKS



Ing. A. OMODEO & C. MARCELLO
 UFFICIO DI MILANO

for raising the derivation sill in relation to the bottom of the bed, for placing discharge sluiceways of large capacity in the weir immediately below the intake gates and for facing the bed in front of the intake mouths and below the discharge sluiceways with a carefully adjusted apron of concrete (the foundation being suitably sectioned).

In this way, through the raising of the intake sill, it is possible to deflect the least turbid surface waters¹ and, thanks to the discharge sluiceways and the facing of the bottom, to create where necessary a strong current which will sweep away any materials that may accumulate.

(b) In *clarifying the water entering the canal*, the first section of the latter is equipped as a sand filter. Accordingly the canal bottom, faced like the sides with concrete, has a very marked slope, and, at its downstream end, regulation and outfall works have been placed.

By suitably regulating the levels it would be possible to reduce the velocity in this first portion of canal where the section is large and thereby cause part of the mud to be deposited.

According to the silt content of the diverted water and the available discharge in the river, the working may be either *intermittent*, periods of working alternating with short periods of suspension, during which, by opening the discharge sluiceways at the end of the sand filter, it will be possible to create a swift current which will loosen and remove the deposits that have been formed; or *continuous*, the filtering sluiceways being kept partially open during diversion. The sinking of the mud to the bottom and its removal will then be promoted by the return movement along the bottom of the canal itself.

The filtering sluiceways direct the muddy water into pipes, which return it to the river.

The sill of the regulation sluiceways will be raised considerably in relation to the bottom of the canal at the termination of the sand filter. In this way, the less turbid upper water will be drawn off here also.

Immediately below the regulation works is placed the set of auto-levelling syphons.²

It will be observed that the arrangement contemplated for reducing the amount of mud carried by using a section of canal as a sand filter has the further advantage that it can be repeated along the course of the canal. Thus the water can be increasingly clarified by successive operations and the effect may, as it were, be *graduated*.

* * *

F. SOME IMPORTANT SUPPLEMENTARY PROBLEMS.

I. *Gross and Net Supply for Irrigation: Operation of the System and Regulation of the Use of Water.*

The *gross* unit supplies (expressed in litres/sec./hectare) which are available for the systems of irrigation examined are 0.43 to 0.51 litre/sec./hectare for the King Ho, 0.48 for the Lo Ho, and 0.81 for the Wei Ho respectively. These quantities are, as has been said, extremely small.

¹ The weir causes the current to flow more slowly, and thus also decreases, though to only a limited extent, the quantity of mud in the water near the surface.

² The drawing shows a section for syphons suitable for use in muddy water.

It is to be noted, however, in addition, that they have been deduced from *the discharge considered as deflectable in the scheme of works*.

In reality this discharge is not always available at the period of irrigation. *Even in normal and abundant years*, the discharge available on the land falls to considerably lower amounts, even less than half the discharge mentioned above.

If it is remembered that, in order to arrive at the *net* supply,¹ the considerable losses by filtration and evaporation along the extensive and complex system of canals (equivalent to at least one-third of the entire discharge) at the intake must be taken into account, it follows that the *net* supply for the crops is, even in normal and abundant years, insufficient to supplement the rainfall and to enable the area it is intended to irrigate to be largely improved, this area being greatly overestimated.

The short and inadequate experience of the King Ho system in the years 1933 and 1934, in which *water was abundant*, has brought out these deficiencies or this overestimate very clearly.

Apart from the possibility or otherwise of adopting thorough-going measures (such as the construction of regulating reservoirs) for supplementing the minimum discharge, it may be well to mention here some considerations on the subject of a rational utilisation of the available water.

(a) The area which it is intended to irrigate appears in general too extensive in relation to the available supplies and the capacity of the works. It is therefore impossible to irrigate completely and on rational lines the whole of the land which it is proposed to convert.

Such a transformation requires close and constant liaison between the technicians of the hydraulic services, by those of the agricultural services and those responsible for operation of irrigation systems.

In view of the small supplies of water available and the very considerable variations in discharge throughout the year, and even during the irrigation period proper, the agricultural programmes should be such as to fit in with the variations in question, the object being to utilise the water as completely as possible.

These programmes cannot therefore be left to the individual initiative of the farmers, who often have little knowledge of new crops; they should be checked, regulated and, where necessary, enforced by the body for the direction and co-ordination of irrigation and agriculture.

(b) The extreme subdivision of landed property and the freedom allowed to cultivators in the selection of crops for varying needs at different times are further causes of the ill-success and inefficiency of the system.

The directing body referred to above should therefore be able to intervene and see that the programme of crops and watering is drawn up on the basis of the best possible topographical distribution.

(c) It would be desirable in the case of suitably situated land surrounded with dykes to apply in winter the "flood" irrigation system.

In this way, water is stored up for the following spring, and less is required during the months when the demand is usually greatest.

2. Wells for Irrigation.

It is desirable not to neglect entirely the innumerable wells (there are said to be hundreds of thousands of them) which are scattered over the area to be irrigated. These wells should be preserved to supplement the supply from the river systems (as is the case in many other countries—for example, in Egypt) during periods of

¹ In this connection, see later remarks on the available water-supplies in Shensi.

water shortage, especially as the development of irrigation with river water will in all probability lead to the increased efficacy and output of the wells.

3. *Ordinary Works.*

The works (secondary deflections, regulators, falls, syphons, aqueduct-bridges, ordinary bridges, etc., frequently required in irrigation systems) built or projected for the new installations are not beyond criticism, and those now completed have caused and are still causing considerable trouble.

In the case of each of the works, the most suitable types should be studied and rationally planned, this also with a view to a *standardisation* of the works as far as is compatible with the utilisation of local resources and the exigences of the ground.

It should be repeated (and this insistence must not be regarded as unnecessary) that we have to deal with rivers with regimes—*especially in regard to the volume of solid matter*—absolutely different from those of any rivers hitherto utilised, and infinitely more difficult.

Accordingly, the types of constructive works to be adopted cannot and must not merely imitate what has been done elsewhere (even in cases erroneously considered analogous but in reality very different), but should, on the contrary, be deduced from a special *study* of the entirely peculiar local conditions.

4. *Possibility of Hydro-electric Installations along the Canals.*

In the irrigation system of the King Ho, both along the principal canal and the secondary ones, there are frequent *falls* on the steeper ground which are intended to reduce the gradients of the canals to a reasonable figure.

More careful study of the system would have made it possible to concentrate a large number of these falls *at a few points*, in such a way as to prepare, without additional expense, for the creation sooner or later of one or more hydro-electric power stations for utilising the energy now wasted. This amounts to some thousands of horse-power, which would be of great value for the district, and would be likely to be useful for the extension and improvement of agricultural production. Attention is called to this *point* in order that it may be borne in mind in future plans, while remembering that the principal objective is irrigation.

5. *Reafforestation: Steppe and Desert Vegetation.*

Much is said of *reafforestation* as the most effective means of diminishing, if not eliminating, the turbidity of rivers flowing through areas covered with loess, and in connection with irrigation there is a commendable intention to plant along the canals and on the banks of the rivers.

It would seem, however, that very few species of trees will grow on loess, and that none grow well.

The basins with loess formations are so extensive and so completely *denuded* that any attempt at *reafforestation*, to produce tangible results even after a long period of years, would be a difficult undertaking for even the most highly organised countries.

Certain trees, and especially willows, thrive along the rivers and canals, owing to the large supply of water; but while they are undoubtedly valuable as furnishing building timber in a district where such material is very scarce, and also as a means of defence, they can do practically nothing to effect an immediate and certain reduction in the amount of solid matter in the water, which is attributable mainly to the washing away of the steep slopes.

There is, however, another measure which might produce some (though a limited) effect, and which the expert discussed on the spot with responsible people. This consists in developing the growth of steppe and desert vegetation on the steep slopes of the deep valleys cut in the high loess plateaux. This vegetation, with its deep roots that greedily absorb water, helps to support the earth and forms a natural means of consolidating it. Suitable measures must be taken, however, to prevent the local population from periodically uprooting these plants (which form the only fuel available) and to ensure that they will go and collect their fuel—at the cost of a little more trouble, it is true—to the high plateaux, where it is very abundant.

G. THE SUPPLY OF DRINKING-WATER AND ELECTRIC POWER FOR THE CITY OF SIANFU (SECOND CAPITAL).

The problems in question, both by their character and object, are far removed from those above considered relating more particularly to the reconstruction of the general hydraulic system of Shensi. Nevertheless, they seem worth mentioning here, inasmuch as they are of vital importance to the life and development of the city of Sianfu, which is to become the "second capital" and is the largest centre in the plain of the Wei Ho and in the whole of Shensi.¹

1. The problem was raised by the Governor of Shensi in the following form :

(a) *Can sufficient drinking-water be supplied to the city of Sianfu for a population which, during the first stage, may be estimated at from 300,000 to 400,000 ?*

(b) *Can the city of Sianfu be supplied with electric power for lighting and industrial purposes ?*

(c) *What would be the cost of executing the works for each of the objects indicated above ? And what time would be required ?*

2. Before these questions are considered, the criteria to be adopted in estimating the city's requirements, both quantitative and qualitative, should first be clearly indicated.

The two problems of the supply of drinking-water and of electric power may, in fact, be of great importance and give rise to many different difficulties according to the scale and the technical perfection of the proposed installations.

The Governor of Shensi expressed the opinion that :

(a) During the first stage, expenditure should be kept as low as possible. Only the most urgent needs in the matter of drinking-water and electric light should be satisfied ;

(b) The works, even during the first stage, should be planned with a view to gradual extension later, so as to be able ultimately to meet all the requirements of a modern civilised town.

The basis taken has been 10 litres per head per day in the first stage. This is a very small quantity when it is remembered that, even for inhabited areas not very highly developed, the daily allowance per head is about a hundred litres.

The smallness of the allowance is explained by the fact that it is considered sufficient at the first stage to have a fountain at each of the city gates which will

¹ The problem of *paramount* importance for a town, and one which comes before water-supply or electric power, is that of *drainage*, which is not dealt with in the present study.

furnish the above-mentioned quantity of drinking-water for the inhabitants. As the whole population almost invariably drinks boiled water only, there is no need to introduce appliances for filtering or purifying the water.

The fountains would take the place of the wells at present found at one of the city gates. These are inadequate and liable to dangerous contamination.

Similarly, electric power would be used during the first stage only for lighting the principal streets and a few public and private buildings.¹

3. These two problems can undoubtedly be solved by degrees under good technical and economic conditions. A cursory examination shows that the waters of the Fun Ho, one of the tributaries on the right bank of the Wei Ho, could be utilised for these purposes. Detailed local, hydraulic and topographical studies and observations will have to be made before complete certainty can be acquired.

It is possible indeed that other watercourses descending from the range which bounds the basin of the Wei Ho on the south may furnish even more favourable solutions. The problem can readily be solved in a great variety of ways, and particularly, if furnace coal can be delivered at a reasonable price, by the construction of thermic works.

Owing to the short time at the expert's disposal, he only reconnoitred the Fun Ho, which is given by way of example principally to indicate the technical and economic limits of an acceptable solution.

4. The favourable natural circumstances of the Fun Ho are as follows :

(a) The Tsinling Shan chain, which bounds the valley of the Wei Ho on the south, and in which the Fun Ho has its source, consists essentially of volcanic rocks covered with loess only over a small area. It is, moreover, comparatively high and sparsely populated.

(b) Although the watershed formed by the chain marks the limit of the copious rainfalls in Southern and Central China, nevertheless, in the upper basins of such rivers as the Fun Ho, the rainfall is still comparatively abundant (1,000 millimetres) in comparison with that of the district of Sianfu (400 millimetres) or of the area north of the Wei Ho (300 millimetres).

(c) The mountains which form the basin of the Fun Ho are much more wooded than those to be met with in the rest of the basin of the Wei Ho.

(d) Owing to the circumstances above indicated, the flow of such rivers as the Fun Ho is much more regular than that of the Wei Ho and its tributaries. The quantity continues to be large even in periods of low water, and it is almost always clear.

(e) The Fun Ho and the other rivers coming down from the same mountain chain, in a direction nearly parallel (south to north) and with a fairly rapid course, come out on to the plain of Sianfu lying between the foot of the mountains and the Wei Ho, at no great distance from the two (about 20 kilometres) and sufficiently high for the water to be carried off by the force of gravity.²

¹ Experience shows—and this is a point to be borne in mind—that it is nearly always impossible to stop here, and that so many requests for electricity are received from individuals that an extension has to be undertaken immediately.

² The regime of the numerous tributaries on the right bank of the Wei Ho, which is decidedly better (from the point of view of both flow and turbidity) than that of the Wei Ho itself, the King Ho and the Lo Ho, the possibility of constructing along the course of such tributaries reservoirs of small capacity but giving good results, the vicinity of the capital and of the railway, the extremely small funds available, the lessons of local hydraulic experience, the want of preparation of the technical and agricultural organisations, which are only of recent creation, are all reasons which would have made it advisable, for the new experiments in irrigation to select, instead of the rivers named, one or more of the tributaries on the right bank, thereby avoiding serious disappointments and keeping the problems within limits permitting of a ready analysis of local conditions.

5. The scheme proposed for the utilisation of the water of the Fun Ho contemplates, for the first stage, a simple deflection by means of a canal from the point where the river enters the plain as far as Sianfu. Here a small reservoir would be constructed on the hills overlooking the city on the south-eastern side, and from this reservoir the pipes supplying the fountains would be laid.

Later, the installation might be provided with the indispensable works for rendering the water fit for drinking and supplying larger quantities to the whole city. A system of *drains for carrying off the water* might likewise be added to the installation.

6. Slightly above the point where the Fun Ho enters the plain, a reservoir could be constructed for the regulation of the flow. This reservoir would be able to supply water for a hydro-electric installation that would utilise the entire flow of the river at low level. The net power available should be sufficient for the needs of the city in the conditions indicated.

7. *To obtain figures for the technical and economic aspects of the proposed installations (from a cursory examination, these would appear to be fairly satisfactory), certain research work, especially of a topographical and hydraulic character, is absolutely essential, and the expert gave the necessary instructions on the spot.*

H. AVAILABLE WATER-SUPPLIES IN SHENSI.

If irrigation is to prove really useful, it must be accompanied by a profound change in methods of farming and agricultural life generally.

Such a change would call for heavy financial sacrifices both from the public administration and from individual farmers, not only during the execution of the works, but also during their operation. The latter will, moreover, necessitate collective discipline, without which failure is inevitable.

Obviously, such obligations can be faced and will be justified only if the proposed irrigation scheme can effect a lasting and adequate improvement in agricultural production and, above all, if it can prevent a repetition of the disastrous famines that hang like the sword of Damocles over the heads of the inhabitants.

In order that this object may be attained, it must always be possible to draw off sufficient water, *even in the years of severest drought*, to meet the strictly essential needs of irrigation *and to save the crops*. Clearly, it is precisely in these years of drought that the land and the crops require most water from irrigation.

As cannot be too often repeated, irrigation must be based upon a flow not exceeding the *minimum continuously available in the watercourse*. In other words, to determine the real available water-supplies for irrigation means ascertaining the *presumable flow practically obtainable*, according to the method described below.

*The determination of this fact obviously constitutes the first and indispensable preliminary basis of any irrigation study.*¹

The irrigation systems in operation or under consideration in Shensi have, however, been based, both as regards the irrigable area and the installations, on overestimates of the available water-supplies, and this has falsified the results.

¹ In the absence of long series of observations which enable these available supplies to be determined simply by using statistical methods, comparative methods, based on a reasoned analysis of hydrological, topographical and meteorological data, can furnish sufficient bases for an estimate.

An immediate consequence of this overestimate is the construction of works disproportionate to their efficacy, and hence an unnecessary *increase* in expenditure ¹ and in financial burdens which were already heavy.²

Another and more serious consequence of this error is that the effects of periodical droughts are particularly disastrous when the illusion of security and abundance created by irrigation has attracted a large agricultural population which has been encouraged to devote all its resources and energy to farming.

The statement made above that the real available water supplies for irrigation in Shensi are far less than those assumed as a basis for the studies relating to the installation rests on two principal classes of facts. The first results from the systematic series of observations of discharges carried out on the King Ho,³ the only series existing over a period of years, though admittedly for a comparatively short period.

In the years 1931 to 1934, the minimum discharge of the King Ho⁴ was, for a long period, less than the requirements necessitated by the irrigation system as designed. The working of the system in the years 1933 and 1934 afforded evidence of this shortage of discharge.⁵

Moreover, the years 1933 and 1934 are to be considered abundant in rainfall and floods, and accordingly the deficiency of water would have been still greater in the preceding years.

The station for which the longest series of data is available (monthly figures from 1921 to 1927 and from 1929 to 1933) is that of Yuan Fong, in the plain of Wei Pei, irrigated by the waters of the King Ho. There are no data for 1928, the year of the disastrous drought, during which all activities were suspended.

The following table shows the annual rainfall and the figures for the irrigation period from April to September expressed in millimetres of water on the ground :

	1921	1922	1923	1924	1925	1926	1927	1929	1930	1931	1932	1933
Annual rainfall.....	356	227	464	382	480	212	356	287 ⁶	414	256	167	706
Rainfall for the spring and summer period	315	211	416	214	473	173	133	161 ⁶	287	204	155	588

The average annual rainfall in the twelve years recorded works out at about 360 millimetres.

It will be observed that, for five years out of twelve, the annual rainfall is below 300 millimetres, and the rainfall for the spring and summer period below 200.

¹ Thus, for example, the system of distribution canals extends to areas which, owing to the scarcity of water, can never be irrigated.

² It has also led, not without serious drawbacks, to a reduction in the *indispensable* expenditure, thereby sacrificing the safety and stability of the works.

³ The quantities are in all cases average daily quantities.

⁴ Even though there may be doubt as to the accuracy of some of the figures (especially as regards the highest discharge), the observations give an idea of the regime of discharge.

⁵ These deficiencies, it should be mentioned, gave rise to continual disputes.

⁶ Incomplete, the July figures not being available.

Accordingly, the year 1933, during which the rainfall exceeded 700 millimetres—that is, about double the average quantity—is undoubtedly to be considered an *excessively rainy year*.

The next wettest year was 1925, but with the enormous difference of 236 millimetres.

Similar conclusions are arrived at by examining the annual rainfall at Sianfu in 1930 and from 1932 to 1934 :

	1930	1932	1933	1934
Rainfall (in millimetres) . . .	463	299	528	571
Rainfall in the spring and summer half-year (in millimetres)	298	282	432	390

The years 1933 and 1934 were by far the wettest years. Further confirmation of the great abundance of rain in 1933 and 1934 is offered by the results of the observations carried out at Sienyang on the banks of the Wei Ho, from 1932 to 1934—

	1932	1933	1934
Rainfall in the first ten months of the year (in millimetres) ¹	257	477	454

and near the point where water is drawn off from the installation on the King Ho, from 1931 to 1934 :

	1931	1932	1933	1934
Annual rainfall in millimetres .	303	248 [*]	701 ²	623

This cursory survey of the rainfall data shows that the *two years 1933 and 1934 in Shensi were abnormally wet years.*

A similar conclusion is arrived at, as regards the discharge of water in the years 1933 and 1934, from an examination of the direct hydrological observations relating to the King Ho, the only watercourse for which, as already stated, systematic observations are available for a number of years.

The general considerations previously set out have made it clear that the essential point for the study of an irrigation system is *the determination of the minimum discharge.*

This does not mean the *absolute minimum*—that is to say, the amount which is permanently available.

The requirements of irrigation can be adequately met even if there is an occasional shortage for a day or two. The discharge is sufficient if the supply of water over a number of days in a given period is large enough to make up for the deficiencies of the remaining days without the crops suffering injury.

In other words, it will be sufficient if, over a given period, the *duration* (in days) of the discharge exceeds a certain fraction—say, nine-tenths or, at the very least, eight-tenths of the total period.

The analysis is facilitated by drawing and examining *duration curves* showing in a diagram, for every quantity discharged, the number of days during which it was available (that is to say, during which the actual discharge of the river was equal or superior to such quantity).

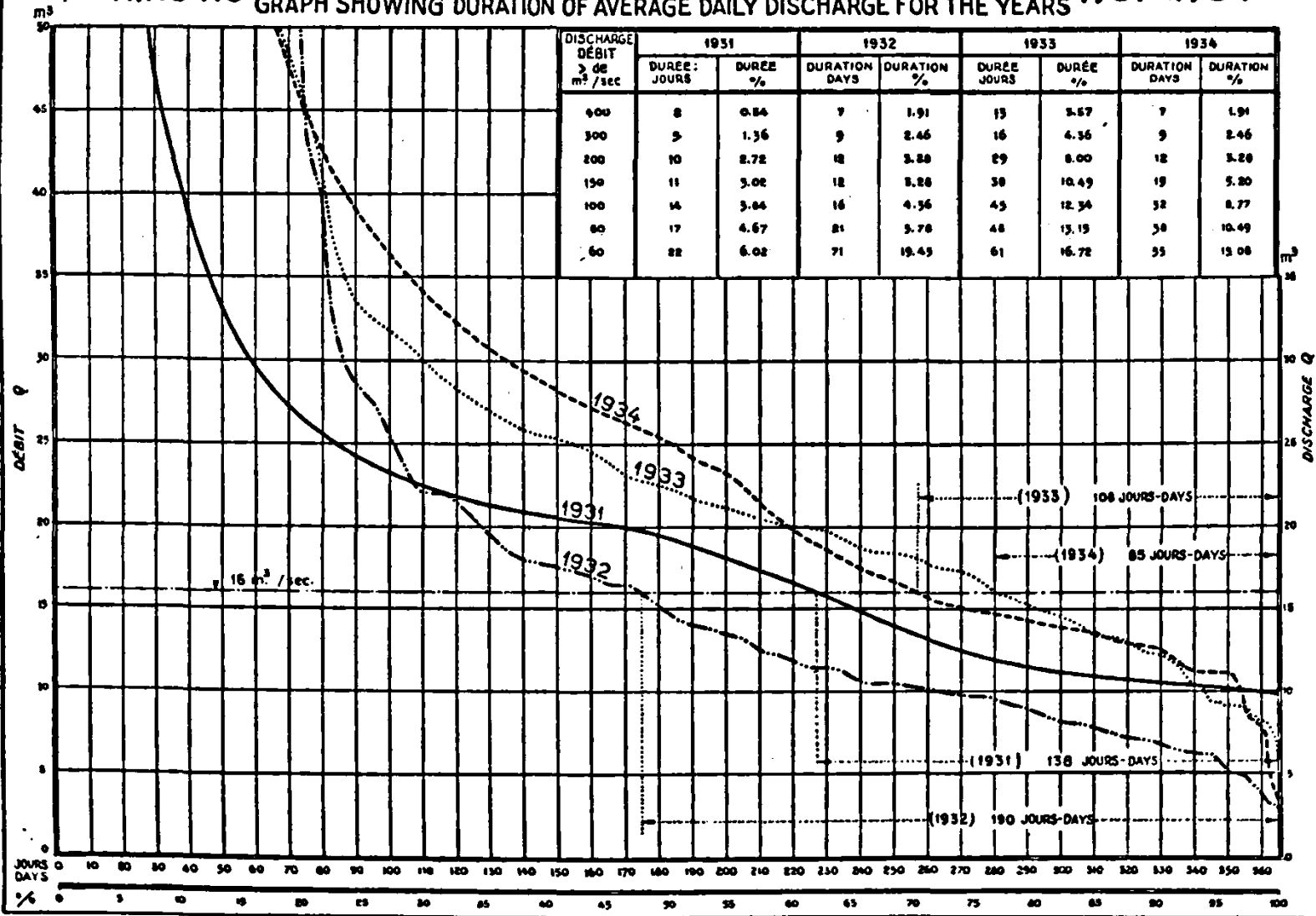
In this way, curves are obtained for the discharge of the King Ho in the years 1931 to 1934 similar to those shown in the accompanying graph.

¹ Only the first ten months are shown, as there are no figures for November and December 1934.

² The data for 1932 and 1933 are not quite complete ; figures are lacking for November and December, and the three months January to March respectively. During these months, however, the rainfall is usually insignificant as compared with the rainfall for the entire year.

KING HO COURBE DE DURÉE DES DÉBITS MOYENS PAR JOUR, POUR LES ANNÉES 1931-1934

GRAPH SHOWING DURATION OF AVERAGE DAILY DISCHARGE FOR THE YEARS 1931-1934



These curves make it clear that the discharge in 1933 and 1934 was much greater than that in 1931 and in 1932.

These curves also make it possible to deduce conclusions of great significance to the examination of the question. It will be remembered that the works on the King Ho were planned on the assumption of a discharge of 16 m³/sec. It will *immediately* appear that, even in the exceptionally good years of 1933 and 1934, the discharge was for a considerable part of the year less than the above amount.¹ In fact, in 1933, the discharge was less than 16 m³/sec. on 108 days (with a minimum of 6.24 m³/sec.), and during 1934 on 85 days (with a minimum of 3.73 m³/sec.).

Much more serious deficiencies are to be observed, however, in 1931 and 1932. Thus, in 1931, the discharge was less than 16 m³/sec. on 138 days and in 1932 on 120 days (with a minimum of 2.83 m³/sec. in 1932).

Hence irrigation would have been impossible in practice in 1931 and 1932.

It is thus easy to see what the irrigation situation would have been in such years as 1928, 1929 and 1930, which were much drier than 1931 and 1932, being regarded as years of exceptional drought.

It has thus been shown :

(a) That it would have been quite impossible to count upon 16 m³/sec. on the King Ho for irrigating the land in the plain of the Wei Pei, and that, accordingly, both the irrigable area and the works are on too large a scale for the actually available water-supplies ;

(b) That if the results of the two years 1933 and 1934 have not shown the insufficiency of the irrigation water even more seriously, this is due—apart from the circumstance that, owing to the defects in the planning and construction of the works the system could only be put into operation partially—primarily to the fact that the available water-supplies in these two years were large and certainly much above the average.

We have so far only considered the situation of the King Ho, because a systematic series of observations covering a number of years were available for that river.

Similar conclusions, however, must be arrived at in the case of the other two watercourses.

As regards the Wei Ho, the area to be irrigated was worked out better on the basis of the supply actually available, the experience of the King Ho having to some extent served as a guide. But the flow itself was again overestimated and ought to be largely reduced. Since the irrigation system is still under consideration, the estimates in question should be revised.

It is, however, as regards the Lo Ho that the situation appears the most serious.

The basin of the Lo Ho at the intake is about 15,000 square kilometres—that is, barely equal to 38% of that of the King Ho.

The vicinity of the basins and the similarity of climate and general situation point to the view that the contribution to the discharge of each unit of area of the basin is also not very different in the case of the King Ho and the Lo Ho. Incidentally, in the four months April to July 1934 (the principal period of irrigation), the minimum amounts of the average daily discharge of the Lo Ho varied between 30% and 86% of those of the King Ho.

The area to be irrigated by the waters of the Lo Ho is about equal to that to be irrigated by the King Ho. Hence if, as already indicated, there is likely to be a very serious shortage of water in the latter case, this shortage will be very much greater with the Lo Ho. Indeed, the utility of the entire scheme becomes highly problematical.

¹ For the sake of clearness, we have considered complete periods of one year. If, however, reference were made to the periods when irrigation requirements are greater, the conclusions would be still further strengthened.

I. THE RESERVOIR PROBLEM.

In the course of our consideration of the works constructed, in process of construction or projected in connection with the irrigation systems in the province of Shensi, we have already had occasion to draw attention to the numerous inherent weaknesses by which their efficiency and safety are impaired.

We have seen, however, that, with comparatively unambitious works and measures based upon sound technical principles, these weaknesses could be overcome, at least in so far as is necessary to bring part of the installations into service.

In addition, however, to the defects of the works themselves—which can be more or less satisfactorily corrected—a grave error has been committed which is likely to compromise the efficacy of the system and render sterile all the efforts made to apply it.

When analysing the hydrological regime of the Shensi rivers, we saw that their discharge is highly irregular and that there are very periodic variations which correspond, as a rule, to the local decrease in rainfall.

In this connection, we may recall that the irrigation works projected or already in process of construction in Shensi are intended to develop and improve an *already existent* agricultural system based primarily upon rainfall. The position is, therefore, very different from that of other countries—such as Egypt, in which, as rainfall is negligible, the agricultural system is based exclusively upon irrigation and has therefore a somewhat special character.

In order to estimate how far it is possible to supplement the rainfall, reference must be made, as has already been done on several occasions, to the actual discharge genuinely available.

On these bases alone would it be possible to work out a final programme.

To neglect this principle would entail the possibility of catastrophes *proportionally more serious* than those which might occur under the natural conditions of a still primitive agricultural system based entirely upon rainfall.

The disastrous consequences of these catastrophes are not only manifested in the actual years of drought, but—as was proved for example in 1928—are felt for a number of years afterwards.

When the agricultural irrigation systems, even though created at the cost of great efforts, prove unequal to ensuring the possibility of existence in abnormal times, the great meteorological and hydrological crises lead inevitably to the abandonment of the land.

This provides a further explanation of the final abandonment of canals and large-scale works carried out by the ancient dynasties.

In general, it may be said that the works constructed or projected in Shensi are on a scale which would imply a discharge twice as great as that utilisable in the years of drought, when irrigation is most necessary. As has already been repeatedly pointed out, therefore, either all illusions as to the efficacy of irrigation must be abandoned and the plans altered accordingly, or else additional works must be specially constructed to ensure a discharge of water equal to that on which the plans for the installations have unwisely been based.

In cases of this kind, additional works can only take the form of *artificial reservoirs to store water in periods of abundant discharge and make it available as required in periods of scarcity*.

In order to construct reservoirs with the necessary capacity, certain conditions must be satisfied, some of which are connected with the regime of the rivers which it is desired to use, whereas others are connected with natural, topographical and geographical conditions.

But in the case considered, which is also the case of the majority of the rivers in northern and north-western China, the difficulties are enhanced by others, due to the *enormous amount of solid matter carried down by the waters of these rivers*. This circumstance must be attributed either to the action of rainwater coursing down hillsides bare of vegetation and covered with deep deposits of loess or to the erosion caused by the rivers themselves in passing through belts of loess.

The inevitable deposit of such matter in quantities which it is difficult to estimate at points where the speed of the river is reduced through the proximity of reservoirs may lead to the gradual silting-up of the latter and may reduce their effective capacity very rapidly.

Accordingly, even if from the standpoint of the hydrological regime and the topographical and geological situation the conditions for the construction of reservoirs were favourable, difficulties far greater than those found elsewhere—which might indeed be insurmountable—may arise, owing to the danger of silting.

In order to show, then, the difficulties that stand in the way of the construction of reservoirs on the rivers supplying irrigation water in the Shensi, we propose to examine briefly the situation on one of these rivers, the King Ho, which is better known than the others. This example may be deemed characteristic of all the others, so far as concerns the aspects under consideration here.

It would obviously be impossible in the absence of reliable data to give concrete figures, which will have to be determined by methodical research on the lines indicated below.

The system of irrigation depending upon the waters of the King Ho is established for a flow of 16 m³/sec. It appears from observations and measurements that the water discharge drops to a minimum of 3 m³/sec. and sometimes remains for considerable periods below 8 m³/sec.

No data are available for the years of catastrophic drought, but it is certain that the volume remained lower than for long periods during those years.¹

In order to ensure the requisite discharge of water for the irrigation system on the King Ho during the principal period of use, it would be necessary to have a reservoir with a capacity of over 100 million cubic metres to regularise the discharge.

Just above the intake works of the existing installation, the valley narrows into a rocky gorge, which continues upwards for some dozens of kilometres. According to the information received, the end of this gorge is fairly flat and at certain points it opens out considerably.

It would therefore seem possible to obtain the requisite capacity by means of a fairly high barrage.

We shall revert later to the geological conditions of the locality; we propose now to examine the problem of silting.

During a recent flood on the King Ho, the total quantity of water that passed down, during a period of five days, in a sector close to that of the intake amounted to 2,890 million cubic metres, carrying 550 million cubic metres of solid matter.

A reservoir of the capacity indicated above, constructed according to ordinary principles and with ordinary works, would therefore be *filled in less than a day*.

In view of this altogether exceptional circumstance, it is not possible to indicate any proved means of preventing or restricting such rapid silting.

Types of works or methods of operation might be considered which would reduce, as far as possible, any obstacles that stand in the way of the free discharge of the waters during the maximum floods, so as to modify the natural situation as little as possible.

¹ We have already noted that the conditions as regards irrigation on the Lo Ho appear to be even more difficult.

The object of the reservoir, designed in relation, on the one hand, to the regime of the discharge and, on the other, to the requirements of irrigation, would simply be to store up the autumn and winter waters—which are not very turbid—and to release them in the spring or in the early summer.

The reservoir would be gradually filled, starting in the autumn, and would be completely or partly emptied during the ordinary period of the great floods.

But apart from the obvious complications in the matter of functioning there would be another very serious, if not insurmountable difficulty—which has certainly not been settled as yet in the case of barrages of great height in very narrow valleys—namely, that of constructing working dam outlets for so large a maximum discharge. (A daily average maximum discharge of over 11,000 m³/sec. has been recorded. This would mean a *peak* discharge of close upon 20,000 m³/sec.)

Apart from the serious difficulties arising out of the carrying-down of solid matter, mention must be made of another difficulty which applies more particularly to the reservoir on the King Ho. The rocky walls which close in the valley of that river consist of limestone, broken by fissures and caverns which, even if they did not prevent the construction—by means of special measures—of a sufficiently high barrage, would mean such considerable losses of water by infiltration as to frustrate any useful purpose that the reservoir might fulfil.

It might be possible to consider a site for the reservoir some dozens of kilometres higher up, where the valley widens out appreciably.

At this point, the rocks are less permeable and the covering of loess itself might be sufficient to prevent leakage. But the cost would probably be much greater, partly owing to the difficulties of obtaining access to the site.

It might be possible also to examine the truth of the statement, which is frequently made, that there is a valley of a tributary completely, or almost completely, without loess, through which clear water flows and where a reservoir would be exposed to no danger. This would, for various reasons, seem very unlikely; it would be desirable, however, to investigate the topographical and geological potentialities, although the difficulties in the matter of access would still remain, owing to the great distance from inhabited centres and the shortage of existing roads.

Another method might be examined for the regulation of the irrigation waters—although it demands particularly favourable conditions, which are not easy to find—namely, the creation of *ring reservoirs* outside the actual course of the river, in the area to be irrigated or quite close to it.

These reservoirs would be established by building dams round low-lying areas of a small agricultural value. The waters of the river, suitably clarified, would reach them by means of a channel.

Lastly, the utilisation of underground water by means of wells might be considered. There are large numbers of these, varying very considerably in depth, more particularly in the area to be irrigated by the waters of the Wei Ho.

Sufficient data are not, however, available as to the hydraulic potentialities of the sub-soil, and the systematic utilisation of the wells on rational lines would appear to be a very big question.

It may be noted incidentally that, from this point of view, the conditions obtaining in the Paoki reservoir in the basin of the Wei Ho are much better, owing to the fact that the walls consist of impermeable rocks.

To the above considerations concerning the possibilities of creating reservoirs and the principles to be observed in this connection may be added another of very particular interest.

A general plan of improvement should, as far as possible, reconcile the already complex conditions of the regulation of the irrigation water with those of anti-flood

measures and the production of power. The system of reservoirs for irrigation should thus form a part of a complete and far more comprehensive system, extending to the Yellow River and its principal affluents, for the regularisation and controlling of the waters, with a view to the protection of human life and property and the reconstruction—so important from a social and political standpoint—of the hydraulic system of the whole country.

In conclusion, the irrigation systems created or proposed by the National Economic Council are not capable of fulfilling their purpose and preventing the catastrophes which, on repeated occasions in the course of history, have ravaged these regions and ruined similar—and sometimes more extensive—systems, which had been constructed but had to be abandoned. The problem of providing for these periodic shortages of water is one of the most delicate and difficult problems that hydraulic engineering has to cope with, and is, further, one in which practical experience can give no help.

The solution, if it exists, can be determined only after a series of researches, observations and studies of a topographical, geological and hydraulic character, *which, in view of the quite unusual nature of the country, will have to be carried out in a critical spirit by competent engineers.*

J. CONCLUSIONS.

The main object of the foregoing survey has been to determine whether the *irrigation systems already established, in process of execution or under consideration* in Shensi, under the auspices of the National Economic Council and in consultation with the League of Nations, *fulfil the requirements necessary to ensure a less ephemeral existence* than has hitherto, owing to serious natural conditions, been the lot of all similar systems set up in vain in this country in the course of the centuries.

The reply is in the negative, for two fundamental reasons :

(a) Neither in the execution nor in the planning of the *intake works* which constitute the *vital centre* of the systems have the precautions been adopted which modern technique would suggest to prevent or limit the effects of *silting*, which have resulted in the temporary or final stoppage of the working of the systems themselves or the reduction—not without damage—of the efficiency of the works.

It is necessary, in consequence, to correct and, in certain cases, to introduce radical modifications in the intake works.

(b) There has been undue optimism in estimating the available flow of the river for purposes of irrigation and the area of land to be irrigated. The rivers cannot provide the supposed supply for sufficiently long periods, even in normal or very wet years.

In years of drought, the volume of water falls so low that there is reason to think that any new agricultural venture established in the area would collapse completely, thus further aggravating the general situation in the country.

It is therefore essential *either to reduce greatly the area to be irrigated, abandoning canal systems where necessary, and to transform the irrigation systems already carried out, or to seek new means of regulating discharges.*

For the study of these means, no data are at present available, so that *a systematic and comprehensive plan of research would have to be devised.*

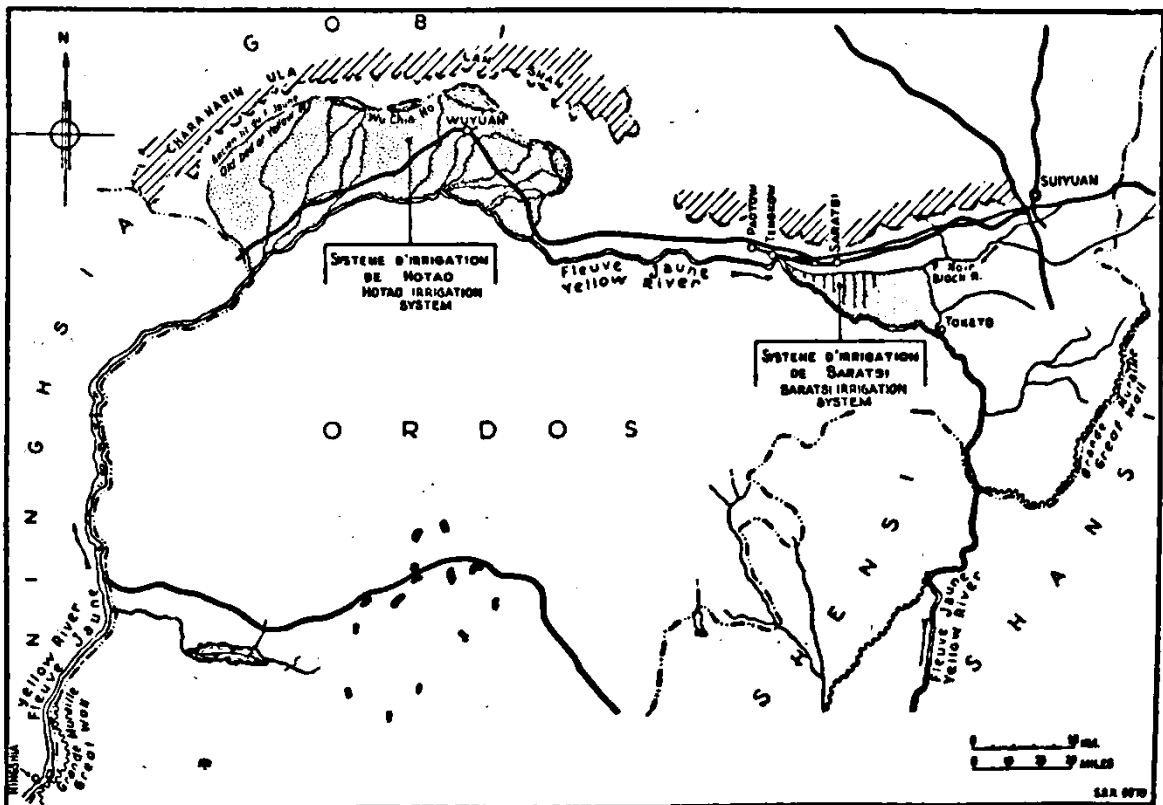
IV.

IRRIGATION PROBLEMS IN SUIYUAN.

THE HOTAO AND SARATSI IRRIGATION SYSTEMS.

The province of Suiyuan, situated north of the Great Wall between 106° and 114° E. longitude, extends up to the northern frontier of China and constitutes a part of what is known as Inner Mongolia.

IRRIGATION SYSTEMS IN THE SUIYUAN.



This province is one of considerable importance, both politically, owing to its geographical situation, and socially, inasmuch as it offers an outlet for domestic emigration, thus relieving the pressure of the agricultural population in the southern parts of China.

The climatic conditions are unfavourable to any extensive development of agriculture, mainly owing to the small rainfall. It is a desert region, with an annual average rainfall of not more than 300 to 400 millimetres. Modern agriculture (within the narrow limits allowed by the climate, of course) can be developed only where the crops can obtain the necessary water by means of irrigation.

The chief source of supply is the Yellow River, which bounds the province on the west, and turning eastwards crosses it approximately from west to east, and then turns south near the eastern boundary. Thus, the Yellow River encircles to the south the huge Ordos Steppe, which covers the greater part of the province. Near the western bend of the river, the changes in its bed have resulted in the formation of the large plain of *Hotao* at the foot of the Charanarin ula and Lan Shan ranges.

Thanks to irrigation, an agricultural system has gradually taken shape through the centuries, though its progress has several times been checked on account of the invasions which that region has suffered. About seventy years ago, a Chinaman organised this agricultural system on as rational lines as possible and good results were obtained. Of late years, however, these good results have tended to disappear, and serious fears are entertained for the future.

Near the eastern bend, where the Yellow River turns south, similar changes in the bed have resulted in the formation of another plain, stretching south and south-east of Saratsi and comparable in size to the Hotao plain. In one part of this plain, near Saratsi, it was decided, after the terrible famine of 1928, to introduce a system of irrigation serving an area of some 120,000 hectares.

Whether on account of faulty planning or construction, or of the unsuitable topographical situation, the system never came into operation, and it is only recently that consideration has been given to the possibilities of improving at all events part of the system.

These two problems are dealt with in the following report, which was drawn up after the experts' investigations on the spot.

A. IRRIGATION OF THE HOTA0 PLAIN IN SUIYUAN.

I. GENERAL.

On emerging from the mountain valley, the Yellow River crosses the Ordos steppe approximately from south to north, and then bends abruptly in a west - east direction, enveloping the steppe in a wide curve.

Near this bend, and north of the present channel of the river, extends the plain of Hotao, formed, like that of Saratsi, by the diversion southwards of the Yellow River, which formerly followed the foot of the Charanarin ula and Lan Shan. The Mongolian word Hotao means " the bend of the stream ", and is also applied to the Ordos steppe. The total area of the plain is estimated to be about 16,000,000 mu (about 1,000,000 hectares).

The topographical conformation is very favourable to irrigation by the waters of the Yellow River, as the ground falls sufficiently (a few units per 10,000) from the river to the depression which, in the north, represents the old bed.

It would appear that irrigation was first attempted about 2,000 years ago, under the Han dynasty ; but the whole system was destroyed during the Mongolian invasion about twelve centuries later. The construction of the present irrigation system was started some 60 or 70 years ago, and is due to the efforts of M. Wang, a Chinaman who, though not an engineer, had a wonderful instinct for hydraulics.

Although absolutely primitive in structure, the form of irrigation adopted in the system is too advanced to be termed a mere makeshift ; but it is designed solely to supplement the rainfall, which is the real basis of this system of agriculture.

1. System of Irrigation.

The system of irrigation comprises ten main canals which take the water direct from the Yellow River through ordinary lateral canals without any intake appliances.

Proceeding from west to east, the first three canals from the Yangchia Ho to the Yung Tsi, which divides into two branches, have their mouths comparatively close together (some 10 kilometres apart); 30 kilometres further downstream is the mouth of the fifth canal, Feng Tsi; and, about 50 kilometres further still, the mouths of the last five canals from Sha Ho to Ta Pu, all close together.

The longitudinal fall of the canals decreases from west to east from about 0.17 to 0.12 in 1,000.

There are no reliable data as to the discharge of water in the individual canals at the various times of the year; from measurements taken in the summer of 1934 (between June and August), they would appear to vary from a minimum of 3 m³/sec. on the Sha Ho to a maximum of about 47 m³/sec. on the Yung Tsi, with an aggregate of about 110 m³/sec.

As the irrigated area for the same year is given as 417,000 mu (about 26,000 hectares), this would give an average theoretical flow of 4.2 litre/sec./hectare—a very high figure even if the leakages along the canals are assumed to be large, though, from the topographical and geological conditions of the latter, they should not be above the normal.

Such a large discharge appears to be due to two sets of circumstances relating to the agricultural and irrigation system at present practised.

As it is unusual either to have crop rotation or to use fertilisers on the fields cultivated (the scarcity of cattle makes natural manuring impossible), about 40% of the land is left fallow for a very long period and is submerged annually at flood-time, chiefly July and August, to a depth of about one metre. The fertile silt helps to enrich the soil and at the same time to neutralise excessive salinity.

Further, as the discharges are deliberately made larger than necessary, they should, in view of the considerable fall in the canals, maintain during floods sufficient velocity to reduce the formation of deposits.

As there are no regulators at the openings of the canals, these are closed at the end of October by dams. At the end of March or beginning of April, the dams are removed so as to restart the flow of water, which can thus not be regulated. Usually, at the end of April the level of the river is high enough to feed the secondary canals.

For the above reasons, therefore, the flow of water is greater than the amount required for irrigation, and the canals discharge at their lower end into the natural outlet drain constituted by the Wu Chia Ho, the old bed of the Yellow River.

The limited discharge capacity of this outlet drain results in the formation along its course of ponds or lakes connected by narrow channels, the level of which rises during the irrigation season. When the waters of the Yellow River rise, they overflow along the Wu Chia Ho, the lowest reach of which ceases to act as an evacuator and becomes a feeder of the lakes.

The hydrological balance of the Wu Chia Ho as between the water flowing in from the irrigation channels and the area naturally drained by the ponds on the one hand, and the outflow returned to the Yellow River (at low water) and the loss from various causes on the other hand, is maintained chiefly owing to the great evaporation from the surface of the ponds.

The information regarding the area of these ponds, the changes in water-level and the discharge capacity of connecting sections, is inadequate, indefinite and unreliable. Nor are there any data regarding the situation of the subterranean water-surface; there is said to be a considerable rise in the level of the water-surface along the upper sections of the main canals, owing to irrigation.

2. *Area irrigated and Crops: Military Colonisation: Agricultural Transformation.*

The information regarding the area under cultivation and irrigation is extremely vague, unreliable and even contradictory. It would seem that the area irrigated (including ground left fallow) does not exceed 1,300,000 mu (80,000 hectares), and in recent years has been less than 800,000 mu (50,000 hectares), whereas the area covered by the channels is at least ten times greater.

The chief crops at present grown are barley, spring wheat, millet, beans, potatoes, flax, oats and sorghum, which are irrigated twice, usually in April-May and in June. Latterly, other crops have been experimentally introduced, such as winter wheat, cotton, maize, beet and lucerne. The results in the case of cotton are not encouraging; beet promises to give a good yield and is irrigated in June and August. As a rule, the land is irrigated in autumn in such a way that the layer of ice which forms in the winter melts in the spring and thus gives the first irrigation.

A special form of agricultural colonisation has been carried out in the belt of land nearest to the Wu Chia Ho—namely, military colonies established for political reasons—to give employment to soldiers on demobilisation, or to form an armed guard for the frontier.

These soldiers, who were still on the strength of the army, tilled the ground and received their pay for the first three years, during which the agricultural produce was sold and the proceeds went to the provincial Government. At the beginning of the fourth year, they were entitled to receive a plot of ground (100 mu = 6 hectares) and to cultivate it for their own benefit, paying the usual taxes.

This experiment of using soldiers for agricultural colonisation seems to have been remarkably successful.

The yield of local agriculture has been and is still being improved as a result of irrigation.

This improvement has been obtained, thanks to highly favourable local circumstances; it is being rationally continued and should, therefore, be encouraged.

All further agricultural progress, even if slow, must, however, be preceded by corresponding improvements in irrigation, more especially in the direction of greater regularity.

Of late years, however, the tendency has been constantly in the opposite direction.

Accordingly, a study of the problem must aim at (a) determining the cause of the rapid decline observed in the present system of irrigation and checking that decline; (b) improving the system, taking into consideration the extremely small financial resources available and the already mentioned advisability of slowly and gradually transforming agriculture.

The works now to be projected should accordingly be planned so as to form the beginning of a much wider co-ordinated and rational system, to be executed as and when the possibility and expediency of further agricultural development make it desirable.

II. DRAWBACKS AND DEFECTS OF THE IRRIGATION SYSTEM.

The chief drawbacks at present complained of are of two kinds:

During the irrigation season, the rise in the level of the lakes along the Wu Chia Ho outlet results in the inundation of a wide belt of ground. The area inundated is gradually and steadily increasing, so that ground that was once cultivated and on which the colonies already mentioned were recently established is unavailable for agriculture.

Further, *the discharge of water in the canals would seem to be insufficient to irrigate the ground in the lower section and particularly in the eastern part of the plain.*

As a result, more particularly, of these circumstances, there has been in recent years a substantial decrease in the irrigated area. This area is estimated at about 42,000 hectares in 1931, 30,000 in 1932 and 26,000 hectares in 1934; there has thus been a decline of 38% in three years.

The information and data furnished to the expert are not sufficient to reveal all the causes underlying these drawbacks. After making a short visit to the spot and studying the facts collected, however, he has reached the conclusion that the system possesses two basic defects.

The surface evaporation of the lakes along the Wu Chia Ho and the discharge capacity of the latter are not sufficient to maintain a balance between the inflow of water on the one hand (due mainly to the very large volume of water discharged from the irrigation canals at their lower end) and the losses due to evaporation and the outflow (through the Wang Lu Hao) on the other hand.

It is, in fact, observable that, when the Yellow River is in flood—*i.e.*, when there is a large inflow of water to the lakes from the irrigating canals—not only is no discharge possible through the Wang Lu Hao, but the waters of the Yellow River help to fill the lakes (though not to a very great extent).

Silting is another cause of the gradual rise of the maximum levels of the lakes.

The fall in the amount of water conveyed by the irrigation canals might be ascribed partly, at least, to a similar cause—*i.e.*, the formation of deposits along the canals—since no steps have been taken to diminish the amount of silt in the waters tapped.

The main reason for the decline, however, is to be found in the changes that have occurred in the intakes, due to the deposits left by the river and to changes in its course, the bed having a tendency to shift southwards.

III. RECOMMENDATIONS FOR IMPROVEMENTS.

So far as the *somewhat vague and inadequate data* permit, we now indicate the more essential investigations that should be made, the principles to be followed in resuming the operation and improving the efficiency of the system.

I. Construction of Intakes.

This may be done for each channel separately; or it might perhaps be better to regroup certain intakes and construct permanent regulators and separators.

A study of the map of the district shows the possibility of such a regrouping if a proper choice is made of the sites which, in view of their topographical and geological features and the regime of the Yellow River, appear to be best suited for permanent works. The latter should be supplemented by rationally devised appliances for controlling and clarifying the water. As far as can be seen at present, the removal of deposits should not be particularly difficult, especially if the regrouping advocated above is carried out.

When this regulation is effected, it will no longer be necessary to have high velocities in the irrigation canals, as the water will already have been sufficiently clarified at the intake itself; the discharges of the canals can thus be reduced and adjusted to irrigation requirements alone.

The smaller inflow into the lakes along the Wu Chia Ho thus obtained will restore the hydraulic equilibrium of these lakes and presumably produce a fall in the maximum water-level; in this way, the ground along the Wu Chia Ho would be drained and restored to cultivation. The subterranean water-surfaces would also be lowered, thus helping to improve the situation in various places.

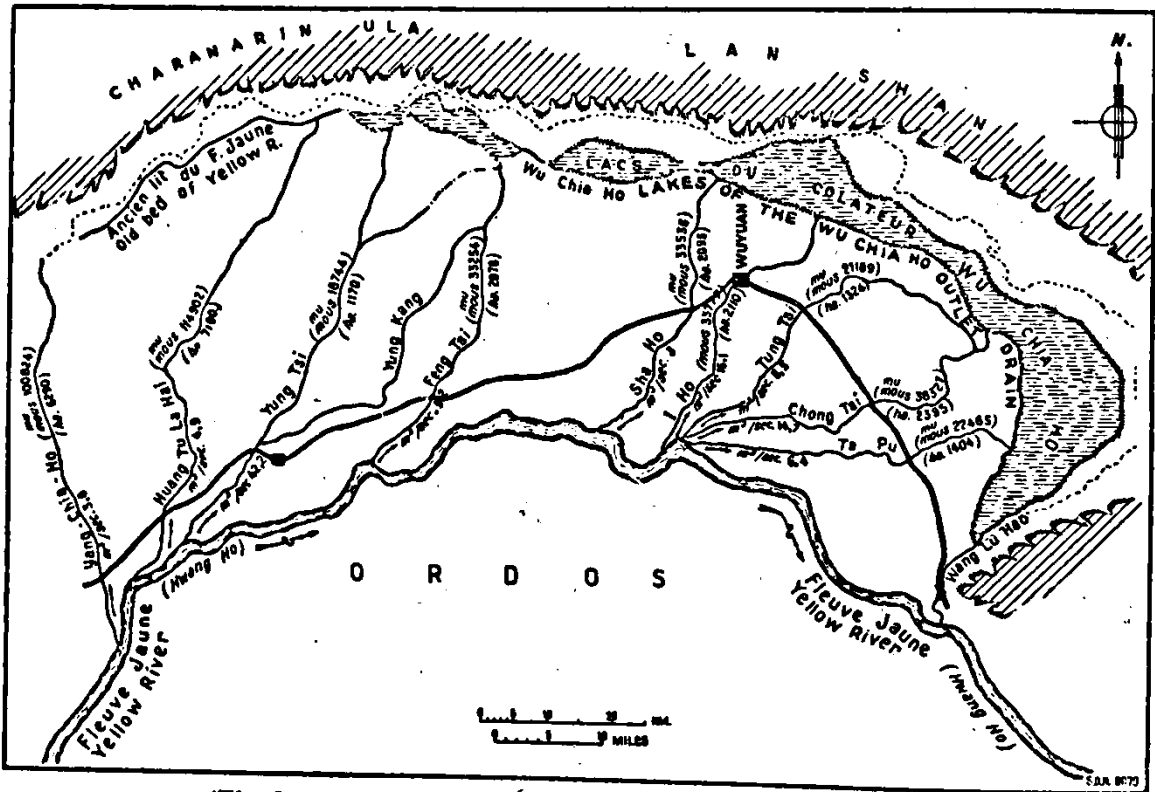
Further, the silting-up of the lakes should be reduced to tolerable proportions, and the same would be true as regards the formation of deposits in the channels.

The above measures, which should take priority of all else, constitute the first part of the programme and would prevent the situation from growing worse; the irrigation necessary for the present type of extensive agriculture could then be assured and the way opened for improvements and individual attempts to carry out rational transformations.

2. *Regulation of the Wang Lu Hao.*

This should be done by regulating the section of the canal and *constructing a barrage and regulator* near the confluence with the Yellow River. This would act as an additional corrective and would be an improvement in the system supplementing the measures indicated in 1.

IRRIGATION SYSTEM IN THE HOTAU PLAIN.



(The figures in parentheses refer to the area irrigated in 1934.)

3. *Improvement of the Irrigation System.*

This can be carried out in successive stages and would include :

- (a) Profiling of the channels (together with reinforcement of certain sections);
- (b) Construction of devices of standard type, and suited to local conditions, for allocating and distributing the water;
- (c) Completion of the main irrigation and of the drainage systems, and construction of corresponding subsidiary systems, which will be greatly facilitated by the favourable topographical situation;
- (d) Regulation of the lands.

The latter is a large-scale enterprise. At the present time, irrigation is applied to 1,300,000 mu (80,000 hectares) of land, including fallow ground, whereas the area that could be irrigated and cultivated by more up-to-date and rational methods is ten times larger.

Local conditions, which are exceptionally favourable, would allow this programme to be carried out in stages.

This scheme has been outlined mainly in order that the first essential works suggested should link up with the general programme.

The problem of draining off the water which flows into the Hotao plain from the mountains bordering it on the north has not been dealt with, since the data collected on the subject are inadequate and need to be supplemented by systematic investigations and observations. The contribution made to the Wu Chia Ho by the mountain basin, however, appears to be negligible.

IV. PROGRAMME OF INVESTIGATIONS.

The first three questions to be investigated, which constitute the first part of the programme, relate to the more urgent scheme of works and the others to the main lines of the general programme :

(a) Large-scale topographical survey and geological studies of the localities suitable for intakes ;

(b) Hydrometrical observations on the site of the intakes themselves and at typical points on the Wang Lu Hao ;

(c) Topographical surveys for the purpose of calculating the minimum and maximum areas of the ponds formed on the Wang Lu Hao ;

(d) Topographical surveys for preparing a general map with contour lines and polygons fixed on the ground, taking of levels and collating them with those of the Saratsi plain (these surveys could be based on the extensive survey work already done in connection with the existing irrigation scheme) ;

(e) Rainfall and hydrological observations ; the purpose of the latter should be to ascertain the regime of the Yellow River (level, liquid and solid matter carried down, etc.), particularly near the new channel intakes, the rate of discharge and the volume of water discharged from the mountain basin on the north and the details of subterranean water-surfaces ;

(f) Researches, from an agricultural standpoint, into the composition and properties of the soil, with a view to the gradual rational transformation of the theory and practice of agriculture on an irrigational basis.

In this connection, the Committee considers it absolutely essential that the hydraulic and agricultural services should keep in close and constant touch with each other.

B. IRRIGATION OF THE SARATSI PLAIN IN SUIYUAN.

I. GENERAL.

The plain of Saratsi is situated near the eastern end of the big bend which the Yellow River (Hwang Ho) makes round the Ordos steppe ; it has been formed as a result of the southerly deviation of the river itself, which formerly hugged the foot of the Yin mountains (Yin Shan).

The part of the plain touched by the irrigation system¹ is bounded on the north by the main channel, to the south and west by the Yellow River, and to the east by the Black River (Hei Ho), a tributary of the Yellow River. It is triangular in shape, with the western apex near Tengchow, and has an area of 2 million mu = 125,000 hectares, about 80,000 of which were to have been irrigated under the system proposed.

At the end of 1932, the following irrigation works could be regarded as finished, though structurally defective and in some parts already falling into ruins when they were inspected by the expert :

The intake from the Yellow River, where the regulator consists of four 4.2-metre sluices, with double flood-gates ;

The main canal, which runs for 72 kilometres approximately from west to east, from the intake on the Yellow River to the discharge into the Black River ; the fall is 1/83,000 for the first 50 kilometres and *nil* for the last 13 ; the width at the bottom decreases gradually from 18 to 14 metres ;

The lateral canals from No. 2 to No. 9 (the latter only partly excavated), each with its own arrangement for drawing off the water from the main canal, the total length being about 90 kilometres ; these lateral canals could cover an area equal to about a quarter of the total area to be irrigated, for which seventeen canals, totalling 250 kilometres, were projected.

The cost of the above works is given as 860,000 Mexican dollars.

The very first attempt to admit water led to silting in the upper section of the main channel. In 1933, the Yellow River submerged the western corner of the Saratsi plain and the flooded streams from the Yin Shan range, breached the northern embankment of the main canal and silted it up in several places. The system was thus put out of action and its very serious fundamental defects were revealed.

The lateral canals were themselves badly damaged, particularly where they crossed the old beds of the Yellow River.

No irrigation could ever be carried out, the result being a total failure almost unparalleled in the history of irrigation.

II. NATURAL SITUATION UNFAVOURABLE TO TRANSFORMATION BY IRRIGATION.

Apart from the basic defects of the system, as regards both planning and execution, defects which will be dealt with later, it must first be pointed out that *the area selected in the Saratsi plain is the one least suited to transformation by irrigation, for the following reasons :*

(a) The topographical conformation and the elevation as compared with the levels of the watercourse to be utilised. — This is, in fact, a case of a flat district, with a very small fall—similar to the extremely slight fall of the Yellow River—from west to east (more or less parallel to the river itself) and a quite insignificant fall from north to south.

Further, in most of the district, when the volume of water is low or moderate, the Yellow River is on the same level as, or below the level of, the land to be irrigated and cannot therefore be led over it. During floods, on the other hand, the land is liable to suffer from inundation.

¹ Planned by the China International Famine Relief Commission (C.I.F.R.C.) and the Suiyuan Provincial Government, following the exceptional drought of 1928.

(b) The absence of any possible natural outlet for the water. — Even before irrigation was introduced, this defect must have been an obstacle to agricultural improvements, and it was to be anticipated that the difficulties would seriously increase, once the irrigation system was established.

(c) The excessive dampness and salinity of the soil over vast areas of the eastern section. — Here the subterranean water-surface comes up to within less than a metre of ground level.

(d) The threat of serious periodical floods and silting caused by the torrents from the neighbouring Yin mountains.

To these unfavourable conditions must also be added the topographical situation ; the area to be irrigated has a very slight fall, as above stated, and the contour is extremely irregular owing to the number of the old beds of the Yellow River, which cover the whole plain.

III. INEFFICIENCY OF THE IRRIGATION SYSTEM : BASIS DEFECTS.

A cursory inspection of the irrigation works built would have shown that the system possessed defects, which were likely not only to impair its efficiency, but also to prevent—as they have done—its working at all. Mention should be made of the following in particular :

(a) The level of the sill of the intake (986.45 metres) is 2.45 metres above the low-water level of the river, as observed in June 1928.

In the chief irrigation season (April-June), in normal years, as the level of the river is not more than 0.5 to 1 metre above the sill, it would be possible to draw off only about 2 to 8 m³/sec. instead of the 48 m³/sec. projected. In years of drought, in particular, when irrigation water would be most needed, *the channels would be left dry.*

The intake, moreover, is situated near the junction of the Yellow River with a torrent subject to violent floods and full of silt, which has already damaged and choked the intake.

But the intake has a still more serious defect ; it has no arrangement which would safeguard the channels against the danger of silting. This is a particularly serious omission, since the waters of the Yellow River are exceptionally turbid.

Thus, even if it were possible to draw off the water, the result would have been a gradual silting-up, which would have taken place all the more quickly owing to the slight velocity of the water due to the small fall, and it would have been constantly necessary to carry out difficult and expensive dredging operations.

(b) In calculating the effect of the system, no account has been taken of the losses from seepage and evaporation, which can be estimated for the maximum discharge at about one-third of the discharge itself. For a very small discharge, the amount would be relatively larger.

Thus, not only in periods of drought, but even in normal years, the land would have received a virtually insignificant discharge of water (roughly, from one-fiftieth to one-tenth of the amount estimated to be necessary).

(c) The lateral channels run from north to south, more or less perpendicular to the main canal, whereas the natural conformation of the ground would have required them to run from west to east. They have no fall and in practice therefore cannot carry the water.

At the points where the lateral canals cross the natural outlet drains (old beds of the Yellow River), no arrangements have been made for draining the latter, so that the banks of the irrigation canals obstruct the discharge downstream of the waters collected by the outlet drains, leave the ground marshy and cause the destruction of the dykes themselves.

(d) The northern dyke of the main canal traverses and obstructs the beds of the torrents which descend from the Yin mountains. At ordinary times, this results in the accumulation of stagnant water over the belt of land north of the canal, where a system of agriculture based on irrigation has developed, though over limited areas; although still absolutely primitive, this system of cultivation is one of the most productive in the district. This fact explains and justifies the acts of sabotage committed by the farmers to avert the damage thus done to their lands.

During the heaviest floods from the mountain torrents, the dykes are liable to be broken down (and already have been broken down at several points), with consequent silting-up of certain sections of the channel.

The problem of draining off the water which runs down from the mountain range on the north border of the Saratsi plain has apparently not been given any consideration; the technical problem involved is quite complicated, in view of the very large discharge and the amount of solid matter carried down.

Lastly, the necessity seems to have been overlooked of protecting the irrigation system against inundation by the flood waters of the Yellow River. As already observed, the maximum flood level is higher than the level of the ground; this is a problem of cardinal importance, as it means dyking the river for some dozens of kilometres.

(e) It has already been stated that the topographical configuration of the district to be irrigated makes any natural discharge by gravity impossible (*i.e.*, without resorting to mechanical elevation). Such discharge, however, is necessary to prevent the ground from becoming marshy and to avoid an increase in the salinity of the soil. This circumstance was not foreseen when the works were considered.

No arrangement whatever has thus been made for draining the soil, though the idea was to irrigate then by the so-called submersion (or inundation) method, which calls for the greatest caution, and though a visit to the spot would at once have revealed the abnormal humidity and salinity of the soil in the eastern section and the frequency of stagnant water in the numerous depressions.

(f) The works (bridges, bridging canals, distributors, main intakes, etc.) are insufficient in number and defective in design and construction. Most of them were already in ruins and would not even withstand the first inflow of water.

IV. PRELIMINARY DATA FOR CONSIDERATION OF THE POSSIBILITY OF PARTIAL OR TOTAL OPERATION OF THE SYSTEM.

Before examining the possibility of partial or total regulation of the Saratsi irrigation system so as to make it more or less workable—though any rational utilisation of the system is now impossible—we must consider certain general rules, which must be given a special interpretation in the present case.

Local agriculture has grown out of the natural conditions of the country, and, above all, of its climate. The temperature and rains determine the cycle of vegetation and, indirectly, the agricultural customs practised. At Saratsi, these are extremely simple and primitive and are applied to crops which are necessarily poor and unreliable.

Irrigation may be introduced solely with the idea of diminishing risks, while maintaining the simple and poverty-stricken character of the agriculture at present existing and giving production a higher degree of security and regularity.

Such solutions, however, can be achieved only under certain natural favourable conditions which are not always easy to find and from which the sound instinct of the natives is almost always capable of extracting the maximum advantage.

But the cost of constructing and operating such works must be very low if it is to show a profit; for the increase achievable in production is small indeed.

Among the more striking examples of such irrigation schemes may be mentioned those of Ningsia and Hotao and several others which utilise over a very small area the water of small streams and springs, particularly where the mountain torrents emerge into the Suiyuan plain.

But unless the natural situation is exceptionally favourable, if it is intended to minimise and even eliminate all uncertainty in the supply of irrigation water, and if the systems proposed are to acquire considerable technical and economic importance, the works must discard their original simplicity and must be brought into line with the types and systems evolved as the outcome of long experience, and each case must be considered separately.

In such circumstances, the expenditure incurred could be justified only by a very substantial increase in production, such as would be achievable only by a radical reform of local agriculture. In view of the climate, however, the latter could never become as productive as in southern districts.

This reform imposes heavy financial burdens on the landed proprietors, who would have to find money for the construction of secondary systems of irrigation canals and drains between the separate farms, land regulation (an extremely important matter in the case of Saratsi), changes of crops, construction of buildings for rural services and houses to accommodate the increased population, road building, increase of live-stock and supplies of tools, and, possibly, introduction of agricultural machinery, and so on.

Accordingly, the landowners, heavily burdened as they already are, could not be expected to bear in addition the cost of constructing tertiary canals for conveying irrigation water from the lateral canals to the farms. Such expenditure should be borne by the central organisation which established the irrigation system.

This discloses *another defect in the agricultural and economic programme proposed for the Saratsi system*. In the types and structural features of the works, in the number of the canals and the aggregate extent of the works, this irrigation system should at least approximate to the rational and complete systems of irrigation above described. No account has been taken, however, of the costly works (canals and engineering works) necessary for distributing the water over the whole irrigation system, and of the fact that the landowners are absolutely unable to supply this need.

Thus, even if the works executed had proved less unsuccessful from the technical standpoint, there would still remain this very serious difficulty, which would have made the utilisation of those works impossible.

Accordingly, in considering the possibility of partially or entirely restarting the Saratsi irrigation system, it must first *be made clear whether the purpose of studying the new improvements to be introduced is merely to have a makeshift irrigation which would maintain the local primitive form of agriculture, or to establish rational, systematic and reliable irrigation which would radically transform agriculture*.

The first alternative would doubtless mean partial adaptation of the system on the most economic lines, so as to enable it to be used as far as technically possible.

The second would imply complete adaptation to sound rules of engineering, and would apply to a considerable part, or even to the whole, of the irrigated area originally projected.

V. POSSIBILITIES OF IMPROVING THE IRRIGATION SYSTEM.

As above stated, the natural conditions prevailing in the Saratsi plain are definitely unfavourable to transformation by irrigation. Nevertheless, in order to utilise as far as possible the work already done, a preliminary examination has been made in order to ascertain from a *purely technical standpoint* what measures would be necessary to put this irrigation system into even partial operation.

This examination is supplemented by an estimate of the relevant expenditure. The measures referred to above may be classed in five separate groups :

- (1) Reconstruction of the intake (to ensure that the necessary discharge of water is drawn off and that the excess of silt is removed) ;
- (2) Raising of the water-level in the irrigation canals ;
- (3) Improvement and completion of the irrigation system in the area to be served ;
- (4) Creation of a drainage system which will ensure the evacuation of the outflow and diminish, where necessary, the humidity and salinity of the soil ;
- (5) Protection against the floods of the Yellow River in the south and the mountain torrents in the north.

1. *Reconstruction of the Intake.*

The site is unsuitable ; as stated above, it is too near the mouth of a mountain torrent. It can be protected, but not easily. The same is true as regards protecting and strengthening the bank above and below the mouth.

The amount of water tapped can be increased by deepening the bed and widening the section of the canal as much as is necessary. This would obviously involve the reconstruction of the regulators at the mouth.

The problem of removing the silt is rather complicated, owing to the very slight fall—0.1 in 1,000 or less—of the Yellow River in the section below the intake (*a fall actually less than that estimated for the outlet canal*).

On the whole, in such situations, the creation of a discharge canal would seem advisable for the water taken from the main canal by the introduction of sluices and regulators. This would enable any deposit accumulated in the section above those works to be evacuated.

By concreting the sides and the bottom of the two sections of the canal, it would be possible, even if the available fall is slight, to obtain sufficient speed for evacuation.

In the case under consideration, owing to the mutually unfavourable situation of the river and of the main canal and the slightness of the fall in the former, the cost of the measures would be prohibitive and their efficacy doubtful.

2. *Raising of the Water-level in the Irrigation Canals.*

This could be done in three different ways :

- (a) By prolonging the canal farther upstream, so as to find an adequate head of water ;
- (b) By constructing a movable weir immediately below the present intake ;
- (c) By raising the water mechanically.

In view of the very slight fall of the Yellow River, the first solution is inadvisable, as it would mean excavating under not always easy conditions a very long and wide canal which would be liable to silt up owing to the low rate of discharge.

The second solution, which entails the construction of a weir, would also seem difficult and costly to execute. Apart from the very serious risks involved on account of possible changes in the course of the Yellow River upstream, difficulties would arise owing to the need for building some, at least, of the work on the loess (which can only carry small loads), and for protecting the bed from erosion lower down.

The solution, therefore, which would seem to be most convenient—from the purely technical standpoint of course—is to raise the water, after partial clarification, from the main canal mechanically by means of pumping-stations.

3. *Improvement and Completion of the Irrigation System.*

The irrigation system might be completely restarted and gradually brought into operation or extended to a part only of the area covered by the original scheme of the C.I.F.R.C.

The operations for improving and completing the irrigation system must therefore be regarded as confined to the part of the system strictly necessary for each solution.

These operations would include the dredging and re-modelling of the canals, the strengthening and, where necessary, raising of the dykes (to cope with the highest water-levels), the construction of new lateral and suitably planned canals to replace the present ones which are unusable, the reconstruction of existing works, and the construction of new works for drawing off and distributing the water, regulating levels, conveying the water across other canals, watercourses or roads, etc.

When a rational agricultural transformation, based on a reliable system of irrigation, has been effected, there will also be the construction of secondary distribution canals and of an adequate system of roads, in addition to the special irrigation works.

4. *Construction of a Drainage System.*

The evacuation of drainage water by gravity would be feasible only in a limited part of the central area and only at some periods of the year. In the case of the higher western section, if irrigation water is successfully brought there, the difficulties caused by the frequent inundations of the Yellow River will have to be overcome. In the eastern section, on the other hand, the only possible solution would seem to be to draw off the water by mechanical pumps.

The object here should, therefore, be to secure a lowering of the subterranean water-surfaces, which, even at present, are too high.

In any case, the establishment of an adequate drainage system for the whole district, properly designed on the basis of the topographical conformation, is an absolutely essential measure if agricultural transformation is to be effected by irrigation.

5. *Protection against Floods on the Yellow River and Mountain Streams.*

The construction of a stout dyke along the left bank of the Yellow River for a distance of several dozen kilometres should protect the land from periodical inundations. To solve the problem of protection against damage (inundations, silting and breaching of dykes) due to floods on the mountain streams intersected by the main canal would seem more difficult.

There is no need to consider syphoning the streams under the channel.

A preliminary clarification of the water from the torrents and its evacuation by means of a special *high-water* canal, approximately parallel to the main canal and utilising, if feasible, an old bed of the Yellow River, might be contemplated ; but such a solution would be difficult and costly.

6. Conclusions.

The above considerations lead us to the following conclusions :

- (1) In present circumstances, the Saratsi system does not irrigate the land and the works executed must be regarded as useless ;
- (2) To restart the system itself, while possible from a purely technical standpoint, would undoubtedly be very expensive ; its advisability should therefore be studied and must be decided in the light, not only of technical, but also—and mainly—of agricultural, economic, social and political considerations ;
- (3) The restoration of the irrigation system, if found advisable, can either be carried out in stages simultaneously with the economic development of the district or can even be restricted in extent and in utility.

In order to make the matter quite clear, we think it advisable to examine three solutions (which can also be regarded as three consecutive and gradual phases among the many possible phases of a final solution).

The work which each of these phases involves will be defined in order to enable the relevant expenditure to be estimated. This estimate will be based on the most optimistic assumptions both as regards confining the works to those most strictly necessary, and as regards the maximum value (particularly in respect to the irrigable area) of the works themselves. Hence, if the conclusion drawn from these estimates is that no solution is possible, that conclusion will be beyond question.

(a) *First stage*: Restoration on a small scale of a provisional system of irrigation. — This could be confined to a small part of the central area, *drainage being by gravity*. It would entail : reconstruction of the intake, of most of the main canal and some of the lateral channels (dredging and re-modelling), construction of a drainage system and partial protection against floods on the Yellow River and mountain streams.

The channels would be utilised as reservoirs (by being filled and emptied), and the water would be brought to the land by the individual occupiers, who would raise it by the primitive means used in the district.

Only in years of plenty and at certain times of the year could any large area be irrigated, but this would never exceed 100,000 mu (6,000 hectares). In ordinary years, such erratic irrigation would be confined to a third of the area and, as already stated, would be completely stopped when the water was low.

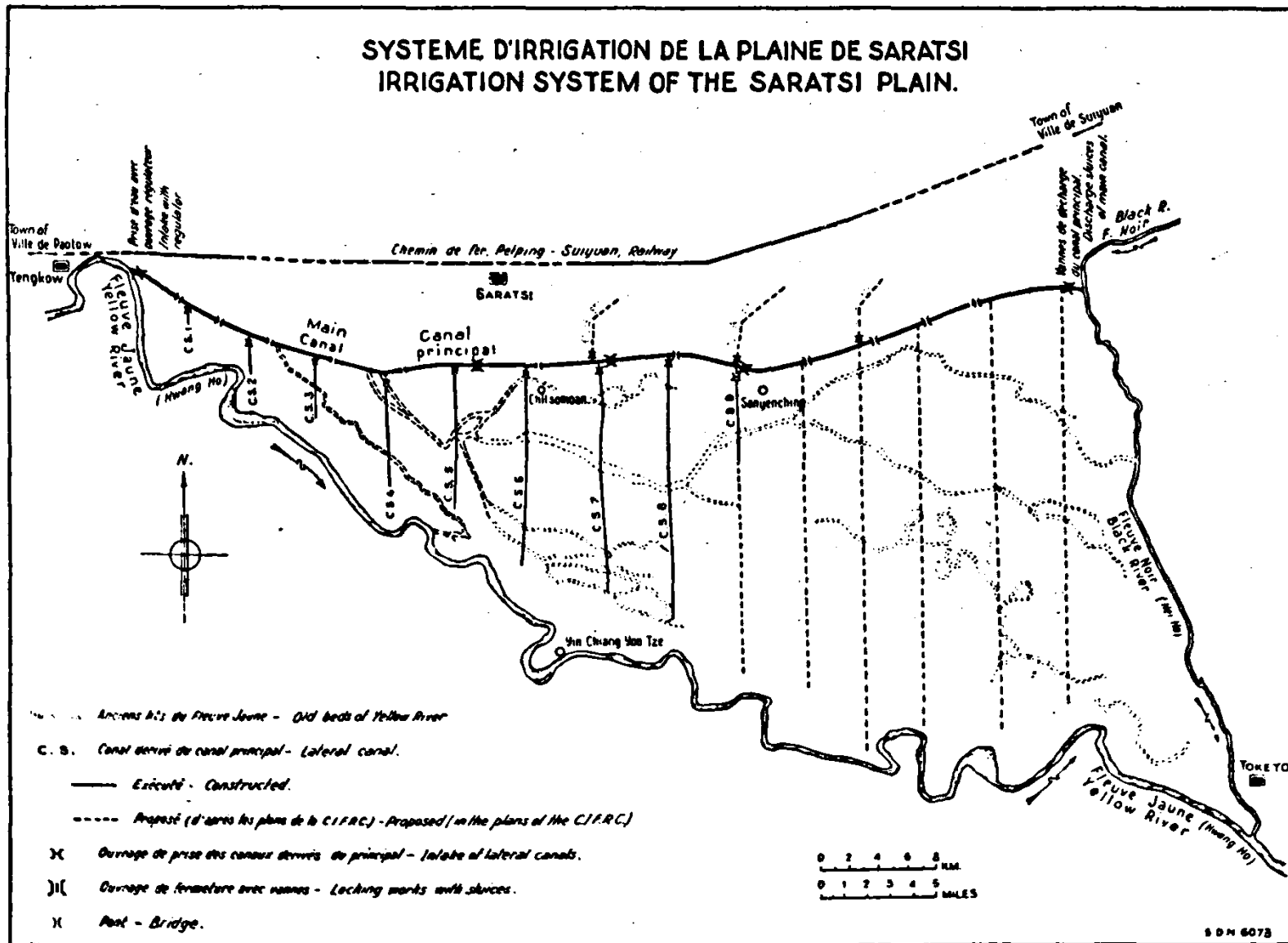
The cost, estimated on the basis of the principles already described, would not be less than 400,000 Mexican dollars. The annual cost of upkeep and operation would, however, be very heavy owing to the great length of the main canal, which is quite disproportionate to the area to be irrigated, while the resultant benefit to agriculture would be extremely small and uncertain.

(b) *Second stage*: Restoration of the system in the central area by systematic irrigation. — This would entail : a new intake, deepening of the bed and installations for clarifying the water ; improvements to the system of lateral canals in the central area and its completion, and also the construction of permanent works ; the creation of a drainage system with possible evacuation by gravity ; protection against floods on the Yellow River and mountain streams. It would further be necessary for the central organisation executing the works to defray the cost also of secondary canals and of the necessary system of roads.

The water would be raised mechanically by one or more central pumping-stations and the irrigation canals would be assured of constant discharge.

The volume of water annually available for irrigation would be sufficient to cover about 400,000 to 500,000 mu (25,000 to 30,000 hectares).

SYSTEME D'IRRIGATION DE LA PLAINE DE SARATSI IRRIGATION SYSTEM OF THE SARATSI PLAIN.



The cost, including that for the secondary canals, would not be less than 1,500,000 Mexican dollars. To the annual cost of upkeep and normal operation of the system would have to be added the cost of pumping the water, which, on the most favourable assumption of the cost of power, may be estimated at 15 cents per mu.

(c) *Third stage:* Complete rehabilitation of the irrigation system. — To the foregoing installations would have to be added a larger station for pumping irrigation water, the construction of systems of irrigation and drainage canals in the rest of the district and the installation of pumping-stations for the discharge of the drainage water.

The area which could be irrigated would amount to 1,600,000 mu (100,000 hectares).

The cost, including that for secondary canals, would not be less than 4,000,000 Mexican dollars.

The annual cost of the power for irrigation and draining may be estimated at 17.5 cents per mu.

Appendix.

A. BLACK RIVER.

The failure of the Saratsi scheme has caused great disappointment and discouragement everywhere in China, and particularly in Suiyuan, more especially as the province itself had incurred heavy expenditure for the purpose.

To meet the wishes of General Fon, who also acts as Governor, M. Omodeo devised a possible use for the waters of the Black River (a tributary of the Yellow River). If this scheme were carried out, similar results to those which it was hoped to obtain at Saratsi might be achieved; and it would also enable irrigation requirements to be met and drinking-water and electric power to be supplied to the capital of Suiyuan. Before any decision is adopted, the technical and economic factors involved in such utilisation must, of course, be exactly determined.

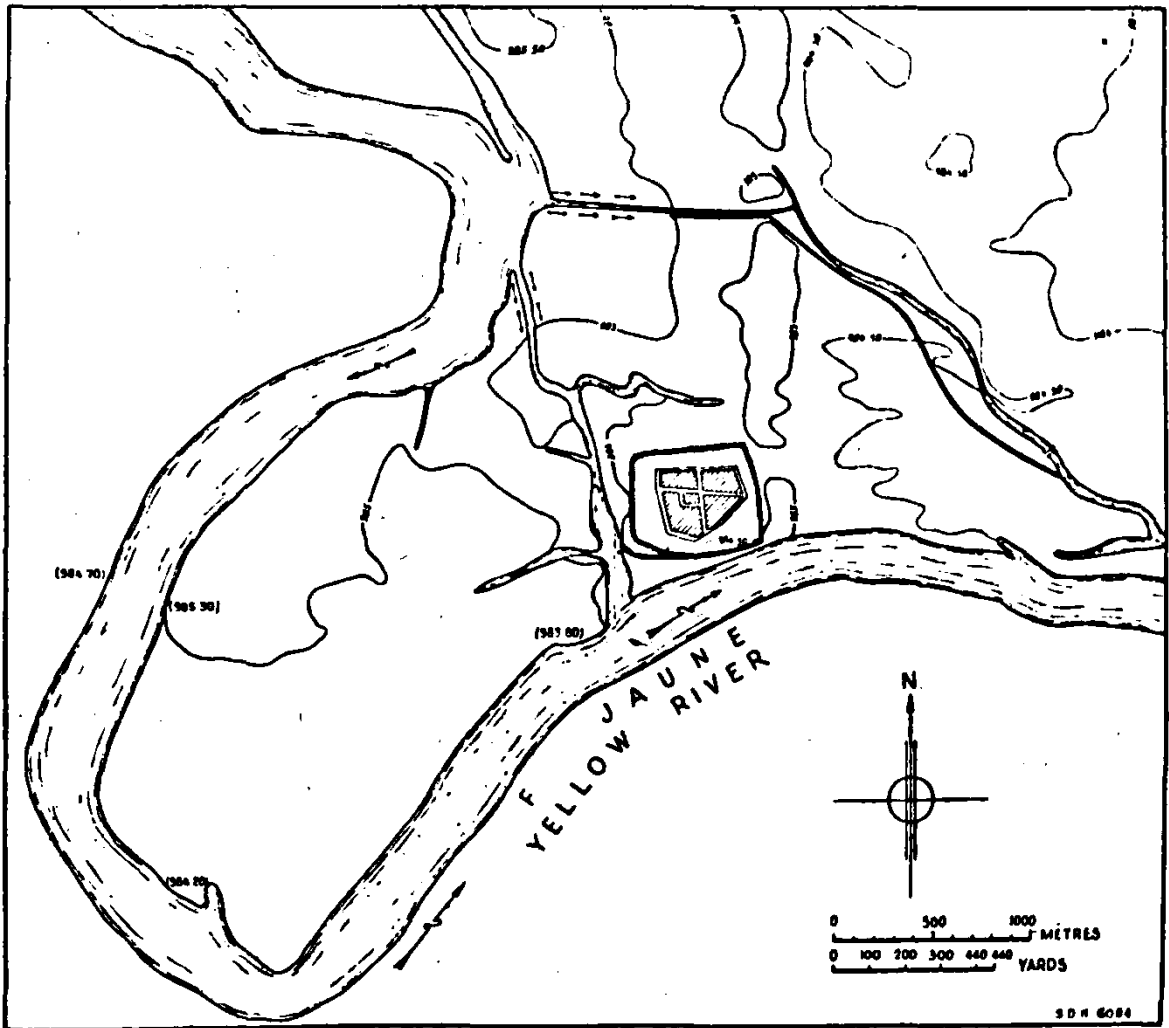
M. Omodeo has accordingly given instructions to have the necessary topographical, geographical and hydrological survey made.

B. ASSISTANCE TO THE VILLAGE OF YIN CHIANG YOO TZE.

This is a village of upwards of 1,000 inhabitants, situated inside a sharp bend of the Yellow River, on a peninsula bounded by water on two of its three sides. The river is gradually eroding the left bank at the foot of the peninsula, and a change in the channel is likely. The population is thus in constant and serious danger. A sudden violent flood might destroy the village in a few hours and give the inhabitants no chance of escape.

Nothing can be done to protect the village. The only solution is to leave it immediately and rebuild it elsewhere on a safe site.

VILLAGE OF YIN CHIANG YOO TZE.



V.

SHANSI : FEN HO.

At the request of the Shansi Provincial Government, the National Economic Council asked the Committee to report on the irrigation and flood prevention proposals submitted in January 1934 by the Chief of the Engineering Section of the Shansi Water Conservancy Commission.

Mr. Coode visited Taiyuan in February 1935 and spent several days inspecting the Fen Ho between Lantsun and Chieh Hsiu and interviewing the authorities and others interested. The Committee expresses its appreciation of the courteous and valuable assistance given by Professor L. H. Wang, who accompanied Mr. Coode throughout his investigations and supplied him with much useful information.

The proposals on which the Committee's advice is desired comprise :

(a) The construction of a masonry dam on the Fen Ho at Hsia Ching Yiu for the storage of irrigation water, at an estimated cost of 2,000,000 dollars ;

(b) The construction of reservoirs for a similar purpose near the three large natural springs at Chintze, Kwang Sheng Sze and Lung Tze Sze, at an estimated cost of 1,000,000 dollars ;

(c) The improvement of the four existing irrigation systems on the Fen Ho at Yung Li, Hsiang Ling, Changhow and Ho Tsiu, at an estimated cost of 500,000 dollars ;

(d) The regulation of the Fen Ho between Taiyuan and I Tang, at an estimated cost of 6,000,000 dollars ;

(e) The improvement of the lower reaches of the Wen Yu Ho with a view to flood prevention, at an estimated cost of 1,000,000 dollars.

In the matters both of irrigation and of flood prevention, much needs to be done in the watershed of the Fen Ho.

Owing to the comparatively low annual rainfall in this region—less than 12 inches (30 centimetres) in some years—improved methods of irrigation are greatly to be desired.

As regards flood prevention, the numerous migrations that have occurred from time to time in the courses of the Fen Ho and the Wen Yu Ho explain the necessity for the stabilisation of the river-bed.

With the possible exception of the Hsia Ching Yiu dam, the proposed irrigation reservoirs would exert a negligible influence on flood prevention. Moreover, the necessity for feeding the irrigation systems which draw their supplies from the river is a further reason for stabilising the river-bed in order to conserve the intakes and ensure their proper working.

From Taiyuan downstream for a length of approximately 115 kilometres to I Tang, history records many major alterations in the course of the Fen Ho, each accompanied by inundation of agricultural lands and much privation. In such circumstances, and for the reasons given in the two preceding paragraphs, it is essential to begin by stabilising the river-bed before incurring expenditure on irrigation systems which would be rendered inoperative should the river subsequently change its course owing to the absence of stabilisation works.

From its source in the north of Shansi Province to its confluence with the Yellow River near Ho Tsin, the Fen Ho has a length of some 450 kilometres and a drainage area of approximately 40,000 square kilometres. The annual rainfall at Taiyuan between 1919 and 1933 varied from 11 inches to 22 inches (28 to 56 centimetres), by far the larger part of which occurred in the months of June, July and August. The freshets rise with great rapidity, bringing down large quantities of silt into the plain, and generally subside within two or three days. In August 1933, a maximum flood discharge of 87,000 cusecs. (2,500 cubic metres) was recorded at Taiyuan and a silt content of 23% by weight (say 16% by volume) was then measured.

The Fen Ho enters the plain at Lantsun, about 16 kilometres upstream of Taiyuan, and it is proposed to re-align and endyke the river for 115 kilometres below the latter city. In principle, the Committee concurs with this proposal, and subject to the remarks submitted hereafter regarding improvement works at the natural springs, it is strongly of the opinion that the stabilisation of the river-bed over this length and wherever else necessary should take precedence over the other proposed works.

The Committee does not possess the data required to enable it to study questions relating to the preferable alignment to be adopted for the new bed: those questions can only be correctly answered after detailed surveys have been made and in the light of local conditions obtaining at the time when the work is carried out.

The Committee recommends, however, that further consideration should be given to the proposed arrangement of the dyke system.

Instead of a couple of dykes on each bank—an inner and an outer dyke as proposed—it would, in its view, be preferable and more economical to construct only one dyke on each bank, spaced at a greater distance apart than the two proposed inner dykes and with a more substantial cross-section. The distance between these two dykes should be fixed so as to ensure that the flood channel is large enough to prevent any appreciable rise in the flood-water level.

These two dykes might with advantage be supplemented by spur groynes facing upstream, so as to direct the flow towards the low, water channel, and set fairly high in the dykes.

These groynes, the cross-section of which should be as smooth as possible, should be protected throughout their entire length by good turfing, which should be kept in proper condition. They would serve to prevent the formation of secondary channels.

Their ends, placed at the limit of the low-water channel, should be carefully protected from erosion.

The Committee also considers that the proposed stone revetments on the inner slopes of the dykes could be safely omitted on all convex lengths and possibly on some of the straight lengths also. The thickness of the revetments should, however, be increased to at least 18 inches (45 centimetres) on all concaves, and in all cases the toe of the revetment should be protected with suitable mattress work.

The remainder of the slopes of the dykes, both inner and outer, should be carefully turfed and kept in perfect condition. The planting of trees on the dykes should be strictly forbidden.

The construction of fixed weirs on that part of the river passing through the plain should be prohibited as being likely to raise the flood-level and hence to make the position worse.

Movable dams are only permissible if the floor is sufficiently low and the run-off section long enough to prevent any change in the regime of the river.

On the other hand, on the upper part of the river and its tributaries, where the fall is rapid and the valleys are fairly narrow, and where the chief erosions occur, the construction of a series of small weirs or sills (in Italian, *briglie*) is to be recommended, in accordance with the standard technique for regulating torrents so as to stop the production of gravel.

As regards irrigation in the Fen Ho valley, the Committee does not consider that any lasting benefit can be obtained from a storage system deriving its supplies from the river, owing to the large amount of silting-up. The construction of the proposed storage reservoirs near the Chientze, Kwang Sheng Sze and Lung Tze Sze springs—which could be filled with clear water—could be of great utility in conserving for irrigation all the water which is now running to waste.

After the river course has been stabilised, the downstream irrigation systems supplied by pumping-stations should be reconditioned and completed wherever necessary.

The movable weirs are a modernisation of the old system of earth dams; they enable the river-level to be raised and the irrigation system to be extended when the river flow is sufficient, so as to fertilise a greater area of land. As stated above, these masonry dams should be constructed so as not to obstruct the passage of the flood water, but it is necessary that due notice should be given of the flood's advent, so that the gates can be opened in ample time.

In this connection, the Committee strongly recommends the organisation of flood-warning services, such as have been established in Western countries.

The sole purpose of the dam at Hsia Ching Yiu is to store water for irrigation.

The storage should occur only in the winter, when the silt content of the river discharge is low and the water is clear.

From this source alone, the normal spring flow of the river (100 to 150 cusecs., or 3 to 4 cubic metres per second) could be supplemented to provide a total flow of 400 to 450 cusecs. (12 to 14 cubic metres per second) throughout the spring and early summer.

During freshets, the sluices should be kept open to allow the silt to pass through.

If it is desired to use the whole of the flood water, which contains an enormous quantity of silt, a larger volume of water could of course be stored for the first few years after the completion of the dam, but if this is done, the available capacity is likely to become clogged up and the dam will thus be rendered useless.

A series of exhaustive local investigations should be carried out, chiefly from the geological standpoint — borings, embankments, levelling, etc. — to make sure that the proposed site is suitable for the construction of a dam under satisfactory conditions.

In any case, the Committee would draw attention to the estimated cost (2,000,000 dollars) of the work; having regard to the volume of masonry and the inaccessibility of the site, which will involve heavy expenditure for the transport of personnel, plant and materials, the cost appears to have been very much underestimated.

VI.

HSIAOCHING HO — PROPOSED IMPROVEMENTS.

The Hsiaoching Ho has a length of 233 kilometres from Tsinan to the sea. The sand bar at the mouth is one kilometre in width and the depth of water thereon at low tide is only 0.6 metre. The rise of spring tides is 3.4 metres. The effect of the tide is felt for about 60 kilometres upstream from the mouth.

It is proposed to regulate the river by means of dredging on the bar and upstream, and the construction of six locks—the two furthest upstream near Tsinan have already been completed—to allow barges of 200 tons burthen to reach Tsinan, larger vessels up to 3,000 tons being enabled to navigate about 18 kilometres up from the mouth, and 600-ton vessels still further.

As training works are considered too expensive, it is proposed to employ a suction dredger to obtain an increased depth of water over the bar and subsequently to obtain greater depth in the lower reaches of the river. In these circumstances, the bar will probably require continuous maintenance dredging.

The two completed locks were inspected by Mr. Coode in February 1935 and appear to satisfy the requirements but, as in the case of the new locks on the Grand Canal, no provision has been made for maintaining craft in the central part of the lock when locking down and preventing them landing on the side slopes (see Chapter IX : "Hwai River").

* * *

REPLIES TO THE QUESTIONS PUT BY M. WOODSON WANG.

1. The Committee agrees with the Yellow River Commission that it would be inadvisable to connect the waterway of the Hsiaoching Ho with the Yellow River.

2. Until all the conditions at the mouth have been investigated, it is impracticable to lay down the preferable method for its treatment, whether by training works or by dredging, or a combination of these means. It can be stated, however, that the construction of a lock so near the mouth as to interfere with the free propagation of the tides up the river would be very undesirable because it would reduce the natural flow of the flood and ebb tides.

3. Except for the point referred to above, the design of the locks appears to be satisfactory.

4-6. The information needed for a reply is not in the Committee's possession.

VII.

NORTH CHINA RIVERS.

The present position in regard to the North China rivers and the Hai Ho outlet to the sea has been discussed with the authorities, and the Committee has been furnished with the latest information in connection therewith.

A radical scheme for the improvement of the conditions in these rivers and outlets was published by the Chihli River Commission in 1925; it comprised a programme of works estimated to cost 53,510,400 dollars, of which the improvements to the Yung Ting Ho were to have absorbed 32,795,900 dollars.

These proposals, however, were not proceeded with, largely owing to the outlay involved, and in 1928, the conditions in the Hai Ho having further deteriorated, mainly due to the silt brought in by the Yung Ting Ho, a "palliative" scheme was put forward under which the flood waters of the latter and the Pei Yun Ho would, when heavily charged with sediment, be diverted over the low-lying areas to the east of the Peiping-Liaoning Railway, so that the silt would be deposited and the clear water carried off, partly through the Chin Chung Ho and partly to the Hai Ho.

For one reason or another, this palliative scheme was not started until 1931, since which date it has undergone many modifications, induced by the opposition of the landowners affected, and is not yet finally completed. The Committee also understands that on various occasions the local farmers obstructed the execution of the scheme, which has only been partly carried out, and also the utilisation of the completed works, with serious detriment to the regime of the Hai Ho.

To obtain the fullest possible results from this palliative scheme, further low-lying areas, in addition to those already earmarked, should be employed as settling basins. Moreover, the requisite works would have to be undertaken in the Yung Ting Ho delta to lead the silt-laden flood waters to these settling basins. A study of the conditions in the three existing channels across the delta shows that, for this purpose, the north channel has great advantages over the other two.

The various means proposed for achieving the desired results may doubtless arouse opposition in several directions, but it should be borne in mind that the navigable conditions on the Hai Ho, involving as they do the prosperity of the port of Tientsin, are of paramount importance to North China.

In these circumstances, if it be decided to proceed with the requisite works, the Committee considers that the questions remaining to be solved in connection with the satisfactory completion of the palliative scheme and its efficient operation are not such as to require technical advisers so much as the appointment of a body with plenipotentiary powers to lay down definite lines for the completion of the work after all the necessary investigations have been made to carry out that programme and to control the operation of the system thereafter.

Although by these means it is probable that, for a few years, further deterioration in the Hai Ho can be arrested and possible that the situation can, for a time, be

improved, there is always the chance that, even if tremendous efforts are made and enormous expenditure is incurred, no final solution may be found. Moreover, the Hai Ho problem is not an ordinary problem of river hydraulics, the phenomena being of a geological nature; the shallowness of the sea-bed for dozens of kilometres in the Bohai Gulf, in particular, is a very important and extremely unfavourable factor, and one which may perhaps make any solution impracticable.

If, on the other hand, it be concluded that the requisite palliative works cannot, owing to the disturbance caused to and by the farming population, be expediently carried out, the only remaining alternative appears to be to proceed in the immediate future with the following works in the upper reaches of the Yung Ting Ho, so as to give a measure of relief from the existing difficult conditions in the Hai Ho.

A modified radical improvement scheme for the Yung Ting Ho was proposed by the North China River Commission in 1934. This scheme comprises the following works :

- (a) The construction of detention basins at Kuang Ting and Tai Tze Mu ;
- (b) The reconstruction of Lu Kou Chiao weir as a regulator and the repair of the Chin Men Chia weir ;
- (c) The regulation of the river, including the repair of dykes ;
- (d) The improvement of the outlet ;
- (e) The construction of check dams on the upstream tributaries, the Yang Ho and the Sang Kan Ho ;
- (f) The disposal of silt on the alkaline lands along the banks of the river.

The total estimated cost of these works amounted to 20,668,600 dollars.

Generally speaking, these proposals should, in their cumulative effect, be of some benefit for a number of years, both by mitigating floods and reducing the silt carried into the Hai Ho.

The construction of the proposed detention basins at Kuang Ting and Tai Tze Mu would undoubtedly, for a small number of years, have an appreciable effect on the flood peak and silt content downstream, with a corresponding beneficial reaction on the navigable conditions of the Hai Ho. It would not be long, however, before silting-up occurred in these basins. Owing, therefore, to the rapid deterioration in storage capacity to which the basins would be subjected by the deposit of silt therein during floods, the expense of their construction hardly appears to be justified. It is true that the League of Nations Mission of 1932 gave its approval to the construction of a detention basin at one or other of the two proposed sites, but it had not at that time been apprised of the heavy silt content in the flood waters at these upstream positions.

On the other hand, the Committee considers that all measures which will serve to reduce the Hai Ho deposits will help to maintain the depth of the channel leading to the port. The Committee accordingly considers it essential that the study of the other works on the improvement programme drawn up by the North China River Commission should be continued.

Among these measures may be mentioned the reconstruction of the existing movable weir at Lu Kou Chiao as a regulator and the repair of the Chin Men Chia sluices, which will enable a portion of the flood discharge to be diverted from the lower reaches of the Yung Ting Ho into the Hsiaoching Ho with less damage to the latter than it now suffers from the uncontrolled weir at Lu Kou Chiao.

Similarly, all measures for the disposal through diversion sluices on both banks of the river of a portion of the flood waters will have the twofold benefit of reducing the flood discharge downstream and fertilising the alkaline lands alongside.

In principle, the Committee concurs in the proposal to build comparatively shallow dams on the upper tributaries of the Yung Ting Ho, which will have the twofold effect of keeping back the alluvial deposits and *concentrating the fall at the weirs and sills*, and also of reducing the velocity of the discharge, as advocated in the case of the Fen Ho. As to the question of constructing detention basins at Kuang Ting and Tai Tze Mu, this should await reconsideration as the result of the experience gained of the effect of these dams.

In addition to the improvement works referred to above, the whole length of the bed should be stabilised after the river has reached the plains by the construction of groynes and bank protection works at suitable places and by the repair and strengthening of the existing dykes.

Although it does not appear to form a part of the North China River Commission's 1934 radical improvement scheme, the study of the proposed Tu Liu flood escape channel to the sea should be continued.

To assist in the drainage of the Ta Ching Ho valley into which the waters from the Hsiaoqing Ho discharge, it has been proposed to provide an improved outlet by cutting a new channel from Tu Liu on the Ta Ching Ho to a suitable point on the Hai Ho downstream of Tientsin.

Such a scheme could be contemplated only if subsequent studies show that it would not be detrimental to the situation in the Hai Ho, and with the approval of the competent authorities.

VIII.

THE KUANG TING RESERVOIR ON THE YUNG TING HO (HOPEI).

The hydraulic improvement works on the Yung Ting Ho and the other chief waterways in Hopei and, in particular, the protection of Tientsin city and harbour from the dangers of floods and silting constitute a serious and urgent problem the solution of which was considered first by the Chihli River Commission (1917-1928), and subsequently by the North China River Commission (N.C.R.C.). In 1929-1930, the latter drew up a general plan (Radical Improvement Scheme) for the final regulation of the Yung Ting Ho.

In 1932, *on the basis of a study of existing documentary material*, a League of Nations Committee of Experts reported, favourably on the whole, on the scheme, more particularly on the advantages of constructing reservoirs.

In January of this year, M. Omodeo visited the district of Kuang Ting, where the above improvement scheme suggests that an artificial reservoir should be constructed.

The inspection thus carried out and a preliminary study of the documents then supplied enabled him to form an accurate idea of the problem of the Kuang Ting reservoir *taken as a separate project not connected with the other improvement schemes*. Owing to the short time available, he was unable to extend his investigation beyond the limits indicated.¹ Discussions and exchanges of views followed with the Chinese engineers dealing with the problem. In the course of these discussions, M. Omodeo stated, on the basis of the data which were supplied to him, but which he was at that time unable to check, his preliminary views and suggestions as to the *conditions under which the reservoir could be constructed* near Kuang Ting, as distinct from the part it would have to play in the general improvement scheme. One of the chief aims of the suggestions made was to direct the attention of the engineers to factors of basic importance which had been inadequately treated in the N.C.R.C. scheme and to encourage further investigations and comparative studies, so as to have material for judging the question both in its technical and economic aspects. The more exhaustive documentation since collected (due also to the results of the studies undertaken on the advice of the League's expert) and the ampler time at his disposal now enable him to make a more detailed and thorough examination of the problem of the Kuang Ting reservoir and also to consider, at any rate in its main lines, the part assigned to the reservoir in the general scheme of regulation. The conclusions reached by the Committee are given below; these confirm, from the point of view of the methods to be followed for the eventual construction of the Kuang Ting reservoir, the

¹ According to the Commission's instructions, the complete study of the problem should have been carried out by the Committee as a whole, which would have divided up the various tasks. As, however, the other members of the Committee were not present on the date fixed, the local investigation was made by M. Omodeo, as stated in the report.

impressions derived from the first cursory examination made, but prove also that the effect of the reservoir would be rather restricted unless it is supplemented by other works as part of the general scheme of improvements proposed.

I. GENERAL.

Before describing the improvement scheme proposed by the N.C.R.C., it is necessary to mention the fundamental topographical and hydrological features of the Yung Ting Ho.

The information on this subject is taken chiefly from the English documents of the N.C.R.C.¹ and from the tables annexed to the original report in Chinese on the regulation of the Yung Ting Ho, a report which it was not possible to use. A direct impression of the morphological, and to some extent also of the geological, situation of the middle section of the river was also obtained by a hurried visit to the spot.

1. *Course of the Yung Ting Ho.*

The principal tributaries of the Yung Ting Ho are the Yang Ho, which flows down from the Mongolian plateaux, and the Sang Kan Ho, which rises in the Wu Tai Shan mountains; the Wei Sui Ho is of less importance. Great stretches of the mountain basins of the tributaries are covered with *Kuang-tu* (loess) and alluvial deposits of various kinds.

About three kilometres below its junction with the Wei Sui Ho, where the catchment basin has an area of 45,000 square kilometres, the Yung Ting Ho enters a narrow rocky (calcareous) canyon with steep walls, more than 100 kilometres long. Here the river-bed falls from a height of 340 metres to about 100 metres—an average of approximately 2.4‰. At the upper end of the canyon—*i.e.*, where the large natural reservoir situated at the junction with the Wei Sui Ho ends, is the Kuang Ting gorge; at the lower end is San Chia Tien, 160 kilometres distant from the confluence of the Yung Ting Ho and the Pei Yung Ho. The river continues to fall steeply up to near Lu Kou Chiao, after which the slope gradually diminishes to about 0.8 to 0.35‰ at the so-called “delta”, just below Shuang Ying. The Yung Ting Ho flows into the Pei Yung Ho, which is then continued through and beyond the city of Tientsin and as far as the sea by the Hai Ho, which forms the so-called “Port of Tientsin”.

2. *Solid Matter conveyed and Deposits.*

Great quantities of silt are carried down at flood time, a maximum of 38% by weight having been registered.² The river leaves abundant deposits in the “delta” (a kind of overflow area created to act as a simple regulator of discharge and to clarify the water), and along the Hai Ho. A comparison of the figures for the “delta” in 1921 and 1927 would give the average annual quantity of deposits as about 25 million cubic metres. Allowing for the fact that deposits are also formed along the bed of the river and in fields submerged by the floods above the “delta”,³ the total amount of

¹ The “Abridged Report on the Radical Improvement Scheme for the Yung Ting Ho” (Tientsin), 1934: “The Kuang Ting Detention Basin Project”, by C. Y. Kao (Tientsin), July 1934.

² The method and the instruments used are not above criticism and the correctness of the results is consequently rather doubtful.

³ It is pointed out in this connection that flooding only occurs below Lu Kou Chiao.

silt deposited annually is estimated at 30 million cubic metres. This estimate is open to rather serious doubt, particularly as regards the amount deposited during floods; in the opinion of the undersigned, this should be much greater.

3. *Extent of the Floods.*

The volume of water discharged and the amount of solid matter conveyed have been observed, particularly in the Kuang Ting sector, where records have been kept of the regime of the floods. The figures for some of the more serious floods at Kuang Ting, San Chia Tien and Lu Kou Chiao mentioned in the report ¹ of the N.C.R.C. already referred to are appended. These figures sometimes differ very considerably from those to be obtained from the graphs annexed to the original report in Chinese.

Flood of	Sector of			Contributed by the basins between the sectors of Kuang Ting and San Chia Tien (1,730 square kilometres)
	Kuang Ting (43,300 square kilometres)	San Chia Tien (47,030 square kilometres)	Lu Kou Chiao	
July 11th to 13th, 1924 :				
Maximum discharge in m ³ /sec.....	4,300 ^a	5,200	4,900	2,600
Volume of water in millions of cubic metres.....	360	540	425	180
July 16th to 18th, 1929 :				
Maximum discharge in m ³ /sec.....	2,100	2,000 ^a	2,650	2,000
Volume of water in millions of cubic metres.....	150	30	205	30
August 1st to 3rd, 1929 :				
Maximum discharge in m ³ /sec.....	1,200	4,200	4,000	3,700
Volume of water in millions of cubic metres.....	207	290	400	183

It is not clear how the contribution of the basin between the Kuang Ting and San Chia Tien sectors has been calculated. The method referred to in the N.C.R.C. report seems inadmissible.

The Committee considers that the fullest reservations must also be made as to the correctness of the figures of maximum discharge in the various sections and the shape of the flood wave—phase of fall as rapid as phase of rise. The estimate of the amount of water which flows off during a flood is probably erroneous as a result of the form attributed to the wave itself.

¹ "Abridged Report on the Radical Improvement Scheme for the Yung Ting Ho."

^a The graphs show 5,750 m³/sec.

^b The graphs show 3,000 m³/sec.

The estimate of the maximum discharge in the case of catastrophic floods—which must be taken into account in examining the works—has been computed by the Chinese Services (N.C.R.C.) on the basis of (1) the amount of rain falling during a storm of the same intensity as that of July 15th to 17th, 1924 (which passed over the Lin Min Kwan), with its centre of maximum rainfall between Kuang Ting and San Chia Tien and (2) the highest presumable figures for the coefficient of discharge.

The following figures for a catastrophic discharge were obtained in the various sectors :

At Kuang Ting : 8,000 m³/sec. (volume of water during the flood : 670 million cubic metres) ;

At San Chia Tien : 10,200 m³/sec. (volume of water during the flood : 1,020 million cubic metres) ;

At Lu Kou Chiao : 9,800 m³/sec. (volume of water during the flood : 1,070 million cubic metres).

The contribution of the basin between Kuang Ting and San Chia Tien has been taken at 4,900 m³/sec. (volume of water : 350 million cubic metres).

4. *Silting and Flooding.*

The chief damage caused by the Yung Ting Ho floods under present circumstances is the silting-up of the Hai Ho (Tientsin could be regarded as impracticable as a port for large vessels, even in 1926), and the raising of the level of the river-bed above and through the "delta", with the flooding incidental thereto. Among the most disastrous floods may be mentioned those of 1917 (Tientsin was then flooded), of 1924 and of July 1929, due to the bursting of a dyke above Chin Men Chia. In its lower course, the river-bed is 3 to 6 metres above the level of the surrounding fields, and the dykes below Lu Kou Chiao have been breached on many occasions.

The flooding is apparently attributable to the low discharge capacity of the river channel below Lu Kou Chiao ; *this capacity is estimated at 2,700 m³/sec. up to Chin Men Chia, 2,000 m³/sec. between Chin Men Chia and Shuang Ying and 1,000 m³/sec. below Shuang Ying.*

There is a diverting spillway at Lu Kou Chiao with a capacity of 1,000 to 1,400 m³/sec. ; the water thus discharged spreads over the land beside the Hsiaoching Ho and the Ta Ching Ho, and is carried off by these watercourses. There is a similar spillway, but with a capacity of 200 to 600 m³/sec. near Chin Men Chia.

II. GENERAL IMPROVEMENT SCHEME FRAMED BY THE NORTH CHINA RIVER COMMISSION.

1. This scheme has the following objects :

(a) *Reduction of maximum flood discharge* : In view of what has been stated, a discharge of 3,000 m³/sec. above Lu Kou Chiao must be regarded as *dangerous* ; a greater volume must inevitably lead to flooding ;

(b) *Defensive measures against deposits* which cause the silting-up of the Hai Ho.

2. The scheme includes the following works :

(a) Construction of flood detention reservoirs on the Yung Ting Ho in the districts of Kuang Ting and Tai Tze Mu ;

(b) Diversion of some of the flood water through the Lu Kou Chiao and Chin Men Chia spillways, after they have been adapted to the purpose ;

(c) Improvement of the lower reaches of the Yung Ting Ho and widening of the Pei Yun Ho by dredging below its junction with the Yung Ting Ho ;

(d) Reafforestation of the mountain slopes and construction of detention reservoirs on mountain feeders, so as to lessen the amount of solid matter conveyed ;

(e) Warping of the natural depressions in the lower section of the river near Tientsin, by means of silt.

III. THE KUANG TING RESERVOIR.

Of the measures above referred to, that which is considered by the N.C.R.C. to be of primary importance and to call for the promptest execution is the construction of the reservoir near Kuang Ting on the Yung Ting Ho. It has therefore been decided to construct it as soon as possible and to give it preference over other works.

On the site of the dam, the river-bed has an elevation of about 439 metres.

The dam proposed in the N.C.R.C. scheme is provided with three discharge culverts with a total surface of 70 square metres and is of the spillway type with a peak elevation of 466 metres. Two variants have been considered, a "gravity" dam and one of the arch type (the latter has been discarded).

Even during the highest floods that can be foreseen, the water-level in the reservoir should not exceed 469 metres. When the reservoir is at its fullest, the amount of water escaping over the dam is estimated at 1,000 m³/sec., and that evacuated through the bottom culverts at more than 1,300 m³/sec.

The reservoir capacities corresponding to the elevations of 466 and 469 metres are 330 and 460 million cubic metres respectively.

By means of the reservoir it should be possible to reduce the flow in the sector below Kuang Ting to 2,300 m³/sec. or less, even if the flood proved to be the most catastrophic conceivable, with maximum discharges estimated by the N.C.R.C. at about 8,000 m³/sec.

In view of the capacity-limits of the river-channel below Lu Kou Chiao already mentioned and of the spillway there, a discharge of 2,300 m³/sec. should not have any dangerous consequences so long as the inflow from the lower basin does not exceed about 1,400 m³/sec., seeing that the total capacity of the channel and the spillway is about 3,700 m³/sec.

I. *Examination of the Works proposed by the N.C.R.C.*

The Committee will later study the conditions governing the operation of the reservoir and its value ; these are factors of primary importance in deciding whether or not the said reservoir should be constructed.

The following are briefly what the Committee considers to be the chief objections to the type of works proposed for the construction of the Kuang Ting reservoir :

(a) Incompatibility of the elevation of 466 metres above sea-level estimated for the overflow sill with the *necessity—as pointed out by the local authorities—to safeguard the town of Hwailai and the Peiping - Suiyuan railway* against possible damage from water, even in the case of the heaviest floods conceivable, and the impossibility, in the view of those authorities, of moving the railway and shifting the town. — The figure assumed for the maximum level in the reservoir (469 metres above sea-level) gives a *negligible margin* of safety as regards the town and railway in their present positions. This margin must be deemed quite inadequate, particularly if it

is borne in mind that the estimate of the volume of catastrophic floods is always uncertain (in the present case it seems to be an underestimate, as will afterwards be explained) and that the above margin must form a guarantee against the inevitable uncertainty of estimates.

To increase the margin of safety sufficiently, the fixed discharge sill must be given a lower elevation and movable detention works (sluice-gates) introduced above it, which would be lowered during floods. This would give every possible guarantee that the maximum level of water would not exceed the elevation of 469 metres assumed in the N.C.R.C. scheme.

(b) Inutility of the fixtures proposed to be placed at the foot of the dam for breaking the force of the water discharged and preventing possible scouring. — The suggestion to put a serrated ridge 40 to 60 metres distant from the foot of the weir must be regarded as absolutely unsuitable and might even justify serious apprehensions of possible damage to the structure.

By giving the water-cushion at the base of the overflow face the rational conformation which technical experience suggests, it would be possible to ensure satisfactory operation and also to keep the defence works within reasonable limits.

(c) The section suggested for the lower side of the dam is not in conformity with the results of the most up-to-date experimental research.

(d) The shape and dimensions of the bottom culverts, provided they are still to form part of the dam itself, must be altered if they are to work better and not endanger the stability of the structure.

(e) The arrangement adopted for diverting the water by means of a lateral tunnel while the dam is being constructed must be reconsidered. — If it is not proposed, when the work is finished, to use this tunnel as a discharge conduit, consideration should be given to the advisability of constructing the dam in separate vertical sections, so that the water could be drained off while the work is in progress.

(f) No works or fixtures have been proposed for strengthening the foundations and making them watertight. — The latter will, in all probability, have to be carried much deeper than proposed. Moreover, in view of the results of further geological research and the measurements made of permeability, special consideration should be given to the importance of injecting cement into the foundation soil, this being essential both on the bed of the channel and on the sides.¹

Finally, in view of the conditions under which the reservoir would operate, the Committee's expert felt that consideration should be given to the possibility of changing the site of the dam to below Kuang Ting. He then suggested that in studying the various localities where the dam might be located, account should be taken of the advisability of placing the spillway and the culverts *outside and alongside the dam—i.e., on and through the banks*. Any opinion formed would, of course, have had to be conditional on a comparative study of the technical and economic results which the short space of time available made it impossible to obtain at the moment, and which

¹ The Committee is not in a position to examine the stability conditions of the section chosen for the dam, in view of the absence of information regarding the hypotheses taken as a basis for the calculations and the fact that, if it is decided to carry out the work, a *fresh study* of it will have to be made in the light of the suggestions and principles which alone can give the absolute guarantees essential to stability and proper working. An examination of the conditions of stability, once suitable bases of calculation have been established, forms part of the ordinary preparation of the scheme.

have since been deduced—too hurriedly, the expert thinks—by the engineers of the N.C.R.C.

According to their investigations, the additional structural security obtained would not compensate for the greater financial outlay. Assuming, with all the relevant reservations, that this is so, sufficient guarantees for stability and proper operation can, as already indicated, be secured with a less costly structure and on the basis of a properly planned scheme.

In conclusion, on the single point of the *possibilities and conditions governing the construction of the Kuang Ting reservoir treated by itself*, the Committee finds :

(a) That the natural topographical and geological situation of the Kuang Ting gorge is favourable and of such a nature that ordinary technical precautions are sufficient to ensure the proper construction of the dam ;

(b) That the details of the dam proposed by the N.C.R.C. do not serve the purpose and must therefore be re-examined in accordance with proper technical principles and ideas, particularly as regards limiting the amount of maximum inflow at flood time, preventing water flowing over the top of the dam (by means of suitable discharge tunnels and spillways, rational planning of the bottom culverts and careful preparation of the foundations, which must be enlarged and strengthened) ;

(c) That, naturally, the resulting expenditure will be greater than estimated.

2. *Conditions governing the Working of the Reservoir, its Utility for the Purposes which it was to serve according to the Scheme of the N.C.R.C.*

The Committee thought it advisable to consider also whether, and if so to what extent, the Kuang Ting reservoir could serve the purposes assigned to it in the N.C.R.C. improvement scheme.

In this connection two main kinds of considerations have to be taken into account, the first relating to the flood mitigating effect of the reservoir and the second regarding the reduction of its capacity due to silting.

(a) *Flood-mitigation Effect of the Reservoir: Estimate of the Volume of Water brought down to Kuang Ting at Flood Time.* — A preliminary observation which may entirely upset the calculations made by the N.C.R.C. regarding the mitigating effect of the Kuang Ting reservoir relates to the estimate of the maximum volume of water flowing into the reservoir at flood time.

If the volume had been correctly calculated in the studies made by the N.C.R.C., it would have been possible to adopt less unfavourable conclusions than the Committee is now obliged to formulate.

Even as things are, the wide valley above Kuang Ting acts as a reservoir which diminishes floods by storing, during their occurrence, a large volume of water. If the largest volumes of water are to be evacuated through the Kuang Ting Gorge, which acts as a spillway, the water-level must rise very considerably and form a veritable temporary lake. Consequently, the flood water drained off which is observed in the Kuang Ting sector is already really smaller in volume because of the storing above referred to, and is less considerable—although the amount varies—than the volume of water which flows into the huge basin and changes it, as stated, into a regular temporary lake.

In the documents supplied, the figure of 5,700 m³/sec. is given as the maximum volume of *discharge observed at Kuang Ting* during the July 1924 flood (the greatest

in living memory). It must consequently be considered that this volume (if accurately *observed*) is actually the volume of the efflux of water at Kuang Ting.¹

Moreover, according to the graph of discharge given in the N.C.R.C. scheme for the Kuang Ting sector, a discharge of 5,700 m³/sec. should correspond to a level of about 462 metres (and therefore equivalent to a water-level in the sector of about 23 metres). The volume of water stored as a result of this elevation in the lake thus naturally formed upstream amounts to about 170 million cubic metres. This means that, even in present circumstances, it is possible to regulate floods to a very considerable extent—*i.e.*, to the extent of more than half of what would be obtainable under the proposed improvement scheme with the water-level at 466 metres (330 million cubic metres).

Taking the volume of discharge through the Kuang Ting sector in the nine hours of the rising phase of the flood (from 10 p.m. on July 12th, 1924, to 7 a.m. next day) at 110 million cubic metres, it may be inferred that the volume of *inflow* in the same period only into the Kuang Ting sector was certainly about $110 + 170 = 280$ million cubic metres. The maximum figure of *inflow* must therefore have been (judging by a rough cursory calculation) *more than double* that of the outflow as observed at Kuang Ting. The regulating effect of the artificial reservoir once the exit has been partially blocked and the sill elevated by means of a dam—*i.e.*, once the cushion effect already *existing* has been artificially enhanced—*must be studied in the light, not of the outflow at Kuang Ting amounting to 5,700 m³/sec., but of the actual inflow, which can be estimated at more than double.*

In other words, if the Kuang Ting reservoir had existed at the time of the 1924 flood there would have been additionally available for securing greater regulation, not the total capacity of the reservoir, but only the difference between it and the capacity of the temporary lake actually formed as the result of the flood—*i.e.*, about half.

The above conclusion, no trace of which is to be found in any of the studies made, shows that the estimates as to the working of the Kuang Ting reservoir are vitiated by a serious error of fact.

As a matter of fact, the estimates have been based on a discharge of 8,000 m³/sec. as the maximum conceivable for a flood of catastrophic proportions, whereas the above remarks show that, in the 1924 flood, the above figure must have been greatly exceeded.

Moreover, it should be borne in mind that the 1924 flood by no means represents the *maximum maximorum* discharge of the river and that rains may occur capable of causing a flood far worse than that of 1924.

The investigations must therefore be based on a much higher flood discharge, in which case, the effect claimed for the Kuang Ting reservoir of reducing the flood volume downstream to below 2,300 m³/sec. (corresponding to the maximum capacity of the lower channel of the Yung Ting Ho) is not obtained. *The anticipated utility of the Kuang Ting reservoir as at present planned is therefore very limited, and much lower than what is required, while, after its construction, there would still be a grave danger of floods.*

There is another conclusion to be drawn as to the value of the Kuang Ting reservoir, if built separately, in limiting downstream floods.

The contribution of the basin between the sectors of Kuang Ting and San Chia Tien, covering an area of 1,700 square kilometres, would, according to the estimates in the N.C.R.C. report (the correctness of which, however, must be seriously questioned), be very considerable; for the August 1929 flood, it amounted to 3,700 m³/sec. and may be taken at 4,900 m³/sec. for a catastrophic flood.

¹ The Committee's expert found in the documentation itself no statement or opinion which would justify the contrary assumption.

It has been seen that, in the lower channel of the Yung Ting Ho, the capacity of the river-bed must be taken at about 2,300 m³/sec. ; it follows that, even allowing for the fall in the flood peak which occurs downstream as far as Lu Kou Chiao, the volume of flood water due only to the basin below Kuang Ting would lead to the bursting of embankments and the flooding of the countryside.

The presence of the Kuang Ting reservoir could not, of course, prevent disasters in such extremely serious circumstances, but only limit their extent to a degree that is hard to determine but which would certainly be *small*. It would, however, be effective in the case of smaller floods which, as is well known, are much more numerous.

(b) *Reduced Capacity due to Silting.* — The situation of the Yung Ting Ho differs from that of other watercourses where flood detention reservoirs have been adopted, owing to the large amount of deposit which is carried down and which can lead to the silting-up of the reservoirs sooner or later, thus reducing their capacity.

Judging from the information in my possession, the N.C.R.C. scheme sometimes credits the Kuang Ting reservoir with a probable life of three hundred years, while, at other times, it assumes a definitive 30% reduction in the useful capacity.

The Committee does not know the grounds for these assumptions, but thinks, in any case, that no estimates can, with certainty, be made of the probable life of the reservoir, when, as in the present instance, it is merely a question of the delaying effect brought about by the reservoir and therefore of taking into account the decanting action due to a reduction in speed. It considers it proper, therefore, to draw inferences only on the basis of past experience of similar cases and to *display the greatest prudence*.

As the amount of sediment at present deposited annually in the lower channel is estimated at 30 million cubic metres (as already stated, this is probably an underestimate), we must anticipate, even allowing for the fact that some of this deposit is due to the very limited area of the basin below Kuang Ting (size unknown), a loss of capacity probably much more rapid than that stated, and one which would seriously *reduce the utility of the reservoir within a few decades*.

It must also be borne in mind that, as a result of the natural conformation of the Kuang Ting basin, the elevation of the water and its contact with the vertical walls of loess surrounding the proposed reservoir will cause frequent and extensive landslides.

It may be mentioned in this connection that, in order not to omit anything which might technically improve the operation of the structure and the reservoir, the expert advised the local engineers, when he discussed matters with them, to see whether, if the weir were shifted to a point further downstream between the rocky gorges, this would give, in the section of the stream which has a greater fall, a capacity large enough to moderate the smaller but more frequent floods. This would be of interest from the point of view of the reduction of silting.

An opinion on this point would, of course, be conditional on a comparative study being made of the technical and economic data collected and worked up by the N.C.R.C. engineers.

An investigation based on the first results secured leads the Committee to believe that the larger expenditure due to substantially increasing the height of the dam—essential to obtain even a moderate storage capacity in the canyon below Kuang Ting—is not compensated by the advantages which would accrue, but the study made of this point seemed to be too cursory for it to be taken as the last word on the subject.

(c) *Possibility of increasing the Capacity of the Reservoir.* — The Committee unanimously pointed out that, in a large number of cases, Western countries had not hesitated to divert important means of communication, such as national roads and railways, for long distances, and even to shift centres of population, some containing several thousands of inhabitants, so as to give reservoirs used for various purposes, such as canal supply, the production of electric power, etc., their maximum capacity.

Moreover, the effective volume of a reservoir increases more or less in proportion to the cube of its depth.

In these circumstances, the Committee suggests that the possibility of shifting the railway should be reconsidered, as the cost of this operation would, in any case, be very small compared with the cost of the dam, and that the lower parts of the town of Hwailai should be protected by a complete system of local dykes and by a pumping-station for the purpose of evacuating rainwater and house-sewage during the short periods when the reservoir is being filled.

IV. CONCLUSIONS.

1. As regards the possibility of constructing the Kuang Ting reservoir, the natural topographical and geological situation is favourable, and is such that ordinary technical precautions would be sufficient to guarantee proper construction of the dam.

2. The details of the Kuang Ting dam, as provided for in the North China River Commission's scheme, are unsuitable and must consequently be re-studied and worked out on appropriate technical principles.

3. The moderating effect of the Kuang Ting reservoir on floods will be appreciably less than stated in the N.C.R.C. scheme and will virtually not diminish the gravity of the problem of combating inundations and silting due to floods on the Yung Ting Ho, for the following reasons :

(a) Because the inflow of water into the Kuang Ting basin at flood time must apparently, according to the Committee's present information, be estimated at a somewhat higher figure than that taken as a basis in the investigation made by the N.C.R.C. of the moderating effect of the reservoir ;

(b) Because the presence of the Kuang Ting reservoir would evidently be of no help in controlling the flood water in the lower basin—a very large discharge if the N.C.R.C. estimates are to be credited (the Committee cannot check the amount and the estimates need confirmation) ;

(c) Because it is probable that silting would seriously reduce the capacity of the reservoir within a period too short to make the expenditure on the works worth while.

4. The Kuang Ting reservoir can only be devised as an integral part of a general programme of works which, although the main lines have been laid down by the N.C.R.C., must be re-studied and worked out in detail.

The reservoir, however, cannot by itself constitute the *first stage* of this programme, as the N.C.R.C. would seem to propose and as might appear at first sight. Its efficacy would be too small and its life too short.

It should, on the contrary, be possible to command, from the outset, a much greater regulating capacity, such as would give useful results for a fairly long period, justifying the huge undertaking contemplated and making it possible to await the gradual execution of the more comprehensive scheme, which alone will constitute a final solution.

This augmented capacity can be obtained in two different ways :

(a) By increasing the height of the Kuang Ting dam, in spite of the necessity for moving the Peiping - Suiyuan Railway and for protecting or even shifting the whole or a part of the town of Hwailai ;

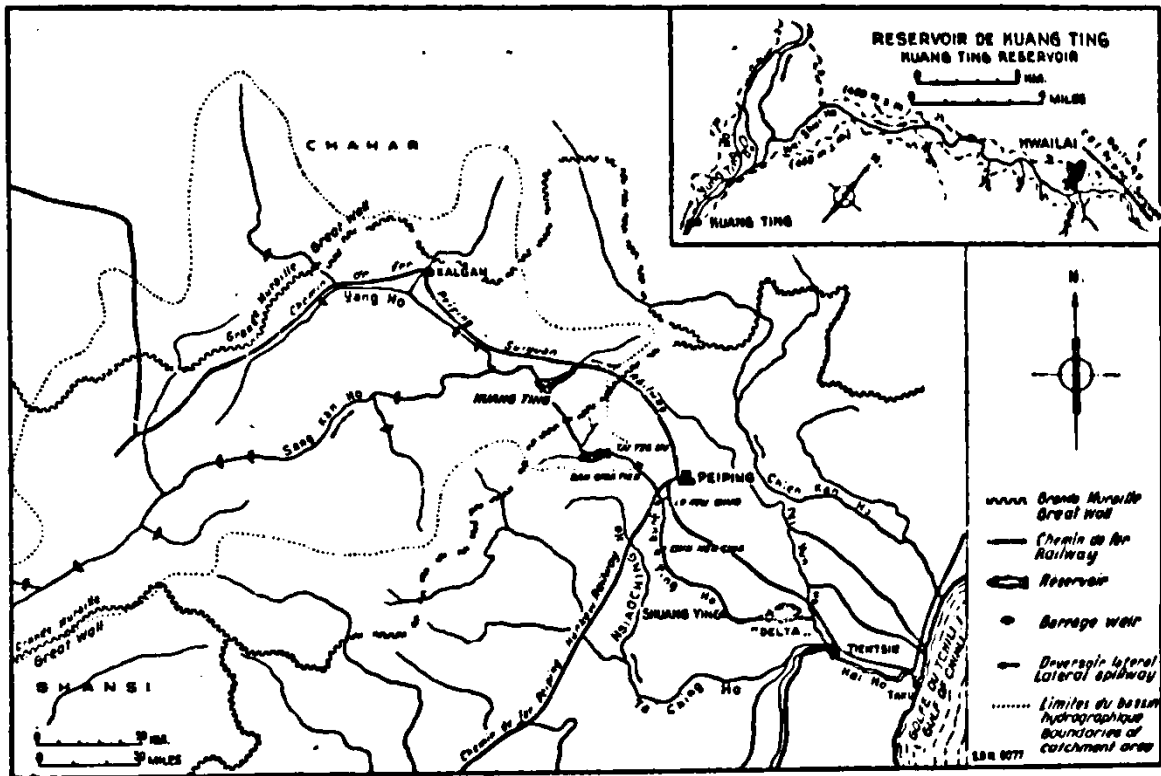
(b) By creating above the Kuang Ting reservoir, as at present proposed, sufficient additional storage capacity in the form of one or more reservoirs.

5. The execution of the above measures would leave unsolved the problem of the floods caused by the basin below Kuang Ting.

6. A general scheme of works, such as is essential for an *initial stage* properly conceived and such as will guarantee satisfactory results will mean a much heavier outlay than that estimated.

The Committee therefore feels that, before taking a final decision, it would be advisable to consider whether, for the first stage of the whole programme, there are no other solutions based on different principles and arrangements much simpler and more economical, by which a similar or even better result could be obtained.

SCHEME FOR THE IMPROVEMENT OF THE YUNG TING HO RIVER.



IX.

HWAI RIVER : IMPROVEMENT WORKS.

The Committee received from M. Shu, Acting Chief Engineer of the Hwai River Commission, drawings and descriptions of works for the prevention of floods, the improvement of navigation and the provision of irrigation facilities.

The works actually in progress consist of three boat-locks at Shaopai, Hwaiyin and Liuchien, and the reconstruction of the western dyke of the Grand Canal between Shaopai and Hwaiyin where necessary. This latter reconstruction work and the locks at Shaopai and Hwaiyin were inspected by Mr. Coode in the early part of March, under the guidance of M. Shu.

Each of the three locks has been designed for a clear length of 100 metres and a width of 10 metres, with a minimum depth of water over the sill of 3 metres, these dimensions being, in the Committee's opinion, perfectly suitable. The lock at Shaopai will have a lift of 7.7 metres and those at Hwaiyin and Liuchien a lift of 9.2 metres. The two former were begun at the end of 1933 and the Liuchien lock in the middle of 1934.

The sites of the locks have been well selected, with due regard for ease of approach and character of foundations. The Liuchien work has the more difficult strata to contend with, boulders being encountered, but generally the foundations are substantial, with all requisite timber and reinforced concrete bearing piles, driven to a satisfactory set. Some of the steel-sheet piling is of a lighter section than the Committee would have advised and difficulties may arise during construction on this account, more especially at the Liuchien site.

After the major part of the excavation at the lock sites had been completed, the piling of the foundations was begun, and, at the time of Mr. Coode's inspection, all the bearing piles and approximately 40% of the sheet piling had been driven at the Shaopai and Hwaiyin sites. The work at Liuchien was naturally not so far advanced, as it had been begun later.

It was hoped to start concreting at Shaopai and Hwaiyin in May of this year and to complete these two locks, with all contingent works, ready for operation by the end of 1935. In addition, however, to the completion of the masonry and the installation of the lock-gates and machinery, large quantities of excavation will remain to be undertaken in the channels leading to and from these locks, and the Committee does not anticipate the works being open for traffic before the spring of 1936.

In connection with these locks, the Committee would draw attention to the absence of provision for fending off craft from the side slopes when locking down. Any negligence in manœuvring vessels during this operation and maintaining them in the central part of the lock might easily lead to craft careening over and causing serious obstruction to traffic. Such an eventuality could easily be obviated by the

erection of a few dolphins of wood or reinforced concrete or other similar posts suitably spaced along each side of the lock inside the toes of the slopes.

The several breaches and openings in the western dyke of the Grand Canal between Shaopai and Hwaiyin were being systematically dealt with at the time of Mr. Coode's inspection, and the Committee hopes that it will be possible speedily to carry out the work contemplated.

It was intended that the reconstruction of Weichi Chai as a sluice should be started in time for completion in readiness for the opening of the Shaopai and Hwaiyin locks to traffic. Subsequently, the two existing *chais* (sluiceways) at the downstream end of the Hwaiyin Canal were to be removed.

With the completion of the works referred to above, navigation along the Grand Canal for craft drawing up to 2.5 metres should be assured throughout the year between Liuchien and the Yangtse, together with increased facilities for irrigation.

The Committee has examined the tentative design of the sluice down at Chiangpa, which work is required for the regulation of the discharge from the Hungtze Lake into the San Ho of the flood waters from the Hwai River system.

The drawings show that the foundation piles for the abutments and piers are designed to be driven to depths of 6.25 metres and 9.25 metres respectively below datum. The borings which have been put down over the site disclose uniformly a stratum of stiff clay at datum level, but were not continued to a greater depth than approximately 1 metre below datum. In view of the depth to which it is intended to drive the foundation piles, the Committee recommends that, before final drawings of this important work are prepared, further borings be sunk on the line of the proposed regulator and carried to a minimum depth of 10 metres below datum, to ascertain whether the hard clay stratum continues at least to the full designed penetration of the piles, and to what extent, if any, modification of design is desirable, having regard to the result of the borings.

It is anticipated that the construction of the Chiangpa regulator can be begun before the end of the current year (1935) and that this work, together with the earth work in the leading channels and the dyke work, around the northern part of the Hungtze Lake will be completed before the end of 1937.

In conclusion, the Committee is pleased to state its opinion that the Hwai river improvements are being conducted on correct lines and in accordance with the recommendations of the League of Nations Mission of 1932, and that, on completion of the works in progress and proposed for execution in the near future, the flood waters will have been afforded the outlet to the Yangtse which both the 1932 Mission and the present Committee consider the most satisfactory solution for flood prevention.

X.

**OBSERVATIONS CONCERNING CERTAIN PROBLEMS OF THE
YANGTSE KIANG.**

**I. IMPROVEMENT OF THE NAVIGABILITY OF THE YANGTSE KIANG
FROM HANKOW TO THE SEA.**

For centuries past, the Yangtse Kiang has been the principal trade artery for a very large, and possibly the richest, part of China.

The volume of the river, its dimensions, its gentle fall as it crosses the Chinese plain, and its general regime are so favourable to navigation that vessels drawing fifteen feet can reach Hankow from the sea throughout the year.

There can be no doubt that if a greater depth were available along the whole route, communications and trade would greatly benefit.

At present, vessels drawing fifteen feet can reach Hankow throughout the year. The Committee is of opinion that, with an additional depth of five feet, vessels of considerable size could make use of the Yangtse, particularly because, during the greater part of the year, there would be a greater depth over the shallows.

The Chinese Government has asked the Committee of Experts for its opinion on the possibility of such an improvement.

Between Hankow and the sea there are eleven shoals with a smaller depth than the remainder of the river. As the draught of vessels navigating on the Yangtse depends on the minimum depth occurring at these places, the possibility of improving the navigability of the Yangtse depends on the possibility of increasing the depth over these shoals.

The eleven shoals have, generally speaking, the same characteristics. They are to be found at the places where the river divides into several branches which meet again lower down. These "nodes" occur at fairly regular intervals.

The best method of increasing the depth of water at these places is gradually to augment the flow of the principal channel by reducing that of the secondary channels, with the final object of gradually giving the river along its whole length a single low-water channel as regular as possible.

Nevertheless, this aim cannot be achieved as easily on the Yangtse as on rivers of smaller volume and dimensions. Fixed works, such as groynes, submerged sills, etc., usually employed to fix or regularise the beds of other rivers, become, in the case of the Yangtse, enterprises of such magnitude and of so high a cost that they cannot be lightly undertaken. It is necessary to seek the least costly method and to act on the basis of the hydraulic experience obtained in connection with works for the regulation of estuaries and inlets of the sea, where as much use as possible is made of the strength of the current to achieve the desired aim.

In the case of several of the eleven shoals mentioned above, it will probably be sufficient to reduce the discharge through one or two secondary channels in order to

secure a greater discharge and hence greater depth in the main channel. In places where the shoals are not easy to wash away and where greater depth cannot be attained merely by strengthening the current, dredging will be necessary to help the scouring action of the current, while, in other places, submerged groynes may be sufficient to direct and concentrate the current.

There are even certain places where the dredging of the principal channel would be sufficient to strengthen the latter's flow and to weaken the discharge through the secondary channels.

But each case must be studied separately; the aim should be to effect improvement by stages, careful study being given to the results of each partial operation.

The central hydraulic laboratory, provided that it is well-equipped and under the direction of a competent specialist, will be able to perform valuable services in seeking the method to be employed in each case and in studying the probable results of the different solutions with the help of models. Nevertheless, these models and a thorough study of the operations to be undertaken will be of use only if all the necessary data and information are available. The first steps will therefore be to collect these data, which, at the moment, are to a great extent lacking.

These considerations apply particularly to the position at Chinkiang, where the port installations have become choked with silt owing to the gradual displacement of the river towards the north. At this place, the influence of the tides makes itself felt through two different channels, and upstream, too, there are two channels the influence of which varies with the discharge of the river.

A permanent solution for the port of Chinkiang cannot be sought until the various factors that are bringing about the gradual change in the river at this place are known; it would be unwise, without knowing these factors, to carry out systems of groynes or other costly works, since it is impossible at present to say whether they would have a good or a bad effect. On the other hand, once the factors involved are known, it is possible that, by changing, for example, the capacity of one of the four channels leading up to the place in question, the desired results can be obtained without the construction of any large-scale regulation works. It is therefore essential to carry out the necessary observations before deciding upon the construction of major works at this place.

The Committee draws the special attention of the Chinese authorities to the impossibility of securing the full regulation of the Yangtse Kiang.

The regulation of rivers with a free current is undertaken whenever the greatest possible depth has to be obtained in relation to the hydraulic power of the river. In the case of the Yangtse, full regulation would mean, owing to the hydraulic power available, a bed of very great depth which would exceed the requirements of navigation and the construction of which would involve a prohibitive outlay. It is necessary, and it would be sufficient, to increase by about five feet the depth of water on the eleven shoals mentioned by the simple methods indicated above.

II. CLOSING OF LAKES AND NATURAL RESERVOIRS.

Along the course of the Yangtse in the Chinese plain there are a number of lakes and basins which communicate freely with the river. These basins, the aggregate capacity of which is very large, exert a valuable influence as regulators, owing to the fact that they reduce the level of the big floods, while in periods of low water they empty themselves into the river and thus maintain its flow.

Several schemes exist the object of which is either to prevent the flood water of the river from entering certain parts of these lateral basins or else to build dykes to

cut off and drain a part of these basins. There can be no doubt that the reduced capacity of the basins would have the effect of raising the level of the river during floods and of lessening the flow at low water, but there is no indication in the schemes in question that any attempt has been made to remedy the unfavourable influence which would be exercised by the draining of the lakes.

The Committee is of opinion that the Chinese authorities should prevent any attempt to interfere with the natural reservoirs communicating with the river, as long as all the necessary steps have not been taken, by raising and strengthening the dykes, to deal with the higher floods that would result from draining the lakes.

III. PORTS ON THE YANGTSE.

The Committee's attention has been directed to the necessity of developing adequate maritime ports to serve the great centres of activity on the Yangtse Kiang.

There can be no doubt that much remains to be done in this connection, both from the point of view of wharves, landing-stages, sheds, etc., and from the point of view of communications between railways and roads on the one hand and inland navigation on the other.

No general recommendations can be given which will apply to all the Yangtse ports, because local geographical and economic conditions vary too widely. Nevertheless, the Committee is opposed to the creation of wet docks, and advises, on the contrary, the construction of wharves along the sections of the bank where the depth is naturally maintained (concave). The Committee is of opinion that on rivers which carry down a great deal of solid matter, like the Yangtse, wet docks have so many drawbacks and disadvantages from the point of view of navigation and the maintenance of depth that they are only acceptable in the absence of any other means of constructing wharves along the river.

IV. CO-ORDINATION OF TECHNICAL SERVICES.

There are far too many authorities dealing with the Yangtse, and there is a regrettable want of co-ordination between the different services. Thus works are carried out by the provincial offices or local authorities without the intervention of the central Government, which should alone decide whether works are admissible or not. The local authorities construct dykes which are sometimes harmful to the interests of the population of the neighbouring districts. There is no uniformity or rule as regards the height or profile of the dykes along the river. In plans for railway-bridges, no account is taken of the requirements of navigation, etc. The surveys and soundings necessary for making maps of the river are carried out by the Customs service, and also by the Chinese navy and by the Yangtse River Commission.

Both for the security of the river populations and in the interests of navigation, it is important to strengthen the influence of the central authorities and to co-ordinate the existing services, while a special service should collect, study and classify all existing information on the Yangtse Kiang and its regime.

The Central Directorate of the Yangtse should be consulted on all proposed measures affecting the interests of the river, including dykes, bridges, ferries, tunnels, electric cables, etc.

The Committee is of opinion that a well-organised service for giving warning of floods would be of great value to the river population and to shipping. Owing to the great length of the river, such an organisation would be easy to set up and would be of considerable assistance to shipping, trade and agriculture.

XI.

THE ROAD PROBLEM — ROAD COMMUNICATIONS IN CHINA.

CONTENTS.

	Page
Object and Plan of the Report	145
<i>Section I. — The Road Problem.</i>	
<i>Chapter I. — General Considerations :</i>	
1. Necessity of a General Transport Plan	146
2. Characteristics of the Various Modes of Transport	147
3. Conception of a Road System	148
4. Information Necessary for the Study of a Scheme and the Execution of the Work	148
5. Co-ordination of Transport	149
<i>Chapter II. — Road Engineering :</i>	
(a) The Economics of Transport :	
1. Factors in the Economics of Transport	150
2. Relations between Traffic and the Cost of the Road	150
3. Influence of the Road on the Running Expenses of Motor Transport	157
4. Conclusions	160
(b) Construction of Roads :	
1. Lay-out	161
2. Surfaces	162
3. Bridges and Other Constructive Works	166
4. Organisation of Works—Material	168
5. Road Signs	169
6. Maintenance	170
<i>Chapter III. — Road Transport :</i>	
1. Engines and Fuels	171
2. Status and Organisation of Public Motor-transport Services by Road	172
3. Postal Transport in France	185
4. Hydrogenation	186

	Page
Chapter IV. — Administration of the Roads :	
1. Regulation of Road Traffic	190
2. Highway Codes	191
3. Financing of Roads	192
4. Staffs	193
Section II. — Road Communications in China.	
Chapter I. — Conditions Peculiar to China :	
1. Desirability of a Road System	194
2. Technical Conditions of the Problem	195
Chapter II. — General Indications :	
1. Improvement and Co-ordination Programme	196
2. Topographical Service	197
3. Utilisation of Staff	198
Chapter III. — Construction of Roads :	
1. Lay-out	199
2. Surfaces	199
3. Works and Construction—Material	200
4. Road Signs	201
5. Maintenance	201
Chapter IV. — Road Transport :	
1. Vehicles	202
2. Fuel	202
3. Organisation of Services	203
Chapter V. — Administration of Roads :	
1. Existing Organisation	204
2. National Economic Council	204
3. Roads Bureau	205
4. Provincial Reconstruction Bureau	205
5. Classification of Roads	206
6. Financing of Roads	206
7. Regulation of Traffic	206
Chapter VI. — Staff :	
1. The Problem of Staffs	207
2. Higher and Intermediate Staffs	209
3. Subordinate Staffs	209

OBJECT AND PLAN OF THE REPORT.

The present report sets out our ideas on the organisation of road communications in China, the question which formed the subject of the mission confided to us by the Chairman of the Advisory and Technical Committee for Communications and Transit of the League of Nations. The report is almost as much the work of the Chinese engineers, with whom we had constant exchanges of views, as our own.

All the facts mentioned are well known to the technicians of China. All the measures indicated have been applied, at least partially, in that country. China is, however, so vast a country and the task to be accomplished is so enormous and varied that contact between engineers is difficult to maintain. The individual engineer is too often absorbed in his own duties and cannot keep in touch with the work of his colleagues and the results obtained by them. This is not peculiar to China and occurs to some extent in every country.

The task we set before us was to observe the facts which were most significant because of their intrinsic importance or their frequency, to compare them and to deduce valuable lessons and methods from them. In this way, we hoped to be able to introduce into the Chinese technique a unity, a homogeneity, a co-ordination and a continuity which have so far been only imperfectly realised.

Plan of the Report.

Section I indicates briefly the general technical features of the road problem and the various solutions proposed. The whole matter has been explained and discussed in numerous publications and at a number of congresses. We have, however, thought it might be worth while to describe and compare briefly, and perhaps incompletely, considerations which, although they are connected with each other, have often been presented and studied independently. Moreover, the present report will in this way cover the whole ground, without it being necessary, except for details, to refer to special technical works.

Section I comprises the following chapters :

Chapter I: General Considerations. — Here attention is drawn to the general characteristics and peculiarities of the various modes of transport—by air, river, rail and road.

These should form the subject of a general transport plan, and be co-ordinated. Attention is then called to the economic, topographic, climatological and other elements and information necessary for the conception and execution of a road system.

Chapter II: Road Technique. — Divided into two sub-chapters. The first of these deals with the economics of transport—that is to say, the influence of roads and traffic on the cost of highway administration and utilisation.

The second sub-chapter is a summary of the classic notions on road construction : lie, types, surface, organisation of works, bridges and constructive works, road signs.

Chapter III: Road Transport. — This chapter is devoted in the first place to an examination, from the point of view of cost, of the various liquid fuels and engines. Then follows an explanation of the technical and administrative organisation of public transport, the organisation of mail transport in France, and, finally, the present technical position as regards the methods of obtaining liquid fuel by hydrogenation.

Chapter IV: Roads from the Administrative and Financial Point of View. — This chapter deals with the regulation of road traffic, with road codes and the financing of road systems, and with staffs.

Section II explains the local conditions of the problem, as we have been able to ascertain them from personal observations made in the course of our journeys and from the indications which have been furnished to us by the Chinese engineers and by M. Okecki, League of Nations expert, whose experience of road questions and of China has been of great value to us. Then follow our conclusions and suggestions. These have necessarily a limited scope, as in a country so vast and so complex as China, there is *more than one problem*, and there cannot be *one* absolutely general and uniform solution.

In view of the extreme importance of the question of technical staffs, we have thought it proper to devote a special chapter to this subject.

Each section is divided into chapters. Each chapter is preceded by a summary of the contents and a list of the documents to which reference is made is given at the end of the report. These documents were handed in to the Roads Bureau of the National Economic Council in February 1935.

* * *

We cannot conclude these opening observations without a tribute to the professional conscientiousness, activity and capacity of the Chinese engineers. We must express to them our deep gratitude for the cordial welcome they always gave us and for the attentions and facilities we constantly received. Their desire was to render our task easy and our stay agreeable, and in this they succeeded perfectly.

SECTION I: THE ROAD PROBLEM.

Chapter I.

GENERAL CONSIDERATIONS.

I. NECESSITY OF A GENERAL TRANSPORT PLAN.

Only twenty years ago, almost all transport was effected by water or by rail; motor traffic was strictly limited to light and short-distance transport; the aeroplane had an exclusively military function.

To-day, motor-vehicles have secured a considerable fraction of traffic by land, and their competition with the railways has made the serious problem of the co-ordination of road and rail a matter of the greatest urgency in Europe.

The aeroplane itself is menacing the railway, and the time-tables of European trains have had to be reconsidered in order to take account of this new competitor. The number of passengers taken by the Paris - London air-lines from the railways is estimated at more than 50,000 per annum.

Thus the absolute liberty of each of these modes of transport is incompatible with the public interest. This liberty should have limits resulting from a general plan of transport, depending on the geographical, economic, demographic and political conditions of the country.

2. CHARACTERISTICS OF THE VARIOUS MODES OF TRANSPORT.

(a) *The Aeroplane.*

The aeroplane, in spite of the stupendous progress it has made, is, and will long remain, an exceptional and very expensive mode of transport which will make little appeal to the great mass of the population. In very large countries with few roads and inadequate railway systems, it will be useful for the movements of high political, military, financial and industrial personalities. By making possible the rapid transport of doctors, medicines, patients, etc., it has a very high health and social value. It serves admirably for the *transport of mail and commodities of great value.*

(b) *Waterways.*

Waterways, all other things being equal, constitute, especially in China, the mode of transport requiring the least expenditure for maintenance, operation and traction. The study of a general plan of transport should therefore begin with the investigation of the navigability of the waterways. These are capable of determining the arrangement of a whole transport system.

The river highway does not allow of rapid communication. It is therefore very rarely sufficient in itself. It is almost always necessary to duplicate it sooner or later by land communications for light and rapid traffic : passengers, mail and relatively valuable goods.

(c) *Railways.*

Until very recently, the railways had almost a monopoly of land transport. With the advance of the motor-car, however, they have been exposed to severe competition and brought into a discredit which is often unjustified and sometimes mischievous.

As a general rule, it may be said that, for bulky transport calling for the employment of complete and sufficiently frequent trains over long distances (and even for short distances, if this does not involve expensive breaking of bulk), the railway is, beyond question, the most effective and economical means of land transport. There is another case in which the railway must be considered : that is the case of countries without materials for the construction of roads. A railway, in fact, constitutes a means which can be effectively utilised for its own construction and its own maintenance. On the other hand, the transport of the materials necessary for the construction and maintenance of a road may contribute very largely to raising its cost and accelerating its wear and tear.

(d) *Roads.*

As regards roads (the subject of the present report), their advantages are to be found in the freedom and adaptability of the traffic and, above all, the possibility of service from door to door, eliminating breaking of bulk and reducing the risks of damage. On the other hand, where traffic increases in intensity and weight, the cost of roads and the dangers of traffic increase very rapidly.

The choice of the mode of land transport to be adopted should be arrived at by a very thorough study of the general system of transport, the characteristics of the traffic to be expected, and the resources, means and conditions of construction, maintenance and utilisation. The real cost price of motor or railway transport is, it must be borne in mind, the sum of two separate items : the cost of working and traction, and the cost of the establishment and maintenance of the road or the permanent way.

The whole problem consists in reducing this sum to a minimum.

3. CONCEPTION OF A ROAD SYSTEM.

Like the general transport plan, the *general scheme* of a road system is a Government question. It is for the *authorities* alone to decide on the programme of connections to be studied. The considerations which are relevant for the preparation of this programme are in the first place : the position of the existing general system of transport ; the political, demographic and economic facts and tendencies ; the resources, needs and possibilities of production of the country.

The general scheme of the system being fixed, the problem becomes exclusively a *technical* one.

The technician must indicate to the authorities the various solutions of the problem, the general conditions of working, and the cost (spread over a number of years) of original establishment, working and maintenance corresponding to each of these solutions. The anticipated cost is, in fact, a most important element in the decision to be taken.

4. INFORMATION NECESSARY FOR THE STUDY OF A SCHEME AND THE EXECUTION OF THE WORK.

The decision being arrived at, the road engineer, in order to proceed with the execution of the scheme, must possess, in addition to the economic information mentioned in 3 above, details as complete and accurate as possible of the *topography*, *climatology*, *geology* and *resources* of the districts traversed by the proposed system and the *means of access* to those districts.

Topography is necessary for the study of the lie of the roads. It may be suitably supplemented by photographs from the air, especially if it is possible to correct their distorted perspective. *In new and large countries, this is the only possible course to follow.*

Climatology must be taken into account when road surfaces are being decided upon ; for differences in temperature and heavy rainfall are largely responsible for the destruction of highways. Moreover, a knowledge of the rainfall, supplementing that of the regime of the rivers, will be useful for determining the position of bridges and other constructional works.

Geology is of great importance. It enables reasonable assumptions to be made as to the nature and behaviour of soils and greatly facilitates the search for natural building materials, the presence or absence of which may influence the choice of the direction of roads and the types and even the characteristics of the means of transport to be proposed.

Whether it is a question of railways, roads or hydraulic works, the geologist and the topographer should, as far as possible, precede the engineer and collaborate with him.

Finally, the *resources* of the regions traversed and the *means of access* to such regions will be taken into account in estimating the expenditure and preparing the plan of execution.

The economic factors being determined and the conditions being recognised, the technician will be in a position to prepare preliminary schemes, to compare the various possible solutions, to establish the figures for them, and to submit them to the authority which is to decide.

Those responsible for executing the work should then have the means of *testing the materials* to be used. For this purpose, a *laboratory* is indispensable. Knowledge of the physical and mechanical properties of the materials will make it possible to increase the safety and durability of the works by the choice, definition and preparation of exactly suitable materials. Such a laboratory may be of a simple character. It will be sufficient if it is equipped for carrying out roughly the ordinary day-to-day analyses and making the measurements relating to the materials mostly employed : stone, brick, wood, iron, cement, bitumen, pitch and tar. The outlay on the laboratory will be very rapidly productive through the utilisation of the information obtained.

Such laboratories might, moreover, be very usefully annexed to research and teaching institutes.

5. CO-ORDINATION OF TRANSPORT.

The road system, as has been said, is one of the component parts in the general transport system. The road should be, in principle, a feeder of the railway, a complement or extension of the waterway.

The itineraries of public motor-bus services and their time-tables, as well as those of the railways, the arrangement of stations and halts should be studied with a view to rendering exchanges between the various ways of communication as easy, certain and economical as possible.

Landing installations, connected by branches with road and rail, should be arranged at points suitably chosen along the waterways.

Stations for passengers and goods should be obligatory stopping-places for suburban motor transport lines, which should be furnished with accommodation in proportion to the nature and volume of the traffic.

Generally speaking, it will not be desirable to construct a railway along a navigable waterway ; a road will be sufficient for taking off the light and fast traffic.

If a railway and a road are parallel, the road should be reserved for separate rapid vehicles. Fast public transport services can be provided at much less expense (including upkeep of the track) by rail motors.

The wear and tear of the permanent way caused by the rail motor is insignificant, whereas motor-buses seriously damage the road unless a great deal of money has been spent on the surface (paving or concrete). Moreover, the tractive effort per passenger is much greater on a road than on rails. Finally, accidents are more frequent on roads.

Further, in many cases, even if it is foreseen that a railway will be necessary after a few years, it may be advantageous to construct a road immediately. The road can be constructed summarily, rapidly and at small expense. It will, in a very short space of time, promote activity in the district through which it runs and increase the economic output of the area. Experience gained from the road will prove to be very helpful when the time comes to plan and construct the railway, and the saving thus effected on the railway may be sufficient to pay the entire cost of the road. The surface and works will, of course, be chosen with a view to the character of the traffic anticipated in the near future.

Chapter II.

ROAD ENGINEERING.

(a) THE ECONOMICS OF TRANSPORT.

1. *Factors in the Economics of Transport.*

In the comparison of various types of surface, it has long been customary only to consider the factors peculiar to each of them—that is to say, *expenditure* on original establishment and on maintenance, and *durability*. If the question is so considered, an important element in the economics of transport is overlooked—the *degree of utilisation* of the road and its influence on the *expense of running the vehicles*.

The road problem consists essentially in providing for a given volume of traffic at the minimum cost. This cost is the sum of the cost of the road (amortisation and maintenance) and the cost of running the vehicles using the road. Where there is a large amount of traffic on a road, the second item is the important one. Thus, in France and Germany, the cost of running transport is about *seven* times as high as that of maintaining the roads.

The cost of the *road* in terms of the nature of the surface and the traffic are considered in paragraph 2 below.

The cost of transport *properly so called*, which we shall call *running expenses*, depends on two factors: the first, the *road*, is dealt with in paragraph 3 below; the other, the *vehicle*, with its special characteristics, will be considered in Chapter III: "Road Transport".

This question of the economics of transport has been dealt with in a particularly interesting manner in the reports submitted to the seventh international Road Congress by the Netherlands East Indies (third question,¹ Report No. 46) and by Japan (third question,¹ Report No. 48).

In the course of this study, we shall borrow frequently and extensively from these reports, which we shall designate by their numbers.

2. *Relations between Traffic and the Cost of the Road.*

In the comparison of surfaces, no account will be taken of the foundation, which may be considered as independent of the superstructure.

We shall assume, moreover, that the prices of labour and materials and exchange rates of the currency are practically constant during the economic life of the surface.

The annual expenditure on a particular road is dependent, on the one hand, on the natural local conditions, materials and climate, and, on the other hand, on the traffic. It may be divided up into three items:

- (1) Interest on and amortisation of construction expenditure;
- (2) Cost of maintenance necessitated by the action of natural agencies (these two items are practically constant);
- (3) An item which is substantially proportionate to traffic *T*, corresponding to the action of the vehicles on the surface.

¹ The following is the text of this question:

"*Third Question.* — Means available for constructing and maintaining in conditions as economic as possible the surfaces of roads, either in centres of population or outside such centres. Processes employed, examination of conditions which recommend one or another as desirable according to the nature of the soil and the climate."

To each surface therefore corresponds a line representing the annual expenses D in terms of traffic (see Fig. 1). This line has generally a flat curve and presents its concavity to the D positives.

For such surfaces as earth and gravel, which are cheap but require upkeep, expenditure rapidly increasing with the traffic (curve 1), the ordinate D is at first small, but the mean angular co-efficient is high. The position is different (curve 2) for improved and expensive surfaces (pavings, concrete, bituminous surfaces), and also for railways, which cost a great deal to construct but require little maintenance, even when they have to cope with intensive and heavy traffic.

In a given region, therefore, it will be possible to determine the curve of road expenditure in terms of the traffic corresponding to each of the types of surface 1, 2, 3 and 4, each curve intersecting the following one at the points $A B C$ of the abscissæ a, b, c respectively (see Fig. 2).

This serves to show that the most economical surface, taking into account *the cost of the road only*, will be :

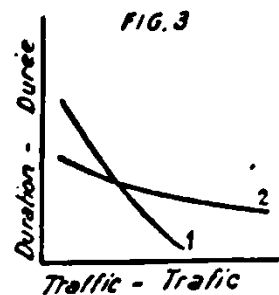
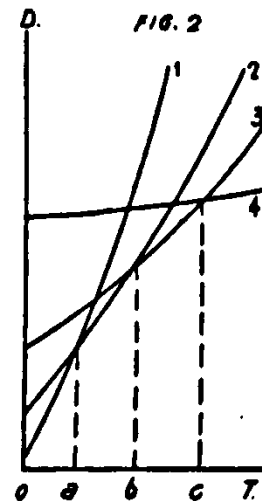
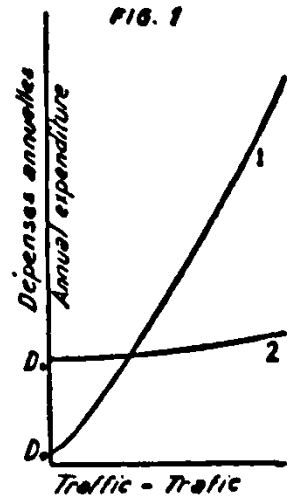
- Type 1, for a volume of traffic between 0 and a ;
- Type 2, for a volume of traffic between a and b ;
- Type 3, for a volume of traffic between b and c .

A railway may, indeed, be considered as a particular type of surface. By applying the method, it would be possible to determine, with all the precision that the subject requires, the volume of traffic at which the railway (so far as economy of transport is concerned) begins to be superior to the road. This would furnish a decisive reply to those who systematically decry any road policy. The detractors of the roads too often base their case on arguments which, though striking, will not stand the test of precise analysis. Conversely, it would be possible to determine the cases in which a rational economy involves the choice of the railway, which is sometimes unjustly criticised. But here, also, *the primitive road is almost always essential as a means of constructing the railway and as furnishing a beginning for the ways of access to the railway.*

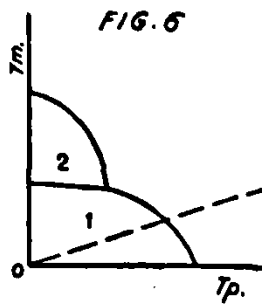
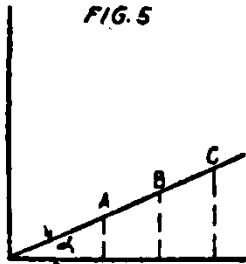
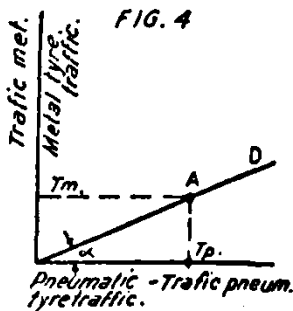
If the *durability of the surface* be now considered, this will be found to be in inverse ratio to the volume of traffic. With the same traffic, the rougher and cheaper the surface, the less its durability.

A graph of these results is given in Fig. 3.

From the strictly economic point of view, the durability of a road surface is a secondary consideration. The convenience of traffic and the facility with which the works can be executed must, however, be considered. Hence when there is a choice between two surfaces which are economically almost equivalent, the preference should be given to the one which, in proportion to its durability, can be most easily constructed.



Matters are less simple if the traffic is heterogeneous, consisting, for example, of vehicles with metal tyres and vehicles with pneumatic tyres. In this case, the expenses, the durability of the surface and the optimum type for a given volume of traffic depend upon the proportion of the two categories of vehicles. The most economical surface may be obtained by referring to Figs. 4 and 5.



Set out in abscissæ the traffic by vehicles with pneumatic tyres, T_p , and in ordinates the traffic by vehicles with metal tyres, T_m . To a point of the plane corresponds, therefore, a traffic $T_p + T_m$, proportionate to the sum of the abscissa and the ordinate at the point.

At any point on a straight line D, produced through the zero point forming the angle α with the axis of the X's, corresponds the same distribution of traffic on pneumatic and solid tyres. To a point of the abscissa X of the said straight line corresponds a traffic $T + T_p = T_m = T_p (1 + T_g \alpha)$. For a certain traffic from O to T_1 , the surface 1, for example, will be the most economical, while, between T_1 and T_2 , the surface 2 will be so. To these traffic limits correspond points A B C of the straight line D. When α varies, the points A B C describe curves which divide the plane into areas indicating the traffic for which each of the surfaces under consideration is most economical, *always on the hypothesis that only the cost of the road is considered.*

The graphs thus obtained are shown in Fig. 6.

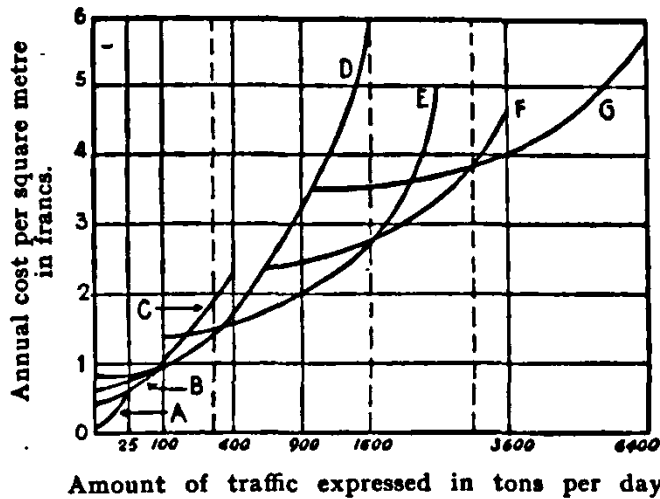
The technical services of the Netherlands East Indies have applied these methods to roads with two lines of traffic in the island of Java of the following types (Report No. 46, presented to the seventh Road Congress at Munich) :

- A. Earth road ;
- B. Sand and gravel road ;
- C. Clayey sand road ;
- D. Stone-metal road ;
- E. Road with asphalt surface ;
- F. Asphalt-macadam road (penetration process) ;
- G. Asphalted road.

Graph I below gives in francs the *annual cost price*: interest, amortisation and maintenance of the different surfaces in relation to traffic.

Graph I.

COST PRICE OF SURFACES FOR DIFFERENT AMOUNTS OF TRAFFIC.

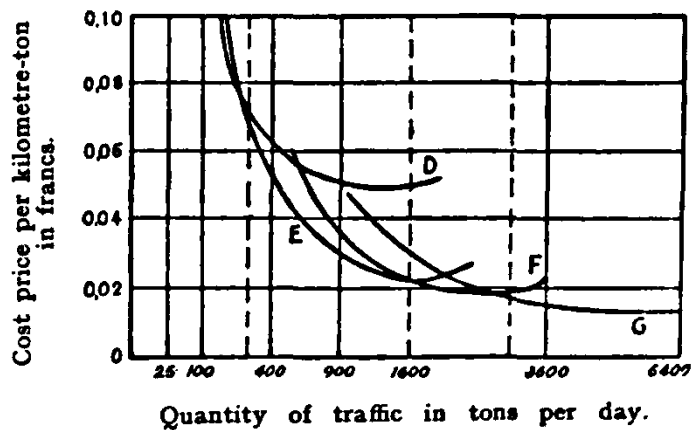


- A. Eart-road. B. Sand and gravel road. C. Clayey sand road. D. Stone-metal road. E. Stone-metal road with an asphalt carpet or surface. F. Asphalt-macadam (penetration process). G. Asphaltic concrete and asphalt-concrete.

Graph II, which may be deduced from the preceding one, gives the *annual expenditure on the road in relation to traffic per kilometric ton*, for each of the surfaces considered.

Graph II.

COST PRICE OF TRANSPORT PER KILOMETRE FOR VARIOUS AMOUNTS OF TRAFFIC.

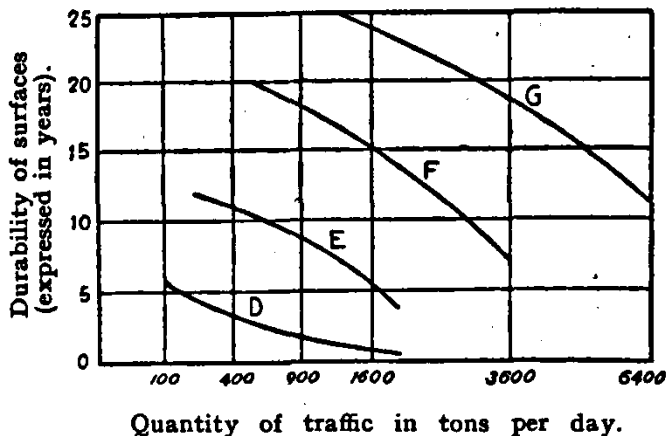


- D. Stone-metal road. E. Stone-metal road with asphalt carpet or surface. F. Asphalt-macadam (penetration process). G. Asphaltic concrete and asphalt-concrete.

Graph III shows the *average life* of the surfaces in relation to traffic. As has been said above, durability considered in itself is, from the strictly economic point of view, only of secondary importance.

Graph III.

DURABILITY OF SURFACES SUBJECT TO VARIOUS AMOUNTS OF TRAFFIC.

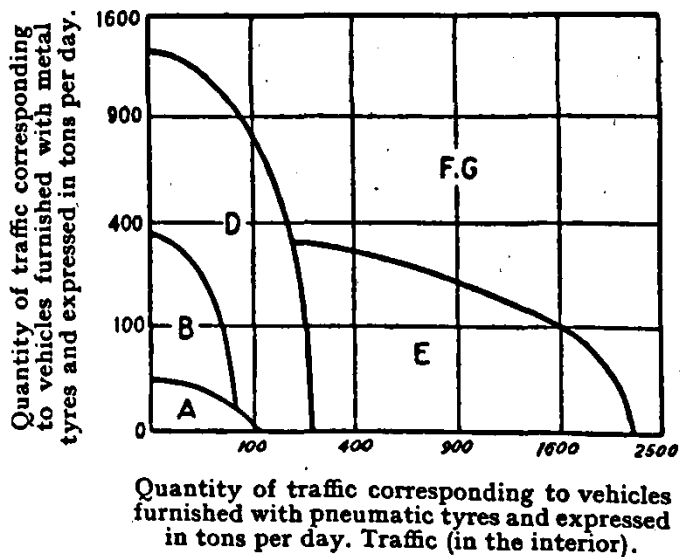


D. Macadam-stone-metal road. E. Macadam road with asphalt carpet or covering. F. Asphalt-macadam (penetration process). G. Asphaltic concrete and sheet asphalt.

Graph IV indicates the most suitable surfaces for traffic distributed between vehicles with pneumatic tyres and vehicles with metal tyres.

Graph IV.

WEAR AND TEAR STRATUM OF ROADS SUBJECT TO DIFFERENT CONDITIONS OF TRAFFIC.



A. Earth road, clayey and sand road. B. Gravel road. D. Stone-metal road. E. Stone-metal road with asphalt covering or surface. F. G. Asphalt surfaces (penetration and mixing methods).

Report No. 48 (Japan) contains a similar study. It is more complete, however, since it analyses the cost of transport and relates to the following surfaces :

1. Gravel road ;
2. Road treated with a bituminous substance ;
3. Asphaltic concrete ;
4. Sheet asphalt ;
5. Cement concrete ;
6. Wood paving.

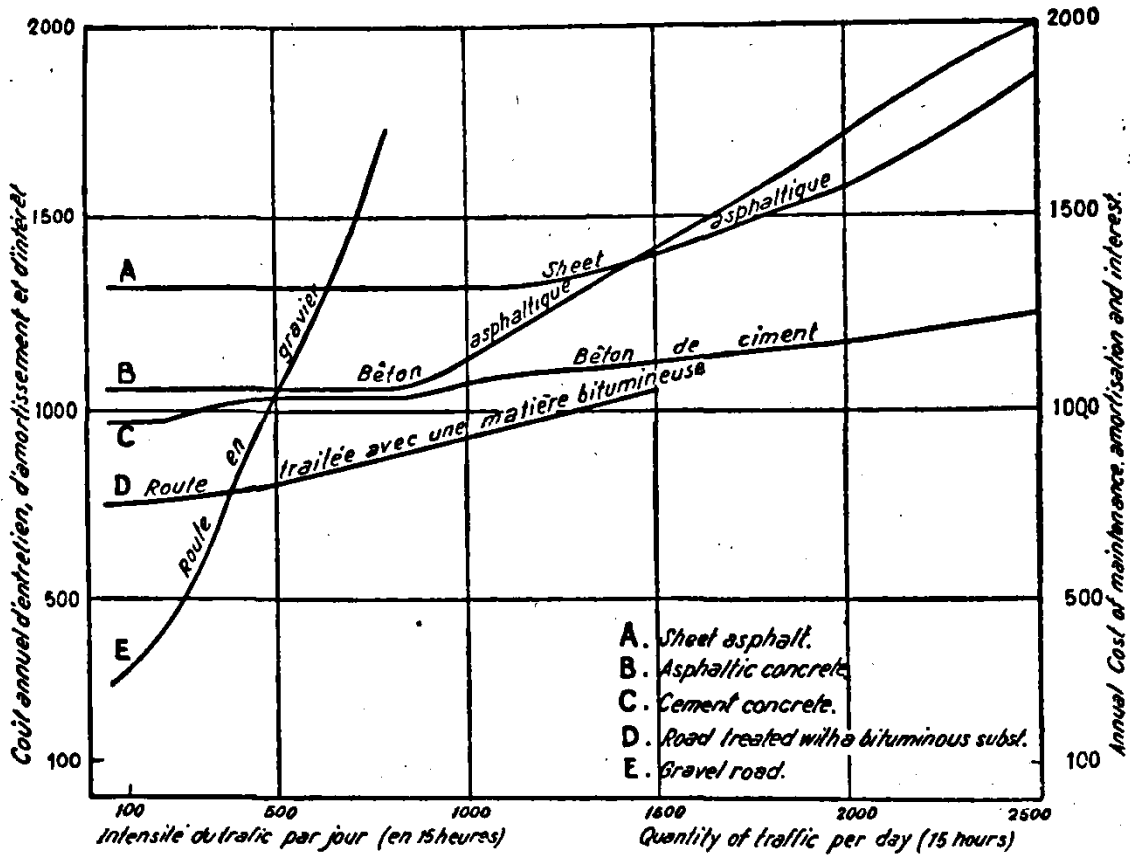
The last-mentioned surface is of practically no importance except for urban highways.

Table I (page 10 of the report) gives the annual amortisation charges for a road 1 kilometre in length and 3 metres in width. This amount is calculated from the cost of establishment, the residual value (nil for a gravel road) and the price of money. It amounts to 180 yen for a gravel road, 659 yen for a road treated with a bituminous substance, 1,083 yen for an asphaltic concrete road and 996 yen for a cement concrete road.

Table II gives the annual cost of maintenance in relation to traffic. It shows that, when the traffic exceeds 50 tons per day, a gravel road is the most costly from this point of view.

Table III gives (these are in the last resort the only indications to be taken into consideration) the *total annual expenses of amortisation and maintenance in relation to traffic*. The particulars in this table are set out below in the form of a graph (Graph V). It will be seen that, in the circumstances considered, the most economical surface, if account is taken only of the cost of the road, is the gravel road, where the traffic is less than 400 tons per day, the road treated with a bituminous substance, where the traffic is between 400 and 1,300 tons per day and the concrete road, where the traffic is over 1,300 tons per day.

Graph V.



Cost price of the road. Total cost of Tables I and II. Yearly amount for maintenance, amortisation and interest. Annual cost for a carriage-way 3 metres wide and 1 kilometre long. Quantity of traffic (number of motor-vehicles) corresponding to a carriage-way per day (15 hours).

If the results set out in the two reports Nos. 46 and 48 are to be compared, it must be borne in mind that the figures do not relate to the same unit of surface area.

Moreover, the maximum weight allowed on the roads in Japan (5 tons) is very low. This explains the advantage presented in that country by roads treated with a bituminous substance, a type of road suitable for motor traffic which is fairly intense but consists of light vehicles. Such roads have given entire satisfaction in the United States and in Tunis, where the traffic is of the same character.

Finally, the following table gives for certain roads in Morocco the cost of construction and maintenance and the total charges (amortisation per kilometric ton gross).

Annual traffic in tons gross	Nature of road	Average cost per kilometre		Charges per kilometric ton gross		
		Con- struction (French francs)	Annual mainten- ance (French francs)	Interest and amor- tisation	Mainten- ance	Total
10,000 ..	Track lightly prepar- ed.....	20,000	500	0.28	0.05	0.33
50,000 } 100,000 } 300,000 ..	Road superficially faced, 4 metres highway ..	100,000	3,000 4,000	0.29	0.06	0.35
0.14				0.04	0.18	
0.062				0.02	0.082	
1,000,000 ..	Road with half-thick surface, 7 metres highway ..	300,000	10,000	0.043	0.01	0.053

Between the *cost* of a particular surface and the *traffic* there are thus *quantitative relations* from which, given the traffic, it is possible to deduce *the most economical surface*. The search for these relations constitutes the first part of the economic problem of the road.

The position of the curves representing these relations and the critical values of the traffic which are deduced from them naturally depend upon local conditions and vary from one area to another. The aspect of these curves, however, and the method followed for determining the most economical surface are of a general character.

3. Influence of the Road on the Running Expenses of Motor Transport.

(In addition to the reports already mentioned, we shall, in this section, frequently borrow from the French reports, Nos. 71 and 86.)

The road exerts an influence on transport operation costs by its *lie* (gradients and curves), and also by its *surface* (regularity and nature).

To negotiate gradients and curves, vehicles require to use additional power, the amount of which is practically unaffected by the character of the road surface.

Regularity of surface prevents vibrations and shocks, which absorb part of the energy expended and are equally injurious to the vehicle and to the road. Accordingly, even on the most primitive roads, the Americans have sought devices which make it possible to section the road-bed with great precision.

In Germany and France, as has already been stated, the working costs of motor transport are estimated at about seven times the cost of road upkeep. These figures show how important a road policy judiciously conceived and carried out may be for the economy of a country and, if the latter does not produce liquid fuel, for its commercial balance.

With better roads, the great body of road users are able to effect economies, and hence money spent on improving roads is a *profitable outlay*.

The surface of a highway influences motor transport by its effect :

- (a) On the expenditure on fuel ;
- (b) On that on tyres ;
- (c) On the maintenance and durability of the vehicle ;
- (d) On its rotation.

(a) *Expenditure on Fuel.* — On a road in excellent condition, the traction coefficient varies little with the nature of the surface. As soon, however, as the condition of the road ceases to be perfect, even where there is no limitation of speed or breakage of material, there is an additional consumption of fuel, which varies a great deal with the nature of the surface.

Report No. 48 gives the following figures for expenditure on fuel in yen per vehicle per kilometre :

	Lorry	Motor-bus
Gravel road	0.033	0.029
Road with asphalt surface	0.0286	0.0245
Road in cement concrete	0.0275	0.0215

The difference in the outside figures of each category of vehicles is about 20%.

(b) *Tyres.* — The following results have been arrived at in France :

(1) Comparative trials, carried out by identical vehicles on surfaced macadam and non-surfaced macadam gave results that were 25% better for the former than the latter.

(2) For the same vehicle, the life of pneumatic tyres varies greatly according to the character of the road surface. Tyres running on roads with modern surfaces may last twice as long as those running on flint metalled roads.

(3) Tyres of the same nature on identical vehicles have given, when running on roads surfaced with tar, a kilometrage 40% higher than when running on an ordinary macadam road in an average condition.

Report No. 48 gives the following figures for expenditure on tyres in yen per kilometre :

	Lorry	Motor-bus
Gravel road	0.015	0.085
Road with asphalt surface	0.0123	0.060
Road in cement concrete	0.0118	0.0051

—a difference between the outside figures of each category of vehicles of about 25% and 60%.

(c) *Maintenance and Amortisation.* — An increase in the kilometric price of maintenance and an increase in the frequency of general overhauling up to 50% have been noted in France as a consequence of the bad state of the roadways.

Report No. 48 gives the following figures for expenditure on maintenance and amortisation per vehicle per kilometre :

	Lorry	Motor-bus
Gravel road	0.012	0.011
Road with asphalt surface	0.0095	0.0098
Road in cement concrete	0.0088	0.0094

The difference between the outside figures for each category of vehicles is about 25%.

(d) *Rotation.* — The rotation of vehicles depends on their average speed on a particular itinerary. A road which makes it possible to increase the speed will also, as a logical consequence, make it possible to secure the same service with a smaller number of vehicles, and consequently to reduce expenditure on initial establishment, while at the same time giving a better service to users.

The speed may be increased by a judicious lie of the road in plane and in section, by a moderate camber of banked turnings and a good surface—clear, regular and anti-skidding.

The Italian report, No. 74, which deals with the fifth question submitted to the Road Congress, gives the following particulars on the economics of transport in relation to the road :

(1) For vehicles drawn by animals, the tractive effort, in terms of tons, may be diminished by ten to fifteen kilogrammes by the improvement of the surface. This advantage, however, is offset by the fact that the improved surface is more trying to draught animals.

(2) The difference between the cost of transport on a road with the old water-bound macadam covering and the cost of the same transport on a road with a modern covering is :

Lire

- 0.10 for a five-seater Fiat car ;
- 0.15 for a seven-seater Fiat car ;
- 0.19 for a seven-to nine-seater Fiat car ;
- 0.20 for a vehicle with a useful load of 2 tons ;
- 0.25 for a vehicle with a useful load of 3 tons ;
- 0.31 for a vehicle with a useful load of 6 tons (Diesel engine) ;
- 0.34 for a vehicle with a useful load of 6 tons (with trailer of 11 tons).

Report No. 48 (Table IV) gives the following figures for the total transport cost per vehicle per kilometre :

	Lorry	Motor-bus
Gravel road	0.273	0.248
Road with asphalt surface	0.2406	0.2202
Road in asphalt concrete	0.233	0.2056
Road in sheet asphalt	0.2279	0.2012
Road in cement concrete	0.2279	0.2012

—a difference in the outside figures of 20% for lorries and 24% for motor-buses.

The total annual running expenses per kilometre for a daily traffic of 100 vehicles, comprising 50 ordinary vehicles, 20 motor-buses and 30 lorries, are thus :

	Yen
On a gravel road	7,201
On a road treated with a bituminous substance	6,350
On an asphalt-concrete road	6,078
On a sheet asphalt road	5,946
On a cement-concrete road	5,946

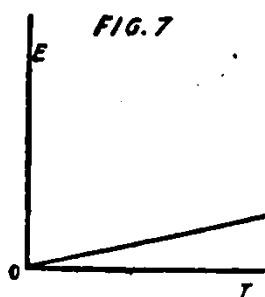
Accordingly, on the above suppositions, the replacement of a gravel road by a concrete surface would have represented an annual saving of 1,255 yen per kilometre for road users.

In Morocco, it has been recognised that the running expenses of transport services might be diminished by 20% by the remaking of a bad network of roads. It is estimated that transport costs on a track may be twice as high as on a good surfaced road.

For the same vehicle and the same surface, running costs vary from one district to another within much narrower limits than the costs of constructing and maintaining the roads.

Finally, as will be seen in chapter III, the cost of transport may be reduced by increasing the capacity of the vehicles; but capacity is often limited by the characteristics of the road. As a matter of fact, long and heavy vehicles and vehicles with trailers cannot be used on roads with radii too short and with too steep a gradient. On roads with an irregular surface, the couplings of trailers are liable to be broken and trailers cannot therefore be used. Light bridges only allow of a limited weight per axle; hence the total load had to be reduced.

The nature and *state of a road* have therefore a very appreciable influence on the *cost of transport*, on the growth of traffic and on the general economy of the country. The measurement of this influence constitutes the second part of the economic problem of the road. In order to obtain it, the road services must make a point of systematically collecting all possible observations on traffic—the counting and census of vehicles and all details of the cost of transport.



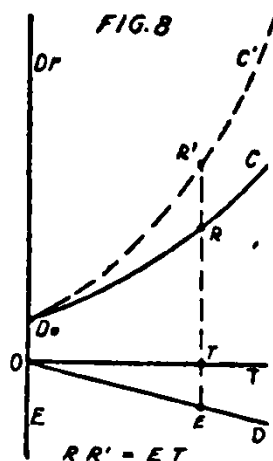
The relation between cost of transport and surfaces may be indicated by a simple graph, similar to the one in the preceding section. The running costs for the same distribution of the different types of vehicles are substantially proportionate to the traffic. If, therefore, the traffic OT is shown in abscissæ (see Fig. 7) and the running costs OE in ordinates, the costs will be represented by a straight line

passing through the zero point, the angular coefficient being dependent upon the surface. This angular coefficient will diminish as the surface becomes more perfect and, therefore, more expensive.

4. Conclusions.

To sum up: (1) the cost of the road depends on the nature of the surface and of the traffic; (2) the cost of the traffic depends on the nature and state of the surface.

In a given region, a type of surface involving a minimum *total expenditure in respect of amortisation, maintenance and running* corresponds to a certain kind and amount of traffic. It is the search for the correspondence between the optimum surface and the traffic which constitutes the economic problem of the road, the two aspects of which have been examined in the preceding paragraphs 2 and 3.



Take a type of surface α . Set out in abscissæ, the traffic T (see Fig. 8); in positive ordinates, the total expenses of the road Dr ; in negative ordinates, the running costs of transportation. The first will be represented by a curve C , the second by a straight line D .

The total expenditure for a specified traffic is represented by the segment ER —that is to say, by the curve C related to the straight line D . If this expenditure is related to the axis OT , we obtain the curve C' characteristic of the type of surface under consideration.

The more perfect the surface, the greater is the ordinate at the zero point, and the smaller the angular coefficients of CD and C' .

The points of intersection of the C' curves will have an abscissa less than that of the corresponding points of the C

curves. In other words, an enlightened policy of saving will lead to the improvement of the surface before the consideration of the cost of the road alone suggests it.

As has been said above, the position and form of the curves and the angular coefficient of the straight lines D vary with the region ; but their aspect is always the same, and the following conclusions, which are of a very general character, may be enunciated.

Where traffic is light, the costs of maintenance and running are small. It is therefore desirable to avoid increasing the total expenditure by unduly high amortisation charges. *The primitive road, the improved earth road, or the earth, sand and gravel road, will be the most economical.*

As the traffic increases, the surface must be improved, either by giving it a bituminous carpet or by replacing it by macadam. In most cases, however, it will be found that the traffic limits within which macadam is desirable are fairly narrow and that the immediate adoption of a more modern type—*cement macadam or macadam with a bituminous carpet*—is almost always advantageous.

For very intense traffic, a modern surface will be desirable : *thick macadam compressed by heavy rollers and covered with a bituminous carpet, thick cement macadam with a rich dose, or concrete*, according as the traffic consists of semi-light or heavy vehicles.

A particular study of the local conditions will give the classification of the optimum types of surface according to the nature and quantity of traffic. It is this classification alone which is economically important. It would, in fact, be a serious mistake to classify roads as rich and poor.

Roads may be more or less easy to construct and more or less expensive. The right and wise course consists in designing *roads that are exactly adapted to the traffic*. It would be just as absurd to employ asphalt-concrete on a road running alongside a railway and carrying only very light traffic as to maintain a gravel surface on a road used by 500 or 600 vehicles daily.

Finally, the economic point of view is not always the only one to be taken into account in the choice of a surface. The construction of costly roads may be dictated by non-technical reasons : political, military, tourist traffic, etc. These considerations are outside the scope of the present report.

(b) CONSTRUCTION OF ROADS.

I. Lay-out.

The technical conditions for the laying-out of the national roads in France have been dealt with in a circular of March 29th, 1933, a copy of which appears among the documents enumerated at the end of this report.

As a general rule, roads for heavy traffic must by-pass populated centres, to which they are to be linked up by short branch roads.

When the road runs along a dyked valley, it will be advisable to place the road on the dyke, the supervision and upkeep of which will thus be greatly facilitated.

(a) *Longitudinal Section*. — On gradients, the tractive and braking effort increases the wear and tear of the road. Inclines increase the consumption of fuel and reduce the limit of the useful load. Gradients should not exceed 5% on low ground and 8% in mountainous districts.

A section with a very slight incline is more favourable to the draining-off of water than a horizontal section. The gradient should be reduced at curves and level or fairly level stretches should be introduced on long inclined sections.

Two consecutive sections of different gradients should be connected by a curve the radius of which must be greater than 1,000 metres.

Small irregularities in the longitudinal section, depressions, unevennesses, cross-drains, ridges produce vibrations that are injurious both to the road and to vehicles and should be avoided.

(b) *Plan curves* compel vehicles to slow down, increase the resistance to traction, produce radial efforts and diminish safety. When their radius is too short, they make it impossible to run road trains and trailers.

In flat or slightly undulating country, bends should have a radius of over 500 metres.

Curves should be given an extra width and a banking.

Two consecutive curves should be separated by a straight alignment.

Hairpin bends in mountains are to have a loop permitting of an increase in the radius of the curve.

(c) *Transverse Section.* — The transverse section should be adapted to the traffic (carriages, foot passengers, rickshaws). It will comprise two plane inclines of 2 to 3% gradient, joined by a curve.

The gradient to be given to the slopes of cuttings will depend on the nature of the land. It is advisable to turf the slopes of embankments. Sufficient land should be acquired when the work of construction begins to allow of the gradual widening of the road.

The road-bed includes the carriage-way and the sidepaths, the latter having a width of from 1.5 to 2.5 metres. They should be raised slightly above the edges of the roadway, so as to check the overturning of vehicles. They will be intersected by numerous and wide gutters or drains, oblique in relation to the axis of the road, and following the direction of the gradient.

The carriage-way will have a width suitable for the traffic; as a general rule, 3 metres for each line of vehicles. The camber will depend on the surface and will be as slight as possible, so as to reduce gullying by rainwater.

The *side of slopes in cuttings will be edged with a ditch* sufficiently deep to allow of the draining-off of the water. *The ditch should carry off the water and not retain it.*

If an embankment is more than 2 metres high, a turfed bank or a parapet should be provided.

It is very useful to establish plantations along roads. These both add to the amenity and contribute to the preservation of the road, while they increase the safety of traffic. The kind of trees will be chosen according to climate.

The rows of trees will be placed 5 metres from the axis of the road and the trees about 10 metres apart.

2. *Surfaces.*

We shall only consider surfaces in common use: earth tracks, whether improved or not, ordinary water-bound macadam, cemented macadam, surfaced macadam (bitumen and silicate), asphalt-concrete, cement-concrete, paving.

Ministerial Circular, Series B, No. 2, of January 2nd, 1931 (included in the documents), gives exact and practical indications on most of the surfaces.

(a) *Earth Roads.* — These roads are suitable only for light traffic (vehicles of from 2 to 3 tons) of inconsiderable amount (less than about 50 tons a day). They do not stand up to metal or solid rubber tyres. They are often impracticable, owing to rain. Generally, the curves and slopes on such roads must be strengthened with rough metalling.

The longitudinal and transverse sections should be very regular and the drainage excellent.

If the subsoil is weak, it should be strengthened.

When the traffic increases somewhat, the road should be improved by covering the bed with a layer (5 to 10 centimetres in thickness) composed of a mixture of gravel or broken stones (none of the stones should measure more than 3 cubic centimetres) and coarse sand. This layer will be rolled with a 3- to 7-ton roller. Good results will be obtained by driving the rollers in a direction *slightly oblique* in relation to the axis of the road.

On a still further increase in traffic, the quality of the road may sometimes be improved, as has been done with success in Tunis and in the United States, by covering it with a thin bituminous carpet. At present, experiments are being made in Indo-China with wood-oil surfaces.

The American Report No. 38 (note 1, question 5) to the Washington Road Congress of 1930 gives interesting information on such roads.

Very valuable particulars are available on the same subject taken from the report of M. Beau, Assistant Inspector-General at the French Ministry of the Colonies.

(b) *Ordinary Waterbound Macadam.* — Ordinary waterbound macadam should rest on a good foundation. This may consist of the natural soil after excavation, if it is sufficiently firm. In this case, the thickness is somewhat increased. Where the soil is not very firm, and on embankments, a foundation layer of stones 15 to 20 centimetres thick should be interposed.

The thickness to be given to the metalling will depend on the quality of the stones and the maximum pressure of the vehicles on the roadway. It will vary from 12 to 15 centimetres.

The materials composing the metalling must be regularly gauged and must possess square edges. Thin slabs and needles should be rejected. The best outside dimensions are 4/6 or 5/7.

Rolling, though an easy and simple operation, must be carefully executed, from the edges to the middle and in thickness of not more than 10 centimetres. It will always be an advantage to roll first with a light roller, which places the materials in position without crushing them, and then to use a heavy roller to compress them. With a view to avoiding or reducing undulations, it is sometimes desirable, in certain light soils, to begin the rolling with the driving-wheels forward.

Verifications of longitudinal and transverse sections should be very frequent.

Ordinary waterbound macadam is seriously affected by rain and prolonged drought. It stands up badly to motor traffic of average intensity.

It produces dust, and should therefore be generally regarded as merely a transitional surface which is to receive a further covering. Where it is possible to obtain a highly cohesive binding material, such as clay or schist, the life of the road surface may be prolonged by 50%.

(c) *Cement-macadam.* — In countries where cement is cheap in comparison with bitumen, cement-macadam constitutes an improvement on ordinary macadam, which is quite sufficient for average traffic.

It is a solution which is indispensable in damp sections, low-lying points and areas sheltered from the sun and liable to submersion.

At the end of one or of two years, the macadam should be protected by a superficial bituminous carpet. This protection is not indispensable *if the execution has been perfect.*

Cement-macadam requires an excellent foundation for the roadway, very hard, clean and well gauged metal (stone and sand), slow-setting cement with a high resistance to compression. It should be executed by experienced specialists.

The most reliable method of laying cement-macadam is that of grouting, which consumes about 130 kilogrammes of cement per cubic metre of stone.

The method of incorporating materials in a dry state is very little employed.

The Sandwich method has shown itself to be the best. If it is well carried out, the application of protective coverings is unnecessary for average traffic, but it requires particularly delicate execution.

There is a tendency to regard cement-macadam as a variant of the concrete road and to lay it by identical processes; in particular, to replace rolling by ramming or vibration.

The *Revue Générale des Routes*, of June 1934, contains interesting discussions of this process.

(d) *Superficial Bituminous Surfaces.* — These surfaces, which are in universal use, have as basis tar or bitumen, or tar-bitumen.

Their technique is very well known and they are relatively easy to apply.

Their efficacy in protecting metalling is now well established.

These surfaces, in order to be successful, require: (1) to be applied to a metalling not more than a few months old, well compressed, in very good condition, very clean and well scoured; further, the employment of heated tar or bitumen necessitates an absolutely dry roadway; (2) fine gravel with sharp edges and containing suitable proportions of fine and medium ingredients; (3) a bituminous binding material suitable to the local conditions and *carefully tested in the laboratory*.

Originally, crude tar obtained from gasworks was used, but it was found that this product contained substances that destroyed its qualities and that it was desirable to select and prepare the tar. As regards bitumen, the principal characteristics—*i.e.*, adhesiveness, viscosity and penetrative capacity—differ widely according to the products. It is necessary, therefore, to determine the limits suitable to the local conditions.

A note and model contracts for the supply of bituminous binding materials will be found among the documents.

The latter also include a note, which appeared in No. VI (1934) of the *Annales des Ponts et Chaussées*, on modern surfaces in Madagascar. This note indicates the considerations which may influence the choice of a type of surface. To this note is annexed a model contract.

Hydrocarbides may be applied hot or in the form of an emulsion. The emulsion requires the manipulation of a supplementary weight, that of the supporting water, but it is easy to apply.

Heated bitumen gives a surface somewhat more resistant than that obtained with emulsion, but, as is also the case with heater tar, it does not adhere well, except on a perfectly dry and clean roadway.

The superficial bituminous surfaces are easy to maintain. *They are suitable for traffic of average intensity and weight.* They have the very great advantage of doing away with dust.

(e) *Silicating.* — Silicate of soda was at one time very much employed in France for improving the strength and quality of calcareous roadways. It has been abandoned in consequence of a number of failures, and especially because the very great development of bituminous surfaces has considerably reduced its importance.

Silicating nevertheless presents advantages in regions in which limestone is abundant and traffic moderate. It should not be used in hot and dry regions.

Silicate of soda is characterised by the coefficient $S = \frac{\text{Si O}_2}{\text{Na}_2 \text{O}}$. This coefficient should be in the neighbourhood of 3.45 and not below 3.3. Limestones suitable

for silicating are those which will score lead and are scored by, or score, zinc, brass, aluminium-bronze and steel.

It is, moreover, possible to silicate non-calcareous materials. Silicated roadways wear more uniformly and slowly, provide a more regular surface, produce less dust and less mud, and are less noisy than ordinary metal roads.

The documents include articles from the *Annales des Ponts et Chaussées* of 1923 and 1924, and also certain numbers of the review *La Route Silicatée*, which give interesting particulars of the application of silicate of soda.

(f) *Asphalt Concretes*. — There is a whole series of asphalt and tar concretes, *tar macadam*, concrete with a basis of tar, which stand up well to rapid and heavy traffic.

Bituminous cement, still more resistant, is capable of supporting any traffic with elastic tyres with a proportion of vehicles with iron tyres, but it becomes slippery rather quickly.

Asphalt applied in a liquid state, which is preferred to-day to compressed asphalt, is suitable for all kinds of traffic, except heavy traffic with iron tyres.

These surfaces, which have a very definite technique, should be laid by specialists. Contracts generally provide, in addition to construction, for maintenance for several years. Such maintenance is a simple matter, and this is one of the principal advantages of these surfaces, which are very costly and should not be contemplated except for urban highways in towns with very heavy traffic.

For details of construction, special works may be referred to, among others "Cours de Routes", by M. Le Gavrian, Secretary-General of the Road Congress, and the reports of international congresses.

For some years past, there has been a systematic study of methods for facilitating the application and improving the quality of bituminous surfaces, whether superficial or in the mass. One method consists of the addition of fluidifying products, which are generally either derivatives of petroleum or coal-oils or cutbacks.

Another process which has been tried with success in recent years consists of the addition of filler to tars and bitumens.

Fillerised bitumens have the following advantages :

(1) With the same weight of bituminous binding material it is possible to cover a larger surface of roadway than with pure material, the surfaces being in the proportion of 3 to 5 ;

(2) Drying is almost instantaneous and spraying and cooling-off are almost completely eliminated ;

(3) Cohesiveness is improved ;

(4) Fillerised tars may be spread on roadways insufficiently dried ;

(5) The expense is lower.

The fillers currently employed are coal and pulverised limestone.

These experiments and the results obtained are set out in detail in No. VI, 1932, of the *Annales des Ponts et Chaussées*. This number is included in the documents enumerated at the end of the present report.

(g) *Concrete Roads*. — These roads have the advantage of requiring only an insignificant amount of maintenance, of being very easy-running, and of standing up to all kinds of traffic. Their technique has made great progress. Their cost has diminished. The material for their construction has been improved and renders it possible to obviate skidding, their principal disadvantage.

The cement content and the necessary thickness have been reduced by a minute study of granulometry, vigorous compression by ramming or vibration carried out

mechanically, and strict verification of the section of the roadway. The surface is rendered anti-skidding by the elimination of mortar and the exposure of the mosaic by means of special apparatus of a very ingenious and simple character.

It has thus become possible to construct roadways which, while possessing all the advantage of the old concrete surfaces, are, as to price and the final cement content, intermediate between the former concrete surfaces and cement-macadam.

For technical details, the special works on the subject may be consulted. We have annexed to the documents a copy of a contract concluded by the Department of the Nord in France and also a note on the latest concrete surfaces laid in France.

(h) *Paving.* — Paved roads take all kinds of traffic. Their disadvantage is their very high price. Large stones are generally placed on a layer of sand of varying thickness, according to the strength of the foundation soil.

Small stones in the nature of mosaic should be laid on a foundation the consistency of which will depend on the local resources, the strength of the soil, the amount of traffic and the authorised weight per axle.

It is advisable to fill in the joints with an impermeable material—such as cement, tar, bitumen or clay—to prevent the foundation from being drawn away and the paving from corrugating and so tending to produce a saw-like edge, a most disastrous result.

The surface of the paving and of the roadway should be regular ; otherwise, the drainage is bad and vehicles sustain a series of shocks and vibrations which may not be felt by the occupants but which loosen the parts of the chassis and use up power unnecessarily.

3. *Bridges and Other Constructive Works.*

(a) *Minor Works and Works under Embankments.* — It will generally be a great advantage to give these works a permanent character without passing through a temporary stage. The body of them should be constructed before the embankments, so that the latter may be executed without interruption or difficulty and the risk of their being carried away by water may be avoided. The ends and finishings may be executed afterwards.

Pipes, with a circular or ovoid section up to one metre in diameter, in metal, or better still in concrete, whether reinforced or not, have the advantage of exerting little pressure, and thus effecting savings on the foundations, where the soil has no great consistency. They should, in principle, have a longitudinal gradient of at least one centimetre per metre, and have a sump above where the deposits are to be made, and a block below.

In districts where flat slabs are found, they may be used for distances up to about one metre.

Earthenware pipes may be utilised with diameters up to about 40 centimetres, but their condition should be carefully tested before they are laid. They should be covered with a filling to a thickness of at least 40 centimetres ; this will deaden and distribute the shock caused by vehicles.

For larger spans, slabs of reinforced concrete will be used, or vaulted aqueducts in heavy concrete or masonry, stone or brick of good quality.

Vaulted works have the disadvantage, if the soil is not very firm or if the embankment is high, of necessitating very massive foundations and abutments. On the other hand, their construction requires nothing in the way of artificial material except a little cement. A series of schemes for pipes and gutters of the types employed in Madagascar is annexed to the documents.

The study and execution of these works must be carried out with the greatest care on the basis of clear and detailed plans with dimensions and references, on a scale of 1/200. By judicious designing, savings may be effected which will be particularly great because these works are usually numerous. Defective execution or an insufficient waterway may often cause the ruin of a whole section of the road through the destruction of the embankments.

The following general principles may be laid down in this connection :

(1) Unless it is impossible to do so on account of special conditions of the work, the axis of the *upstream* connection of the work should be placed in the axis of the stream.

(2) If the work can be shortened by means of diversions, it will be preferable, where there is a choice, to make the diversion *downstream*. In this case, if the stream were to return to its old bed, the work would not be affected.

(3) If the axis of the road coincides with a bend in the stream, it will be well to divert the stream in order to avoid curved works, particularly on streams which have a large solid discharge.

(4) Inclined wing walls are generally preferable to return wings, especially where there are high embankments and where the foundation does not rest on firm ground.

(5) If a depression with very slight longitudinal and cross slopes has to be crossed on an embankment, it will often be better not to apply principle (1) above, but to remove the axis of the work clear of the bed and arrange for a diversion of the stream. In such a case, the solid ground on which the work can rest generally rises regularly as the bed is left behind. Before any decision is taken, however, this will have to be verified by soundings.

(b) *Medium-scale Works*. — Every scheme for a work of medium importance should be the subject of a special study, for which it will be necessary to constitute a file of the following type :

(1) Plan (with dimensions and references), to a scale of 1/5,000, of the road and the watercourse, carried considerably beyond the site of the work and the flooded area at high water. The equidistance of the curves will be 2 metres.

(2) Plan (with dimensions and references), to a scale of 1/200, of the proposed site of the work and its approaches, on which will be shown lines of the sections and the borings. The equidistance of the curves will be 1 metre, with formlines in the level parts.

(3) Section (with dimensions and references) of the river, to a scale of 1/200, with indication of the highest and lowest water-level.

(4) Geological sections of the soil determined by borings and the taking of samples.

(5) Graph of the heights of water and the flow characterising the regime of the watercourse.

(6) Resources in building material ; means of access.

(7) Special conditions of the work—those relating to navigation, traffic, discharge of solid matter, floating, substances carried down the watercourse, and where necessary the outlet of the works constructed above and below, observations on such works, test of strength of foundation soil where necessary, result of ramming of trial posts. It would be advantageous, for the sake of economy and to facilitate execution, to standardise the works and create very complete collections of model schemes.

Where the foundation soil is very good, and where stone-cutters are available and the execution is not urgent, a vault in masonry which only necessitates the transport of cement will often constitute the best solution. The material which will be desirable in the majority of the other cases is reinforced concrete. If the country contains limestone, clay or pozzuolana, these materials may be used for making the binding portion of the mortar.

The piles will be reduced in size or, where the current is not too strong, replaced by sheet piling.

Massive abutments will be avoided and replaced by abutments in auto-stable concrete of the type used in Madagascar and described in the note on constructive works in Madagascar (see documents).

The system of overhung or cantilever girders with semi-articulation in reinforced concrete is very economical, since it introduces negative bending moments at the supports, which reduce the positive bending moment at the middle of the girder. These types of works make it possible to pass through a semi-permanent stage with permanent supports and provisional deck in wood. A series of schemes of model works for a road executed in Madagascar (overhung girder, straight girder, cantilever girder) and model schemes of metal bridges and reinforced concrete bridges constructed in France and Indo-China are inserted among the documents enumerated at the end of the present report.

For the same live loading, a girder is heavier and dearer in proportion to its length. Moreover, a pier or abutment foundation is costly in proportion to its height and the poorness of the foundation soil. It is therefore necessary to seek the optimum solution which satisfies both these conditions. Where the foundation soil is firm and the bridge low, it will be advantageous to use short spans. If, on the contrary, the bridge is high and the soil poor, longer spans should be employed.

Finally, the *openings* of the work should depend, not on the width of the valley, but on the *flow* of the watercourse.

A provisional solution is a bridge of boats suitably stiffened, furnished with openings if this is required by shipping, or a ferry—a trail ferry if the conditions on the river permit.

Finally, ferries should be stable and should have easy means of access furnished with strong moorings.

(c) *Large-scale Works.* — For the study of these works, a file of documents should be collected similar to that which has been indicated above for medium-scale works.

As to materials, the choice will lie mainly between reinforced concrete and metal. Metal works are always lighter and more rapidly executed. On the other hand, in spite of recent progress in the metallurgy of special chrome and copper steels, the maintenance they require is usually costly.

(d) *Submersible Works.* — Rivers with a torrential flow, on which spates are violent but short, may be economically spanned by submersible dykes with sluices that will run off the ordinary flow. Such works should have very solid foundations, since they create violent eddies capable of producing deep erosions, especially downstream. This part of the work should therefore be specially protected.

4. *Organisation of Works—Material.*

Bed. — As regards the *bed*, it will be desirable to carry out immediately the permanent section, which should be as regular and homogeneous as possible. So long as the traffic is not very considerable, however, it will be possible to postpone

by means of provisional deviations, the execution of important and costly works such as large-scale construction works, raised embankments, deep cuttings or cuttings in rock. In principle, the embankment works will be carried out in such a manner as to secure connection, in the first place, by a temporary and narrow but continuous path that will be widened and finished later.

The works under embankments, and culverts and aqueducts will be of a permanent character, and will be executed before the embankments. The medium scale construction works may be provisional, but it will be an advantage in the majority of cases to construct permanent foundations and supports immediately.

The width of land acquired should, whenever possible, be permanent, in order to prevent roadside owners from erecting buildings which it will be necessary to demolish for the subsequent widening of the road.

Superstructure. — While the problem of selecting an economic type of surface is theoretically simple, it is less so in practice, since its solution requires knowledge of cost and estimates of expenditure, the exact determination of which is not always easy.

Where the estimates show a very small difference in price between two surfaces, it will be desirable to adopt the one which, though more expensive, will be more durable and the maintenance and utilisation of which will always be the most economical.

When a road is opened, it serves for traffic which, beginning at zero, increases at an extremely variable rate that is the principal unknown factor in the road problem.

The surface should be selected to suit the traffic. It should be modified whenever the traffic reaches a certain degree of intensity. It is desirable, therefore, to arrive at a scale of types of surface corresponding to different intensities of traffic, and thus to ensure that in passing from one type of surface to the next there will be the minimum of demolition and the maximum utilisation of old materials.

In any case, the sections to be surfaced and consolidated most urgently are those on which the soil has no great consistency, declivities, hollows, crossings of other roads, sections where the traffic is heaviest, where the rains have the most destructive effect and where maintenance is the most difficult.

Lastly, when there is a choice between two solutions, preference should be given to the one in which the larger amount of material of *national origin* would be employed, even if the final cost were somewhat higher.

Material. — It is hardly possible to give general indications as to material. Each scheme constitutes a case by itself, a special technical and economic problem the principal data of which are the comparative prices of labour, material and consumable matter.

There are some kinds of works which it is practically impossible to execute by means of labour alone.

For these works, the necessary mechanical appliances and the production of motor-power require to be studied in each particular case.

For the others, the comparative advantage of employing well-equipped labour or mechanical means should be estimated with due regard to the times required for execution and the expense.

5. Road Signs.

The object of road signs is, in the first place, to ensure *safety* on the road by giving warning of danger and, in the second place, to inform road users of the special points and the direction to be followed. *They are therefore intended for drivers and*

travellers who do not know the country. They should be complete, homogeneous and uniform.

A heterogeneous and varied system of signs does more harm than good. It is better not to set up any danger signs at all than to set up only a few. In the latter case, the driver is apt to be misled and to believe that all obstacles without exception are marked. Thus his attention and vigilance are not kept on the alert.

Road signs should be reduced to the indispensable minimum. It is unnecessary to indicate a slope which is clearly visible and well outlined. A bridge which will take any weight and which is exactly in line with the road in plan and section should not be shown as dangerous. Plantations will be used for marking the road. In curves, at least those of large radius, the limits of the road should be indicated by stones or barriers of very light colour.

Any sign, if it is to be effective, must be visible at such a distance from the danger point that a motor-vehicle running at full speed can stop within that distance. Inscriptions should be so arranged and of such dimensions that they can be read by a driver without slackening speed.

Road signs were dealt with at an international Conference which prepared a number of recommendations and rules. These have been published by the Communications and Transit Organisation of the League of Nations. The question was also the subject of an interesting study which appeared in the number of the *Revue des Travaux publics* for July—August 1914. This number is included in the documents.

The order of urgency to be adopted for the setting-up of road signs is the following :

- (1) Safety signs : bends, cross-roads, level crossings, open drains across roads ;
- (2) Direction signs ;
- (3) Local signs ; names of villages, rivers, noteworthy points ;
- (4) Distance signs and milestones.

The points from which distances are measured should be as few as possible and should be clearly indicated. The unit of length selected should be uniform.

6. *Maintenance.*

The *road-bed* is practically unaffected, except by the destructive action of natural agencies ; accordingly, its maintenance is of a seasonal character.

It should be examined periodically and the following tested in particular : the foundations and supports of bridges, culverts and drains, embankments and, especially, the drainage works. These latter works should be tested, cleansed and cleared out continuously before and during rainy periods.

Embankments, especially recent embankments, should be watched. Their subsidence is, in fact, liable to cause fissures which, if not immediately stopped up, may be the commencement of deep and dangerous crevasses and interrupt traffic.

Surfaces in earth, improved earth, sand, gravel, and water-bound macadam are readily affected by atmospheric agencies and by traffic. *They should be maintained continuously.* This maintenance requires more work, and the labour supply should be reinforced during bad seasons and at the seasonal traffic peaks.

Stagnant water softens surfaces, and accordingly every rut and every depression should be repaired almost immediately, otherwise the wear and tear rapidly increases, the rut becomes a pool, then a quagmire, and finally a crevasse.

This maintenance requires a *permanent supply* of well-chosen and well-prepared materials, which should be deposited on a side path, the line of which should be discontinuous, so as to allow the free drainage of water. It is often an advantage,

for ensuring such supplies, to apply for the assistance of farmers, who, during the dead season, have labour and means of transport unemployed.

The current maintenance staff will be permanently employed on the road. It will be equipped with the immediately necessary tools : pickaxes, shovels, hammers, rammers, wheelbarrows, watering-cans and light rollers.

Bitumen or cement surfaces are but little affected by the action of natural agents. They are worn out slowly and progressively by the traffic. They should be constantly supervised, but their maintenance involves *discontinuous work on a comparatively large scale* carried out by veritable movable workshops.

In France, the national and departmental roads are all of surfaced macadam or concrete. Their maintenance is one of the functions of the Service of Roads and Bridges and of the local service of the department, under the direction of an engineer-in-chief. The subordinate grades are the circuit engineer, the subdivisional engineer and, finally, the chief roadman and the roadman.

The sections under these several authorities are, on an average : roadman, 4 to 5 kilometres ; chief roadman (supplied with a bicycle), 25 to 30 kilometres ; subdivisional engineer, 300 to 500 kilometres ; circuit engineer, 3,000 to 4,000 kilometres ; engineer-in-chief, 8,000 to 10,000 kilometres.

The annual cost of maintenance is about 10,000 francs per kilometre.

Chapter III.

ROAD TRANSPORT.

In the preceding chapter, the economics of transport were considered in relation to the *road*. The object of the following Sections 1 and 2 is the study of the economics of transport in relation to the *vehicle*.

I. ENGINES AND FUELS. ¹

The development of motor traffic, as has already been indicated, has produced in countries possessing dense networks of railways a veritable crisis in the competition between road and rail.

It has been necessary, on the one hand, to find means of utilising railway-lines deserted by traffic and, on the other hand, to adapt the road system to traffic for which it was not originally intended. The crisis has been specially acute since the motor-car has used its success and development as a source of improvement. Motor-car technique records a new advance every year.

The latest progress, and perhaps that which will have the most important consequences, relates to the employment of fuels other than petrol, the high price of which has been a handicap to the development of the motor-car.

In France, and no doubt in all other countries importing petrol, efforts have been made to lower the cost of transport by mixing petrol and less expensive fuels, such as benzene and alcohols. There is an infinite number of formulæ for these mixtures. The most satisfactory proportions depend on the nature of the products added, the

¹ The information regarding motors, hydrogenation and low-temperature carbonisation was kindly given us by M. Bihoreau, Engineer at the National Liquid-fuel Office, Paris.

chemical composition of which is extremely varied. These mixtures, which are employed especially for lorries, are experimented with and systematically measured in the laboratory and elsewhere before being released for general use.

(a) *The Petrol-engine.* — The petrol-engine, which has been in use for more than thirty years, has reached a point of indisputable perfection.

Petrol, which can be employed in a great variety of ways, is obtained by the distillation of petroleum oils, and sometimes of tar. It is not without disadvantages. The first of these is its price, which makes it the dearest of liquid fuels.

Next comes the world distribution of petroleum deposits, which confers a quasi-monopoly on certain privileged countries.

Further, petroleum is very volatile and its flash point is extremely low, the result being a considerable loss by evaporation and a danger of fire, which is clearly brought out in insurance rates.

Finally, a mixture of petrol and air explodes at a relatively low pressure and this limits the thermodynamic output of the engine. Efforts have been made to improve this output by increasing the compression by the addition of anti-detonating materials, but it would appear that researches in this direction have not resulted in a practical solution. Perhaps, moreover, the progress made with the low-power Diesel engine has lessened the value of such research work.

(b) *Use of Alcohol as Fuel.* — There are, as yet, no engines of practical use which burn pure alcohol. At the present stage reached in the technical development of motor-vehicle engines, alcohol, on account of its low calorific power—4,500 calories, as compared with 7,500 in the case of petrol—is employed chiefly as an auxiliary fuel.

In consequence of this low calorific power, the utilisation of pure alcohol would necessitate the construction of engines which, as regards conditions of operation, power, consumption, weight and bulk, are comparable with that of petrol-engines, would have to provide *excessively high compression rates*, and would therefore entail numerous drawbacks from the point of view of strength of metal, ignition, cooling, etc.

On the other hand, employed as an *auxiliary*, alcohol, while it reduces the calorific power of the mixture, provides it with *anti-detonating* properties not possessed by pure petrol. These properties, by enabling the engine-compression to be raised without risking premature explosion, make it possible to recover the decrease in power due to the reduction in the calorific power of the mixture.

A mixture of petrol and alcohol in which the proportion of the latter is greater than 20% would be suitable, for example, for engines having a compression ratio of more than six.

The addition of alcohol further gives the fuel the advantage of being *anti-carbonising* and of *preventing the sooting-up* of the inlet valves and exhaust tubes.

In this auxiliary form, therefore, it is possible to use alcohol in ordinary petrol-engines, and even to retain the ordinary petrol fuels.

The alcohol employed in practice as fuel in France is, however, *anhydrous or practically anhydrous—i.e.*, having a content of 99.6°. Alcohol at 95°—the maximum degree of dehydration obtainable by ordinary methods of distillation and rectification—cannot, in practice, be employed in a mixture with petrol only; whatever the proportion of the mixture, the result is sometimes *a lack of stability and homogeneity* which leads to faulty working of the engine and carburettor. Anhydrous alcohol (99.6°), on the other hand, mixed, for example, in equal parts with petrol behaves quite well; but a mixture of 99.6° alcohol and petrol decomposes if, the alcohol content being insufficient, a small proportion of water is added or if the temperature is lowered. The critical alcohol content therefore depends on this proportion of water or on the temperature contemplated; for example, to separate a mixture at 0° containing 10% of 99.6° alcohol, it is sufficient to add 1.39 c.c. of water per 1,000 c.c. of fuel.

Working of Engine fed with Different Fuels.

Fuel		Results of engine with optimum compression								Observations
Density	Nature	Results on ordinary engine, p: 4.55, cylinder bore 25 mm., volume of consumption	Results on supercharged engine, p: 5.4, cylinder bore reduced by 8 mm., volume of consumption	Volume of optimum compression	Nature of modification		Volume of consumption	Consumption increase in percentage of volume		
					Bore of cylinders	Pistons		Of supercharged engine, p: 5.4, as compared with ordinary engine, p: 4.55	Of optimum engine, as compared with ordinary engine	
0.721	Light war-petrol	354 c.cm.	—	p: 4.55	ordinary	ordinary	—	—	—	Ordinary engine, p: 4.55, runs normally
0.732	Medium war-petrol ..	353 c.cm.	—	p: 4.55	—	—	—	—	—	Ordinary engine, p: 4.55, runs normally
0.743	Heavy war-oil	355 c.cm.	—	p: 4.55	—	—	—	—	—	Ordinary engine, p: 4.55, runs normally
0.764	Borneo war-petrol ...	342 c.cm.	—	p: 4.55	—	—	—	—	—	Ordinary engine, p: 4.55, runs normally
0.732	Medium war-petrol ...	351 c.cm.	—	p: 4.55	—	—	—	—	—	Ordinary engine, p: 4.55, runs normally
0.757	Roumanian petrol....	355 c.cm.	—	p: 4.55	—	—	—	—	—	Ordinary engine, p: 4.55, runs normally
0.740	Heavy shale-oil	—	—	p: 4.1	block of 6 mm.	—	370 c.cm.	—	—	Ordinary engine, p: 4.55, knocks very badly ; 6 mm. blocks have to be placed under the cylinders
0.719	Ordinary motor-car petrol	371 c.cm.	—	p: 4.40	block of 2 mm.	—	370 c.cm.	—	0.27%	Ordinary engine, p: 4.55, gives rise to very slight self-ignition; blocks of 2 mm. have to be placed under cylinders
0.745	Commercial spirit	—	—	p: 4.25	block of 4 mm.	—	370 c.cm.	—	—	Ordinary engine, p: 4.55, knocks very badly ; 4 mm. blocks have to be placed under the cylinders
0.875	Pure benzol	311 c.cm.	295 c.cm.	p: 5.4	dimin. of 8 mm.	—	295 c.cm.	5%	5%	Engine p: 4.55 and 5.4 run satisfactorily
0.875	90% benzol	308 c.cm.	309 c.cm.	p: 5.13	dimin. of 6 mm.	—	301 c.cm.	—	2.3%	Supercharged engine, p: 5.4, knocks
0.810	10% petroleum									
0.875	85% benzol	307 c.cm.	295 c.cm.	p: 4.93	dimin. of 4 mm.	—	304 c.cm.	—	1%	Supercharged engine, p: 5.4, knocks
0.810	15% petroleum									
0.875	90% benzol	317 c.cm.	304 c.cm.	p: 4.93	dimin. of 4 mm.	—	305 c.cm.	—	3.8%	Supercharged engine, p: 5.4, knocks
0.720	10% petrol									
0.875	80% benzol	323 c.cm.	—	p: 4.55	ordinary	—	—	—	—	—
0.720	20% petrol									
0.849	{ 50% alcohol	420 c.cm.	401 c.cm.	p: 6.4	ordinary	superch. 14 mm.	382 c.cm.	4.5%	9%	Engine runs well, p: 4.55, p: 5.4 and p: 6.4
0.790	{ 50% benzol									
0.740	50% anhydrous alcohol	418 c.cm.	390 c.cm.	—	—	—	—	6.7%	—	Engine runs well, p: 4.55 and p: 5.4
0.790	50% commercial spirit	397 c.cm.	—	p: 4.55	—	ordinary	—	—	—	Engine runs well, p: 4.55
0.740	15% anhydrous alcohol									
0.790	85% commercial spirit	—	383 c.cm.	p: 5.4	dimin. 8 mm.	—	—	—	—	Engine runs well, p: 5.4
0.740	40% anhydrous alcohol									
0.745	60% petrol	403 c.cm.	368 c.cm.	p: 5.4	dimin. 8 mm.	—	368 c.cm.	8.7%	—	Engine runs well, p: 5.4
0.817	{ 33% alcohol at 95°									
0.817	{ 33% benzol at 90°									
0.817	{ 33% petrol									

Operation of Ordinary Motor, p: 4.7.

Nature of fuel	Density at 15°	Volumetric consumption per h. p. hour	Observations
<i>Tourist petrol</i>	0.721	385 c.cm.	Motor knocks slightly at all speeds
95% tourist petrol, 5% anhydrous alcohol	0.725	388 c.cm.	Knocks appear below 720 tm. at full throttle
90% tourist petrol, 10% anhydrous alcohol	0.729	392 c.cm.	Knocks appear below 700 tm. at full throttle
85% tourist petrol, 15% anhydrous alcohol	0.733	398 c.cm.	Very slight knocks appear below 650 tm. at full throttle
80% tourist petrol, 20% anhydrous alcohol	0.737	405 c.cm.	Motor runs normally
<i>Commercial spirit</i>	0.746	385 c.cm.	Motor knocks at all speeds at full throttle
50% commercial spirit, 50% anhydrous alcohol	0.750	412 c.cm.	Motor runs normally
95% commercial spirit, 5% anhydrous alcohol	0.750	387 c.cm.	Motor begins to knock below 875 tm.
90% commercial spirit, 10% anhydrous alcohol	0.752	391 c.cm.	Knocking appears below 850 tm. at full throttle
85% commercial spirit, 15% anhydrous alcohol	0.754	392 c.cm.	Knocking appears below 820 tm. at full throttle
80% commercial spirit, 20% anhydrous alcohol	0.756	394 c.cm.	Knocking appears below 700 tm. at full throttle
75% commercial spirit, 25% anhydrous alcohol	0.758	403 c.cm.	Very slight knocking appears below 650 tm. at full throttle
70% commercial spirit, 30% anhydrous alcohol	0.760	413 c.cm.	Motor runs normally
<i>Pure benzol</i>	0.880	330 c.cm.	Motor runs normally
85% benzol, 15% commercial spirit	0.856	328 c.cm.	Motor runs normally
50% benzol, 50% alcohol at 95°	0.842	415 c.cm.	Motor runs normally
1/3 benzol, 1/3 alcohol at 95° — 1/3 commercial spirit	0.804	391 c.cm.	Motor runs normally

If it is nevertheless desired to utilise 95° alcohol, it must be employed either in a mixture of alcohol, petrol and benzol, the latter possessing the property of retarding the separation of the mixture, or in a mixture with benzol only.

Mixtures of three substances are much more stable as regards cold and the addition of water.

A very large motor-transport company running public services in France, which consumes large quantities of fuel, has carried out extensive tests of fuels to determine which was the most economical in use while enabling the engine to run smoothly (alcohol being sold cheaper by the monopoly in France than petrol). The preceding tables summarise the results of these tests, which have led this company to employ the following fuels with success for several years :

- | | | |
|-------------------------|---|-----------------------------------|
| Three-substance mixture | } | one-third alcohol at 94° to 95° ; |
| | | one-third benzol ; |
| | | one-third commercial spirit. |
| Two-substance mixture | } | 50% dehydrated alcohol (99.6°) ; |
| | | 50% commercial spirit. |

There is a special carburettor, known as the hydro-carburettor, which can be fitted to various types of engine and has several jets, each fed from an independent tank. By this means, non-mixable fuels can be used simultaneously; these do not mix until they enter the cylinders, and it has proved possible in this way to feed an engine with petrol and strongly hydrated alcohol.

The army and the State Railways are making practical trials with this carburettor, but the tests have not yet been carried far enough and have not given sufficiently decisive results for final conclusions to be drawn.

The use of alcohol in the maximum possible proportions indicated above requires, to bring it from 95° to 99.6°, rectification which can be carried out only by special processes necessitating costly plant, and this would be justified only if consumption were very large.

The economic and financial advantage of the use of alcohol and benzol depends on the conditions governing the production and importation of the products in each country, and also to some extent on its system of taxation.

(c) *The Diesel Engine.* — The Diesel engine has progressed by leaps and bounds in recent years. It may now be considered to have reached a high pitch of perfection. It was formerly criticised on the ground that its cost price was appreciably higher than that of the carburettor engine, that it emitted thick and evil-smelling fumes, and that it was more difficult to drive, requiring, in consequence, specially trained personnel. Finally, the supply of fuel could not always be obtained easily.

At present, the difference in price between a vehicle with a petrol-engine and the same vehicle with a Diesel engine of equal power varies from 15 to 50%. The heavier the vehicle, the less the difference. Presumably, this difference in price will go on rapidly diminishing. In France, it does not appear to exercise any influence on the employment of vehicles with Diesel engines, which is developing very rapidly, and it is considered that, for average and large capacities and long distances, the Diesel engine is without any doubt the most economical.

The Diesel engine, thanks to a better thermodynamic output resulting from a higher degree of compression, consumes from 30 to 40% less fuel than the petrol-engine. It is quite evident that, if the time came when a litre of gas-oil cost as much as a litre of petrol, one great advantage of this type of engine would disappear. At the present time, however, the saving effected on the kilometric charges, not including amortisation, by the employment of vehicles with Diesel engines is as much as 40% on the average.

Diesel lorries may now be entrusted to drivers without special training.

As regards the exhaust fumes, where the pumps and injectors are well regulated and a sufficiently purified fuel is used, this disadvantage disappears; in certain large towns, in particular in London and Nanking, urban motor-buses with Diesel engines are employed.

(d) *Gas Generators.* — Gas-generator lorries are comparatively little used in France. This type of lorry has, however, been tested and found satisfactory at certain great competitions, and, quite recently, at the last National Motor Fuel Rally organised by the Automobile Club of France. In the Chad country, it has for several years past maintained regular public services under economic conditions and without untoward incidents. Unfortunately, in the first place, the difficulties experienced in getting supplies of suitable fuel (prices of charcoal of the right size or dry wood) and, in the second place, the fact that the various parts have to be cleaned daily hamper its development. Experiments have recently been made with gas-generator engines utilising wood not previously converted into charcoal. These experiments seem to have given satisfactory results. With the gas generator, a specially powerful engine is necessary. Some setbacks have resulted from overlooking this fact.

TRANSPORTS AUTOMOBILES.

FRAIS D'EXPLOITATION ET PRIX DE REVIENT KILOMÉTRIQUE DE QUELQUES VÉHICULES.

Type	Autobus — Motor-omnibus				
	Essence - Petrol	Gazoil - Gas-oil	Essence - Petrol	Alcool - Alcohol	Gazoil - Gas-oil
Capacité ¹	23	24	30	31	
Poids total (en kilogrammes)	3 600.00	3 700.00	4 100.00	4 300.00	1 800.00
Prix d'achat (en francs)	60 000.00	84 000.00	66 000.00	69 000.00	3 500.00
Amortissement annuel (en francs)	20 000.00	28 000.00	22 000.00	23 000.00	45 000.00
<i>Frais fixes annuels (en francs) :</i>					
Intérêt du prix d'achat	3 000.00	4 200.00	3 300.00	3 450.00	2 250.00
Impôts	500.00	500.00	600.00	600.00	600.00
Assurances	6 000.00	4 000.00	7 000.00	7 000.00	2 000.00
Conducteurs	12 000.00	12 000.00	12 000.00	12 000.00	12 000.00
Total	41 500.00	48 700.00	44 900.00	46 050.00	31 850.00
<i>Frais kilométriques :</i>					
Essence	24.00	—	27.00	27.00	—
{ quantité aux 100 km. (en litres)					
{ prix au km. (en francs)	0.48	—	0.50	0.54	—
Gazoil	—	18.00	—	—	14.00
{ quantité aux 100 km. (en litres)					
{ prix au km. (en francs)	—	0.25	—	—	0.196
Huile	1.00	2.00	1.20	1.20	2.75
{ quantité aux 100 km. (en litres)					
{ prix au km. (en francs)	0.06	0.12	0.072	0.072	0.165
Entretien (rechanges) (en francs)	0.15	0.22	0.16	0.17	0.25
Pneumatiques (en francs)	0.14	0.15	0.18	0.19	0.17
Total des frais kilométriques (en francs) .	0.83	0.74	0.91	0.97	0.78
Prix de revient en (francs) au kilo- mètre pour un parcours annuel de					
{ 20.000 km. .	2.90	3.17	3.15	3.27	2.37
{ 40.000 km. .	1.86	1.95	2.04	2.12	1.58
{ 60.000 km. .	1.52	1.55	1.66	1.74	1.31
Prix de revient en francs de la tonne kilométrique utile ou du voyageur- km. pour un parcours annuel de . .					
{ 20.000 km. .	0.126	0.130	0.105	0.106	1.32
{ 40.000 km. .	0.082	0.082	0.068	0.069	0.88
{ 60.000 km. .	0.666	0.064	0.055	0.560	0.73

¹ Les chiffres se référant aux autobus indiquent le nombre de places et ceux se référant aux camions le nombre de kilogrammes.

Note. — Les chiffres ci-dessus ont été calculés d'après les hypothèses suivantes :

a) La durée d'amortissement est de trois ans,

b) Le taux d'intérêt est de 5%.

c) Les prix par litre sont de

Essence	2,—
Essence alcool	1,80
Gazoil	1,40
Huile	6,—

d) Les impôts et tarifs d'assurance sont ceux en France en 1934. Les prix sont exprimés en francs français ; les cours sont ceux de 1934.

Table I.

MOTOR TRANSPORT.

OPERATING COSTS AND COST PRICE PER KILOMETRE OF CERTAIN VEHICLES.

Camions — Motor-lorry						Type
Alcool - Alcohol	Gazoil - Gas-oil	Essence - Petrol	Gazoil - Gas-oil	Essence - Petrol	Gazoil - Gas-oil	Fuel
1 900.00	2 600.00	2 600.00	3 800.00	3 800.00	5 500.00	Capacity. ¹
3 750.00	5 000.00	5 000.00	7 500.00	7 500.00	10 000.00	Total weight (kilogrammes).
34 500.00	58 500.00	51 000.00	84 000.00	69 000.00	135 000.00	Purchase price (francs).
11 500.00	19 500.00	17 000.00	28 000.00	23 000.00	45 000.00	Annual depreciation (francs).
						<i>Annual fixed costs (francs).</i>
1 725.00	2 925.00	2 550.00	4 200.00	3 450.00	6 750.00	Interest on purchase price.
600.00	1 000.00	1 000.00	1 500.00	1 500.00	1 600.00	Taxes.
2 500.00	3 200.00	4 000.00	3 500.00	4 500.00	6 000.00	Insurance.
12 000.00	15 000.00	15 000.00	15 000.00	15 000.00	15 000.00	Drivers.
27 725.00	41 625.00	39 000.00	52 200.00	47 450.00	74 350.00	Total.
						<i>Cost per km.:</i>
27.00	—	33.00	—	40.00	—	Petrol : { consumption per 100 km. (litres). cost per km. (francs).
0.50	—	0.61	—	0.74	—	
—	23.00	—	28.00	—	40.00	Gas-oil : { consumption per 100 km. (litres). cost per km. (francs).
—	0.32	—	0.39	—	0.56	
1.25	3.10	1.5	3.50	1.60	4.00	Oil : { consumption per 100 km. (litres). cost per km. (francs).
0.075	0.186	0.09	0.21	0.096	0.24	
0.155	0.35	0.205	0.35	0.255	0.45	Upkeep (spares) (francs).
0.16	0.30	0.30	0.39	0.39	0.55	
0.89	1.15	1.20	1.34	1.48	1.80	Tyres (francs).
						Total costs per km. (francs).
2.27	3.23	3.18	3.95	3.86	5.52	20,000 km. } Cost price in francs 40,000 km. } per km. for an an- 60,000 km. } nual mileage of
1.58	2.19	2.19	2.65	2.67	3.66	
1.45	1.84	1.86	2.21	2.27	3.24	
1.19	1.24	1.22	1.10	1.02	1.01	20,000 km. } Cost price in francs 40,000 km. } per km.-ton useful 60,000 km. } load or passenger km. for an annual mileage of
0.83	0.84	0.84	0.70	0.70	0.67	
0.76	0.72	0.74	0.58	1.60	0.58	

¹ The figures in this line refer, under " Motor-omnibus ", to places and, under " Motor-lorry ", to kilogrammes.

Note. — The above figures have been calculated on the following assumptions :

- (a) Depreciation is spread over three years.
- (b) The rate of interest is 5%.

(c) The prices per litre are

{	Petrol	2.00
{	Alcohol	1.80
{	Gas-oil	1.40
{	Oil	6.00

(d) The taxes and insurance rates are those current in France in 1934. Prices are expressed in French francs. Rates of exchange are those of 1934.

For transport services where the rounds are comparatively short and the vehicles can thus be frequently inspected in the workshops and obtain supplies of charcoal of good quality from the garages, the gas-generating engine, which is hardly more expensive than the petrol-engine, is easily the *most economical type*.

In the technical organisation of services utilising this type of engine, account should be taken of the requirements of the system. The engines must be sufficiently powerful, the gas generators have to be cleaned every day and the engines frequently overhauled by specially trained gangs.

(e) *Steam-engines*. — In England, where there is no oil produced but abundance of coal, technicians have been led to seek for a means of directly utilising the latter fuel. They have succeeded by designing very ingenious steam-lorries, comparatively light, some of which maintain regular services. For further details, reference should be made to the documents supplied by the makers, the Sentinell firm.

* * *

COMPARATIVE COST PRICES OF TRANSPORT.

The cost price of transport, independently of the cost of making and maintaining the road, which is the same whatever the engine employed, consists of (a) amortisation, (b) fixed charges, (c) kilometric charges.

Amortisation varies within very wide limits, according to the characteristics and condition of the roads, the skill and conscientiousness of the driver and the way in which the maintenance of the vehicles is organised. In average conditions, it is usual to allow for a well-built vehicle an amortisation of four years and an annual mileage of 50,000 kilometres.

The fixed charges are insurance, taxes and duties on the vehicle and the wages of drivers.

The kilometric charges are the expenditure on fuel and oiling, tyres, current mechanical maintenance, washing, etc.

Table I gives the detailed kilometric cost price arrived at in France for certain vehicles with pneumatic tyres. It will be easy to adapt it to different conditions.

The work "Combustibles liquides et lubrifiants" gives the following figures for the comparison of the cost of running a chassis of 6 tons useful load (or about 11 tons total load) fitted with pneumatic tyres and a petrol or a Diesel engine :

Fixed expenses per day (300 working days per year)	Petrol-engine	Diesel engine
Interest on capital :		
Petrol..... 87,876 francs at 5%	14.64	—
Diesel 103,873 francs at 5%	—	17.32
Insurance (third party accidents and fire)	7.21	7.05
Taxes	7.14	8.32
	28.99	33.18

Kilometres	Per kilometre per day	Per kilometre-vehicle	Per ton-kilometre
	Petrol : Francs	Francs	Francs
50.....	$2.12 \times 50 + 29 = 135$	2.70	0.45
100.....	$2.12 \times 100 + 29 = 241$	2.41	0.40
150.....	$2.12 \times 150 + 29 = 347$	2.31	0.38
	Diesel :		
50.....	$1.98 \times 50 + 33 = 132$	2.64	0.44
100.....	$1.98 \times 100 + 33 = 231$	2.31	0.38
150.....	$1.98 \times 150 + 33 = 330$	2.20	0.36

Kilometric expenses		Petrol-engine	Diesel engine
Fuel :			
Petrol : 40 litres at 1.35 per 100 kilometres, per kilometre ..		0.54	—
Diesel : 28 litres at 0.40 per kilometre		—	0.11
Oiling		0.10	0.12
Repairs, spare parts		0.20	0.22
Amortisation :			
Petrol :			
Chassis : 75,100 francs per 150,000 kilometres.....		0.50	
Tyres : 12,776 francs per 30,000 kilometres		0.42	
Diesel :			
Chassis : 91,100 francs per 150,000 kilometres			0.61
Tyres : 12,776 francs per 30,000 kilometres			0.40
Driving and upkeep		0.36	0.50
	Per kilometre	2.12	1.98

From the foregoing figures, the following general conclusions may be deduced :

(1) Amortisation accounts for a part varying from about 50 to 30%, according to the way the vehicle is used. If this head of expenditure is to be reduced, workmen and drivers should be given a good professional training, and there must be well-equipped and well-arranged workshops and garages and also good roads properly maintained.

(2) The additional interest invested in equipping a vehicle with a Diesel engine is more than compensated by the saving on insurance, and the aggregate annual fixed charges are less with a Diesel engine than with a petrol-engine.

(3) The kilometric expenses of a Diesel engine are very much lower than those of a petrol-engine. If the fuel is to be carried a long way, as is the case with services operating at a distance from landing ports, the advantage in favour of the Diesel engine is considerably increased.

(4) With an equal coefficient of utilisation, the cost price of the unit of traffic diminishes if the capacity of the vehicles increases. This price may be still further reduced, where road conditions (moderate gradients, large radius, bends, regular surface) permit, by attaching trailers to the lorries.

The figures given above represent only the *haulage* expenses of a motor service.

To arrive at the balance-sheet of such a service, it would be necessary to add overhead charges and costs of operation.

Table II gives the total kilometric expenses for the months of July and August 1934 of a public service in the Department of the Aude.

Table II. — Kilometric Averages.

Circuit: Aude Motor-omnibus — 1934

Expenditure :	July		August	
Repairs :				
Workmen's wages.....	0.256	0.516	0.257	0.618
Spare parts, accessories	0.260		0.361	
Consumption :				
Petrol.....	0.522	0.843	0.542	0.646
Oil.....	0.121		0.104	
Tyres.....		0.160		0.091
Drivers.....	0.317		0.307	
Station staff.....	0.458	0.906	0.420	0.867
Trailer staff.....	0.131		0.140	
Overhead expenses :				
Fixed and variable insurance.....	0.060		0.055	
Proportional insurance.....	0.098		0.096	
Lump-sum payments, salaries, inspection costs, tickets, printing		1.273		1.246
Lighting and heating of stations and trailers, upkeep of plant and fittings of workshops and stations, workshop power supply	1.102		1.074	
Upkeep of buildings :				
Wages, materials	0.013		0.021	
Rolling-stock :				
Depreciation		0.360		0.349
Renewals fund		0.015		0.015
Interest on capital		0.063		0.060
General expenditure ratio per kilometre		3.936		3.894
Revenue :				
Passengers.....		1.256		1.491
Luggage, parcels.....		0.191		0.210
Ordinary goods traffic		0.175		0.198
Miscellaneous (articles not transported) ..		0.269		0.113
Mails.....		0.133		0.119
Revenue coefficient per kilometre...		2.024		2.131
Operating results :				
Profit		—		—
Loss		1.912		1.763
Kilometres operated :				
Monthly.....		51,291.4		50,969.2
End of month		348,964.6		399,933.8
General results :				
Monthly.....		98,047.81		89,661.52
End of month		779,955.69		869,817.21

This service is carried out by sixteen Saurer-Diesel lorries of seven tons useful load which have been in service for three years. Each of the lorries hauls a tractor capable of carrying the same useful load. Each unit therefore can transport 15 tons useful load. This means therefore, a coefficient of utilisation equal to 1, a remarkably low cost price of about 40 centimes per kilometric ton.

Finally, Table III gives the general results of the operation in 1932 of the Madagascar motor-services run by the colony on poor roads with very heterogeneous and often badly worn rolling-stock, fitted only with petrol engines. The average vehicle is capable of carrying approximately ten passengers and one ton of merchandise.

The expenses do not include either overhead charges or interest on capital.

We have thought it useful, in order to supplement the documentation on the question, to include a note (document No. I/III/18) on motor transport in the Belgian Congo. This note gives particulars of the characteristics of the roads, the dimensions of vehicles, the fiscal dues, transport rates, road policy and the co-ordination of transport.

Table III. — Madagascar Public Railways: Financial Results of Operation of Motor Services for 1932.

Revenue. — The revenue amounted to 3,159,294.26 francs, consisting of :

	Francs	Francs
Passengers (7,606) :		
Private	215,038.15	
Official	<u>1,360,838.90</u>	1,575,877.06
Luggage (254 tons) :		
Private	62,422.95	
Official	<u>266,563.65</u>	328,986.60
Goods (756 tons) :		
Private	334,644.40	
Official	<u>442,852.30</u>	777,496.70
Postal transport (mails and parcels)		447,244.25
Miscellaneous (hire, transfers, sales)		<u>29,689.66</u>
Total		3,159,294.26

or, per kilometre operated : $\frac{3,159,294.26}{843,266} = 3.746$ francs, apportioned as follows :

	Francs	Francs
Passengers	$\frac{1,575,877.05}{843,266}$	= 1.869
Goods	$\frac{777,496.70}{843,266}$	= 0.922
Luggage	$\frac{328,986.60}{843,266}$	= 0.390
Postal transport and miscellaneous	$\frac{476,933.91}{843,266}$	= 0.565
Total		3.746

Expenditure. — The expenditure amounted to 3,225,498.47 francs, consisting of :

	Francs
Personnel (wages and allowances)	1,789,628.47
Current supplies (petrol, heavy oil, oil, grease, miscellaneous)	959,682.09
Spare parts and tools	212,279.60
Tyres	244,251.31
Miscellaneous (upkeep of stations, charges payable to the Posts, Telegraphs and Telephones and rebates)	<u>19,657.00</u>
Total	3,225,498.47

The number of kilometres operated being 843,266, the expenditure per kilometre amounts to : $\frac{3,225,498.47}{843,266} = 3.825$ francs, which is composed as follows :

	Francs	Francs
Personnel	$\frac{1,789,628.47}{843,266}$	= 2.122
Current supplies	$\frac{959,682.09}{843,266}$	= 1.138
Spare parts and tools	$\frac{212,279.60}{843,266}$	= 0.252
Tyres	$\frac{244,251.31}{843,266}$	= 0.290
Miscellaneous (upkeep of stations, charges payable to the Posts, Telegraphs and Telephones and rebates)	$\frac{19,657.00}{843,266}$	= 0.023
Total		3.825

Tyres. — It should be added that, whatever the fuel and the type of surface, it will be an advantage to furnish vehicles with *low-pressure pneumatic tyres*. The advantages of these are the following :

- (1) The unit burden on the roadway is almost independent of the total load of the vehicle ;
- (2) Slight irregularities in the roadway have no effect ; shocks caused by larger irregularities, which are so injurious to vehicles, are appreciably deadened ;
- (3) By permitting of an increase in speed, they make it possible, with the same comfort and the same wear and tear, to accelerate the rotation of vehicles and accordingly to provide the same service with a lower initial establishment expenditure.

2. STATUS AND ORGANISATION OF PUBLIC MOTOR-TRANSPORT SERVICES BY ROAD.

Public motor-transport services by road may either be organised by public administrations (State, departments or provinces, communes), or leased to private companies, or finally may be free.

No public services are run by the administration in the home territory of France.

Leased public services have been developed since the war of 1914-1918. At that period, the profits were uncertain, and, accordingly, the State, with a view to promoting trade, granted them subsidies subject to certain conditions : regular services for specified localities, fixed tariffs, transport of mail. These subsidies formed the subject of regulations (Law of August 21st, 1923, Decree of March 29th, 1924, model agreement, executory instructions) which are included in the documents enumerated at the end of the present report.

As the traffic increased and the cost of motor transport diminished, the State ceased to grant subsidies and many public-transport undertakings were organised freely and without obligations. These undertakings were only subject to the general regulations applicable to the use of roads. Vehicles and drivers had merely to satisfy certain special technical conditions designed to ensure the safety of the users.

At the present time, in view of the often incoherent profusion of motor-transport undertakings and the competition of such undertakings with the railways, which is disastrous for the State, a legislative decree was issued on April 19th, 1934, which makes regular public motor-transport services subject to the system of *previous authorisation*. In principle, only public services which supplement the railways or answer an obvious need and do not overlap with existing services are authorised. Such a system, moreover, is tending to become general in Europe.

In the French oversea territories, in Africa, Madagascar and Indo-China, countries in full course of evolution, the various situations which have arisen successively in France may be observed existing simultaneously. A whole series of solutions may be found corresponding to a wide variety of conditions and requirements.

In Madagascar, at remote stations of small importance, where the weekly traffic comprises only a few passengers and the mail, the administration endeavours to make arrangements with the owners of motor vehicles who, in consideration of a small grant and the monopoly of administrative transport, undertake to follow a specified route once a week, or more often, and to carry passengers and also the mails at a fixed tariff. The grant is proportionate to the number of journeys made. On the other hand, a penalty is imposed for every journey not effected for reasons other than *force majeure*.

If the traffic foreseen or the stimulus to be given to the district concerned justifies the organisation of a service involving such risks that no transport undertaking will be attracted by it, or if the development of the district presents such uncertainties that the administration does not desire to enter into long-term engagements, the administration organises a transport service under *State control*. As soon as the position changes, however, and provided an undertaking is found which offers terms acceptable to the public, the administration makes arrangements with it in accordance with specifications which define the obligations of the carrier : time-tables and frequency of services, characteristics of the vehicles employed, commercial service, administrative transport, financial conditions, supervision, tariffs.

Among the documents enumerated at the end of the present report will be found the specifications of the transport undertaking which has replaced the service under State control between Antananarivo and Majunga, a distance of 580 kilometres.

Where, finally, the traffic is important and remunerative, or where the road competes with the railway, the motor services are obliged to obtain authorisation beforehand and to pay dues to the State. This has been the case in Indo-China and French West Africa (Decree of May 6th, 1933 ; Order of November 23rd, 1933, inserted in the documents).

In Morocco, the running of public transport services for passengers and goods by road is subject, not only to authorisation, but also—a very important point—to the production of an *insurance policy for 20,000 francs per place available* ; the insured sum must not, however, be less than 400,000 francs (see documents: “Public Transport Regulations in Morocco”).

It would be advisable for leased services not to bind themselves for too long a term. The period should be that of the normal amortisation of the material. Three years is a reasonable period, five years the maximum.

So far as we know, there are no public transport undertakings in Europe or America which contribute funds for the construction and maintenance of the roads.

* * *

Whatever its status, the technical organisation of a public transport undertaking of any importance depends on the particular conditions of the service; but there are certain general principles which should govern the matter.

1. The rolling-stock should be strongly built and as homogeneous as possible. Efforts should be made to ensure the interchangeability of vehicles and parts, even at the cost of a slight diminution in the coefficient of utilisation. Regularity being an important factor in operation, vehicles should be chosen according to the section of the roads with a *slight reserve of power*, so that it may be possible to make up delays due to incidents on the road without straining the engines.

Tyres should be of uniform low-pressure type.

2. Vehicles should be furnished with appliances for limiting the speed. They should have the greatest capacity compatible with the characteristics of the traffic, the state of the roads and the strength of the constructive works. The employment of trailers is recommended wherever the conditions of the road permit. As has been seen, with an equal coefficient of utilisation, the cost per ton carried diminishes as the capacity increases.

3. Reserve units and spare engines should be available so as to permit of and accelerate the regular periodical overhauling of vehicles in service.

4. Workshops should be equipped with a large stock of spare parts and be carefully fitted up, so as to enable all parts to be dismantled, replaced and reassembled rapidly and without unnecessary journeys. They should be provided with lifting and transport appliances and inspection pits or stages. Proper organisation of depots will reduce the time spent in repairs and overhauling, and thus reduce the expense of initial establishment.

The operations of inflating tyres and supplying water and petrol at depots and workshops should be so grouped together as to enable the vehicles to be put on the road quickly. At the terminus of lines served by vehicles using charcoal fuel, special engine-cleaning gangs should be provided.

The stocking, transport and distribution of fuels should be specially studied. Precautions should be taken against the danger of fire.

Every service should organise a small advanced school for drivers. Drivers should be frequently inspected.

5. A good average distance between depots is 300 kilometres and between workshops 900, or better 600, kilometres. The distance of 300 kilometres, moreover, corresponds to the maximum daily run of a lorry.

Depots should have inspection pits, and should be furnished with spare parts and current supplies: oil, fuel, tyres, breakdown lorries and reserve vehicles.

Finally, it might be desirable, in the case of a delivery of some importance, to provide in the contract that the supplier should maintain the rolling-stock and train engineers and apprentices for a specified period.

3. POSTAL TRANSPORT IN FRANCE.¹

The railways, whether operated by the State or assigned to private companies, are under obligation to place coaches or compartments in certain trains at the disposal of the postal administration, which is entrusted with the entire handling of postal matter and mail-bags.

The bags are thus forwarded by rail and delivered at the various stations to road transport services, which provide the connection between stations and post offices.

These services, which are carried out by persons on foot, by bicycle or motor-cycle, or by horse-drawn or motor vehicles, necessitate the following types of organisation :

- (a) Services entrusted to contractors selected by the postal administration ;
- (b) Services organised for the conveyance of passengers by departments or communes with the financial assistance of the State ;
- (c) Services under State control, with a staff and material belonging to the postal administration ;
- (d) Services concerned with the service of rural communes and known as " Rural Motor Post ".

(a) *Services entrusted to Contractors selected by the Postal Administration.*

These undertakings are selected as a result of public tender. The obligations of the persons conducting the services are set out in the model specifications (annexed to the documents) attached to the several contracts.

The contractor's obligation arises out of his tender or out of a private agreement.

As a general rule, the method of private agreement is feasible only when the contract does not exceed 5,000 francs a year, or where it has not been possible to negotiate by tender. In urgent cases (default, death of a contractor, etc.) a provisional contract is entered into in accordance with a model form.

The period of the contracts varies from 3 to 6 years. It is increased to 12 years where the undertaking necessitates the employment of a large quantity of material the amortisation of which would have to be spread out over a long period.

The undertakings to which postal transport is confided in large towns (Paris, Lyons, Marseilles, Bordeaux) are governed by special specifications which take into account the particular features of the service.

(b) *Services organised for the Conveyance of Passengers by Departments or Communes with the Financial Assistance of the State.*

The specifications comprise special obligations in the matter of postal transport for contractors providing these services.

Clause 22 of this instrument (inserted in the documents) enumerates these obligations.

In the case of a transport undertaking organised by a department or commune without a State subsidy, the person in charge of the undertaking is not under any

¹ These observations are in reply to a question asked by M. T. K. Chao, Deputy Director of the Roads Bureau.

special obligation as regards postal transport, but the postal administration endeavours to obtain advantages equivalent to those provided in the case of subsidised undertakings.

- (c) *Services under State Control operated with a Staff and Material belonging to the Postal Administration.*

These services are not very numerous. Experience has shown that it is an advantage for the administration to treat with private undertakings.

- (d) *Services known as "Rural Motor Post".*

The "Rural Motor Post" services are intended to remedy to some extent the isolation of country districts by arranging for the rapid transport of correspondence to or from communes not possessing a post office and situated at a distance from roads connecting important localities.

The postal vehicles in addition carry postal parcels, commercial orders, parcels for delivery of a weight not exceeding 50 kilogrammes, and also passengers as a subsidiary service.

Of the 326 vehicles at present in service, however, 13 do not carry passengers. The other 313 have 3, 6, 10 or 16 seats, according to need.

Each vehicle runs twice a day (morning and evening) over an invariable route, generally in the form of a closed loop, of a length of 50 to 60 kilometres.

A "corresponding" establishment, which takes part in all postal operations, including the distribution of the mail, is in operation in each of the communes served.

The motor vehicles are supplied by contractors, selected by competition, who provide for all the expenses of driving and haulage (fuel, oil, maintenance, garaging, etc.), and who receive an inclusive kilometric remuneration. All the receipts from the services (transport of passengers and parcels) accrue to the Administration of Posts, Telegraphs and Telephones.

Services of this kind are regulated by contracts and schedules of specifications, the models of which are inserted in the documents.

4. HYDROGENATION.

Hydrogenation, a question of immediate and vital interest, affects all countries producing coal but not possessing mineral oil. It seems desirable to describe the present position.

Hydrogenation is a method of treatment which may be applied to organic substances containing carbon for the purpose of extracting from them hydrocarbides utilisable for combustion or lubrication.

The hydrogenation of coal was carried out for the first time by Berthelot in 1869. By causing iodhydric acid in a sealed tube to act on coal at a temperature of 270° c., Berthelot obtained 60% of liquid products, consisting principally of hexane, with some traces of benzene and higher saturated hydrocarbides.

Later, in a series of experiments carried out from 1897 onwards, Sabatier and his collaborators established and extended to a large number of cases a general method of hydrogenation of organic matters, based on the employment, as catalysers, of divided metals and particularly of reduced nickel.

(a) *Hydrogenation in France.*

France at the present time possesses two hydrogenation processes absolutely independent of foreign assistance, one belonging to the Société nationale de Recherches and the other to the Compagnie de Béthune.

A practical programme has now received a vigorous stimulus, thanks to the action of the Office nationale des Combustibles liquides, which, with the assistance of important French colliery and petroleum companies, has decided to construct in the Pas de Calais two pioneer factories for the hydrogenation of coal.

(b) *Hydrogenation in Germany.*

In 1910, Bergius experimented with the conversion of heavy petroleum-oils by hydrogenation under pressure without catalysers. He subsequently applied his process to the direct hydrogenation of coal. His method consisted in treating at a constant temperature, with hydrogen under pressure, coal dust mixed with 40 to 50% of heavy oil, derived from an earlier operation, and 50% of iron oxide. A semi-industrial factory was constructed at Rheinau, near Mannheim.

The results obtained in this factory were published in 1925. From a ton of coal were obtained by hydrogenation about 150 kilogrammes of petrol, 25 kilogrammes of lubricating oil, 300 kilogrammes of various non-viscous oils containing about a fourth part of phenols, 200 kilogrammes of gas and 300 kilogrammes of coal residue.

The Interessen Gemeinschaft für Farbenindustrie (I.G.) had also carried out experiments in the hydrogenation of lignite tar with catalysers. This company acquired the Bergius patents, and, in 1926, undertook the construction of a factory for the hydrogenation or liquefaction of lignite at Merseburg.

In 1927, part of this factory was working and producing 1,000 tons of petrol per month.

The process consisted of hydrogenation in two stages.

In the first operation, the lignite, pulverised in a crushing installation and mixed with oil, was forced back at 200 atmospheres into a reaction chamber, where it was brought into contact with hydrogen.

The tar product resulting from this first operation was deprived of its petrol and subjected to a second hydrogenation with catalysers, which resulted in the conversion of the major part of the oil into petrol.

The two operations together made it possible to extract from 470 to 500 kilogrammes of petrol from a ton of dry lignite.

This process was subsequently abandoned, and the I.G. confined itself to treating by hydrogenation the tars resulting from the distillation of lignite.

This treatment was applied from 1929 to 1932 in the Leunawerke at Merseburg.

The hydrogenation of lignite tar is carried out under 200 atmospheres in two stages :

- (1) A treatment in the liquid phase at 450° c. ;
- (2) A treatment in the gaseous phase at 500° c..

The final output is from 75 to 80% in weight, with a consumption of 760 to 800 cubic metres of hydrogen per ton of petrol.

The capacity of production of the Merseburg factory is from 100,000 to 120,000 tons of petrol per annum.

Since 1932, the I.G. has again had recourse to lignite itself as a raw material for hydrogenation. According to a communication made to the London Congress, the output per ton of dry lignite without ash is about 650 kg. of liquid fuel. By

transforming into petrol, in a second hydrogenation at the gaseous stage, the heavy parts of this liquid fuel, the total output in petrol is 600 kg.

About 25,000 tons of petrol are said to have been produced in 1933 from lignite.

The Merseburg factory is at present increasing the capacity of its hydrogenation installations. According to certain reports, the output of petrol will in the near future be increased to 300,000 tons.

While the transformation of lignite into petrol is technically possible, that does not mean that it is economically profitable. In fact, petrol produced by hydrogenation is appreciably dearer than petrol from rock oil. According to a German estimate, tariff protection of 18 pfennig (1.08 Fr. franc) per kg. of petrol would be necessary, if the present prices of petrol are taken into account, to make the direct hydrogenation of lignite or coal economically feasible. It will be seen presently that protection has also been considered necessary in England, but that the amount is distinctly less (about 0.40 Fr. franc per kg.). It is certain that the effort of the I.G. has only been undertaken in consideration of certain special advantages and subsidies.

Outside the Leunawerke, various schemes are under consideration in the Ruhr Basin for transforming certain existing installations, utilised hitherto for the treatment of nitrogen, for the purpose of producing synthetic petrol.

Further, a process different from that of the I.G. for the hydrogenation of tars is at present the subject of experiment in a lignite mine. From 5 to 10 tons of lignite tar per day are treated by the Klever process. The output in petrol is said to be 52% on an average and to have reached 66% in certain cases.

As a matter of fact, this production is negligible, and it may be said that the Merseburg factory is the only one producing large quantities of petrol. This petrol, moreover, appears to be of inferior quality, as it is not used for touring cars, its consumption being reserved for heavy lorries.

Notwithstanding this unfavourable circumstance, and although hydrogenation can only constitute a profitable operation with the aid of tariff protection, an important programme of enlargement and extension is at present being carried out at the Leunawerke.

This circumstance brings out clearly the real object of the Merseburg factory; it is not an ordinary industrial installation, but a national defence factory. This is shown, moreover, by a lecture delivered in Berlin by Dr. Pier of the I.G.

(c) *Hydrogenation in England.*

Imperial Chemical Industries (I.C.I.) have, for several years past, been at work on perfecting the hydrogenation of coal.

They have studied the possibility of liquefying solid fuel by catalysis. But in doing so they employ a cheap catalyst and use so small a quantity of it that there is no financial objection to eliminating it with the ash, without troubling to recover it. As a subsidiary consequence of the solution of this problem, the hydrogenation of coal has become more profitable than that of lignite. The latter contains more oxygen and consequently requires a greater quantity of hydrogen. Moreover, lignite generally has more ash than coal has, and the consumption of catalyst increases with the proportion of ash.

According to the I.C.I., the hydrogenation of coal is technically perfect, but the price of the petrol obtained by this process appreciably exceeds the price of ordinary petrol if the import duty on the entry of the latter into the United Kingdom is deducted. Petrol could thus be produced on a large scale by the new process only if the industry could count on protection against the imported product.

The British Government accordingly brought in a Bill which has recently been passed. The Act establishes a relationship between the *rates* of Customs duty and the

period of the guarantee thus offered to the British industry. The intention is that this guarantee shall consist of a duty of 4*d.* per gallon on imported petrol and continue for a period of nine years. If the duty is higher, as is the case to-day, when it is 8*d.*, the period of the guarantee will be diminished accordingly. The rate of 4*d.* per annum being equal to 1*d.* per quarter, there will be an increase or reduction of three months in the period of guarantee for every penny by which the Customs duty is increased or diminished on the basic rate of 4*d.*

For example, with the present rate of duty, the three-monthly margin is 2*d.* instead of 1*d.* If it is maintained, the period of application will be $\frac{36}{2} = 18$ quarters, or 4½ years. If the duty is assumed to be reduced to 6*d.* per gallon, the margin of protection will be only 1½*d.* per quarter, and, accordingly, the period of guarantee will correspond to $\frac{36}{1\frac{1}{2}} = 24$ quarters, or 6 years.

As will be seen, the margin of protection considered necessary by the I.C.I. is appreciably lower than in Germany. The protection accorded in England is, in fact, 30 centimes per litre or 40 centimes per kilogramme, while in Germany 1.08 Fr. franc per kilogramme is considered the indispensable protection.

The I.C.I. have undertaken the construction of a factory capable of producing annually 100,000 tons of petrol by the hydrogenation of coal. The cost of the factory will be £2,500,000, and the quantity of coal treated about 350,000 tons per annum. According to estimates, the factory was to start working during 1935.

Other schemes are also on foot in England for the hydrogenation of low-temperature tars. Efforts will be made to combine the industry of low-temperature carbonisation with the hydrogenation of tars. It is even thought by some that this method of treatment will be more profitable than hydrogenation directly applied to coal.

To sum up, hydrogenation is an industry in full process of development. Apart from the application of this method to the treatment of petroleum, which has not been mentioned in this report and which is applied in the United States, three countries—England, France and Germany—are about to develop or establish industrial installations.

In Germany, where this technique originated, a factory has existed for some years, but its activity, which was originally directed to the hydrogenation of liquid fuels, seems to be turning more and more to the treatment of solid fuels. Moreover, the capacity of this factory is being increased, and, from 1934, Germany has reckoned to satisfy a by no means negligible part of her requirements in liquid fuel by means of national products.

In England, a factory for the hydrogenation of coal is at present in course of construction, and there is talk of applying this technique to the treatment of low-temperature tars.

The hydrogenation of solid fuels therefore seems to be technically perfect and, if the operation appears to be open to discussion as an economic proposition, it nevertheless enables countries with no oil deposits but with sufficient supplies of coal to procure petrol.

* * *

LOW-TEMPERATURE CARBONISATION.

For a number of years past, efforts have been made in several countries to carbonise coal at low temperatures for the purpose of extracting tar and at the same time producing a semi-coke, poor in volatile substances and capable of replacing anthracite.

The development of this industry was at first held up by the quality of the semi-coke, which was not sufficiently hard and homogeneous to compete effectively with

anthracite. Progress has been made, however, and there are now in France several low-temperature distillation works which supply good artificial anthracite to the consumer. A market being assured for the semi-coke, it is expected that low-temperature carbonisation will develop, since it makes it possible to convert into valuable products bituminous fines which are difficult to sell.

The capacity of the installations for semi-carbonisation in France is at present about 150,000 to 180,000 tons per annum. With the installations which are contemplated or in course of construction, an annual capacity of treatment of about 500,000 tons may be expected for 1935.

The output in primary tar being about 8%, the quantity of this product annually prepared was from 12,000 to 15,000 tons and was to reach 40,000 in 1935.

Unfortunately, this primary tar, which was at one time considered a choice product comparable to crude petroleum, is in reality a mediocre commodity which is at present sold mixed with high-temperature tar for the maintenance of roads. This tar might, however, be improved in value by hydrogenation, and this is certainly the solution which will be adopted when it is sufficient in quantity.

Low-temperature carbonisation will therefore involve in the near future the production of a certain tonnage of primary tar which can be transformed into petrol by hydrogenation. It must be borne in mind, however, that this primary tar is a *by-product*, and that the available tonnage will depend on the quantity of semi-coke which can be placed on the market.

Chapter IV.

ADMINISTRATION OF THE ROADS.

I. REGULATION OF ROAD TRAFFIC.

The regulation of road traffic is far from being definitive and uniform. It was the subject of the sixth question submitted to the Seventh Road Congress which met in Munich in September 1934.

Something approaching agreement exists as to the rules concerning the regulation of traffic and safety: drivers' licences, running-licences, meeting, overtaking, priority, signals and the general requirements concerning the accessories of vehicles, lighting, brakes, etc.

For this part of the regulations, the Decree on Road Traffic in French West Africa may be taken as a model (see documents).

There is, however, little agreement on the dimensions and weight of vehicles and especially on the question of maximum speed, all of these being factors which affect the cost of transport but the limitation of which is nevertheless necessary for the safety of traffic.

The three fundamental elements of the question—they are often contradictory—are, in effect: the preservation of the roads, the safety of traffic and economic requirements.

As regards the *preservation of the roads*, speed and the pressure on the road are the main factors. The total weight only affects the stability of bridges and other constructive works.

Safety of traffic depends in the first place on rapid braking action. This is a purely mechanical question, which has in general been fairly satisfactorily solved. In the second place, it depends on stability. This leads to an effort to lower the centre of gravity of vehicles, and, accordingly, to limit their height in relation to their width. Finally, it depends on ease of running. This is directly connected with the length and breadth of vehicles.

Economic requirements, whether in the case of the transport of passengers or goods, lead to the employment of vehicles of large dimensions—motor-buses carrying thirty to fifty passengers, and lorries capable of taking over 10 tons.

It is hardly possible in this matter to lay down hard and fast instructions, but the following rules would seem to be desirable :

(a) Particularly in countries with a poor railway system where long distances have to be covered, the lowering of the cost of transport is a specially important factor in economic development. The authorities should therefore be very liberal in laying down regulations regarding the capacity of vehicles. The total weight will be limited by the strength of bridges and other works. Where necessary, their strength should be increased. This will incidentally allow of the passage of heavy rollers.

(b) It is desirable to limit speed in relation to suspension. Solid tyres will be penalised, both from the point of view of speed and taxation, and they might even be prohibited, as has been done in Italy.

(c) The pressure of the wheels on the road should not exceed 10 kilogrammes per square centimetre for vehicles with low-pressure pneumatic tyres. This pressure should be reduced for high-pressure pneumatic tyres and solid tyres. Further, the total weight per axle should be less than 10 tons.

(d) The width should be limited to 2.5 metres. Vehicles exceeding 2.2 metres, however, should slow down, and, if necessary, stop to allow more rapid vehicles or vehicles of smaller dimensions to pass.

(e) The maximum length of vehicles should be fixed at 10 metres. Unsupported posts overhanging in the rear must not exceed one-fourth of the total length of the vehicle.

(f) The maximum height should be fixed at 4.5 metres.

2. HIGHWAY CODES.

The object of a highway code is to classify roads according to their character and the quantity of traffic, to unify the general rules relating to the road system, and to organise road administration.

The classification of roads was discussed at the International Road Congress held in Washington in 1930. The very elastic conclusion which the Congress adopted—the division of roads into three classes—is almost universally applied.

In France, roads are divided into three categories :

- (a) National roads (about 80,000 kilometres) ;
- (b) Departmental roads ;
- (c) Communal roads.

The national roads, all of which are macadamised and tarred or paved, or concrete, are administered by the Directorate of Road Administration of the Ministry of Public Works, which distributes the credits, approves schemes and contracts of importance and decides on regulations.

This Directorate has a central technical service, concerned more especially with the study of constructive works and building material.

In each department (they number ninety in all) there is a service under the direction of an engineer-in-chief of roads and bridges, who is, in the majority of cases, in charge of the departmental roads, the hydraulic service and the supervision of public transport services.

The chief of service is authorised to settle all questions relating to the execution of works within the limits of the credits assigned to him and of the regulations in force.

Traffic-police regulations and regulations relating to the use of roads are uniform throughout the country. A motor vehicle registered in any town in France has the right to run on all French roads.

Communal roads are administered by the mayor under the authority of the prefect of the department, representing the Minister of the Interior; the Engineer-in-Chief of Roads and Bridges is his permanent technical adviser.

A Bill on the highway code is at present before Parliament. The text will be found among the documents. The principal object of the Bill is to ensure by legislation a centralisation and uniformity which already exist in practice in most of the departments.

In the preparation of a code, care should be taken to avoid two extremes. On the one hand, excessive centralisation is apt to paralyse and discourage the executive services. On the other hand, if the central organs are few in number, they will be weak, and hence a variety of divergent rules will spring up in different parts of the country and subordinate staffs will not be employed to the best advantage. The same problem will have to be settled by a great number of local authorities each for itself. Although these authorities will find a fairly satisfactory answer, there can be no doubt that a single investigation carefully carried out by a central authority with a full knowledge of the facts would give far better results.

The central organisations should concern themselves with the study of general plans, purely technical research work, documentation, liaison and co-ordination with research institutions and laboratories, and with the administrations that maintain relations with the road services, such as those of finance, railways, agriculture, etc.

The executive services should examine in detail the organisation of work, furnish the central authorities with all possible information and suggestions, and abstain from all investigations where there is likely to be overlapping. In a word, the aim should be centralisation of technique and decentralisation of execution.

In any case, close and frequent communication between the central organisations and the executive services is necessary.

3. FINANCING OF ROADS.

Closely connected with the highway codes is the question of the financing of roads. On this subject, there are two opposing theories: on the one hand, the old doctrine of budgetary unity, which rejects all "specialisation" of receipts and requires that all items of expenditure, whatever their nature, should be voted annually. This artificial and arbitrary doctrine, which, with the industrialisation of certain State services, has become out of date and obsolete, is still applied in France where, however, it has been the subject of very severe criticism supported by strong arguments.

Under the other doctrine, which is more modern, the question is regarded objectively. The administration of a road system has a strictly industrial character. It implies organisation and the preparation of programmes conceived on a large scale and realisable over long periods. For this purpose, it is necessary to secure a certain fixity in the resources assigned to roads and to make them available for the services at the proper time, which is hardly possible with a budget voted annually.

In France, a beginning which has not been pursued has been made with the application of this doctrine by means of a bill relating to a Roads Office, the text of which will be found among the documents.

England, America, Italy and Czechoslovakia have road boards or road offices possessing administrative and financial autonomy, the action of which has been considered to be decisive.

The Washington Congress pronounced clearly in favour of the more modern theory of the specialisation of certain receipts and the financial autonomy of the roads.

There is no doubt that a State possessing stability and external and internal economic political and financial security, and contemplating the execution of a road programme on a vast scale, has the greatest interest in entrusting the preparation, study and carrying-out of such a programme to a special body endowed, under the authority of the Government, with a certain administrative and financial autonomy and assured of a minimum of permanent funds.

4. STAFFS.

The output of even the most perfect organisation depends, above all, on the moral and technical value, the permanence and the steady activity of the staff of the organisation.

In the matter of public works and roads in particular, the quality and cost of the works and the public safety will vary within very wide limits with the value of the technical staffs of all grades.

This value is a resultant of their general culture, professional knowledge, moral qualities and physical aptitudes, different posts requiring different combinations of these qualifications.

In all grades, common sense, conscientiousness, probity and character are essential qualities. They are, unfortunately, the qualifications which it is the least possible to discover by isolated tests over a short period.

The subordinate grades should have a very advanced specialised technical instruction and physical powers enabling them to set an example and giving them prestige with the general body of labourers.

The higher grades should, in addition to extensive technical knowledge, possess a wide general culture and administrative education.

All grades should be imbued with the idea that, while work is prepared in the calm of the office, the origin, object and end is execution *on the spot*, and that the outdoor work, often arduous and obscure, is as honourable and useful as the intellectual work carried out in the office.

The link between the offices and the yards should be close and continuous, and the responsible chief should visit the works as often as possible.

For a long time, little thought was given in Europe except to the training of the intermediate and higher staffs. It was soon found, however, that, while the profit to be expected from the quality of a worker and his foreman was small, this profit had an important coefficient, and that the organisation of apprenticeship and occupational instruction are of an importance comparable to that of the organisation of higher technical instruction.

Finally, the quality and quantity of the work performed by an average man will be the greater the more he works in tranquillity and the better he is acquainted with the questions with which he deals. *Continuity* and *stability* of employment are the more necessary the higher the employment. All great public and private administrations have recognised this and have given their officials a status securing their future and protecting them against interested interference.

Officialism has been very much decried in recent times, owing to abuses committed by certain officials, which have been facilitated by negligence on the part of the authorities. But no better system has yet been found to take its place.

Roads call for the services of very various categories of technicians : For *the preparation of schemes* and office work—surveyors, draughtsmen, secretaries and accountants, engineers ; for *execution and upkeep*—supervisors and foremen, engineers ; for *operation*—superintendents, foremen, workshop managers, engineers.

From this is deduced the general organisation of the different staffs which should compose the structure of a road administration. In France, engineers are divided into two groups : a higher grade (the engineers of roads and bridges), and a lower (the grade of engineers of State Public Works). There is another group, that of technical assistants, which is intermediate between the State Public Works group and the surveyors and supervisors. There are no public road-transport services in France operated by the State.

The organisation of staffs should reconcile two opposing principles. There should be as few grades as possible. On the other hand, the maximum results should be obtained from the knowledge of officials and, as a consequence of this, care should be taken not to require knowledge the acquisition of which is difficult and which will never be employed.

It would be bad policy, for example, to employ in office work or as topographers officials who have studied the strength of materials and the practical execution of works.

SECTION II. — ROAD COMMUNICATIONS IN CHINA.

Chapter I.

CONDITIONS PECULIAR TO CHINA.

I. DESIRABILITY OF A ROAD SYSTEM.

China possesses, in addition to river highways and canals, a very ancient and very remarkable network of roads constructed for rustic vehicles drawn by men or animals, which, moreover, still run on them to-day.

These roads are only suitable for light and slow traffic over short distances.

During last century, the construction of railways and of a certain number of roads was commenced. It is particularly during the last few years, under the energetic stimulus of the present National Government, that a programme of roads for motor vehicles on a large scale has been undertaken.

Notwithstanding the remarkable results already attained, however, the country is so vast and the programme so extensive that an immense task still remains to be accomplished in this direction.

China has an area of 11,000,000 square kilometres and a population of 451,000,000. At the end of 1934, she had about 80,000 kilometres of highways and 50,000 registered motor vehicles. There is therefore one kilometre of road per 135 square kilometres, whereas, in England and the United States, there is one kilometre of road per 0.8 and 1.6 square kilometre respectively.¹

The Chinese farmer is very industrious and active and the soil he cultivates is fertile. Social assistance organisations are relatively few in number, and there are not

¹ Extract from a report of the Roads Bureau : " Some Information on Highways in China ".

many railways. The desirability of a road policy, therefore, cannot be seriously questioned.

It might be objected that China possesses an extensive system of navigable waterways. This system, however, lies chiefly in the north-east and is insufficient for present needs.

A road system is necessary for the formation and maintenance of a national economic and political entity. Moreover, its social importance is undoubted. It is rare that such scourges as drought, flood and famine, which periodically desolate the country, affect the whole extent of it. A system of roads would make it possible to obtain from the provinces which are spared the necessary supplies for relieving and reprovisioning the stricken provinces.

The reduction of the time occupied in transport will increase the efficacy and extent of the area of influence of social assistance organisations and improve the output of the technicians, who are too few in number.

The extension of the system of roads practicable for motor-cars will bring the townsman and the peasant closer together and save the latter long and difficult journeys, while making it easier for him to exchange his commodities.

There is no doubt economically that the extension of the railway system is justified. Roads, however, which can be constructed rapidly and at small expense with national resources and materials, should precede railways, the construction of which is costly and slow, should prepare the way for them and bring them traffic by stimulating and encouraging trade in the districts they serve. The objection has been raised that roads have been constructed on which the traffic is insignificant. It is, however, generally admitted that a certain time must elapse between the opening of a road, or of a railway, and the appearance of an adequate volume of traffic. Moreover, if mistakes have been made—which is excusable—in deciding on the degree of urgency, this is not an argument against a practical road policy.

It would be a disastrous error to deduce from the fact that there is as yet no traffic on a certain road that roads in general are useless.

A policy of road construction in China would meet obvious and imperative economic, political and social needs. Such a policy is in no way irreconcilable with the extension of the railway system, for which it should prepare the way. In point of fact, countries which have a highly developed railway system also have a very extensive road system.

2. TECHNICAL CONDITIONS OF THE PROBLEM.

From the administrative point of view, the principal characteristic is decentralisation, a large measure of autonomy being enjoyed by the provinces, which are practically masters of their own budgets and taxation, and of the regulation and execution of the works. The intervention of the central powers is confined to general technical studies, very useful co-ordination works, organisation and documentation, and to loans for certain roads. These administrative questions are considered in Chapter V below.

One of the great difficulties of the problem lies in its very extensiveness. In Europe and America, it is a question of continuing, improving and completing. In China, it is a question of *reconstruction*.

The programme is a very vast one, while the financial and technical resources are limited, and, accordingly, the establishment of an order of urgency is particularly important.

No map exists on a scale that could be used for studies of roads except for a small portion of the territory.

Labour is almost everywhere abundant, industrious, docile and cheap. Technical staffs are insufficient in number for the extent of the task with which they at present have to deal. The result is that, in spite of their activity and zeal, they have not the time essential for a full study of all possible solutions of a problem and for keeping abreast of technical developments. This situation will improve as construction progresses. At the present moment, however, it is all the more critical inasmuch as technical archives and documents are few and precedents and examples to be followed are rare.

The natural resources of stone, gravel and sand are found almost everywhere at varying distances. In the north-west, stone is rarer, and this scarcity constitutes, together with the absence of wood, one of the great difficulties confronting the services which are constructing the road from Sianfu to Lanchow.

The only construction materials at present prepared in China are cement and a certain amount of timber.

Coal, generally of poor quality, is comparatively abundant. Workable forests are somewhat rare, notwithstanding the large-scale reforestation now in progress.

No deposits of mineral oils are exploited. All liquid fuels are imported. On the other hand, the country produces oils of vegetable origin (cotton-seed, ground-nut, wood-oil), though these are rarely employed as fuels.

Finally, motor traffic is generally carried out by comparatively light lorries (five-ton load) and is moderate in quantity. The relatively high cost of transport retards the growth of traffic. Traffic on foot and with wheelbarrows, carts and pack and draught animals is very considerable.

To sum up, the *technical* conditions of the road problem peculiar to China are :

- (a) Extensive and unmapped country, possessing a system of navigable waterways and some railways ; a very extensive road programme ;
- (b) Abundant cheap labour, few persons with technical training ;
- (c) Absence of local supplies of artificial materials, except cement and a small amount of timber ;
- (d) Absence of mineral fuel, abundance of vegetable-oil products ;
- (e) Very considerable traffic on foot with wheelbarrows, carts, pack and draught animals ; motor traffic inconsiderable.

Chapter II.

GENERAL INDICATIONS.

I. IMPROVEMENT AND CO-ORDINATION PROGRAMME.

The extent of the programme of reconstruction raises the all-important question of the order of urgency, which depends to a certain extent on the general transport system.

In the first place, it is necessary to make an inventory of existing highways and to study the means of increasing their utility.

As regards navigable waterways, it is desirable to lengthen the navigable sections or deepen the channels. This may be effected by dredging, conservancy and regulation

works and by undertakings which may or may not be combined with agricultural improvement schemes. These works come within the province of the hydraulic services, but they affect the road services, particularly as regards the distribution of traffic and the co-ordination of the different means of transport.

The practicability and capacity of the traffic on the roads will be increased at small expense by strengthening bridges and other such works, carrying out drainage, reducing heavy gradients and improving curves and the worst sections. Railways will be equipped with light and rapid rail-motors, so as to take the place of the public services on the roads running parallel to them. Such vehicles would be of real importance on the following lines: Nanking - Wuhu, Shanghai - Hangchow, Hangchow - Nanchang, Wuchang - Changsha and its prolongation to the south, Nanchang - Kiukiang, Kowloon - Canton.

This would relieve the roads of a traffic that represents a heavy wear and tear, thereby lightening the cost of upkeep, while the same transportation would be effected at a much lower kilometric cost, and with greater speed and less risk. *This is an important question* which should be considered at once with the railway administration.

The next thing to be done is to organise the distribution of traffic. River transport is the cheapest, and heavy and slow traffic should thus be systematically directed to the waterways. The density of the system of waterways raises a minor problem, particularly in Chekiang—that is to say, how the roads are to be carried over the waterways. In many cases the crossing is effected by hog's-back bridges with very steep slopes, the idea being to permit the passage of junks with masts. The section of the road and its safety are thereby seriously affected. *It is desirable, therefore, after consultation with the engineers of the hydraulic services, to issue regulations laying down the maximum height of junks above the level of the water and the minimum free space between the bridges and the level of the highest navigable waters.*

All these measures—the taking of the inventory, the improvement programmes, the distribution of traffic, the co-ordination of different highways, the order of urgency—will be studied by the *reconstruction services of the provinces*. In the order of urgency, roads of national importance subsidised by the National Economic Council will take first place.

The co-ordination of road and rail transport, and particularly the substitution of rail-motors for motor-bus services, will be discussed at Nanking by the National Economic Council and the Railway Department.

Finally, it will be necessary to study the organisation of intercommunication between waterways, railways and roads—*i.e.*, their connection with each other, the arrangements for transshipment, and the co-ordination of time-tables of train and motor-bus services.

The other considerations—economic, political and demographic—which affect the order of urgency, have been explained in Section I, Chapter I, and it is not necessary to repeat them. *In view of the immense network to be created, the study of the order of urgency is particularly important and delicate.*

2. TOPOGRAPHICAL SERVICE.

The difficulty resulting from the vast scope of the road programme is aggravated by the lack of maps on a scale which would make it possible to study preliminary schemes of lay-out direct. *It is therefore desirable to make extensive use of photographs taken from the air.*

The aero-topographical service of Nanking, which we inspected in detail, is remarkably organised. It is a pleasure to pay this tribute to its Director, M. Lu, and

his assistants. The resources at their disposal, however, are inadequate and should be greatly increased. Photography from the air will make it possible to increase the output of the land topographical services and to speed up the study of projects; in short, it will save time, staff and money.

It is further indispensable to organise the systematic co-ordination of the works, studies and observations of the various geographical, topographical, hydraulic, railway research and other services. For this purpose, there will be set up under the direct authority of the Commissioner of Reconstruction, in combination with the Central Service at Nanking and the railway construction services, the road services and the hydraulic service, a *topographical service* in charge of geodesy and topography. This service will prepare accurate *skeleton triangulations* (with indication of heights and distances on the level) plotted in connection with reference marks linked up to geodetic points already determined or to be determined, *to which all surveys executed by the different services of the province will be compulsorily related.*

The Chief of the Topographical Service will keep the catalogue of reference marks and the inventory of plans up to date, and will ensure the co-ordination and harmonising of the works carried out by the different services. The latter must assist each other. Nothing is easier than for a road-service team surveying an area alongside a river to take transverse sections of the river for the hydraulic service, to prepare a plan of a town for the municipal council, to survey a bridge site, etc. By the standardisation of the skeleton outlines and scales, the methods and the instruments, the maximum output will be obtained from the topographical teams.

Naturally, the various topographical services must come to an agreement with their neighbours, to ensure that there will be common polygons at the boundaries of provinces.

The services responsible for the study and construction of bridges must be in touch with those responsible for the hydraulic services. The latter should, in particular, be consulted in fixing the line and area of openings and the headroom below the bridge.

3. UTILISATION OF STAFF.

In view of the cheapness, abundance and quality of labour, there is rarely any advantage from the point of view of cost in employing mechanical material for current works, and such material, moreover, would have to be imported. Embanking work, transportation, drainage, manufacture of ordinary mortar and cements will therefore be carried out by hand. *Labour must, however, be rationally used, installed and equipped,* both for the purpose of increasing its output and lowering the cost, as well as for reducing the time allowed for execution.

Subordinate staffs should be trained and guided. They will act both as *instructors* and as leaders to their workmen. They will receive special instruction regarding the safety of the workers. The latter, in their ignorance, too often neglect elementary precautions against the dangers of falling earth and explosions, or even of ordinary movement on the roadways on the works.

Technical staffs being insufficient in number, all means and methods of lightening their task and improving their output should be sought and utilised. These are, among other things, programmes carefully prepared and followed, well-studied schemes, standardised methods and types of construction works to the full extent permitted by the utilisation of local resources, the co-ordination and diffusion of the studies and projects of different services, the training of subordinate grades and the grouping of yards and workshops. If the latter are widely scattered, supervision is difficult, and time (a vital consideration) is lost in going from one to another.

There must be, finally, and we emphasise this point once more, *continuous liaison between those who direct and those who execute, between the office and the yard or place of work*. An engineer's occupation is not a sedentary one. The elements of a scheme are to be sought in the first place on the *ground* and the solution adopted is applied on the *ground*. The office is a *means* and not an *end*. The *execution of a scheme* should be checked and followed with the same care as that which has been brought to the preliminary studies on the ground and to the preparation of the scheme in the office.

Just as the foundation of the scholar's knowledge is acquired by the long study of texts, so the engineer's groundwork is acquired in the workshop, and any engineer worthy of the name will make a point of lending a hand in the work as often as may be necessary.

Chapter III.

CONSTRUCTION OF ROADS.

I. LAY-OUT.

The general rules for the lie of roads are the subject of the appendix to the Report of the Roads Bureau, June 1933, Vol. I. These regulations are rather summary; they should be supplemented and made clearer. It is especially desirable to make their application general and *effective*.

The characteristics of the roads will depend on the characteristics of the vehicles that use them. There is no difference in this respect between China and Europe. The supplementary rules to be introduced may therefore follow exactly those which appear in the annexed documents and which are mentioned in Chapter II of Section I of the present report.

Even at the cost of additional work and expenditure—usually small in the case of new roads—*it will often be advantageous to reduce gradients and curves* in order to make it possible to employ trailers and vehicles of large capacity and so reduce the cost of transport.

The drainage of the roads should receive very special attention.

The surface should be *fixed* in the bed of the road and drained by gutters placed in the side paths. If it is merely *laid*, it will lead to accidents through the swaying of vehicles drawing up to pass each other or to let others pass.

In the preparation and execution of schemes, every effort should be made to interfere as little as possible with *agricultural works such as irrigation and drainage canals*.

2. SURFACES.

The choice of a surface is the question of paramount importance.

As has been explained in Section I, Chapter II (a) ("The Economics of Transport"), the choice should be based on the traffic. In China, motor traffic, with very rare exceptions in the outskirts of certain great centres, is moderate in weight and amount.

The regulations on the construction of roads, mentioned above, indicate six classes of surfaces. This classification is somewhat too rigid.

Since China produces cement, it is desirable to mention *cement macadam*. This can be obtained *entirely from local materials*, and with modern means of execution it is capable of supporting fairly heavy traffic. When well made it does not require a hydrocarburetted carpet. Hydrocarbides are at present imported, but China possesses vegetable oils and coal. It would be desirable to lay before the research institutions and the Ministry of Industry the problem of the production of tar and the utilisation of the by-products. If it were possible to produce tar cheaply in factories well situated in relation to the coal-beds and well served by roads or other means of communication, such tar, with or without the addition of "filler", might be used with advantage for the improvement of gravel or macadam roads.

The same research institutions should be instructed to analyse the various kinds of coals with a view to their utilisation as fillers, so as to reduce the importation of tars and bitumens. This question is discussed in Vol. VI of the *Annales des Ponts et Chaussées* of 1932, a copy of which is inserted among the documents transmitted to the Roads Bureau.

The researches and measurements should deal with the degree of humidity, density, regularity of the crushed products, form of the grains, physical affinity for tar.

The successive stages of a road in proportion to the increase of traffic will be :

- (1) Earth, gravel or sand ;
- (2) Ordinary macadam, made as far as possible of clayey material ;
- (3) Cement macadam or macadam with superficial asphalt surface ;
- (4) Surface of concrete or small paving-stones on a good foundation.

If tar can be produced or imported at a low price, a tar carpet might be placed on a gravel or sand road.

In each case, it will be necessary to determine by the methods set out in Section I the proper moment for passing from one stage to another.

Except on a few sections in the outskirts of certain centres, an earth, sand or gravel road, well made on a perfectly drained and prepared bed and well maintained, is the rational solution called for by the present traffic.

For the making of this surface, which is largely employed in America and the French oversea possessions, see the documents referred to above.

Low-lying parts, slopes, bends, embanked sections and crossings of other roads should be strengthened by metalling.

In Volume II of the Report of the Roads Bureau for 1934, there is a very interesting map showing the intensity of road traffic. Such a document should be kept up to date in each province. It will form the basis for the programme of supplementary works and the improvement of roads.

A feature of the traffic which is peculiar to China is the large number of carts and wheelbarrows with very thin iron-tyred wheels. No surface, except concrete or paving, can stand up to such vehicles, which are suitable for roughly constructed roads. *For this traffic, therefore, which is very important chiefly for the rural population, it will be necessary to provide and maintain special ways or paved strips, such as those which are still found on very old roads.* If this is not done, the peasant will not unnaturally be hostile to roads, and their value and efficacy will thus be considerably reduced.

3. WORKS AND CONSTRUCTION—MATERIAL.

The principal characteristic is the abundance and quality of labour, which must be allocated, equipped and organised. There is no particular observation to be made on this point.

The draining-off of water must at all times be fully secured.

As a general rule, a gang employed in embanking work will be preceded by a gang for carrying out constructive works under embankment and provisional medium-scale constructive works. For the latter, a width of three metres will be sufficient, but they should be clearly indicated.

For works under embankment, which should be permanent, concrete tubes or earthenware pipes, which involve the minimum foundation and the execution of which requires few specialised workers, will be generally employed.

Unless the situation of a work can be modified by a deviation, *supports, piles and abutments will be permanent*. It will therefore be necessary to prepare immediately *the study of the definitive work and to construct the definitive supports*, supplemented, if necessary, by provisional intermediate wooden supports. If the soil is capable of supporting vertical and horizontal stresses and the opening to be left free allows of it, arches in masonry of ordinary concrete or of reinforced concrete will be adopted in preference to every other method. The materials will be supplied and prepared during the dead season by the farmers. If the foundation soil is incapable of compression and the scheme comprises several girders, it will be an advantage to adopt the interlocked girder type. The spans of the middle and outside girders will be in the ratio of 4 to 3.

If the foundation soil, though incapable of compression, can be excavated, it will not be necessary for the work to be deeply embedded, but it will be indispensable to protect it by stout defences: pile-planks, gabions and enrockments. Wooden stakes beaten down into the damp soil or constantly submerged constitute a good foundation in a soil of poor consistency. The points should be hardened or furnished with ferrules.

For studies of bridges, whatever their span, it will be essential, as we have said, to confer with the hydraulic services responsible for the watercourses in question as regards the fixing of the headroom and the line and area of openings.

Whenever possible, embankments will be constructed in horizontal layers of moderate thickness and rolled with a light fluted roller.

Ferries will consist of two pirogues or junks joined by a plank. Approaches will be furnished with slopes and stout mooring appliances.

In general, mechanical material need not be employed unless there is a lack of labour or for the carrying-out of works which cannot be executed by hand. As soon as the traffic becomes considerable, the construction of roads will require the employment of rollers with mechanical traction. *It will be desirable to use simultaneously light machines (3 to 5 tons) and medium machines (11 to 13 tons) fired with coal.*

In each case, the question of the material to be used should be specially investigated. It should always be borne in mind that the simplest solutions are nearly always the best and most reliable.

4. ROAD SIGNALS.

If, as is desirable, the tourist traffic develops, it will be necessary to make use of the international signal system already employed in China; inscriptions should as far as possible be in two languages, Chinese and English. The system of signs should be unified and *applied in a very homogeneous fashion*. Distances and starting-points should be clearly indicated.

5. MAINTENANCE.

The conservation and practicability of roads, and particularly of those of improved earth, gravel or metal, which will be the surfaces applied in the majority of cases, require perfect drainage and *continuous upkeep*, allowing at every point of the repair of local damage as soon as it appears and before it is felt by traffic, and offering the

advantage of preventing the aggravation of the damage and of reducing the costs of upkeep. Such upkeep must therefore be carefully organised and frequently inspected.

Permanent gangs under the direction of a ganger will be placed along the roads. They may be temporarily strengthened by auxiliary hands chosen from among the peasants.

The size of the gangs will depend on the local conditions. As a rule, the ganger should be able to cover his section once a day, which will mean a length of road of from 15 to 20 kilometres.

These gangs will be organised in groups of five or six under a foreman or district head, who will cover his portion of road about once a week.

District groups will form upkeep subdivisions under the orders of engineers, who will be placed under the direct authority of the chief of the road service of the province.

The optimum size of the various subdivisions will depend on local conditions, the nature of the roads and the means of communication. In average conditions, 500 kilometres of road should be considered as a maximum. It will be desirable to reckon, on an average, one man per 2 kilometres.

The foreman will give instructions to the gangers, inspect tools and keep them in proper condition, and see that supplies of materials for upkeep are available. Such materials will be deposited in a discontinuous line, so as not to interfere with the draining-off of water along a side path.

As far as possible, farmers should be asked to excavate and convey the material. In this way, they will be induced to take an interest in the roads.

Chapter IV.

ROAD TRANSPORT.

I. VEHICLES.

A reduction in the cost of transport increases traffic and promotes economic development. It may be obtained, in the first place—as has been shown in Section I, Chapter II (“The Economics of Transport”)—as a result of the lay-out and upkeep of the road. The gradients should be such as to enable trailers to be employed on certain important sections.

Well-kept roads allow of high speeds. The same vehicle can thus perform a larger number of journeys in the same time. This means that less capital need be invested in initial establishment.

The second factor in lowering transport cost is the organisation of transportation itself.

Vehicles should be built up to the *maximum capacity* permitted by bridges and other constructive works. They should be fitted with low-pressure tyres.

It may be an advantage to supply some lorries with tackle or appliances for lifting light loads. This would make it possible to reduce the time spent in handling goods and prevent damage to packages.

2. FUEL.

Vehicles should be equipped with Diesel engines in preference to petrol-engines. If local conditions permit (supply of wood, arrangements for cleaning gas-generators and engines, moderate gradients), charcoal or wood will be used. This fuel is by far the most economical, but if it is to be used with success, the *precautions indicated in No. 3 of Chapter III are indispensable.*

The saving effected with a Diesel engine in comparison with a petrol-engine is no doubt comparatively small, but it is probable that, before producing petrol, China will be able to avail herself of heavy vegetable or mineral oils of local origin. Moreover, the transport, handling and storing of gas-oil are easier, less dangerous and less expensive than in the case of petrol. Finally, the advantage of the Diesel engine increases with the distance the fuel has to be transported.

The University laboratories should undertake research work on ground-nut, cotton-seed and wood oils with a view to their utilisation (in a crude state or converted) as fuel. Another subject of research will be the composition of fuels consisting of imported petrol and alcohol of local production.

If native products capable of being employed as fuel were of higher value than imported fuel, it would obviously be advantageous to sell them abroad and purchase petrol and mineral oil from foreign countries.

Hydrogenation is a process in which rapid progress is being made. The services concerned should follow the question closely, since hydrogenation is capable of yielding a satisfactory solution for the problem of national fuel. At present, however, any practical steps in this direction in China would appear to be premature.

Finally, it would be worth while making trials with steam-lorries of the most recent and lightest models. Preference should be given, at the cost of a slight lowering of the thermic output, to models containing *boilers with the largest tubes*.

3. ORGANISATION OF SERVICES.

The general organisation of motor-services does not call for any observation special to China, except that already made with regard to the distribution of traffic and the co-ordination and interconnection of the different modes of transport.

The plan and equipment of workshops should be carefully studied and organised so as to reduce the period of immobilisation of vehicles and the cost of repairs.

Workshops will be strictly forbidden to make spare parts. The makers, who possess suitable materials and equipment, manufacture such parts in mass at a very low price. The workshops would have to devote to the production of small quantities of spare parts time and equipment which would be more usefully employed in the periodical overhauling of rolling-stock and the vocational training of the staff.

The technical education of engineers, foremen and even workmen should be organised.

The inspection of staffs, workshops and drivers should be carried out periodically and without notice being given. The supervisory personnel should in particular satisfy itself that drivers take care of their engines on the road and change gear at the proper moments.

The transport, stocking and distribution of fuel and oil are details which should not be neglected.

At the present time, petrol is transported entirely in four-gallon tins, notwithstanding the fact that savings can usually be effected if it is bought in drums of large capacity and still more if it is transported in tank-lorries.

Lastly, the filling of the tanks from petrol-pumps facilitates checking and prevents the small losses that constantly take place when petrol is poured by hand from tins. Such apparatus, however, is only advantageous in depots and stations where very large quantities of petrol are distributed.

Whether the installation of such apparatus will lead to economies is a question that must be examined in each particular case.

In Section I, Chapter III ("Road Transport"), and also in the documents, will be found detailed particulars of the cost of motor transport. From these figures, the corresponding costs in China can be determined with sufficient accuracy.

Chapter V.

ADMINISTRATION OF ROADS.

I. EXISTING ORGANISATION.

With rare exceptions (Sianfu - Lanchow, Sianfu - Hanchung), roads are exclusively studied, made, maintained and operated by the reconstruction services of the provinces.

The *Roads Bureau at Nanking* plays a very important and very useful, but mainly technical, part. It does not act administratively, except in regard to questions of staff or regulations, or financially, except to supervise and follow up the employment of subsidies allocated to the provinces by the National Economic Council.

The *National Economic Council* has not, like a ministerial department, any means of action of its own. It has nevertheless carried out certain work direct, such as the two roads mentioned above.

On the whole, the administrative organisation of the roads is well suited to the situation. The latter, however, is constantly changing, and it would seem that certain adaptations and improvements in detail, which will be set out later, would be likely to improve the working and increase the output of the various branches of the road administration.

2. NATIONAL ECONOMIC COUNCIL (N.E.C.).

The creation of the National Economic Council must be regarded as an extremely happy and effective Government measure, which came at the right time. The rôle assigned to the N.E.C. under its constitution, however, corresponds to a situation in regard to which progress has since been made. The N.E.C., therefore, in order to maintain its efficacy and continue its action, should progress in its turn.

In our opinion, the N.E.C. should be relieved of all purely administrative and executive functions and should devote its whole activity to the study and co-ordination of all general measures concerning national economy, and, in particular, those relating to *all kinds of transport*, including, of course, railways.

In this respect, it will operate as a *Supreme Transport Council* and will have the explicit duty of co-ordinating railway and road transport and examining the programmes of the provinces for the purpose of harmonising them, both road programmes and national production programmes. Its authority will extend to the departments of finance, railways, industry and the great public research and technical education establishments. It will ensure liaison between these bodies and will co-ordinate their efforts. It will act as a technical council and an office for the collection and dissemination of documentary material. In order to fulfil this task, it should possess offices for study and research placed under its direct authority.

It would be well to attach to it the central air photographic service.

If reasons of high policy or general administration are opposed to this conception and the Council continues to possess executive functions, it should be organised accordingly and be placed in the same position as a ministerial department.

Finally, in view of the extreme importance of qualified staffs, the functions of the N.E.C. should include that of training technical personnel.

3. ROADS BUREAU.

The Roads Bureau is, and should remain, the department of the N.E.C. in charge of all questions relating to road communications: construction, exploitation, regulation and co-ordination. It should be the permanent technical adviser of the provinces and their liaison agent with the administrations dealing with questions connected with roads: railways, hydraulic services, laboratories and technical universities.

Its internal organisation might be slightly modified. We propose to provide for three sections, each divided into sub-sections. Two sub-sections might be either grouped together or placed under the authority of a single chief if their importance justified it.

(1) *Administrative Section*, divided into :

(a) Accountancy sub-section, in charge of all financial questions ;

(b) Legal sub-section, in charge of all studies relating to regulations, administration, traffic, upkeep of roads and the administrative organisation of road transport.

These two sub-sections might, at least for the moment, be amalgamated.

(2) *Road Construction and Maintenance Section*, which will have a particularly important function in the collection and distribution of documentary material, divided into :

(a) Technical sub-section for bridges and other constructive works, in charge of the examination and preparation of schemes of works, the study of materials required for them and the methods of execution ;

(b) Technical sub-section for roads, in charge of the examination and preparation of road schemes and all questions relating to materials for the construction of roads, surfaces, organisation of works, quarries, etc.

(3) *Transport Section*, divided into :

(a) Technical sub-section for motor transport, in charge of all questions relating to vehicles and to solid and liquid fuels ;

(b) Traffic sub-section, in charge of questions of operation : organisation, regulations, supervision of transport services, statistics of traffic, schedules of rates ; *co-ordination of transport*.

The sections and sub-sections should maintain continuous contact in their work. Heads of sections and sub-sections will confer together for this purpose as frequently as may be necessary. The sections and sub-sections will have laboratories of their own, or use laboratories belonging to research or educational establishments.

4. PROVINCIAL RECONSTRUCTION BUREAU.

This bureau, which is the principal executive organ, is placed under the authority of the Reconstruction Commissioner. He will be personally entrusted with the co-ordination of transport and liaison between the services. He will be assisted in the study of all relevant questions by a *Provincial Transport Committee*, consisting of the heads of the hydraulic, roads and communications services, a representative of the railway operation service and the production services.

The internal organisation will be modelled on that of the Roads Bureau. It will comprise :

(1) *An administrative section*, placed under the direct authority of the Reconstruction Commissioner ;

(2) *A road service*, comprising : (a) internal services : secretariat, accountancy branch, study bureau ; (b) active or executive services : study groups, subdivisions of new works and upkeep ;

(3) *A topographical service*, the function of which has been indicated in Section II, Chapter II.

5. CLASSIFICATION OF ROADS.

The classification of roads in three categories, which is generally accepted, is very well adapted to China. (It is, of course, understood that urban highways are not included in the classification.) We would propose the following division, which in fact already exists, as indeed in European countries : (a) national roads, (b) provincial roads, (c) district roads.

The national roads would be designated by the N.E.C. They should, before being classified, fulfil a number of technical conditions.

The national budget would supply part of the funds for their construction, completion or improvement. The work would be executed, under the supreme control and direction of the N.E.C., by the provincial services.

The system of national roads should only comprise a small number of arteries of very great political or economic importance.

The other roads will be classified by decision of the local authorities.

The provincial system should not, especially at the beginning, be too extensive ; this will prevent a dissipation of effort and permit of the upkeep of the whole system. It will always be more advantageous to finish completely, keep in good repair and subsequently to extend a limited system than to plunge at once into a vast programme of which only a part will be completed at a distant date.

6. FINANCING OF ROADS.

Continuity and stability are indispensable for the smooth and efficient working of every organisation, and especially of every undertaking of an industrial character, such as the administration of a road system, which involves the preparation of programmes to be carried out over a long period. These conditions imply at least approximate certainty of financial resources, which is not realisable by the procedure of a budget fixed annually.

I think it would be premature to make the roads financially autonomous. I recommend the following intermediate measure.

A grant, fixed for ten years, should be reserved for roads in the national budget and provincial budgets. In addition to this grant, and in accordance with the financial situation, a supplementary grant would be fixed annually. Some items of revenue obtained from the roads should also be assigned to the roads.

7. REGULATION OF TRAFFIC.

The rules relating to the construction and equipment of vehicles generally applied in Europe could be put into force in China without modification. The same is the case with rules relating to the regulation of traffic. Account must be taken, however, of the

quantity of rural traffic, which is ignorant of the dangers of motor traffic and which requires to be educated.

A most important point is the unification of rules, especially those relating to the issue of drivers' licences and of running licences for vehicles. *Every licence and permit issued and every tax paid in a province should be valid for the whole national territory.*

Chapter VI.

STAFFS.

I. THE PROBLEM OF STAFFS.

Nothing is impossible in China. The worker is industrious, clever and tractable. He possesses extraordinary powers of adaptation.

Well organised and trained, he would be capable of executing any kind of work, however delicate and complicated it might be.

The technical services possess distinguished engineers with a high sense of duty and often remarkable executive power.

This, however, is not enough. The spirit of progress and the desire for practical achievement which inspire the present Government are in marked contrast to the attitude of the old regime—a fact that is strikingly brought out by the exceptional magnitude of the programme of reconstruction. So large is the country that the engineers, who are too few in number and of very different origin and training, are compelled to make very long journeys. Finally, the services which are somewhat remote from the great centres possess very summary documentary material.

For these reasons, the technical staffs, notwithstanding their high qualifications and zeal, are too few in number to be able to study and compare the various solutions of every technical problem, to investigate the urgent questions involved in the industrial equipment of the country, to obtain the necessary documentation on such questions, and often even to follow the work done and keep themselves informed of the results obtained in the immediately adjoining provinces.

In matters of civil engineering, however, any restriction imposed on studies owing to insufficiency of time or staff inevitably involves less safety, heavier expenditure, more time for the work, or a smaller output for the same expenditure. Each one of the experts has found this to be true only too often in the course of his career.

Accordingly, every effort and every sacrifice made with a view to training and improving the staffs and organising the necessary preliminary studies must be regarded as a sound investment.

Endeavours should therefore be directed (1) to improving and increasing the output of staffs, (2) to improving methods of collecting documentary material and studying plans, (3) to obtaining the right type of employee.

These three aims cannot be considered separately, and the measures taken to achieve them should be examined together and properly co-ordinated.

It must be borne in mind that "reconstruction" is an immense and very *lengthy undertaking*, requiring long and *patient observation* and study and continuity of method and aim. The attainment of the object in view would be compromised—or, at any rate, greatly retarded—by undue haste, inadequate preparation and frequent and unnecessary changes in staffs and programmes of work.

The numbers employed depend upon the programme of work and the time allowed for its completion considered over a very long period. The programme and the time

depend in turn on the funds available. Thus, in dealing with *the problem of staffs, the first step is to fix the numbers of the new staff, which is as much a financial as a technical question. It should be pointed out that there is the greatest advantage in utilising and co-ordinating existing staff, whose experience will be immediately profitable.*

The proverb "Practice makes perfect" is applicable to engineering. The technical school teaches general processes, methods of observation and investigation, analysis, synthesis and calculation; in a word, it provides the instruments and means of work of which only experience teaches the use. *Technical instruction* is a matter of classes and books; *technical training* can only come later and must follow experimental lines. Technique is an art even more than a science. It is the result of a long tradition, of empirical work, and of a long experience which is systematically interpreted and the results of which are constantly made use of. Accordingly, the young engineer must have *chiefs* who are also *masters*. This condition is always fulfilled in Europe and America, where the beginner is upheld, guided and assisted by everything around him: workyards, operations, constructive works, documentation and the experience acquired by his chiefs, his colleagues and even his subordinates. All these are things the reality of which is impressed on him every day and on which he knows he can rely. The environment of collaboration and security and the daily spectacle of the abstract idea taking concrete form contribute in a very large measure to giving life and reality to theoretical knowledge and to developing an invaluable common sense. In a word, they exercise a decisive influence on the *technical training* of the engineer. This, it cannot be too often repeated, is the result of the concerted efforts of many persons and of the empirical method. *It is necessary therefore to promote and utilise this common action, this mutual knowledge and this pooling of individual efforts.*

Any sudden increase in the numbers of the staff would be attended with certain disadvantages. In the first place—and this is invariably true—there would be a certain falling-off in average efficiency. Next, if the rate of the work had to be slackened, there would be a danger of overstaffing or unemployment. Finally, such an increase would have to be preceded by a rapid extension of the institutions giving technical instruction. The results would inevitably be unsatisfactory. *The increase in staffs should therefore be gradual.* This increase should be brought about by progressively increasing the number of students attending Chinese schools and universities, and by sending students abroad and appealing for the technical co-operation of the League of Nations, etc.

Instruction abroad should be organised. Students will as far as possible be grouped and special supplementary lectures will be given them by competent teachers on the adaptation to China of general processes and principles. This instruction will be supplemented by periods of practical training in the course of which students must prepare a complete documentation on a limited number of current questions. The system will, moreover, have the important advantage of giving Chinese technicians the benefit of the most recent work accomplished abroad in similar local conditions.

In this respect, there is an even better method, that of sending abroad, not students, but *selected engineers with sufficient workshop experience behind them.* These engineers would be employed on Government active work for one or two years and would thus obtain all the necessary elements, not only for completely following up certain problems, but also for studying their adaptation to Chinese conditions. This method would have another result: it would promote the establishment of relations, exchanges of views and currents of ideas, which could not but reinforce the bonds of that technical solidarity, the importance and utility of which have been demonstrated by constant experience.

To fill up the void momentarily left by the sending of these engineers abroad, foreign countries might be asked to place at the disposal of the Chinese Government veritable *teams* which, supplemented by Chinese engineers, might prepare

certain important schemes and act at the same time as a study bureau and experimental school with a small staff. It would be indispensable to constitute "homogeneous" teams consisting of technicians of the same nationality, familiar with the same methods and trained under the same systems. Such teams, even of medium quality, will be much more effective than groups of eminent technicians, of different nationality, with different habits and different methods.

All these methods—exchange of engineers, employment for purposes of training—are in general use in Europe.

The recruiting and training of technicians being secured, it is further necessary to organise *corps*—that is to say, to ensure stability, continuity and homogeneity in methods and conceptions, and also in the staff by giving it a special status.

The corps should in the first place be limited in numbers and include only officials of proved value. Their numbers should then be gradually increased by competition, but a probationary period of at least a year should be required.

They might be as follows : (1) a higher corps of engineers ; (2) a subordinate corps of superintendents ; (3) a corps of technical officials (draughtsmen, mechanics surveyors) ; (4) a corps of office officials (accountants and secretaries).

The first two corps would be divided into two large categories : civil engineers and engineers engaged in transportation. The first two corps would cover the whole of China. The others would be organised provincially according to uniform rules.

2. HIGHER AND INTERMEDIATE STAFFS.

Chinese engineers lack, in the first place, the immense museum, the vast school of applied knowledge, the technical environment which are constituted in Europe and America by the multifarious works executed in the course of the nineteenth and twentieth centuries (the responsibility for this deficiency rests with the old regime). They lack, in the second place, documentary material, mutual contacts and, lastly, homogeneity and tradition. The whole problem consists in filling up these gaps. The country already possesses a large number of *individual engineers* of high technical quality. The work of these men requires to be co-ordinated and harmonised.

The means of obtaining this result, apart from the organisation of the central services described in Chapter V, are suggested by the considerations set out in the previous section. The diffusion of documents and the exchange of views between engineers should be encouraged and facilitated by meetings, journeys, lectures, congresses and publications. An atmosphere and fruitful spirit of solidarity will thereby be created. In this respect, the *Journal of the Association of Chinese and American Engineers* is an excellent example.

Finally, to meet the disadvantage resulting from diversity of origin and training, we should propose the creation of a *centre of higher technical studies*, to which a small number of engineers would be admitted, selected according to their record of service and their experience. The instruction would consist of lectures and training period in such subjects as the following : supplementary courses in strength of materials, processes of hydraulic construction, roads, railways, ports, organisation and administration, etc. The period of the courses at the beginning would be six months and would be progressively extended to two years. The foreign technical missions and the universities would collaborate in the organisation of this centre, which might work with a very small budget.

3. SUBORDINATE STAFFS.

In these staffs, it is necessary to distinguish *office employees* (secretaries and accountants), *technical officials* (draughtsmen, surveyors, mechanics) and *labour staffs* (managers of works, foremen, clerks of works and heads of workshops). The vocational

instruction of all these grades should be systematically organised by provinces or groups of provinces, according to uniform rules adapted to the different categories of employment.

The *office employees* should have received a general elementary education and also be familiar with typewriting and book-keeping and the rudiments of technical terminology, and a foreign language.

The *technical officials* should receive more complete training. They should in the first place be competent draughtsmen and should be capable of drawing up a simple scheme, making the measurements for the latter, *preparing a small plan* and organising and managing works of average size. The best of them should be given promotion to the higher ranks. They should have some knowledge of book-keeping.

The *labour staff* will receive an essentially practical training : elementary principles of organisation of small works, the use of tools, laying of roadways in the works, laying-out of a very simple constructive work, simple plans, use of the level and the collimator, some knowledge of natural materials (stone, wood, sand, etc.), the making of mortar and cement, hygiene and safety in works, explosive mines and quarries, elementary works, book-keeping.

Subordinate staffs of good professional quality will relieve the engineer of unimportant routine work (often tedious and exacting) which he must always check but which he will thus no longer need to carry out himself. Such staffs, moreover, are a guarantee of good work and economy.

Accordingly, their organisation deserves to receive the attention and care of the National Economic Council and the reconstruction services.

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Documents.

Section I: Chapter I.

Brief outline of ideas exchanged and information communicated in the course of a conference which took place on August 20th, 1934, between M. Haas, Secretary-General of the Communications and Transit Organisation of the League of Nations, M. Bourdrez, assistant representative of the said Organisation in China, M. Coursin, Director of Public Works in Madagascar, and M. Beau, Engineer-in-Chief for Roads and Bridges at the Ministry of the Colonies (Paris).

Section I: Chapter II.

Circular, March 29th, 1933, regarding the improvement of the national roads in France.

Circular Series B 32, of January 6th, 1931, on road surfaces (France).

Extracts from the reports of M. Beau, Engineer-in-Chief for Roads and Bridges, Assistant Inspector-General for Public Works in the Colonies of France.

Notes and specimen contracts regarding supplies of tar, bitumen and bitumen emulsions, and the spraying of these products.

Annales des Ponts et Chaussées, 1923, I.

Annales des Ponts et Chaussées, 1923, VI.

Annales des Ponts et Chaussées, 1924, V.

Note on the use of sodium silicate and technical memoranda regarding the silicated road, December 1st, 1931-July 1st, 1932.

Circular of December 12th, 1932, on concrete roads and contracts for cement concrete surfaces (France).

Sketch-book of typical schemes of one-way roads with straight girders.

- Sketch-book of typical schemes of one-way roads with cantilever girders.
Sketch-book of typical schemes of one-way roads with suspension girders.
Plans for metal bridges with triangulated main girders of 24, 30, 36 and 40 metres.
Plans for reinforced concrete bridges with bow-string beams of 24, 30 and 36 metres.
Bridges with reinforced concrete arches with higher roadway:
 with two sections of 30, 36 and 40 metres, fixed at points of 30 and 36 metres.
Plans for bridge with higher parabolic flanges of 27.94 metres.
Plans for bridge with higher parabolic flanges of 92 metres.
Plans for works with higher trellis flanges.
Plans for Siem Reep cantilever bridge.
Plans for suspension girder bridges with double-carriage way of 10 and 22 metres.
Collection of typical plans for tubes and water-leaders.
"Cours de Routes", by M. Le Gavrian, Inspector-General of Bridges and Roads (France).
"Cours de Routes et Chemins", by M. Hubie, Engineer of Bridges and Roads (France).
La Revue des Travaux Publics, July-August 1932.

Section I: Chapter III.

- Note on road transport in the Belgian Congo.
Regulations regarding public motor-bus services in France (Law of August 21st, 1923; Decree of March 29th, 1924).
Specifications for a public transport service between Antananarivo and Majunga.
Regulations regarding the system of public transport services in Indo-China.
Regulations regarding public transport in Morocco.
Documents on the conveyance of mail in France.

Section I: Chapter IV.

- Regulation of Traffic in France.
Draft Law on the French Highway Code.
Draft Law on the Roads Office (France).

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Bibliography

Section I: Chapter I.

- "Le Problème des transports au Maroc"; by M. Henri BOUSSER (Librairie du Recueil Sirey, 22, rue Soufflot, Paris).

Section I: Chapter II.

- Reports submitted to the Sixth Road Congress at Washington.
Reports submitted to the Seventh Road Congress at Munich.
General Review of Roads and Road Traffic, June 1934.
Annales des Ponts et Chaussées, 1932, VI; Note on the improvement of road-tars by fillers.
Road signals; recommendations and prescriptive rules of the European Conference on Road Traffic.

Section I: Chapter III.

- "Combustibles liquides et lubrifiants; leurs applications" (Librairie polytechnique Béranger, Paris).

December 1935.

ANNEX.

HWANG HO : INSPECTION OF THE GOLDEN DYKE ON THE LEFT BANK OF THE RIVER.

LETTER FROM MR. A. T. COODE AND M. G. P. NIJHOFF TO THE SECRETARY-GENERAL
OF THE NATIONAL ECONOMIC COUNCIL, NANKING.

Nanking, March 25th, 1935.

As a result of our report, dated March 9th, on the situation arising out of the failure to close the Kwantai breach, it was agreed that Mr. Coode should inspect, at the earliest possible date, the Golden Dyke on the left bank of the Hwang Ho to determine generally the extent to which that work required strengthening in order to safeguard the country to the north and north-east from disasters consequent upon any breaches in the dyke during the approaching season of freshets.

2. The requisite arrangements having been completed with the assistance of the Shantung Provincial Government, Mr. Coode accordingly made his inspection between March 19th and 21st, under the personal and invaluable guidance of General L. Chang, Director of the Shantung Water Conservancy Board.

3. The waters from the Kwantai breach, after passing along the Golden Dyke, re-enter the Hwang Ho proper immediately downstream of Tao Cheng Pu, and the inspection covered a length of 135 kilometres lying between that place, which is 80 kilometres below the upstream boundary of Shantung Province, and Wang Tao Ko, a point 20 kilometres above Pu Yang and 2 kilometres inside the province of Honan.

4. In so far as the present investigation is concerned, the Golden Dyke, *qua* dyke, extends from Tao Cheng Pu up to a point some 20 kilometres inside the Hopei Province, a length of 100 kilometres in all. Upstream of this latter point, there is nothing, for the next 35 kilometres at least, in the nature of protective work.

5. The river bank in Hopei, a length of 53 kilometres, and doubtless also for a considerable distance upstream in Honan, takes the form of a ragged and much-fissured low earth or sandy cliff, completely exposed to the attack of the river, which generally runs either directly alongside or within a short distance of the bank. On the shallow dyke running along the downstream portion of 20 kilometres, it is obvious that no proper maintenance has been undertaken for years, and over the remainder of the length upstream there is, as has already been mentioned, no protection.

6. The country behind the present river margin in Hopei is, however, sufficiently elevated to remove all apprehension of extensive inundation, and, in such circumstances, the worst that can happen is the loss, through erosion by freshets, of

more or less considerable strips of the river bank. Consideration might be given, however, to the question of protecting the village of Ching Ho Tou, which lies about midway between the Hopei boundaries, and is entirely open to the attack of the waters.

7. Although the Golden Dyke in Shantung, throughout the 80 kilometres length now in question, is in good condition and generally of substantial construction, yet it is over certain portions of this length that strengthening work is now most urgently required to prevent possible catastrophe.

8. From Yang Ying, close to Tao Cheng Pu, upstream to Shao Shih, a distance of about 20 kilometres, the dyke is of suitable dimensions, with the summit one metre above the 1933 flood-level, and is provided with a dry rubble wall at the toe of the slope and occasional buttresses and short spur groynes. With careful maintenance, this length should prove capable of satisfactorily withstanding the flood season.

9. From Shao Shih to Fang Hsien, 30 kilometres in length, the dyke was raised 1.5 metre in 1934 to bring its level into conformity with that of the dyke downstream, the top width being 6 metres. Over this length, the river waters run generally alongside or close to the dyke, and strengthening work is required at several positions. In places, the dyke should for greater security be widened and be given a flatter slope on the outside, and especially is it necessary that, along certain lengths, the outer slope should be protected with stone.

10. From Fang Hsien to the provincial boundary, a distance of 30 kilometres, the elevation of the land on the inside of the dyke is generally such as to obviate the danger of a breach, but there are three positions at least, the first immediately upstream, and the others at 4 and 6 kilometres, respectively, upstream of Fang Hsien, at which it is essential that stone protection should be given to the outer slope of the dyke without delay. Evidence of the undermining action even now proceeding is afforded by the many large willow-trees outside the dyke that have been felled by the action of the current.

11. Having regard to the limited time remaining available, we strongly recommend that the Shantung River Conservancy Board be given instructions forthwith to proceed with the execution of the essential works to which we have drawn attention and such additional work, including any requisite raising of the dyke surface to bring it at least one metre above the 1933 flood level, as may be deemed necessary on a more detailed examination of the position. Practically the whole of the requisite work is situated in Shantung Province and the Board is fully acquainted with the local conditions.

12. On the assumption that the work of dyke strengthening and reparation is treated as urgent and undertaken without delay, we are confident that the Golden Dyke can afford adequate protection to the country behind.

13. We may add that the results of M. Bourdrez' recent visit of inspection to Kwantai confirm us in the conclusion expressed in our report of March 9th that all available resources should be concentrated on the strengthening of the Golden Dyke where necessary.
