REPORT
OF THE DELTA COMMITTEE

FINAL REPORT

PART 1

STATE PRINTING AND PUBLISHING OFFICE - THE HAGUE - NETHERLANDS

REPORT OF THE DELTA COMMITTEE

FINAL REPORT

DELIVERED BY THE ADVISORY COMMITTEE TO PROVIDE AN ANSWER TO THE QUESTION OF WHAT WATERWAYS-TECHNICAL PROVISIONS MUST BE MADE FOR THE AREAS DEVASTATED BY THE STORM FLOOD OF FEBRUARY 1, 1953, (DELTA COMMITTEE) INSTITUTED BY DECREE OF THE MINISTER OF TRANSPORT AND WATERWAYS OF FEBRUARY 18, 1953

STATE PRINTING AND PUBLISHING OFFICE — THE HAGUE — 1962

FOREWORD

The Delta Committee conveys in the present report the results of the research carried out by the Committee or on its behalf. The report is published in six volumes.

The contributions, which are contained in Volumes 2–6, are the reports of investigations made at the request of or in consultation with the Delta Committee. They concern subjects connected with the activities of the Committee. Since the Committee anticipates interest in these studies in various quarters, they are published in unabridged form.

The Committee is, however, not responsible for the contents of the contributions, with the exception of considerations taken from them and included in the Final Report. In these cases the authorship is indicated by references in the text to the relevant contribution.

The Committee wishes to express its appreciation to all those who have in any way contributed to the preparation of this report.

THE DELTA COMMITTEE

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INTRODUCTION

1.0 INSTITUTION, COMPOSITION AND WORK OF THE DELTA COMMITTEE

1.1 Institution and Installation of the Committee. Mandate

By Decree No. 8976 Section P, Directorate of Waterways, of February 18, 1953, the Minister of Transport and Waterways has instituted an Advisory Committee to provide an answer to the question of what waterways-technical provisions must be made for the areas devastated by the storm flood of February 1, 1953, and including an investigation into whether the closing of the sea-arms should be part of those provisions.

In view of the harbour interests of Rotterdam and Antwerp, however, the Rotterdam Waterway [1]) and the Western Scheldt are excluded from the last mentioned investigation.

This Order of the Minister was later on orally expanded by requesting the Committee to express its views about the remaining coastal areas in connection with the water levels which should serve as a basis for the improvement of the main water protection, and that it should supply directives for such improvement.

The Committee was installed by the Minister of Transport and Waterways, His Excellency Dr. J. Algera, in the State Hall of the Ministry of Transport and Waterways. At that installation, the Minister made the following speech:

Gentlemen:

The disaster which hit our country on February 1 is weighing heavily on the hearts of us all, of you and of me, of the whole land. This is a sad burden for all of us. You will agree with me that we must, as far as possible, try to prevent a repetition of such a disaster. I have called you together here to form a waterways-technical committee of experts to plan measures within as short a period as practicable to prevent such a possible catastrophe in the future.

In my opinion, expressed in a simple way, we face the choice of whether to heighten the dykes over more than 1,000 kms (620 miles) by one metre (or more), which in some areas will be a difficult operation to execute, or to close off the sea-arms in such a way that the coastline threatened by stormfloods will be considerably shortened.

I know it sounds simple: coast-shortening; but I also know that this simple term presents problems to our hydraulic engineers which have never before been placed in front of any group of hydrological experts in this country.

You will, however, be able to take up your investigation from the studies which have previously been made into these questions. For more than 15 years the Government Waterways Department has been working on the preparation of plans which also for a great part deal with the area in which the work of your Committee will be carried out. These plans have mainly had a twofold purpose:

1. The discharge of water from areas which at somewhat high floods are regularly inundated, as well as an increase in the safety against the flooding of areas which were regarded as water-free for the highest floods so far observed; and

2. the protection of the land against salting.

In connection with the plans which are under study for the water clearance of the areas around the rivers Donge and the Oude Maas and the Brabant Biesbos which, according to calculations, would result in some storm-flood heightening near Dordrecht, a Committee was instituted to give information on the following questions by Decree of the Minister of Waterways of April 28, 1939, No. 426^{I}, Directorate of Waterways, afterwards changed by Decree of the Secretary-General of the Ministry of Waterways of October 8, 1942, Litt. S^{I}, Section N, Directorate of Waterways:

a. What storm floods must now be calculated for along the Netherlands North Sea coast and the waters lying in the Netherlands and in connection with the North Sea?

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[1]) By the Rotterdam Waterway is meant that part of the river running from the Rotterdam bridges to the sea.

b. To what extent must calculations be made for future changes in the storm-flood levels if no change is made artificially in the waterways situation?

c. How far can dyking, river improvement, dredging and other hydraulic works be of influence on the storm-flood levels?

d. In the present circumstances existing along the North Sea coast of the Netherlands and the areas of the waters in open connection with the North Sea, what is the position in respect of the safety of undesirable situations created in the waters lying within the Netherlands when storm floods occur there?

e. Whether, and if so what, safety measures are necessary in connection with point d?

As Chairman of that Committee, Chief-Engineer-Director of the State Waterrays in the South Holland Division, Ir. D. A. van Heyst, was appointed. Other members included a number of Chief-Engineer-Directors of the Waterways Department and their colleagues of the Provincial Waterways Services, the Director of the Municipal Works of Dordrecht, and Professors Thijsse and Tienstra of the Delft Technical University. Dr. Ir. J. van Veen, Chief Engineer of the Waterways Department, acted as Secretary.

During its investigations this so-called Stormflood Committee forsook the working method previously followed by which the crown or top of the dykes was determined on the basis of the water levels observed at the different storm floods occurring formerly. Instead, this Committee investigated separately each of the factors which cause a storm flood and determined the maximums of each of these factors more closely. Furthermore, a number of past storm floods was studied, while a chance-calculation was made for the determination of the height of the high storm floods along with the various frequencies to be expected. In addition, a tide calculation, was prepared to assist in approaching the whole problem along the road of calculation.

In the first place it was necessary to determine the so-called fringe or edge conditions, namely, the sea levels in front of the mouths of the sea-arms.

In view of the time that was expected to elapse before the necessary protection works would be completed, these fringe conditions were taken for the year 2000, taking it for granted that levels which will increase by about 20% a century will be forestalled or exceeded. The influence of the geological fall of the bed, as well as that of the hydraulic works to be carried out in that period which would radically change the river regime, was also taken into consideration upto the year 2000.

For the Hook of Holland, after a lengthy investigation and discussion, a figure was reached for the year 2000 which was about between 4 m+and 4.05 m+N.A.P. In 1894 a storm flood had been observed there of 3.28 m+N.A.P., and in 1916 of 3 m+N.A.P. During the last storm flood the high water had apparently risen to 3.85 m+N.A.P.

In respect of this storm-flood level determined by the Storm Flood Committee as the fringe or edge condition for the Hook of Holland, reservations were made from several sides. But it is now certain that the whole problem of the fringe conditions will again be studied by your Committee and a check made whether the figures given by the Storm Flood Committee need to be changed.

Starting from the fringe conditions having been calculated, the Storm Flood Committee also determined similar storm-flood heights for the places lying further inland. These appeared to be so high that a great length of dykes would have to be heightened unless a change was made to executing a system of damming off by which in the future the dyke sections lying between those dams would be protected against the threat of storm floods.

In the construction of new dykes and dyke heightening started on the mainland of North Brabant since 1940, as well as in connection with the works for closing the rivers Donge and Oude Maasje and the poldering of the Biesbos, the determining of the dyke heights was started from the figures of the Storm Flood Committee, and this made it clear that considerable heightenings, in comparison with the existing crown heights were the result of the storm-flood levels calculated by the Committee.

In addition to the heightening of the dykes, plans were also designed for the closing of some of the branches of the complex Lower Rivers and sea-arms. Examples of this are to be seen in the damming of the Brielse Maas in 1950 and of the Botlek. There is no doubt that this damming has resulted in safeguarding islands along the Brielse Maas basin against even greater floods than have so far occurred.

The plans for the dams in the complex of Lower Rivers, however, resulted not only from the desire to protect the adjoining areas against possible storm floods but were also part of a series of measures aimed at combatting salting by the formation of fresh water basins and by decreasing the amount of salt water streaming inside from the sea as a result of a limitation of the basin storage.

It is not surprising that the continued study of the two mentioned problems gave rise to the idea of carrying out a greater project, even to a consideration of whether the damming of the Haringvliet would not achieve a more or less considerable decrease in the storm floods in the river complex located upstream.

At the same time the possibility could then be opened up of leading a portion of the fresh water of the Rivers Rhine and Meuse, which now flows away to the sea, past Rotterdam and thus uppose the continual salting of the Rotterdam Waterway as well as to help those areas which are now needing fresh water.

To take full advantage of such a plan not only would complementary measures be necessary but it would be essential to act with great care because very important shipping interests would also be involved.

During the war, of course, all earlier plans could only be studied theoretically, but since then very careful attention has been given to the series of plans as well as to the storm-flood forecasts.

Moreover, today there are available a large number of observations and measurements in the Hydraulic Laboratory at Delft where a model of the network of the Lower Rivers has been constructed. It is also intended to study the damming of the sea-arms between the islands of Goeree and Schouwen and those of the Eastern Scheldt which until recently had not been included in the plans. It is true that very attractive features had already been recognised in that direction but it had been thought that the difficulties connected with that work were so great that it was preferred first to carry out closures of less gigantic character before daring to start on that really difficult project.

Meanwhile, however, last November, I had given the order also to study this part of the scheme more closely, so that the flood disaster at the beginning of this month has certainly come as a tragic stimulus to us to carry on with even greater speed than had previously been felt necessary for this problem. Of course, only the damming of the three sea-arms just mentioned can be included in the investigations, as both the Western Scheldt and the Rotterdam Waterway, by reason of their vital shipping connections, must be maintained as open sea-going channels.

The closing of the Haringvliet, of the sea-arm between Goeree and Schouwen and of the Eastern Scheldt, possibly combined with the connecting up of Walcheren and North and South Beveland, will perhaps have to be carried out, in view of the prevailing water depths, further inland than at the mouths of the rivers themselves. This, in turn, will then considerably reduce the length of the dykes that will serve as protection against the sea.

Another point that is important is that the execution of these works will be of special benefit for the supply of fresh water to a great part of the country and to combat the results of the continuous salting-up in various areas, while it will also create possibilities for the improvement of road connections between the various islands which are now accessible only by water. In the meantime, it is necessary to be very watchful of the possible hydraulic consequences of such large damming up in connection with shipping, the discharge of water and ice, and other obvious problems.

If, after studying the hydraulic-technical results to be expected from such damming of the sea-arms, your Committee has come to the conclusion that such a project is not only advisable but should actually be carried out, then the questions will remain, firstly, whether *it is technically possible and secondly, how the whole work must be organised. I certainly trust you will be able to answer these questions extensively.*

Again, if your Committee is of the opinion that the sea-arms must be closed, there will still remain considerable lengths of dykes which fall outside the damming project and for which the situation as a result of the closures will probably become more unfavourable than it is at present. So you must also include in your studies possible measures to meet the danger there, while in fact this must also be done for all the other protective measures along the other river branches which will have to remain in open connection with the sea but which will probably need some sort of extra stability or attention.

If, on the other hand, your Committee cannot advise all the sea-arms closures which have been mentioned, then also the water protections along the parts of the arms which will remain in open connection with the sea will have to have safety measures proposed for them as part of this comprehensive investigation.

It is realised, of course, that the problems I have just briefly sketched form only a facet – though an important one – of the whole scheme that will be necessary to examine. I have mentioned them mainly in a chronological aspect, but the various provisions which will have to be made will in time necessitate a closer investigation in other respects, such as in the field of agriculture.

Gentlemen:

The task which I am requesting you to undertake is a very responsible one. Much has already been done by others; but there is much that you will have to do yourselves to ensure producing a thorough and practical report as your advice to us. But remember: time is pressing; this problem is very urgent.

As far as the repairs now being made to the breached dykes are concerned, every effort must be made to improve the weak points of dyke construction immediately, although that will not by any means solve the problem put before us. It will be necessary that the areas just hit by the heavy floods, as well as those areas which this time escaped, be strongly protected against new and extremely high floods which may again occur. It cannot be otherwise, because many years will elapse before any definite protective measures such as you will suggest can be fully carried out. Yet we all pray fervently that God will spare us another great flood during that period.

I am grateful to you, members of the Delta Committee, for having agreed to devote your rich experience to this mighty task.

To you, Mr Chairman, who heads our national service which for such a long time has been carrying out a responsible work and which has learned once again that there can never be certainty over natural phenomena, I entrust the leadership of this great body of experts.

And so I formally request you to accept your very important mandate: to do everything possible to safeguard the south-west of our country against the evil influences of the sea, as seen in high floods on the one hand and continuous salinisation on the other.

In replying on behalf of the Committee the Chairman, Ir. (Engineer) A. G. Maris, said:

Your Excellency,

As Chairman of the Committee which has been ordered to advise you on the best replies to the question of what hydraulic-technical provisions must be made for the areas stricken by the great storm flood of January 31, 1953, and in which investigation there will have to be a thorough study as to whether the closing of the sea-arms must be the main provision, I wish to express my thanks, and that also of the other members of the Committee, for the faith you have placed in us, the confidence you have given us, and the fact that, despite being so very much occupied in these tragic times, you have taken the time to instal our Committee personally. This alone shows us how important you think the task you have given us to do.

I can assure you that we wish to carry out this task with the greatest possible speed, for we are al fully aware of the necessity of our advice reaching you as quickly as possible. Already during the repairs of the dykes that have been damaged plans must be made for further *improvement of the protective measures, so that they can be commenced in as short a time as possible in connection with the repair works themselves.*

Your Excellency, you have not hidden from us how difficult is the problem handed over to our judgment, although at the same time you have drawn attention to some points that can make our work lighter. It appears, for example, that much preparatory work has already been done by the Storm Flood Committee and by the various services of the Government Waterways Department in cooperation with the Hydraulic Laboratory at Delft. A series of plans has been studied there, and it seems from your speech that even the construction of a large enclosing dam in the Haringvliet was already accepted as a serious possibility. From this I think I can conclude that those concerned have not seen it impossible to solve any technical problem that might arise in such a project. However, it will probably be wise for us to make up our minds to proceed step by step in achieving the final purpose that was before your eyes when you presented our task and responsibility to us. In other words, we might well remember the saying: "It is not possible to step from the floor into the attic."

Nevertheless, we certainly hope to reach the attic before high water floods surprise us again.

We fully realise, however, that our Committee would not be able to fulfil its task if it could not count on the help of experts in various fields, such as, for instance, that of soil mechanics. As far as the Government Waterways Department is concerned, I personally give the assurance that this will be completely and willingly available for the work of the Committee. But I also feel I can depend fully on other people or organisations or institutions being ready to give whatever help or cooperation will be asked for.

As for our actual work, I feel that in the interests of both speed and decision it will be advisable, or even necessary, for the Committee to supply interim reports to Your Excellency before actually presenting our Final Report. I believe, too, that from Your side such a policy will find no objections, while it is even possible that this will unable you to make certain suggestions while we are still at work on our investigations.

Your Excellency, I do not think more than this short reply is needed, expecially as the Committee wants to start its work as soon as possible. But once again I assure you that within the bounds of the thoroughness that this matter demands we will work with all speed, and in closing I express the hope that the work of the Committee will serve the good of the Fatherland.

1.2. Composition of the Committee

At the time of its installation the Committee, christened by its Chairman, The Delta Committee, consisted of the following members:

IR. A. G. MARIS, Director-General of the Government Waterways Department, Chairman;

DR. IR. V. J. P. DE BLOCQ van KUFFELER, former Director-General of the Zuyder Zee Works;

DR. IR. W. J. H. HARMSEN, former Director-General of the Government Waterways Department;

PROF. IR. P. PH. JANSEN, Professor at Delft Technical University and Chief Engineer, Government Waterways Department;

IR. G. P. NIJHOFF, Advisory Councillor, Ministry of Transport and Waterways;

PROF. IR. J. TH. THIJSSE, Professor at Delft Technical University and Director of Delft Hydraulic Laboratory;

IR. R. VERLOREN VAN THEMAAT, Director of the van Hasselt & de Koning, Engineering Consultants Bureau, Nijmegen;

IR. J. W. DE VRIES, Chief Engineer, Directorate Lower Rivers, Government Waterways Department; and

IR. L. T. VAN DER WAL, former Director and Chief Engineer, Provincial Waterways of South Holland.

Secretary: DR. IR. J. VAN VEEN, Chief Engineer A, Directorate Lower Rivers, Government Waterways Department;

Assistant Secretary: IR. K. F. VALKEN, Engineer, Government Waterways Department.

Since its original composition, the Committee had several changes.

By Royal Decree of February 21, 1953, No. 9511 Section P, Directorate of Waterways, it was enlarged by the appointment of

DR. IR. J. A. RINGERS, former Director-General of the Government Waterways Department and former Minister of Public Works and Reconstruction;

By Decree of February 16, 1954, but starting on May 1, 1953, No. 9821 Section P, Directorate of Waterways, of

JHR. IR. C. L. C. VAN KRETSCHMAR VAN VEEN, Director of the N.V. Hollandse Aannemings Mij.; and

By Decree of March 2, 1954, No. 12591 Section P, Directorate of Waterways, of

DR. IR. F. P. MESU, former Director of the Land Development Technical Service; and

PROF. DR. J. TINBERGEN, Professor of the Rotterdam Economic University and Director of the Central Planning Bureau at the Hague.

By Decree No. 18213 Section P, Directorate Waterways, of March 26, 1954, the Secretary, DR. IR. J. VAN VEEN was appointed a member of the Committee.

The members DR. IR. W. J. H. HARMSEN, IR. G. P. NIJHOFF and DR. IR. J. VAN VEEN died respectively on January 11, 1954, February 4, 1956, and December 9, 1959.

By Decree No. 29391 Section P, Directorate Waterways, of May 29, 1953, IR. F. J. VOS, Engineer of Government Waterways Department, was appointed Assistant Secretary, and then by Decree No. 11593 Section P, Directorate Waterways, of March 10, 1960, as Secretary.

By Decree No. 58797 Section P, Directorate Waterways, of September 14, 1960, IR. K. F. VALKEN was granted honourable resignation as Assistant-Secretary.

1.3. Working Method of the Committee

The Delta Committee met 46 times in full session. But in addition to the plenary meetings there was a great number of meetings of members formed into working groups for discussions on various features of the investigation.

Many of these meetings were attended by experts whose help had been called for so that the study could be given as broad a base and as thorough an analysis as possible.

It was a happy circumstance that at the very start of its work the Committee could immediately make use of the information collected by the so-called Storm Flood Commission of 1939 and that it could also build up the extensive studies which the Government Waterways Department - largely through the Hydraulic Laboratory at Delft - had already made into the possibilities of increasing the safety of the waterworks situation, especially in the northern part of the Delta area. Bilbliography (20).

Particular mention must be made of the research done by its members and by the Secretary. DR. IR. JOH. VAN VEEN (who died during the investigation), in his function as Head of the Study Service of the Directorate Lower Rivers of the Government Waterways Department in both of the fields mentioned, even before the 1953 Flood disaster.

The Committee gladly expresses here also its appreciation of the great amount of work done by the Secretariat as well as of the valuable services rendered by the Government Waterways Department, especially the Study Service of the Directorate Lower Rivers and - since its establishment - by the Delta Service, the Directorate General Service and Water Household and later by the Central Study Service.

Valuable assistance has, furthermore, been obtained from a few other services, of which the following are mentioned with special gratitude:

1. The Central Planning Bureau of The Hague;
2. The Royal Netherlands Meteorological Institute of de Bilt;

3. The Soil Mechanics Laboratory at Delft;
4. The Laboratory for Experimental Stresses Research at Delft;
5. The Mathematics Centre at Amsterdam;
6. Provincial Waterways Services;
7. The Government Service for the National Plan;
8. The Government Fisheries Research Institute at IJmuiden;
9. The Hydraulic Laboratory at Delft; and
10. The Zoological Station at Den Helder.

The work of the Delta Committee has been mainly applied to protection against storm-flood levels and to the improvement of the fresh water supplies. During its study, which ultimately led to the setting up of the "Delta Plan", it has made good use of the results of the various commissions that were appointed to study the possibilities which such a Delta Plan offered in other fields. In this connection special mention must be made of:

The South-West Planning Commission and
The Commission for the Study of Space Organisation in Agriculture.

The problem of the shell-fish breeding (oysters and mussels) was discussed with representatives of this branch of industry, the so-called Committee of Thirteen.

From the very outset of its work the Delta Committee realised that advice concerning an increase in the safety and the fresh water household in the south-west is a very extensive matter which would include or necessitate the study of many affiliated problems, and would therefore take a great amount of time. Nevertheless within one year after its installation the Committee was convinced that the closing of the sea-arms was not only imperative in this connection alone and also that it was technically possible. This answered to the main question set by the Minister when he inaugurated the Committee: "Is there to be damming of the sea-arms or a widespread strengthening of the existing dykes?"

Further, it soon became clear that a few works could be indicated which would guarantee important local improvement in safety within a short time while also fitting into the final comprehensive plan. So they could be recommended at once without raising any difficulties, and actually, indeed, consisted of works which were considered as forming the first stage of the execution of the whole project.

Based on its preliminary studies the Committee presented five Interim Reports giving specific advice, namely:

1. Raising the height of the Schouwen dyke – May 26, 1953;
2. Closing of the Hollandse IJssel – May 26, 1953;
3. Damming the sea-arms (Delta Plan) – Feb. 27, 1954;
4. Damming the Veeregat and Zandkreek (Drie-Eilandenplan) – Jan. 5, 1955; and
5. Further considerations related to the damming of the sea-arms – Oct. 18, 1955.

Of these, the first, second and fourth applied to the already mentioned scheme to promote a rapid increase in the existing safety but within the scope of the Delta Plan; the third was the complete plan to close the sea-arms; and the fifth covered the detailed working out of that plan. The Committee felt that in this way they would meet the objection that its complete and detailed study would take a great deal of time.

It should be added here that in drawing up the Interim Reports which have been added to the Final Report, IR. K. F. VALKEN played an important part.

For the compilation and editing of the Final Report a committee of editors was appointed, consisting of three members of the Delta Committee and a Secretary:

DR. IR. V. J. P. DE BLOCQ VAN KUFFELER (Chairman),

IR. L. T. VAN DER WAL,

DR. IR. J. VAN VEEN, in 1957 replaced at his own request by IR. J. W. DE VRIES,

IR. F. J. DE VOS (Secretary).

Taking into account the date of publication of the Report, the spelling of the Dutch geographical names was in accord with the directives then being prepared by the Vocabulary Commission of the Ministry of Education, Arts and Sciences during the drawing up of the Report. However, because a few parts of the Report were ready at an early stage, this spelling could not be introduced in some of the diagrams and appendices. (For this English version, the spelling used will be in simple style conforming in the main with the usual way the names are seen on English maps.)

The Interim Reports have been added to the Final Report in their original and unabbreviated forms.

It must also be added here that during the compilation of the Final Report and the appendices no official names had been fixed for the closings in the Delta area or for the waters to be closed off by the dykes. Therefore the names actually used in those sections of the Report must be regarded as preliminary names.

Finally, attention is also drawn in this connection to the footnote to Para. 1.1 of the Final Report and the footnotes belonging to Para. 1.2 of Contribution IV. 3 (Part 5).

RESULTS OF THE INVESTIGATION

2.0 THE NECESSITY OF AN INCREASE IN SAFETY

As it was the task of the Committee to give an opinion on the necessity of increasing the safety of the various coastal areas of the Netherlands, a study of previous floods and the damages they caused – especially the flood of 1953 – was the preliminary essential.

The number of flood disasters which had harassed different parts of the country, sometimes even over long distances, is, according to reliable figures which are available since about A.D. 1200, in the region of 100, giving an average of 16 a century. See (6) and (17) listed in the Bibliography Section.

A particularly notorious flood was that of 1825, for although in that case the water did not reach the high level of the 1953 flood, it inundated about 925,000 acres, or almost three times the ravaged area of the most recent one.

In 1877 the Government Waterways Department started to publish storm flood reports giving details of all the damage that was caused. During the period 1877–1916 the record shows that there were 8 floods which produced serious damage, which gives a frequency of about 18 per century, whereas by taking the 9 floods occurring between 1877 and 1953, a frequency of 12 per century is registered. In the decrease of the number of inundations after 1916 there is reflected the increase in the safety measures mainly resulting from the closing of the Zuyder Zee.

The areas flooded within the main water protection system for the 9 floods between 1877 and 1953 (excluding swampy or marshy areas) were respectively:

Table 2.0.1 Areas flooded at different inundations

Year	Area in acres
1877	153,500
1881	89,000
1883	104,250
1889	95,500
1894	62,250
1906	75,750
1911	9,250
1916	153,000
Average 1877–1916	92,750
1953	322,500

In addition by these floods – as also with others – large areas outside the main water protection system were flooded, irrespective of whether the water-courses had built-up sides or not. In the Biesbos alone and along the Amer there is an area of about 19,000 acres that has been repeatedly flooded.

Another important point, however, is that the floods of the period 1877–1916 mainly affected the same area on every occasion.

In connection with the 1953 flood, when the main water protection measures have appeared inadequate along great lengths in the south-west of the Netherlands, certain facts must be mentioned. According to the Storm Flood Report 1953 (1), about 90 torrent gaps originated together with about 500 breaches in the dykes, while of the total dyke length of more than 625 miles (1,000 kms) in the south-west of the Netherlands, almost one-half was damaged. At a few places the dykes were completely swept away, such as on the island of Goeree-Overflakkee over a length of about 15 miles.

According to information supplied by the Central Bureau of Statistics, the 1953 disaster resulted in 1,835 people losing their lives, with more than 72,000 having to be evacuated. Even one year after the disaster 5,565 persons had not yet returned to their former place of residence. The toll of that flood also included 47,000 cattle and 140,000 poultry. More than 3,000 houses and 300 farms were destructed while more than 40,000 houses and 3,000 farms were damaged. See also Bibliography (4).

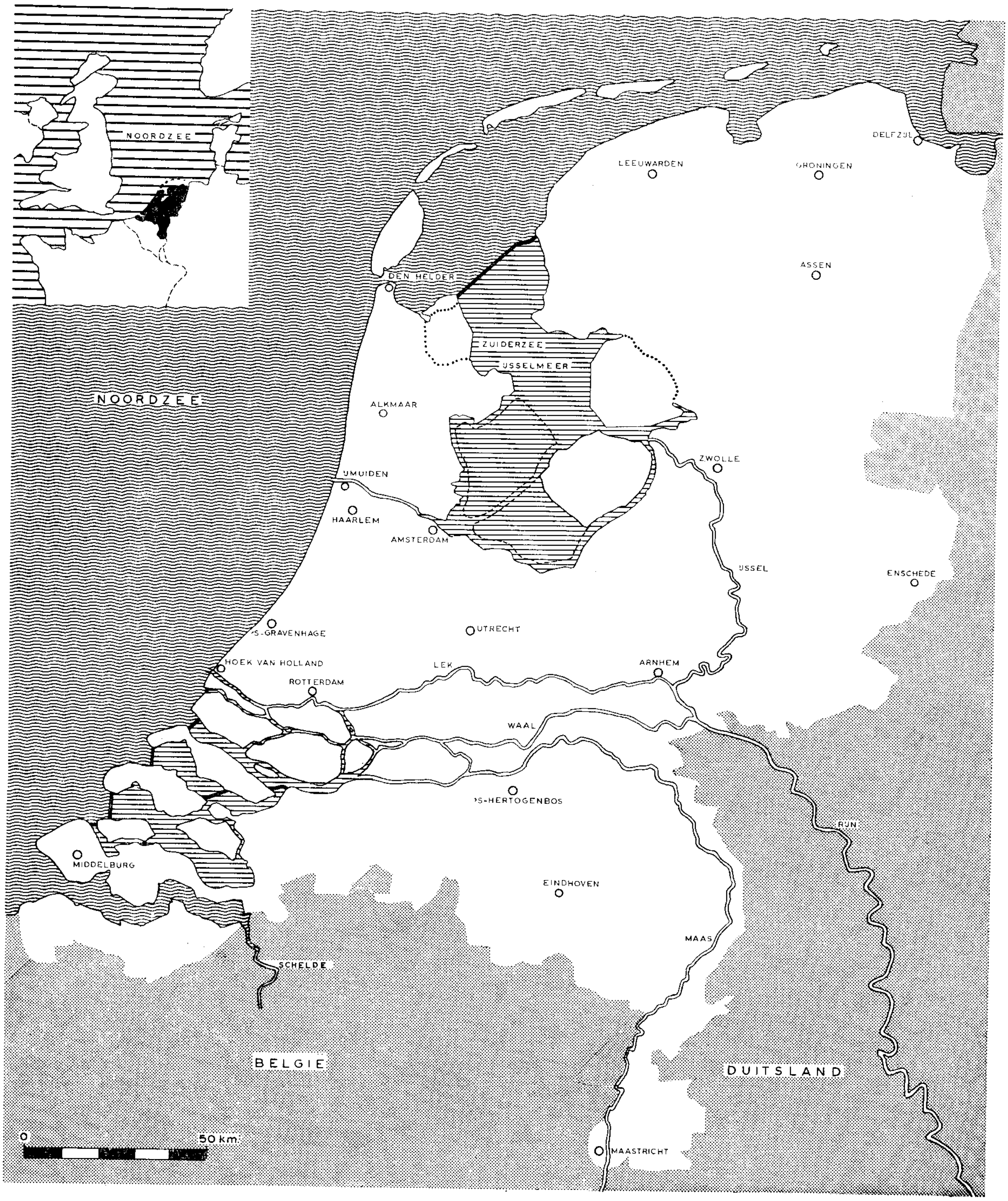

Figure 2.0.1. General Map of the Netherlands

According to statistics supplied by the Netherlands Ministry of Finance, the total sum spent by the Government and the Disaster Fund in connection with the catastrophe was about Fl. 1,100,000,000 (£ 110,000,000), of which Fl. 390,000,000 was for repairs to the water protection works.

Apart from the sum just mentioned, however, the flood resulted in damage not compensated by either the Government or the Disaster Fund, which means that the total figure of the material damage caused is considerably over the sum of Fl. 1,100,000,000 given officially.

It is obvious from these facts and figures that once again a serious flood disaster has hit the Netherlands. It is also clear that in a modern society such a situation encompassing such a threat cannot be tolerated, especially as the lowering of the soil level, the increase in the country's population and the strong economic development give such a disaster an evergrowing seriousness. For these reasons it is essential to take the requisite measures now, even though formerly they have not been considered because of their very high cost.

The great human sorrow and the tremendous damage caused by the 1953 flood disaster undeniably demonstrate the absolute necessity of improving the situation and also that considerable, even very high, expenditure is justified to increase the safety factors.

Moreover, it must be accepted that any improvement must not be based merely on the highest storm-flood levels that have so far been registered as having occured in the past, but that efforts must be made to take into account the water levels that can be expected in the future, so that dyke improvements can be made in each area which ensure an acceptable situation justified economically and socially.

All this means that in the opinion of the Committee, there must be a national system of flood protection based on well-founded norms and directives, and that such a system must be put into operation as speedily as possible.

As for the existing situation of main water protection in the south-west, middle and north of the Netherlands, the following brief summary will show how things stand (see also Figures 2.0.1 and 2.0.2).

In *the south-west* the general situation remains unsatisfactory, despite the fact that the damage to the dykes during the 1953 floods has been repaired and also that a large number of weak places in the main water protection have been, or are going to be, strengthened.

A speedy increase in the safety of this region is urged because of the extensive stretch of the main water protection in the area and the generally bad or rather uncertain situation connected with it, namely, an unfavourable profile, poor composition of the dykes which are also considerably built on, and coastal works of doubtful construction and the attendant danger of partial collapse.

In *the central area*, more particularly the mainland of South Holland and the connecting low areas of North Holland and Utrecht, special and continuous attention is needed. Although here, in contrast to the south-west and the areas around the former Zuyder Zee, there has never been a great disaster, danger may be said to be always threatening. In 1953, for example, the situation during the flood period became very critical for this area. Only by the greatest possible efforts were the engineers able to prevent heavy flooding, after a start had been made in breaking the dykes along the Hollandse IJssel. During the flood of 1954, again, the situation here was once more dangerous and the Schielands Hoge Zeedijk had to be quickly strengthened with sandbags over a considerable length.

The main water protection works going eastward from Hook of Holland have certain weak points near Maassluis and east of Rotterdam, especially along the Hollandse IJssel.

In the generally very low-lying area, often today called the Randstad Holland, which is protected by this system, there are admittedly a few inner dykes. Yet, until important improvements are made to them they are of little significance as in-between protection. But it must here be remembered that the interests demanding protection are extremely great, because of the fact that Holland's largest ports, with all their economic activity, lie in this region, and that today about 4,000,000 people are already living and working in this low-lying area between the Rotterdam Waterway, the River Lek and the North Sea Canal. Moreover, in any serious inundation the Government Centre of The Hague would be cut off from the rest of the country, a factor which could produce serious dislocation.

The necessity of increasing safety is therefore greater here than anywhere else in the Netherlands. This entails that the greatest provisions must be made for the main water protection of this area and also that these essential improvements be made as quickly as possible.

The level coast from the Hook of Holland to Den Helder has over a greater part of its length a good beach flanked with a belt of dunes which generally offers adequate safety as a main water protection,

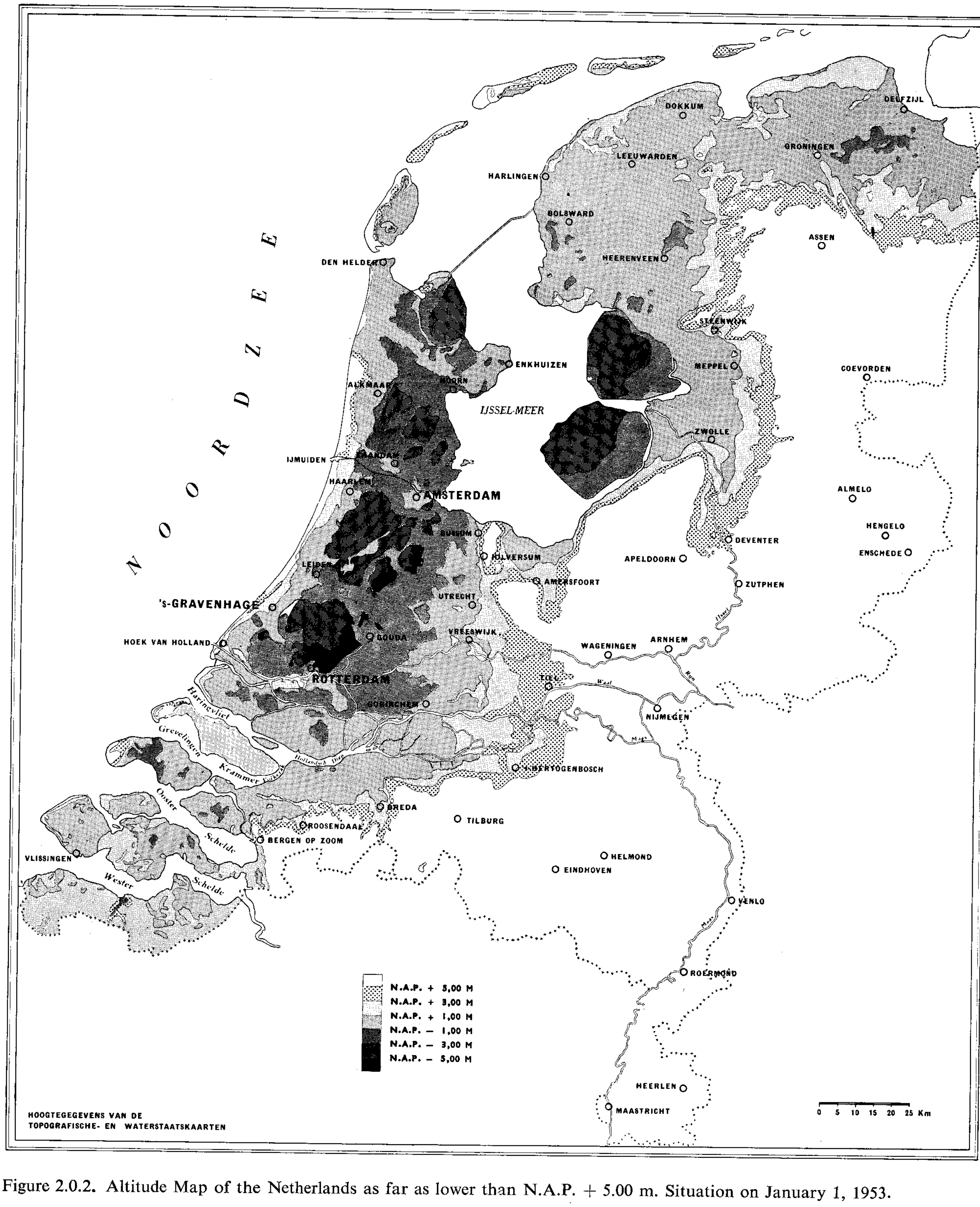

Figure 2.0.2. Altitude Map of the Netherlands as far as lower than N.A.P. + 5.00 m. Situation on January 1, 1953.

although there are certainly a few unreliable parts in this dune line. For example, the cuttings near IJmuiden and Katwijk especially need attention as part of the present coastal works.

From Den Helder through Wieringen to the Frisian coast, the Zuyder Zee Works have provided an improved water protection. Although the Enclosing Dam and the Amsteldiep Dyke do not meet the present height requirements, the situation here can nevertheless be called relatively favourable, especially as there are secondary water protections. In the Den Helder (Nieuwe Diep) area itself, however, the dyke is now much too low and at many places also perforated with pipes, which weaken it.

Coming now to *the northern area*, it can be said that though no flood has ever occurred in the Friesland and Groningen Provinces comparable to that of 1953 in the south-west of the country, thus making flood dangers less apparent there, and, moreover, though the land behind the main water protection here is on a higher level than in the rest of the country, it must be recorded that the dykes do not meet the requirements laid down by the Committee for complete safety. There is especially danger from the weak spots in the Friesland main water protection system, a danger added to by the fact that this province has practically no inner dyke system. Special attention must also be given to the situation in Harlingen and to that of the adjoining dyke sections. However, by the plan to close the Lauwerszee these weak spots will then lie inside the dykes, while there will also be a second protection line here.

The storms of 1953 and 1954 have further shown that the main water protections of the Wadden Islands must be strengthened.

From all this it follows that the safety of the stormflood protection is definitely inadequate and insufficient along the whole coast and that the necessary improvements must be carried out as expeditiously as possible.

3.0 BASIC LEVELS AND DESIGN LEVELS ALONG THE COAST AND THE SEA-ARMS IN THE SOUTH-WEST AND IN THE WADDEN AREA

Before any plans for the improvement or construction of main water protection works can be made, it is necessary to determine the storm-flood levels which must serve as the basis for the determination of the main dimensions of the hydraulic structures.

In the first place, a thorough study is needed of the storm-flood water levels. Secondly a study will be needed of the storm surges which can be expected in the future.

The height of the storm flood of February 1, 1953, exceeded the previous flood levels in the south-west of the country as far as they were known from observations in former years. The level highest measured at the Hook of Holland, N.A.P.+3.85 m [1]), was, for example, more than half a metre ($19\frac{1}{2}$ inches) higher than the registered maximum of N.A.P.+3.28 m on December 23, 1894.

During the heaviest storm flood of the 150 years preceding that of 1953, namely, that on February 4, 1825, no observations were made at the Hook of Holland because the Rotterdam Waterway did not yet exist. However, it may be accepted with certainty that the high water at such a flood would under present circumstances not reach the 1953 level, even when taking into account the rise of the sea level in respect of N.A.P. since 1825.

The flood of 1825 caused disaster along the whole of the south-east and east coasts of the North Sea to the north of Jutland, while that of 1953 especially produced high water levels in the southern part of the North Sea along the English and Belgian coasts and then along the coast of the Netherlands upto about IJmuiden. At Texel, as far as can be judged, the storm-flood levels of 1953 and 1825 varied very little. Further to the east the 1953 flood was not extremely high; at Delfzijl a level was reached which occurs upto 40 times in a century.

It might be asked whether floods occurred before 1825 which equalled that of 1953, or even exceeded it. No definite answer to this, however, can be given. It is true that there are extensive descriptions of earlier floods which caused serious disasters, such as the St. Elizabeth's Flood of 1421, the Allerheiligen Flood of 1570, and the great floods of 1686 and 1775. But modern engineers are completely in the dark about the heights of the water levels in those catastrophes. However, the impression, but not the certainty, is gained that not one of those disastrous floods was greater than that of 1953, even when considering

[1]) N.A.P. = Ordnance datum (= mean sea level of Amsterdam).

the changes caused through the centuries in the sea level in respect of the land. It seems rather that the 1953 flood was the highest of them all. However, this view into the past, although somewhat hazy, certainly demonstrates the special character of the flood of 1953.

Another question which must be asked is whether the flood of 1953 caused the highest possible levels, or whether still higher ones must be planned for.

The answer to the first question is a definite negative, while to the second it could be in the affirmative. No matter how unfavourable the circumstances were, they could undoubtedly have been worse. The maximum storm effect [1]), greater than has ever been observed in the Delta area, certainly occurred on February 1, 1953, during the spring tide, but not at the moment of the astronomical high water which, moreover, can be higher than that which actually occurred on that day. It is also possible to imagine that the storm effect could be still greater than in 1953 through still worse meteorological circumstances.

The Committee has chosen the Hook of Holland as the starting-point for the further study of the storm-floods levels. On February 1, 1953, the highest flood level there was N.A.P.+3.85 m, which was formed by the astronomic high water of N.A.P.+0.81 m and a storm effect of 3.04 m. Now the highest astronomical high water mentioned in the tide tables of the Hook of Holland for the season of the heaviest storms (1952–1953, middle of November to middle of February) is N.A.P.+1.25 m, which is 0.44 metres higher than the morning tide of February 1, 1953. If that storm had occurred two weeks earlier, it could have coincided with the very high astronomic high water.

Furthermore, it appeared that during the morning high water of February 1, the storm effect that occurred was not the highest of the effects registered during that morning. A few hours before, indeed, it was 3.30 m. If this had coincided with the just-mentioned higher astronomic high water, then the water level at the Hook of Holland would have risen about $\frac{3}{4}$ metre (29 inches) higher.

According to our present knowledge there is no certainty that the peak of the storm effect avoids the moment of astronomic high water, so that the chance of these coinciding cannot be excluded. But there will be a reduction of the water height by the mutual opposition of the composing factors.

The storm effect itself would have been even greater if the depression which caused the disaster had taken a somewhat different course, a possibility that must be considered. Moreover, there occur in the Atlantic Ocean storms of even greater force than that which wrought havoc here in 1953, and meteorology knows no reasons why such storms cannot or will not occur in the North Sea.

From the calculations of the Royal Netherlands Meteorological Institute (K.N.M.I.) at de Bilt it seems that the storm of January 31/February 1, 1953, could have led to much stronger wind effects along our coast if the depression be imagined as having returned to its own course and if the storm had lasted longer. Moreover, a possible fluctuation of the North Sea caused by a preceding storm could have increased the maximum storm effect by a few decimetres. In Contribution I it is shown by deduction that if there has been an unfavourable coinciding of the various factors which can all determine the storm effect, the result along the Netherlands coast could have been a storm effect of 5 m. The occurrence of such a big storm effect meteorologically is not regarded as impossible, although naturally the chance of the simultaneous occurrence of such extremes is very small because of the necessity of the coinciding of factors which in themselves are rare.

These considerations, added to the previous figures given, have led the Committee to taking the level at the Hook of Holland at N.A.P.+5 m, which is 1.15 m higher than occurred in 1953, as its starting-point for further investigation.

In this connection it is presumed that no account will be taken of the influence of hydraulic works to be executed, nor of a drop in the N.A.P., nor of waterlevel fluctuations for short periods (see also 8.2.2.).

From the afore-mentioned outline of the possibilities, it can be seen that no absolute maximum for a storm-flood level can be indicated. Indeed, the astronomical high water is tied to a maximum; but this is not the case for the storm effect.

Whatever flood level is taken as the basis of the main water structure, it must always be remembered that such a basis does not offer absolute safety and that a certain risk is being taken that the protection will, at a certain time or moment, not produce the required security. This risk, however, gets smaller when the factors which must serve for the design flood level are made more unfavourable. And finally,

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[1]) For a definition of "storm effect", see Contributions I and III.1.

account must be taken of the greatness (or rather the smallness) of the chance that the flood level taken as a standard will one day be exceeded.

But continuing along the road already chosen by the so-called Storm Flood Committee in 1939 (see the Installation Speech of the Minister of Waterways in 1.1), the Delta Committee has promoted as much as possible the making of studies of wind effects and frequency curves of the high water levels along our coast.

In 1939 IR. P. J. WEMELSFELDER drew attention to the occurrence of floods. See Bibliography (21).

Then, too, the comprehensive observation material (of which a survey occurs in Part V of the Ten Years' Survey of the water levels from 1941–1950) confirms that there is a certain law in the occurrence of floods along the Netherlands coasts. This law may be clearly seen in a diagram in which the floods occurring during a certain period are placed alongside the level they reached. By using half-logarithmic paper, the so-called possibility paper, and marking thereon as ordinate the storm flood situation and as absciss the number of times the high water level was reached in a certain period or exceeded (the so-called excess frequency), then the points which show the individual floods are as a rule not far from being a straight line or perhaps a slight curve.

Such a diagram is shown in Fig. 3.0.1 for the Hook of Holland. In the first place are indicated the floods occurring in the period 1859–1958 inclusive. (Before 1864 there was no registered information available of the water levels at the Hook of Holland. These, however, have been deduced fairly easily with the aid of information about water levels at Hellevoetsluis, Brielle, Scheveningen and Katwijk.)

The 30 highest storm floods [1]) have been indicated by points, as well as the 40th. The highest are connected step-wise. The 40th already appears to lie under the limit level for the Hook of Holland (N.A.P.+2.42 m). Under the limit level are all high water levels which have occurred at the Hook of Holland for a long period (1888–1948) compiled in a so-called annual excess curve. From this diagram it can be read that in the century under consideration

levels over + 3.85 m have not occurred
levels over + 3.28 m have occurred once
levels over + 3.00 m have occurred twice
levels over + 2.97 m have occurred four times
levels over + 2.96 m have occurred five times
levels over + 2.91 m have occurred seven times.

With rather great certainty, therefore, it can be said that the chance of the occurrence of storm floods over N.A.P.+2.91 m in a certain winter is 7 in 100, or about one-fourteenth. But the uncertainty becomes greater when one wants to determine the chance of still more rare – higher – storm floods. It is not absolutely certain, for example, that the chance of exceeding a level of N.A.P.+3.50 m in one winter is 1 in 100, and also that if that chance were 1 in 200 or 2 in 100, the intended level in 100 successive winters could very well have been exceeded once.

In the century under observation there are so many points present between the limit level and the level of N.A.P.+3.0 m that there can be drawn through them a flowing excess line with great certainty for the high water levels under the limit level.

Over N.A.P.+3 m the number of available storm-flood levels is, however, so small that it is no longer possible to draw the excess line for the storm-flood levels with sufficient certainty, although the fact can be taken into account that this line based on the observations in the more frequent field is either straight or slightly curved. There are no indications, moreover, that the character of this line would change for the less frequent cases.

As already stated, the Committee took as its starting-point for its further studies a water level of N.A.P.+5 m at the Hook of Holland. A look at the diagram shows what an important extrapolation of the available information is required to determine an excess frequency of this level. Many lengthenings of the determined excess line under N.A.P.+3 m can be thought of, which demonstrates the difficulty of determining the excess frequency of the level of N.A.P.+5 m.

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[1]) A storm flood can be explained as a high flood at which, somewhere along the coast the so-called limit level is passed. This is the level which on an average is reached over a long period once every two years at that spot. The limit level is usually not passed until the wind strength has reached an hourly average of 15 m/sec (wind force 8). Bibliography (21).

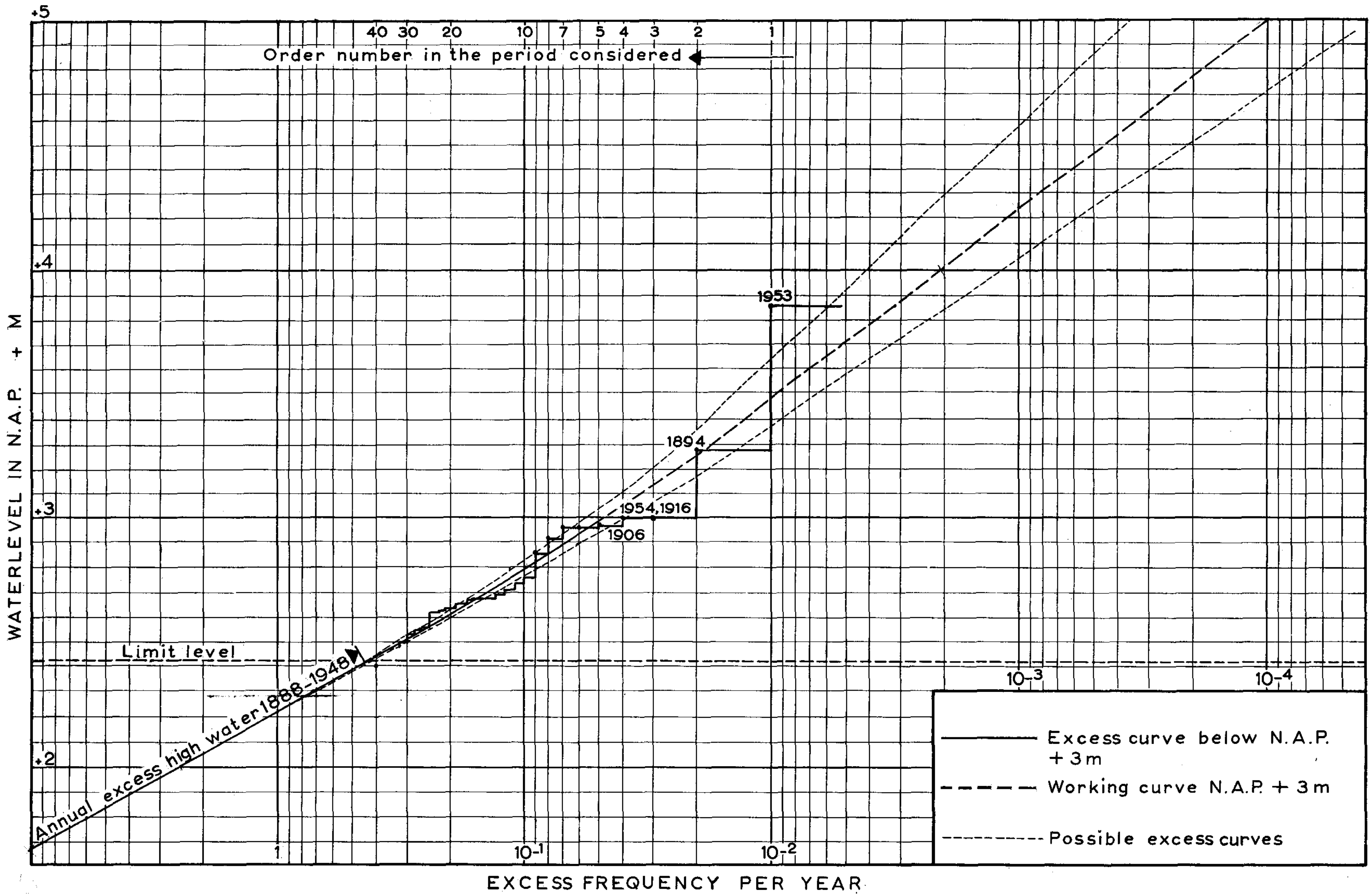

Figure 3.0.1. Excess curves of the storm-flood levels at the Hook of Holland 1859–1958 inclusive

The uncertainty about the course of the excess frequency over the level of N.A.P.+3 m resulted in the Committee putting the problem before the Mathematical Centre, as well as seeking the cooperation of the General Service and Water Household Department of the Ministry of Waterways (see Contributions III.2 and III.3) and the K.N.M.I. of de Bilt. See Contribution II.1.

When the Mathematical Centre had offered the results of its investigations the problem was discussed by the Committee with representatives of that Centre for further elucidation of certain factors, and also with the Ministry of Waterways.

This led to accepting a working-line as indicated in Fig. 3.0.1, in which for the water level of N.A.P. + 5 m an excess frequency belongs to the order of 10^{-4}. Further research was then carried out by the Mathematical Centre which led to a somewhat higher level at an excess frequency 10^{-4}. Finally the Mathematical Centre said that it considered "the value N.A.P.+5 m at the Hook of Holland not entirely unacceptable as an estimate of the exclusively statistically determined height with excess chance 10^{-4}, although on the low side".

The line indicated on the diagram was called the "working-line", which really shows that it gives the acceptable excess frequency of certain storm-flood levels for further discussions. This is not, however, the only possible line that could be thought of. There can be many such lines drawn running straight or slightly curved which join up in an acceptable way with the excess line of the water levels lower than N.A.P.+3 m. Over and below the working-line on the diagram there are drawn dotted lines which link up in an also acceptable way with the observations below N.A.P.+3 m and which, although not indicating an absolute of the real excess frequency, can still give an idea of the deviations which are possible. Also if another starting period is taken, namely, replacing 1859–1958 inclusive by the period 1853–1952 inclusive, a somewhat changed excess line is obtained, because then the storm floods of 1953 and 1954 are replaced by a few less serious floods in the years 1853–1855.

On the basis of all this the Committee thinks it may put the range of largeness of the excess frequency of the water level at the Hook of Holland of N.A.P.+5 m at about 1% per century, or one-tenthousandth per year. That is, the Committee feels that a storm-flood level with such an excess frequency may be accepted as the starting-point for its further investigations. [1])

In the Committee's further remarks this level of N.A.P.+5 m at the tide gauge at the Hook of Holland and the levels of equal value at other places (levels with equal excess frequencies) will be called *basic levels.* The excess frequency of the basic levels, therefore, is by definition equal to 10^{-4}. They will serve as the general foundation by which – in connection with the importance of the area lying behind – the requirements for the main water protection must be tested.

In order to determine the basic levels along the whole coast and the sea-arms, the Directorate General Service and Water Household of the Government's Waterways Department – in agreement with the Mathematical Centre and the K.N.M.I. – has made excess curves for the flood heights at the various coastal spots. For most stations on the Western Wadden Sea the number of available observations was too few after the closing of the Zuyder Zee to enable a reliable excess curve to be composed. So neighbouring stations were used that had not been influenced by the closing as well as those taken before the Zuyder Zee was closed. Bibliography (15).

From the excess curves drawn by the Government Waterways Department (see Contribution III.2) the basic levels have been deduced which are mentioned in Table 3.0.1. (Column 1). As is evident, those for the Wadden Islands stations have been taken on the Wadden Sea side.

It should be noticed that the difference between the basic levels and the highest levels occurring almost constantly in the south-west is somewhat over 1 m, while this difference in the Western Wadden Sea and along the River Ems goes up to about 2 metres (Column 8 of Table 3.0.1). The cause of this is that in the observation period covering about 150 years no such special flood occured in the north-east as that of 1953 in the south-west.

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[1]) The significance of the improvement of the main water protection on the basis of a level that at the place concerned has an excess frequency of 1% per century appears from the following. After the repair of the breaches in the dykes and the reinforcement of the weak spots in the flood protections no complete safety indeed was obtained against such a flood as that of 1953; yet it can be said that such a flood will no longer produce such a disaster as in that year. The excess frequency of the stormflood level of 1953 can be put at about 1/300th a year, which confirms the impression already obtained about the special nature of this level. Improvement of the main water protection on the basis of the levels of the excess frequency of 1% per century therefore gives a safety 30 times as great as that which exists now.

The highest known floods, including that of 1825, remain far behind the level that, on the basis of the lengthened excess curve, is attached to the storm flood, of which the chance of occurring in a certain year is 1 to 10,000. The top level of such a storm flood for Delfzijl lies 1.40 m higher than the similar top level for the Hook of Holland (tide- gauge). See Column 1 of Table 3.0.1. The difference between the highest storm-flood level known, however, is for these places only 0.75 m, which shows that the difference between the basic level and the highest observed level is larger in the north than in the south-west.

It has already been stated that the basic levels determined for various places along the coast and for a number of the sea-arms are not more than general norms by which the requirements for the main water protective works have to be tested. In themselves, however, they may not yet be taken as the starting point for the reinforcements to be carried out.

The interests to be served by the main water protections are very varied. There are great differences in the size and the character, and especially in the location of the height of the area lying behind the protective works. According to whether the main water protection has to serve an important area, so will the requirements for the protective measures have to be higher. The Committee therefore started to prepare so-called design levels from the basic levels. For the main water protective works which have to safeguard vital or extremely important economic interests the design level could go somewhat over the basic level, while where the interests are limited it will be justifiable to accept a somewhat lower security margin and to maintain a design level height under the basic level.

All this has meant that the Committee has tried, by weighing the factors which determine the high water levels, tested by the excess frequency, to come to the height of the basic levels and of the design levels deduced from them. But in addition to following this logical way of working, the Committee has also studied the possibility of determining the justifiable design levels by means of an entirely different method, namely, by means of econometric (i.e., mathematics-economics and mathematics-statistical) calculations. For this for a number of areas ("compartments") the costs of the various design levels based on strengthening the main water protections were compared with the economic value of the better protective system which would be obtained from each of the reinforcements.

For various design levels for each area the total was calculated of the amount needed for the improvement of the main water protection and the cash value of the imaginary insurance premium which would be wanted to cover the areas lying behind the protective works against the remaining risk of flooding. This sum has a value at a low design level which is mainly determined by the size of the risk. By heightening the design level the sum first decreases and then rises again. The larger part of the amount is then formed of the costs of the improvement of the water protection. In this way there exists for each main water protection a design level at which the intended sum has a minimum value. This is the most economically justified design level.

The actual result, however, depends on the estimates concerning the storm-flood level at which the dykes would break, the time at which the first and any subsequent disaster would take place, the floodings that would then occur, and the material damage that would result from them. Because of the great number of uncertainties which necessarily lie behind what must in any case be guesses, the results of any calculations vary greatly from the estimates from which a start has to be made.

It must also be realised that the importance and significance given to the disorganisation, human sorrow, loss of life and other consequences of such a disaster cannot really be expressed in terms of money, so that these factors cannot be introduced into the econometric calculations in the same way as the others are.

Yet in spite of the great divergence in the possible estimates and calculations, the conclusion must still be that the economic maximum for the storm-flood level to be guarded against (namely, the design level) for the area or compartment between the Rotterdam Waterway and the North Sea Canal would not lie much below N.A.P.+5 m at the Hook of Holland. It can be taken with certainty that a design level there of N.A.P.+$4\frac{1}{2}$ m, or even lower, would not be economically justified. In Contribution II.2 a level is recommended for the Hook of Holland, on the basis of an econometric calculation, that lies much over N.A.P.+5 m. The level mentioned here, however, does not agree with the design level because, as will be discussed later, a little excess of the design level does not necessarily lead to an immediate disaster. In calculating the level mentioned in the Contribution just mentioned, a start was made from the idea that excess would lead to disaster with maximum damage. This level, therefore, could be called a disaster level; the design level could be lower.

In spite of the uncertainties which are present in the results of the econometric method of calculation, it has appeared that along this way useful views and indications can be obtained for giving an answer to the question as to how far it can be considered economically justified to start from certain design levels for the improvement of the main water protection measures.

Comparison of the results obtained in this way with those formed on the basis of the views first indicated finally led the Committee to the composition of a list of design levels which are given in Table 3.0.1 (Column 4 and 5).

Because of the very great interests which are being safeguarded by the main water protection works from the Hook of Holland to Den Helder inclusive, there is no doubt that the basic level must be kept in that region as the design level.

The sea protective works south of the Hook of Holland and those of Friesland and Groningen protect interests which can be regarded as about equal but which are not entirely of the same order as those safeguarded by the main water protection of Central Holland. So in that connection the design level there can be put somewhat lower.

For the south-west of the country, which is divided into smaller areas each separately protected by main water protections, design levels have been fixed at about $2\frac{1}{2}$ times as much chance of excess as the basic levels at the various places. The excess chance there, therefore, is about 1:4,000. The difference from the basic levels is thus about 12 inches or 30 cms. (Column 3 of Table 3.0.1). In Column 4 of this same Table the design levels are shown, with the mentioned correction given in Column 2. This correction was necessary because the damming of the sea-arms will lead to a slight increase of the storm-flood levels in the vicinity. See also Contribution IV.2.

For the main water protections along the Frisian and Groningen coasts giving security to an area without a second line of defence but which is not so low-lying as the south-west of the country, design levels have also been determined (Column 4 of Table 3.0.1) which have about $2\frac{1}{2}$ times as large a chance of excess as the corresponding basic levels. As appears from Column 3, these levels along the Frisian coast west of Nieuw-Bildt lie about 12 inches (30 cms) lower than the basic levels valid for those places, while along the remaining part to the Frisian coast and the whole of the Groningen coast they are 8 inches (20 cms) lower.

Near the Enclosing Dam of the Zuyder Zee and for some of the Wadden Islands a still greater difference between design and basic level is justified. The dykes of the IJssel Lake polders have been designed taking into account a possible breach in the Enclosing Dam, while the old sea protections have been maintained along the old land. A break in the Enclosing Dam, therefore, would – apart from the discharge until the dyke was closed again – only result in the silting of the IJssel Lake, with effects that would be removed again within a few years after the gap was closed. In view of this, a decrease in the design level to 24 inches (60 cms) under the basic level is considered justified for Den Oever and Kornwerderzand (at the ends of the Enclosing Dam). For Wieringen and the Balgzand dyke which protect more important interests, this figure can be put at 16 inches (40 cms). The island of Texel would be so greatly harassed by a flood that it does not seem justified to make any reduction of the design level from the basic level. On the Wadden Islands of Vlieland, Terschelling, Ameland and Schiermonnikoog a flood would cause only limited damage, with no fear of loss of human life, so here the reduction of at least 20 inches (50 cms) for the design level from the basic level is considered acceptable.

For the reduction figures see Column 3 of Table 3.0.1.

When it is accepted that within the near future (50 years is the period visualised) the sea-arms between the Wadden Islands will be closed and that from one of those islands a dyke will be constructed to the Groningen coast along the River Ems, and if dykes might be made in the Dollard, it can be investigated how far the coastal sections, which as a result of those works would lose their high water protecting function, would need a still higher excess frequency as a starting-point for the determination of the design levels. This concerns the Zuyder Zee closing, including the Balgzand dyke and the Noorder dyke from Wieringen, the coast of Friesland, part of the coast of Groningen, and the Wadden Islands. For this category the indicated design levels are to be found in Column 5 of Table 3.0.1. These levels have been obtained by decreasing the corresponding levels in Column 4 by 6 inches (15 cms). To distinguish them, the levels mentioned in Columns 4 and 5 have been indicated as design levels for a permanent

Table 3.0.1.

Basic and design levels along the coast, in the sea-arms and in the Wadden area

Place	Basic level = water level in excess according to the level of N.A.P. + 5 m at Hook of Holland (tide-gauge) in m + N.A.P. (existing situation)	Increase in cms to be expected as a result of the closings	Economic reduction in cms	Design level in m + N.A.P.		Highest level registered in m + N.A.P.		Difference in m between water levels in columns	
				For continuing situation (1+2—3)	For situations regarded as temporary (15 cms lower than 4)	Year	Height	1 and 7	4/5 (in bold type) and 7
Excess value	10^{-4}								
	1	2	3	4	5	6	7	8	9
Cadzand	5,80	+ 5	30	**5,55**		1953	4,75	1,05	0,80
Breskens	5,85	+ 5	30	**5,60**		1953	4,80	1,05	0,80
Hoofdplaat	5,90	+ 5	30	**5,65**		1953	4,85	1,05	0,80
Terneuzen	5,90	+ 5	30	**5,65**		1953	4,96	0,94	0,69
Walsoorden	6,40	+ 5	30	**6,15**		1953	5,25	1,15	0,90
Hedwigpolder	6,55	+ 5	30	**6,30**		1953	5,43	1,12	0,87
Bath	6,60	+ 5	30	**6,35**		1953	5,60	1,00	0,75
Waarde	6,25	+ 5	30	**6,00**		1953	5,15	1,10	0,85
Hansweert	6,15	+ 5	30	**5,90**		1953	5,07	1,08	0,83
Hoedekenskerke	6,05	+ 5	30	**5,80**		1953	4,90	1,15	0,90
Ellewoutsdijk	5,85	+ 5	30	**5,60**		1953	4,75	1,10	0,85
Borsele	5,80	+ 5	30	**5,55**		1953	4,70	1,10	0,85
Zuid-Kraaijert	5,75	+ 5	30	**5,50**		1953	4,70	1,05	0,80
Flushing	5,65	+ 5	30	**5,40**		1953	4,55	1,10	0,85
Westkapelle	5,45	+10	30	**5,25**		1953	4,35	1,10	0,90
Top of Walcheren (Domburg)	5,40	+20	30	**5,30**		1953	4,30	1,10	1,00
Dam Veerse Gat (Vrouwenpolder)	5,45	+40	30	**5,55**		—	—	—	—
Dam Oosterschelde (Top of N-Beveland)	5,35	+40	30	**5,45**		—	—	—	—
Dam Oosterschelde (Burghsluis)	5,25	+35	30	**5,30**		1953	4,20	1,05	1,10
Top of Schouwen	5,10	+25	30	**5,05**		1953	4,10	1,00	0,95
Oude Hoeve	5,20	+25	30	**5,15**		1953	4,10	1,10	1,05
Dam Brouwershavense Gat (Repart)	5,25	+40	30	**5,35**		1953	4,18	1,07	1,17
Dam Brouwershavense Gat (S-point Goeree)	5,15	+30	30	**5,15**		—	—	—	—
Top of Goeree	5,05	+30	30	**5,05**		1953	4,00	1,05	1,05

Dam Haringvliet (Goederede)	5,20	+40	30	**5,30**		1953	4,05	1,15	1,25
Dam Haringvliet (Rockanje)	5,20	+40	30	**5,30**		1953	4,10	1,10	1,20
Top of Voorne	5,05	+30	30	**5,05**		1953	3,95	1,10	1,10
Dam Brielse Maas (Oostvoorne)	5,05	+25	30	**5,00**		—	—	—	—
Hook of Holland (outside the piers)	5,15	+10							
Hook of Holland (tide-gauge) b)	5,00	+ 0 a)	0	**5,00**		1953	3,85	1,15	1,15
Scheveningen b)	5,35	+ 5	0	**5,40**		1953	3,97	1,38	1,43
Katwijk b)	5,40	—	0	**5,40**		1953	4,05	1,35	1,35
IJmuiden b)	5,15	—	0	**5,15**		1953	3,85	1,30	1,30
Den Helder	5,05	—	0	**5,05**		1953	3,25	1,80	1,80
Oostoever	5,35	—	40	4,95	**4,80**	—	—	—	—
Westerland	5,75	—	40	5,35	**5,20**	1953	3,63	2,12	1,57
Den Oever (Wieringen)	5,85	—	40	5,45	**5,30**	1953	3,70	2,15	1,60
Den Oever (Enclosing Dam)	5,85	—	60	5,25	**5,10**				1,40
Kornwerderzand	5,90	—	60	5,30	**5,15**	1954	3,86	2,04	1,29
Harlingen	5,80	—	30	5,50	**5,35**	1954	3,69	2,11	1,66
Nieuw-Bildt	5,65	—	30	5,35	**5,20**	1954	3,70	1,95	1,50
Oostmahorn	5,80	—	20	5,60	**5,45**	1906	4,20	1,60	1,25
Nieuwe Zijlen	5,95	—	20	5,75	**5,60**	1944	4,30	1,65	1,30
Friese Sluis	6,35	—	20	6,15	**6,00**	1944	4,46	1,89	1,54
Zoutkamp	6,25	—	20	6,05	**5,90**	1825	4,45	1,80	1,45
Delfzijl	6,40	—	20	**6,20**		1825	4,60	1,80	1,60
Fiemel	6,70	—	20	**6,50**		—	—	—	—
Nieuwe Statenzijl	7,20	—	20	7,00	**6,85**	1877	5,41	1,79	1,44
Texel (Oude Schild)	5,20	—	30	**4,90** c)	**4,75** d)	1953	3,32	1,88	1,58/1,43
Vlieland	5,20	—	50	**4,70** c)	**4,55** d)	1953	3,16	2,04	1,54/1,39
Terschelling	5,30	—	50	**4,80** c)	**4,65** d)	1953	3,18	2,12	1,62/1,47
Ameland (Nes)	5,60	—	50	**5,10** c)	**4,95** d)	1906	3,56	2,04	1,54/1,39
Schiermonnikoog (Oosterburen)	5,65	—	50	**5,15** c)	**5,00** d)	1906	4,00	1,65	1,15/1,00
Rottumeroog	5,70	—	—	— c)	— d)	1916	4,20	1,50	—

The levels in bold type are the design levels now to be maintained.

a) The increase resulting from the outside influence of the Delta Works is considered to offset by the decrease caused by the suction effect of the basin in the inland waters.

b) The figures given for these stations are not mutually equal in value because the tide gauges at Scheveningen and Katwijk are located directly on the coast while those of Hook of Holland and IJmuiden are not only further inland but also situated in deep water. The first two, therefore, also indicate the local sand drift.

c) These levels are valid for the outside and the tops of the Wadden Islands.

d) These levels are valid for the inside of the Wadden Islands.

situation and for a considered temporary situation respectively. The design levels which now have to serve as the foundation for the strengthening of the main water protection are in bold type. As is seen in Table 3.0.1, the dykes along the Ems are regarded as being outside the future enclosing works in the north of the country.

Attention is drawn to the fact that the deduction of 6 inches (15 cms) has not been made for the outside and top of the Wadden Islands as they will not be included in the future enclosures. This can be seen in Table 3.0.1, footnotes c and d under the table.

When the plans have to be made for these enclosing works, it will sooner or later have to be decided which main water protection works will have to have higher design levels. In this respect thought is given to sections of the security measures for a few of the Wadden Islands in which at the moment the interests to be served are not so important as those of the mainland of Groningen and Friesland but which in the future – after parts of the Wadden Sea are closed – will protect a more important area as part of a longer main water protective scheme.

The water levels of the Lower Rivers correspond to the river discharges, and are dealt with in 6.1.

In the foregoing paragraphs it has been made clear that in the determination of the basic levels and the design levels deduced from them a great deal of uncertainty is hidden. This is particularly the case for the area which is influenced by the closing of the Zuyder Zee. See Contribution III.2.

It will be necessary, therefore, for the studies already made into this problem to be continued and for all information concerning storm-flood levels available in the future to be carefully analysed so that the basic and design levels can be regularly tested in the light of new facts, and that the design and basic levels are corrected whenever necessary in the light of additional information.

Moreover, when working out the future plans full notice will also be taken, as has been done in Column 2 of Table 3.0.1 in connection with the Delta Works, of the influence which can be effected or produced by the carrying out of the hydraulic works on the design levels.

The Delta Committee, however, thinks it necessary to warn seriously, when plans are being made for the improvement of the main water protective measures, against accepting lower design levels than those mentioned in Table 3.0.1, or the design levels calculated from them for the in-between stations.

Starting from the design levels, the measurements of the main water protections must be determined. In this it is required that when there occurs a water level equal to the design level there is still complete safety against the breaking of the dykes.

The conditions which must be made in this connection to the main water protections are indicated in 8.2. When these conditions have been fully met, there will still exist an adequate safety reserve even though the design level is somewhat exceeded.

After considering further ideas and views and making rough drafts, the Committee started from the design levels given in Table 3.0.1. Although it has appeared from the results of the econometric calculations made that dyke strengthenings based on design levels lie within the sphere of economic justification, the Committee, because of the relative value of those calculations, has generally studied the question as to whether the starting-point mentioned led to disproportionate or inadmissible charges and costs or whether perhaps a higher measure of safety should be required.

As has been mentioned in 2.0 the storm flood of 1953 caused material damage of more than Fl. 1,100,000,000 (£ 110,000,000). A storm flood causing levels about one metre (39 inches) higher – which is a flood against which the Committee's proposals provide safety – would result in very serious dislocation of the country and cause heavy material damage many times greater than resulted from the 1953 inundation. Such a greater flood, moreover, would also considerably limit the possibility of taking measures to relieve the distress and to carry out repairs and reconstruction.

If for the safeguarding of the country the aforementioned design levels are selected as the foundation, the cost on a 1955 price basis can be estimated at a total of from Fl. 2.000,000,000 to Fl 2,200,000,000 (£ 200,000,000 to £ 220,000,000) to protect the south-west region of the country (see also 4.0). To this can be added a very considerable amount for the strengthening of the main water protection works along the coast and the sea-arms north of the Hook of Holland. But when set against the damage which an extreme storm flood can cause, such expenditures as these cannot be called very high.

The expenditure required for this protection would have to be spread over a period of between 20 and 25 years, giving an average of Fl. 100,000,000 to Fl 125,000,000 annually (£ 10,000,000 to

£ 12,500,000). This annual charge, however, would scarcely equal 10% of the damage caused by the 1953 storm flood and which was dealt with financially within a very short time without serious disturbance to the nation's economy. When it is considered that the national expenditure of the Netherlands in 1955 amounted to Fl. 27,700,000,000 (£ 2,770,000,000), then it appears that the yearly cost for the protection of a large area of the country is not even 0.5% of this. From this it is surely obvious that because of the tremendous and important interests here involved, the figure of the cost of the protective works cannot be regarded as an injustifiable charge on the nation's exchequer.

The question now arises as to whether an even higher requirement of safety should be demanded. On this point, therefore, the following remarks are made.

The estimates of the costs given above deal with the plans based on the requirement that the most vital parts of the country must be safeguarded against storm floods with an excess frequency of 1% per century, while for the remaining parts of the country a few times greater excess frequency has been taken as the starting-point. As the highest reachable storm flood level cannot be indicated, the risk of a disaster always remains, no matter what storm flood height is accepted as the basis for the improvement of the main water protection. As has already been stated (see footnote on page 26), at least 30 times greater safety is obtained at a design level with an excess frequency of 1% per century, than would be obtained if the storm flood of 1953 is taken as the standard.

It is possible, of course, on the basis of other considerations, to come to higher design levels in relation to the socially acceptable risk against floods (see, for example, Contribution III. 3). The Committee thinks, however, that with the choice of the risk to be taken as a beginning, the safety against storm floods cannot be considered by itself but that account must be taken of the risks in other fields. It feels, therefore, that with a security based on the proposed design levels, an acceptable limit has been made for the storm-flood risk in the present situation.

That is to say, the Delta Committee believes that the execution of protective works in *the south-west of the country*, including those along the Western Scheldt, in the basis of the design levels it proposes will not cause inadmissible costs. Nor should it be forgotten that there is a possibility of carrying out the safety measures in such a way that various co-advantages are realised from which an advantageous balancesheet might ultimately be expected.

As for *the central part of the Netherlands*, no closer explanation is required to show that these provisions are very desirable and that they should be ready as soon as possible, because of the especially large interests involved and the comparatively less costly provisions which must be taken here to obtain very good security.

For *the north of the country*, too, both the temporary and permanent provisions will be justified.

Summarising, the Committee recommends that the design levels indicated above, including those deduced for the in-between stations, be adopted as the foundation for the construction of new main water protective measures and for the improvement of the existing main water protection works.

4.0 THE CHOICE BETWEEN STRENGTHENING THE EXISTING MAIN WATER PROTECTIONS AND CLOSING THE SEA-ARMS IN THE SOUTH-WEST

An increase in the security of the south-west of the Netherlands generally can be obtained in two ways: either by strengthening the existing main water protective works or by excluding the flood waters as much as possible through closing the sea-arms.

If it is decided to use a system of dykes consisting mainly of closing the sea-arms by means of dams connecting the rows of dunes on the neighbouring islands, then the protective height required there can be obtained without any special difficulties. The dune areas for a greater part already have a sufficient capacity for repelling the waters, and where this is not the case they provide abundant opportunities for strengthening works. As far as the dams across the sea-arms are concerned, of a total length of not more than 15½ miles (25 kms), they can within practical limits be given both the height and the strength which appear necessary for the future. Moreover, this system of coastal protection keeps open the possibility of the construction of additional, even considerable, heightening at any time in a simple way. Thus it will be possible to cope, at a comparatively moderate cost, with difficulties which may ultimately arise if the levels between the sea and the land further develop unfavourably.

In this way a modern main water protection can be constructed which will meet a high standard of safety and of which the maintenance will not only be easily ensured but will also be simple and effective.

The situation of the existing dykes is such that, used as a second line of defence, they will be able to prevent a disaster should an enclosing dam suddenly break.

The increased measure of safety that arises, when as the result of a large dam, the old water protection is no longer threatened by storm floods, can clearly be seen, for example, in the Zuyder Zee. Although this sea had been responsible for about 70% of the national inundations between 1877 and 1916, as already mentioned in 2.0, there is now hardly any question of even thinking of storm-flood disasters since the construction of the Enclosing Dam. Similar favourable results of the coastal shortening in the Netherlands are found in the south-west of the country where the island of Voorne west of the canal remained safe in 1953 because of the dams built in 1950 in the Brielse Maas and the Botlek, while parts of Zeeuws-Vlaanderen were much less endangered because of the closing of the Braakman in 1952.

These examples show that the right road is being taken towards an increase in safety when using such methods of coastal shortening made possible by modern technical advance.

It is a different thing, however, when the safeguarding system is to consist of strengthening the existing main water protective works. The total dyke length that would have to be improved in such a case – not including the dykes along the Western Scheldt – is about 900 kms (560 miles). But many difficulties would arise. First of all, the heightenings themselves, in conformity with the aforementioned design levels and the requirements connected with wave attack, would have to be of 1½ metres or more (at least 4½ feet). Then many of these dykes would have to be made more solid, while others would have to be widened. Apart from the technical details linked to this, it is clear that this could prove to be extremely difficult, and at certain places totally impossible, because of the presence of houses, industrial buildings, harbours, etc., along and even at times located on these dykes in the area of the waters of Zeeland and parts of South Holland. Then, too, when that work was completed, there would remain the disadvantage that should it be necessary or desirable at some later time to carry out further strengthening, this would be virtually impracticable and impossible. To this, moreover, must be added the circumstance, as has already been seen in many breaches of the dykes, that both the composition of the foundations and bases of the various dyke sections as well as of the coastal works present there are now showing deficiencies and defects which cannot, however, be fully investigated and cannot therefore be completely remedied.

Again, attention should also be drawn to the symptom that in the south-western sea-arms, and particularly to a serious degree in the Eastern Scheldt, there are many dyke and bank break-aways which are a danger to the safety and stability of the adjoining land. These break-aways are mainly caused by the presence of strong currents close to the banks which take away the sand and so attack the underwater section of the banks or dykes.

If in carrying out the essential safety scheme the engineers are limited to the heightening of the existing dykes, then the result will be a water protective work many hundreds of miles long (equal in length, in fact, from Rotterdam to Basel), consisting of a series of dyke sections of very differing composition, so that in many places hidden deficiencies or weak spots will continue to exist while the general maintenance in a regular and efficient manner will demand considerable attention and trouble. Moreover in such a case the advantages of obtaining in a natural way a valuable second storm-flood protection will be lost, while the bank and dyke break-aways will not be removed.

The system of damming up the sea-arms also creates the possibility of achieving a considerable improvement in the fresh water household. This will be of great importance for agriculture over a large part of the country and also make it possible to profit fully from the canalization of the Rivers Rhine and Lek.

Further advantages of the sea-arm closure are to be seen in the fields of traffic, land reclamation, recreation and the possibility of more advanced development of the whole area affected, such as by the establishment of industries.

Without the damming, the important improvements in the fresh water household cannot be achieved, nor can full advantage be taken of the canalization of the Rhine and Lek, while the other benefits just mentioned will also be unobtainable.

There is, however, one disadvantage to be seen in the closing of the sea-arms, namely, that as a

4.0

result of the water becoming fresh the salt water fishery and the shell-fish cultures will be driven out of the waters of the south-west. But however much this is felt to be an objection, it does not outweigh the very great advantages to be obtained in the south-west of the Netherlands from the closing of the sea-arms. Moreover, certain provisions will have to be made to minimise the effects on the fisheries section as much as possible.

The Committee has also investigated whether there are financial considerations of a substantial character which should or could influence the choice between the two systems aiming at increasing the safety.

The cost of the works between the Hook of Holland and Westkapelle can be roughly estimated (at 1955 prices) at about Fl. 1,800,000,000 (£ 180,000,000) for the closing of the sea-arms, and at about Fl. 1,600,000,000 (£ 160,000,000) for strengthening and heightening the dykes. The difference in cost when compared with the difference in quality between the two possible solutions is so small that this in itself does not provide a decisive factor in the choise between the two systems. See Contribution VI and the second Pre-Advice given in Bibliography (12).

The total cost of obtaining the proposed protection of the south-western part of the country devastated by the 1953 flood by the closing of the sea-arms (Delta Plan) will amount, according to a preliminary rough estimate to a total of about Fl. 2,200,000,000 (£ 220,000,000), of wich about Fl. 1,800,000,000 will be for the work between the Hook of Holland and Westkapelle and about Fl. 400,000,000 for the strengthening of the main water protections along the Western Scheldt, all figures based on 1955 prices.

Summarising this section, the Committee believes that, if only from the viewpoint of the desired security, work must now be started on the closing of the sea-arms in the south-west. There will then be obtained a continuous storm-flood protection, consisting of a short closed coastline formed of dunes and dykes which will provide completely the strength now desired but which could possibly later be further strengthened and which will be a reliable and very modern construction capable of easy maintenance.

Behind this storm-flood protection will be the existing dykes and coastal works which will be maintained to supply an important safety reserve. There will also be formed a valuable fresh water reservoir, or basin, along with several other advantages. Along the Western Scheldt and the Rotterdam Waterway with their connecting river sections the present protective works will be strengthened to remove any danger of storm-flood water penetrating those rivers.

5.0 MEASURES AND PROVISIONS TO BE MADE IN THE SOUTH-WEST

5.1 Introduction

In the preceding pages an outline has been given of the desirability of preventing the inrush of storm floods as much as possible by the construction of dams across the sea-arms. But now the question must be answered as to which sea-arms are to be considered for damming and what further closing works will be required in connection with the scheme. Investigations must also be made into what measures are necessary to ensure safety at periods when there are very large river discharges or quantities of ice. In addition, too, consideration must be given to the strengthening of the main water protections that will fall outside the dams. See 5.2.

In the second place, study must be given to the possibilities which have originated for the fresh water household, and measures which have to be taken in connection with them. See 5.3.

Then come the further provisions which have to be made to obtain an acceptable situation as seen from a hydraulic-engineering point of view. See 5.4.

Under 5.5 there will follow a summary of the various works and provisions proposed for this south-west area.

Finally the question is answered whether the designed dams are technically capable of execution. See 5.6.

The closing works discussed in this chapter are shown in Enclosure 5.0.1.

5.2 Measures to increase the safety

5.2.1 *Closure works directly connected with the increase of safety during a storm flood*

In the general idea of increasing the safety by damming up the sea-arms the Minister of Transport and Waterways has made an exception, in view of the interests of shipping, of the *Western Scheldt* and the *Rotterdam Waterway.* The Committee can agree with this. It is fully aware, of course, that by omitting these two waterways from the whole closure scheme the areas lying along them do not have the benefit in the security scheme of a continuing second line of protection such as there will be troughout the whole Delta area after the construction of the chain of dykes. However, a complete closing of these two waterways would produce so many as yet partly unrecognised technical and other problems that the time is not yet ripe for a decision to be taken on this, nor will it come in the near future. The Committee thinks that the desirability of closing these waters is being kept in mind. The Committee learns with satisfaction, however, that meanwhile another Committee has already been instituted charged with a study of the advisability and possibility of constructing a movable storm-flood protection in the Rotterdam Waterway. Such a protective work in that waterway would – apart from providing general safety – be of great significance to the economically important areas lying outside the dykes along the Rotterdam Waterway. A movable protective work in this important waterway would certainly be a huge construction for which, particularly in the interests of shipping, such high demands must be made that it would not be provided with a reserve protection. Although such a construction does not provide sufficient safety with a single protection, the Committee feels that its construction in the future does not provide grounds for lowering the requirements which are now being made in respect of the strengthening of the main water protections lying in the rear which protect such a vital part of the country. The studies into this plan to construct a storm-flood protection are still in the first stage, and the finding of a solution will take so much time that the Delta Committee thinks it unnecessary to include in its advice any recommendations about the possible building of a separate storm-flood protection in the Rotterdam Waterway.

It is even more certain for the Western Scheldt than for the Rotterdam Waterway that it is not possible to take into account in the measures now being proposed any form of closing this sea-arm up either at or near the mouth.

So as far as the sea-arms to be closed are concerned, those to be dammed are the *Haringvliet*, the *Brouwershavense Gat*, the *Eastern Scheldt* and the *Veerse Gat.*

After these dykes have been completed, high storm-flood levels in the sea-arms lying behind them will belong to the past, thus ensuring the safety, at least from the threatening seas, of the whole area.

The basin formed behind these dams, which will be connected with the sea only via the Rotterdam Waterway, will be so large that during a stormflood it will be impossible for it to fill up to a very high level.

As the closing of the Rotterdam Waterway at or near the mouth has been excluded from consideration for the time being, an investigation has been made into whether it should be recommended to close the rivers which are in open connection with the Waterway during a storm flood. (See Contribution IV. 3). As the Western Scheldt has no connecting rivers on Netherlands territory, the problem of further damming does not arise, especially as there is no thought of closing the river itself just like the Rotterdam Waterway.

The Committee's studies have shown that a storm-flood protection in the *Hollandse IJssel* will have no disadvantageous results for the storm-flood levels outside the closure. Because of the important interests which have to be protected by the dykes of the Hollandse IJssel and the less favourable condition of those dykes, the construction of a storm-flood protective work was therefore recommended in the mouth of that river, and which has meanwhile been constructed.

Building storm-flood protective works in the Rivers *Lek* and *Noord*, however, cannot be thought of, because the storm-flood levels on the Rotterdam Waterway would thereby be considerably increased. Moreover a movable protective measure to ensure safety along the Noord is considered less necessary because the sucking-off effect of the basin lying behind it already has a strongly lowering influence on the water levels. However, the strengthening of the main water protections which are necessary along the Rotterdam Waterway, the Nieuwe Maas and the Lek must also be continued along the Noord and perhaps even along the Beneden-Merwede.

Investigations were also made about whether the closing of the *Oude Maas* should be provided for at a storm tide. Naturally the high water levels in the basin to be formed there will be lowered by the closing. The advantage of a further drop produced by the influence of the suction in the already considerably lowered storm-flood levels would, however, be small and would not counterbalance the disadvantage that as a result of the closing of the Oude Maas, the Rotterdam Waterway and the Nieuwe Maas, the levels would be increased by several decimetres. Upstream of Vlaardingen the high water levels which are to be expected at a storm flood at a top level of N.A.P. + 5 m at the Hook of Holland and normal river discharges would be about half a metre (19 inches) lower with an open Oude Maas than if that river were closed (see Fig. 6.1.2.).

An open Oude Maas, therefore, is helpful to the safety of the central part of Holland. This is a point the Delta Committee considers as of such importance and interest that in its judgment a storm-flood protection in the Oude Maas cannot be permitted. To increase the safety, however, it will be necessary to raise the height of the existing dykes along the downstream part of the Oude Maas in connection with the strengthenings of the dykes over a certain distance along the Rotterdam Waterway.

Originally the Committee thought that the *Spui* also should be considered for closing, but further investigation showed that this is not desirable.

5.2.2 *Closing works necessary for the execution of the safety measures proposed in 5.2.1*

The works for the closing of the Brouwershavense Gat and of the Eastern Scheldt with the Veerse Gat are of such magnitude that for technical and administrative reasons they cannot all be carried out and completed at the same time.

Successive execution, however, makes it necessary to take special measures. For example, as long as the basin-storage areas of the Brouwershavense Gat and the Eastern Scheldt via Zijpe–Mastgat–Keten are connected with each other, the closing of one of the sea-arms would mean that the filling and discharge of the water area closed on the sea side would have to take place through that branch. As a result of this the tidal streams in the Zijpe – to a lesser extent also in the Mastgat and the Keten – would become so strong that not only would shipping be obstructed but also there would arise the danger of a threat to the maintenance of the banks. In view of this, during the construction of the dams in the Brouwershavense Gat and the Eastern Scheldt a separation of both basin-storage areas will be necessary. As the damming of Zijpe, Mastgat or Keten is not desirable for various reasons, a dam has to be made in the upper mouth of the *Grevelingen.*

Also in the *Zandkreek* the tidal streams would be given too fast a speed when the Veerse Gat is narrowed or totally closed as long as the Eastern Scheldt is still open. For this reason also the Zandkreek must be dammed, a work which has meanwhile been carried out.

If the state of the current which will occur after the closing of the Haringvliet and the Grevelingen raises difficulties in the *Volkerak* or elsewhere, the necessity will arise of closing the Volkerak during the building of these dams.

5.2.3 *Measures of safety connected with the discharge of water and ice*

It should be pointed out at this early stage that the closing of the sea-arms certainly will result in the storm floods being kept out, but that at the same time the discharge of water and ice will be obstructed. In the existing situation the water of the Rivers Lek, Waal and Meuse streams through the system of the Lower Rivers freely to the sea, by which the Haringvliet discharges considerably more than the Rotterdam Waterway. But after the closing of the sea-arms the discharge of the water from the rivers must be ensured at all times, as otherwise the areas protected in the future against the sea would be threatened with flooding from the land by heavy river discharges. As the profiles of the Noord, the Nieuwe Maas and the Rotterdam Waterway, including that of the Oude Maas, are not large enough to take up the big river discharges, huge discharge sluices will have to be built in the dams of the sea-arms. To obtain as efficient a discharge as possible, and also in the interests of a fresh water reservoir in the Zeeland water area, the so called Zealand Lake (to be dealt with in 5.3), these discharge sluices must necessarily be constructed in the dam in the Haringvliet and not in the more southerly located dams. During storm floods these locks naturally must be closed.

In severe winters it is necessary, to ensure the safety of the dykes along the big rivers as well as of the shipping, that the ice forming on the rivers is broken by means of ice-breakers and then discharged into the sea as quickly as possible. As the way of discharge along the Nieuwe Merwede, the Hollands Diep and the Haringvliet is the most suitable, in the present situation the ice is broken along that route, while the ice in the Beneden-Merwede (Lower Merwede) is deliberately not broken until the end of the ice period.

After the damming of the Haringvliet the ice formed in the rivers will have to be discharged into the sea through the discharge sluices in that dam, which means that the sluice openings will have to be adequately large. In addition, to prevent the settling of ice in the Haringvliet in severe winters, a strong tidal movement will have to be maintained in that river. If necessary, the Haringvliet sluice-gates will have to be kept open both at ebb and flood tides during a heavy freeze-up. See also 6.2.4.

By the closing of the *Volkerak* a regular ice discharge will be promoted, and in this dam a throughway must be contructed for the fresh water household of the Zealand Lake (to be dealt with more fully in 5.3.).

To limit the level in the Haringvliet basin during the coinciding of a storm flood and a heavy river discharge it will be useful to link up the basin storage of the Zealand Lake. So an investigation will have to be made to see whether in this connection larger measurements should be given to the proposed throughway works in the Volkerak dam than would be necessary only for the fresh water storage.

5.2.4 *Strengthening of the existing main protection works in the south-west lying outside the dammings*

To increase the safety against storm floods and very large river discharges the existing main water protection works in the south-west of the country must be strengthened along the Rotterdam Waterway and along those parts of the water in open connection with it at storm tide, further along the Western Scheldt to the Belgian border, and along the coast between the Belgian border and the Rotterdam Waterway insofar as these fall outside the dammings.

The strengthening of the water protective works along *the Rotterdam Waterway* and its connecting waters is necessary to adapt them to the requirements which have to be met based on the design levels recommended for these rivers. See also 6.1.

Because of the decrease of the storm-flood levels which will be obtained by the suctioning off after the execution of the closing works, a smaller strengthening will suffice for these waters, however, than would have been necessary had the closing works not been done.

For *the Western Scheldt* the strengthening of the main protections is also necessary to adapt them to the requirements based on the design levels for this area, but this strengthening here has no connection with an increase of the storm-flood levels as a result of the closing of the sea-arms. As is indicated in Column 2 of Table 3.0.1, the works on the Western Scheldt will cause no increase worth mentioning of the high storm tide levels. See also Contribution IV.2.

The strengthening of the main water protections *along the coast* is also necessary to adapt them to the security requirements based on the accepted design levels at the various places.

5.3 Measures to improve the fresh water household

The closing of the sea-arms between the Western Scheldt and the Rotterdam Waterway will result in salt water no longer entering through them, with the exception of the Haringvliet when the sluice gates are open during high tides. In this way the opportunity arises to achieve a considerable improvement in the fresh water supply in an important part of the country. The measures necessary for this are to take every step practicable to obtain as great a use as possible of the river water. Although this water forms part of the whole fresh water economy of the country, it does not directly or completely come within the scope of this Committee which will, therefore, limit itself to indicating the possibilities for improvement which will originate as the result of the damming of the sea-arms. The Committee will not, moreover, enter into a discusson of the ways in wich such possibilities can be made use of or into the size of the improvements that can be achieved. For this, reference is made to the study of the Commission for the Study of Space in Agriculture (Bibliography 5), an investigation from which this Delta Committee has used a few results.

As already mentioned in 5.2.3, the damming of the Haringvliet will include the provision of huge gates with a great discharge capacity and which will have to be closed during a storm.

By also keeping these Haringvliet sluices closed under normal conditions and opening them only at ebb tide when advisable or necessary because of the river discharge, the Haringvliet will soon be filled with fresh water when the works mentioned in 5.2 will be completed, while the penetration of salt into the Haringvliet basin lying behind this closure can also be definitely obstructed in periods of small river discharge. The closing of the Haringvliet will also make it possible to regulate the distribution of the discharge of river water along the Rotterdam Waterway and the Haringvliet. By thus limiting this discharge through the Haringvliet gates, more fresh water can be pushed into the Rotterdam Waterway there by forcing the salt water border of that river backwards towards the sea. See Contribution IV.4.

At the same time the decreased supply of upper water along the Neder-Rijn (Lower Rhine) and the Lek as a result of the canalization of those rivers will be compensated. The top dam of the Rhine canalization works, for example, is aimed at changing the existing discharge distribution over the Rhine branches in dry periods in favour of the River IJssel.

To push back the salt frontier of the Rotterdam Waterway as far as possible after the canalization of the Neder-Rijn and the Lek – not only in the interests of agriculture and horticulture but also on behalf of industry and domestic water supply – it will be necessary to build a dam in the downstream mouth of the *Oude Maas*, especially after an increasing withdrawal of water from the rivers. By this means a greater part of the available upper water discharge can be led via the Noord along the Nieuwe Maas and the Rotterdam Waterway. Without the closing of the Oude Maas, the discharging upper water passing along this river could only be fully effective for the pushing back of the salt border on the Nieuwe Maas if the salt could be kept below the mouth of the Oude Maas. For this, however, such a large quantity of upper water would be needed that it would only be possible on rare occasions. See also 6.2.1.

In connection with what has been said in 5.2.1. regarding the safeguarding of Central Holland, the dam to be constructed in the Oude Maas must be movable.

The stormy development during the past few years in the area between Dordrecht and the sea makes it necessary for the closing of the Oude Maas to be considered against the background of the interests of Europort and Dordrecht. Although the Delta Committee feels it is not its duty to deal with this aspect of the situation, it believes it should nevertheless point out that in connection with the desire to make a use as valuable as possible of the fresh water streaming off along the rivers, the objection that the harbour of Dordrecht will then lie behind locks, will have to be over-ruled, or at least tolerated. On the other hand, however, is the fact that transport on the Oude Maas will come into somewhat better conditions as the channel in the new situation will lose practically all of its current.

As a contribution to the fresh water economy the *Volkerak* must be dammed up in the completed Delta Plan. Such a dam can, when necessary, completely close the Zealand Lake lying south of it and thus turn it into a fresh water reservoir. As already pointed out in 5.2.3, this dam will have to be provided with a throughway for fresh water in the Zealand Lake. For the small river discharges to be expected, it will as a rule be possible to increase the level of the Zealand Lake by letting in large quantities of water from the Haringvliet basin. It will then be possible to supply water from this storage in the summer to the surrounding agricultural lands without making the situation worse elsewhere, as for example on the Rotterdam Waterway or the River Lek.

If the closing of the Volkerak would not be carried out, during severe winters when the Haringvliet sluice-gates were fully opened for a considerable period, the salt coming in with the tides would be able to penetrate into the Zealand Lake, from which it would be much more difficult to be removed than from the Haringvliet. The closing of the Volkerak, therefore, also has the advantage that it can prevent the salting of the Zealand Lake during periods with ice. The salt that penetrates into the Haringvliet will be quickly discharged with the normal river outfall after the ice has gone.

In order to make fresh, and to keep fresh, the water in the Zealand Lake and possibly also the part separated from it by the Grevelingen Dam (the so-called Grevelingen Basin), the basins must be thoroughly flooded. To achieve this, there must be an opportunity to pass the water through or in the vicinity of the dams in the Eastern Scheldt and the Brouwershavense Gat and in the Grevelingen Dam, while there must also be provision for water to be discharged into the Western Scheldt.

Similarly, in the dam through the Zandkreek an opportunity must be provided for the passing of water to help the fresh water household in the area west of that dam, the so-called Veerse Meer. For the discharge of the Veerse Meer through the canal through Walcheren or in any other way, adequate provisions are also needed. Through the execution of the works outlined here, the salting danger to the Zeeland and South Holland waterways which are to be closed and also of the greater part of the Lower Rivers, will be removed, and in dry periods important quantities of fresh water will be made available for the passage of basin waters and polder waters, as well as for agriculture, horticulture and industry.

5.4 Further provisions in connection with the proposed dams

As a result of the execution of the closing works and those directly connected with them additional works of various kinds will have to be carried out.

5.4.1 *Provisions for shipping*

In addition to a storm-flood protection in the Hollandse IJssel, a lock had to be built which, in the interests of the shipyards lying inside the protection, had to be large enough for ocean-going vessels to pass through.

Mainly because of the maintenance of the discharge sluices in the Haringvliet Dam with the access channels, a lock was wanted in this dam. This was meant for contractors' material, ships to supply sand, fishing vessels and possibly also coasters. But for regular shipping it is of no importance, as admittance from the sea is unreliable and, as may be presumed, will become still more unfavourable because of sanding.

The building of locks in the dams in the Brouwershavense Gat, the Eastern Scheldt and the Veerse Gat is not considered desirable because outside these dams also much sanding is to be expected and, moreover, salt would be brought inside the dams through the locks which would be difficult to remove under the conditions existing there.

In the Grevelingen Dam a lock must be built for the supply of materials and equipment needed for the closing of the Brouwershavense Gat, as well as for shipping to the area west of the Grevelingen Dam.

In the dam in the Zandkreek, too, a lock has to be provided as part of the shipping route along the canal through Walcheren and also for the harbours located along the Zandkreek itself and the Veerse Gat. Probably this lock, constructed as a current lock, can also serve the interests of the fresh water economy, already referred to in 5.3.

In the Volkerak Dam a complex of locks will have to be constructed. If these locks have an adequate capacity, the damming need not be regarded as an objection from the shipping point of view, as modern locks ensure speedy handling and a short locking time. The delay caused by these locks will be much less than is now caused by the locks at Wemeldinge which can be put out of use after the closing of the Eastern Scheldt.

In the protective works in the lower mouth of the Oude Maas, one or more locks will be needed for sea shipping to and from the Dordrecht Harbour as well as for inland shipping.

Through these locks, and the sluices in the Haringvliet, salt water will certainly penetrate, but it must be taken for granted that this can regularly be removed.

Apart from the provisions outlined in the foregoing paragraphs which have had or will have to be made in the dams themselves, other protective measures against ice will have to be taken in the interests of shipping. Moreover, in some places arrangements will have to be made for the adaption to the changed water levels and the changed current situation in the river beds and harbours, near the unloading quays, and at harbour entrances which are to be maintained, and possibly also for shipyard slipways.

5.4.2 *Provisions on behalf of land traffic*

If only because of maintenance requirements, it will be absolutely necessary to construct roads on all the dams. In addition to that, however, the new dams will offer, if sufficiently wide berms are made, the opportunity of constructing a number of much needed new roads not only for regional traffic but also within the scope of the important highways serving the through traffic north-south routes.

In the first place, therefore, it is expected that over the dams of the Haringvliet, Brouwershavense Gat, Eastern Scheldt, and Veerse Gat a coastal road will be built connecting Western Holland with the dune areas of the islands and, via the Flushing-Breskens ferry, with the Belgian coastal road.

Further, by using the dam in the Volkerak in connection with the projected bridge across the Haringvliet near the east point of Overflakkee, a through route from Rotterdam to the western area of North Brabant will be made, with an extension to Antwerp. Between it a road over the Grevelingen Dam and the bridge across the Haringvliet can connect the island of Schouwen-Duiveland via Overflakkee and the Hoekse Waard with Rotterdam. Then by means of a road over the Zandkreek Dam, the sailing channel of the ferry across the Eastern Scheldt can be shortened, while later on possibly this route will increase in importance by the construction of a dam (with a bridge) through the Eastern Scheldt as a central permanent connection.

The road over the closing of the Hollandse IJssel already supplies a good connection for Rotterdam in an easterly direction with the Krimpenerwaard and via Schoonhoven with the southern part of the Utrecht Province.

5.4.3 *Provisions to limit the damage to fisheries and shell-fish cultures*

As a result of the change to fresh water after the sea-arms are closed, the existing fisheries and the shell-fish cultivation will no longer be able to carry on those activities in their present form.

As far as the sea and coastal fishing is concerned, the most important part of the supply is delivered by the shrimp fishery with an average annual production worth Fl. 1,500,000 (£ 150,000) over the years 1950–1959 inclusive (converted into the purchasing power of 1959). The largest part comes from the small ships, is caught just outside the coastline, and is dependent on the auctions within the Delta area to which it is supplied. However, when this fishing is unsatisfactory in the neighbourhood of the Delta area, a number of the fishermen go fishing farther away, in which cases the fish is supplied to auctions in the north of Holland. The remaining fishing consists of eel, conger-eel, flounder, sole, smelt, sprats, anchovies, white bream, periwinkles, whelks and lobsters, and brings in about Fl. 500,000 (£ 50,000) a year. In addition, there is a sum of about Fl. 600,000 (£ 60,000) from the proceeds of the trade in imported lobsters.

Of the shell-fish cultivation mussels contribute an annual average of about Fl. 10,000,000 (£ 1,000,000) to the country's gross national income, and the oyster breeding in the Zealand waters a sum ranging from Fl. 4,000,000 to Fl. 5,000,000 (£ 4,00,000–5,00,000). A great part of the mussels, however, is supplied from the Wadden Sea, only the so-called "verwateren" occurring almost exclusively in Zealand.

The total number of persons working in the fisheries and shell-fish industries in the Delta area can be put at about 400 for the sea and coastal fisheries and at about 1,200 for the shell-fish cultivation and trade.

According to information supplied by the experts, it can be expected that after the execution of the Delta Plan shrimp-fishing will still be done along the coast, while the sole and flounder catching need not entirely disappear. See Bibliography (7).

The effect of the building of the dams will be mainly felt in the shell-fish cultivation, and especially in that of the oysters, because according to experts the mussel breeding will probably find a place in the Wadden Sea. The adaptation capacity of the Wadden Sea, indeed, is so great that it would be able to meet a very large portion of the demand for mussels. How far this can be realised in practice, however, depends also on the extent to which the shrimp-fishing will also be carried out from the Wadden Sea. Probably preference will be given to "verwatering" of mussels in the north, because this would make the transport of the mussels to the southern "verwater" beds unnecessary. An attraction for "verwatering" in the south, however, would be that in combination with it the lobster trade in Zealand could continue to exist on a fairly large scale.

The transfer of the oyster culture to the Wadden Sea is, on the other hand, considered as impossible by the experts for various reasons of a biological character. Nor can transfer to the Western Scheldt be considered, if only because that water is more liable to pollution and becoming fresh.

The suggestion made that the Eastern Scheldt be left open or that current gates be built in the dams of the Eastern Scheldt to maintain a limited tidal movement in the water cannot, say the experts, be considered as feasible. In the first case, not only would the principle of obtaining as maximum safety as possible be endangered but moreover a great part of the Zealand Lake as a fresh water reservoir would be lost, while for the through sailing in the channel from the Western Scheldt to the Rhine two more additional complexes of locks would have to be constructed. The objections to such a remedy far outweigh the value of retaining the oyster cultivation, even taking into account the social significance of the problem. In the second case, the same objections arise concerning the fresh water economy, while for shipping such expensive works would have to be carried out that here again such a solution would not be justified by the value of the oyster cultivation.

The Committee is aware of the fact that the possibility of taking the oyster culture to the water area between the dams in the Brouwershavense Gat and the Grevelingen, which would then remain entirely or partially salt, is being studied. Should such a plan appear technically or economically possible, however, an enquiry must then be made as to whether the reduction in the size of the Zealand Lake area is permissible in view of the need for water storage for the fresh water economy as well as the safety of the whole area. Only after a thorough study of the fresh water household situation and prospects can a basic decision be made about this problem. Then, too, the question of using the Grevelingen basin as a recreation area must also be taken into consideration.

At the request of the Committee a study has been made as to whether it would be economically justified to make a tidal power station for parts of the water area falling within the dams not only to make a contribution to the electric power supply of the country but at the same time also to serve as a replacement in the economic sphere of the shell-fish cultivation in the salt basins. But from the investigations made (see Bibliography 19) it appeared that with the small tidal differences along the Netherlands coast there is no possibility of an economically justified exploitation of water power from the tidal movement. This means that no support can be given to the idea that the shell-fish cultivation could be economically replaced by using the water in this way.

Furthermore, it can also be pointed out that in the Delta area – when it becomes fresh water – there can originate a fresh water fishery of which the annual production can be estimated at about Fl. 1,000,000 (see Bibliography 7). In this connection special provision will probably have to be made in the dams to permit the elvers, or young eels, to enter (as was done in the Enclosing Dam of the Zuyder Zee).

5.4.4 *Further provisions*

Under this heading there can first be counted the river works necessary to ensure a good discharge of water and ice as well as for the protection of the bottom and banks against the effects of the current.

As a result of the closing of the sea-arms, the normal tidal movement in the area north of the Volkerak dam will change in such a way that the high water levels will be lowered and the low water and middle water levels will be raised. These last mentioned increases will hinder the discharge of polder and waste water from the surrounding areas and, indeed, make this as a rule completely impossible, as far as any water is discharged in a natural way.

Similarly in the southern part of the Delta area, where the tidal movement will also disappear completely, the discharge of water from the surrounding terrain will either be hampered or become impossible with the existing means.

As in both the midway situation and that of the completed work the discharge of superfluous water must be ensured, it is clear that provisions for this will have to be made. See also Contribution IV.4.

The Committee finally in this connection draws attention to the fact that an exact and detailed study of the water household is required before the various measures indicated can be finally determined.

5.5 Summary of the works and provisions proposed for the south-west

To give a summary, the following works and provisions are considered necessary to increase the safety and to improve the fresh water economy; in short, to produce a situation entirely acceptable from a general hydraulic point of view:

a. Constructing a movable storm-flood weir with a shipping lock in the Hollandse IJssel.

b. Damming the Haringvliet, including constructing discharge sluices (for the discharge of upper water and ice) and a lock.

c. Damming the Brouwershavense Gat and constructing discharge equipment.

d. Damming the Eastern Scheldt and constructing discharge equipment.

5.5

e. Damming the Veerse Gat and constructing discharge equipment in the vicinity.
f. Damming the Grevelingen at the upper mouth and building a lock or possibly a current sluice.
g. Damming the Zandkreek and building a (possibly combined) lock and current sluice.
h. Damming the Volkerak and building shipping and discharge locks.
i. Constructing a movable closure of the Oude Maas, with locks.
j. Strengthening the existing main water protections along the Rotterdam Waterway and connecting waters.
k. Strengthening the existing main water protections along the Western Scheldt.
l. Strengthening the existing main water protections along the coast from the Belgian border to the mouth of the Rotterdam Waterway, insofar as they lie outside the closures of the sea-arms.
m. Provisions in connection with shipping.
n. Provisions to limit the damage and losses to fisheries and shell-fish cultivations.
o. River provisions.
p. Provisions for the discharge of polder water and waste water.

The works under a. and g., it should be mentioned, have already been completed meanwhile.

The works under b. to f. and under h. must be carried out in such a way that there is an opportunity for road construction along them.

5.6 Views on the technical feasibility of the closings

It has been shown in the foregoing pages that to ensure adequate safety against future floodings the construction of a number of dams is essential. As a few of these dams are projects for which there is no engineering precedent, it is necessary to study whether they are really technically capable of execution.

During the past 40 years a great deal of experience has been gained in the Netherlands in closing waters liable to tidal movements. After the Amsteldiep had been closed as early as 1924, the complete closing of the Zuyder Zee was accomplished in 1932, while in 1945 and 1946 the dyke breaches in Walcheren were closed. Then in 1950 and 1952 the Brielse Maas and the Braakman were respectively sealed off, while finally the gaps in the dykes in the south-west were closed in 1953. In addition, a few smaller closures have been carried out such as those of the Zuidersloe, Dijkwater and Pluimpot. As a result of these various works valuable experience has been gained in the use of modern material and equipment for closing large gaps.

As is evident from the information in Table 5.6.1, a few of the closings now added to the list must be achieved under appreciably more difficult conditions and circumstances than those executed so far. Moreover, they have to be carried out at places where the water attacks are strong, and where the execution will be hampered by waves and fog so that many days of lost work will have to be allowed for. Then, too, the constructions themselves will have to be built so that they can withstand heavy wave movement while still in the unfinished state.

With the closings carried out more inland on the Hollandse IJssel and the Zandkreek – and not mentioned in the table – no special difficulties were encountered. Nor are any expected at Grevelingen, the Oude Maas and the Volkerak where there is little trouble anticipated from wave movement. Moreover, the closing of the Zandkreek is being done at a spot where the speed of the normal stream is small and where no great speeds have occured during construction. In the plan for the Grevelingen Dam also the current will not become very strong during the closing operations.

The storm flood weir in the Hollandse IJssel has a special character. The remaining opening, which is closed only at very high water levels, is almost as wide as the original river profile, so that there has been no actual closing here.

In the Volkerak the closing itself would be facilitated if a large culvert is built in advance to reduce the great difference in levels during the closing of the last dyke sections. With an effective working programme the currents could then be limited in the real closing gap.

The same is applicable for the Oude Maas closing.

Table 5.6.1

Tidal data of the already executed closings made and those still to be carried out

	Date	Average tides differences in metres	Transverse section of opening under N.A.P. in m²	Average tidal volume [1]) in m³
1	2	3	4	5
Zuyder Zee Enclosing Dam				
Original profile	1925	0.9	120,000	575
Vlieter + Blinde Geul + Middle Shallows	May 1931	1.1	20,000	475
Vlieter + Middle Shallows	October 1931	1.2	15,000	375
Vlieter, with restraining dam	December 1931	1.3	10,000	300
Vlieter, just before the closing	May 1932	1.5	500	20
Walcheren				
Nolle (Flushing), largest extension	June 1945	3.7	750	11
Westkapelle, before the closing	October 1945	3.3	225	5
Vrouwenpolder (Vere), before the closing	October 1945	3.0	300	13
Rammekens, before the closing	January 1946	3.8	600	25
Brielse Maas				
Original profile	1948	1.8	2,700	17
Before placing the closing pontoon (Botlek closed)	July 1950	1.8	300	12
Braakman				
Before placing the last but one pontoon	July 1952	4.0	850	17
Before placing the closing pontoon	July 1952	4.0	350	14
Dyke repair 1953				
Kruiningen	June 1953	4.4	550	26
Schelphoek, during large extension of the gap	May 1953	2.8	8,000	130
Schelphoek, Klompegeul and Gemene Geul	July 1953	2.8	2,000	80
Ouwerkerk, before the placing of last two pontoons	November 1953	3.0	1,500	36
Ouwerkerk, before placing last pontoon	November 1953	3.0	750	33
Delta Works [2]) (original profile)				
Veerse Gat	1955	2.9	7,500	70
Haringvliet	1955	1.9	18,000	260
Brouwershavense Gat	1955	2.4	30,000	325
Eastern Scheldt	1955	2.8	90,000	1,100

[1]) By this is meant the average of the quantities of water which stream inside through the opening at high tide and outside at ebb tide at average tide. In cases where there is also discharge of river water, the details for the average river discharges should be applied.

[2]) The values given in Columns 3, 4 and 5 apply to the plans given in Contribution 5.0.1.

At the damming of the Haringvliet also the presence of a series of locks will have a favourable influence on the actual dyke closing. As a result of the large stream-profile necessary for the Haringvliet locks, the reduction of the tidal currents in the closing gap will be very strong during the closure works when the locks are completely open. The difference in level will remain to the last moment smaller than it was at the actual closing of the Enclosing Dam.

The greatest problems concerning the closing project, therefore, lie with the remaining sea-arms, namely, the Brouwershavense Gat, the Eastern Scheldt, and the Veerse Gat.

Both when designing and executing these dams it will be necessary to know in advance all the circumstances under which the work will be carried out. This includes a full knowledge of the existing sea-bed location and of how it will change during the works, the size and direction of the tidal currents before the work starts and during the various consecutive situations occurring during the execution, and the nature and force of the wave attack and of ice movement in those areas. During the past decades many studies have been made in these fields, as a result of which new ideas have been formed and new knowledge gained.

To obtain adequate information about the sea-bed or river-bed a number of modern instruments and apparatus are available today for sounding the depth and measuring the location, making it possible to work quickly even in bad visibility and also providing an opportunity to check regularly any changes in the bed. Furthermore, an insight into the behaviour of the bed has been rendered much easier and more accurate by the latest studies concerning the movement of sand, silt and mud, aided by new measuring instruments which have been developed. The development of research in soil mechanics has also greatly increased knowledge about the nature of the subsoil.

In connection with the closing of the Zuyder Zee, LORENTZ introduced a method of tide calculations which has been further worked out by subsequent research workers. By this it has become possible to calculate the tidal movement in the various stages of the execution of a project, and form this to deduce the current speeds occurring in the remaining openings. The development of electronic calculating machines now makes it possible to tackle calculations which formerly seemed impossible.

Next to the calculations stands the investigation that can be made by means of hydraulic models. The fluid currents observed in these models enable the research worker to reach conclusions respecting currents and water levels in the Delta area under circumstances which greatly differ from present ones. Closely related to this are the electric models in which the analogy between electric currents and fluid currents is applied to solve physical problems without using auxiliary mathematical means.

Between these three methods of working (calculations, hydraulic model research and electric analogy) there is a close relationship. In many cases they supplement one another; in others, they control one another. See Contributions III.6, 7 and 8.

Again, in addition to normal visual observation the engineers of today have instruments which register the wave movement, so that a view is obtained of the actual character of the wave attack which can be expected under various circumstances.

About the ice movement also much information has been gathered by a number of observations in the severe winters of the recent past. In this respect air surveying and air photography have played an important role.

As a result of the investigations above mentioned, and of a number of others, it is now possible to obtain an adequate advance survey of the circumstances which will occur during the various stages of the execution of the works.

Attention must also be drawn to the development of equipment capable of carrying out earth movement and transport on a large scale. This makes it possible to overcome some of the obstacles in the struggle against the water, especially on occasions and under circumstances in which the time factor is all-important when working with a sandy bottom which offers little resistance to the waves. This offers a greater chance of success.

Yet another important factor is to be seen in the new methods of determining location which now render it possible, even in poor visibility, to make the necessary observations and thus keeping the work going on without delays or interruptions.

The development of science and technique also enables such a project as the Delta Plan to be very fully prepared, while it has also contributed to tracing the causes of many of the difficulties met with in constructing previous dams in the past few years and to becoming acquainted with methods by which such difficulties can be remedied as much as possible, or even solving the problems to ensure that they need not arise at all.

On the general principle of the technique of closing the sea-arms, the following comments may be made.

In the sea-arms to be closed there are both shallows and deep channels. The transport of water takes place mainly through the channels and only for a small part over the shallows. This means that the construction of a dyke section on the shallows does not greatly influence the tidal regime, as the speeds of the currents will increase only slightly. The same holds good for the construction of groynes as thresholds in the channels. From this it is clear that the best policy is to make the dyke sections on the shallows and, as far as they are necessary, the groynes in the deep channels. Only when this is done will the dyke sections get their turn on these groynes.

During the construction of the last-mentioned dyke sections the sizes of the gaps through which the currents stream will become smaller and smaller, resulting in the speeds of the currents greatly increasing, and in their turn also increasing the working difficulties. So during the closing of the sea-arms the problem concentrates on the making of a closing dam in a closing gap which often is to be found over a groyne. When this closing dam has been finally made, the building up of the closing dyke to the definite required profile presents no further fundamental difficulties.

When the current profiles in the line of the closing become steadily smaller during the construction of the closing dyke, the tidal movement of the water that is to be enclosed gradually decreases, while that on the sea side of the dyke increases, resulting in the difference in water levels and also the current speeds at the remaining openings becoming greater. Because of this, the period in which the currents are slower, and during which work with floating equipment in and near these openings is possible, is limited. Moreover, as the current speeds increase, the danger becomes greater that the constructed work and the sea-bed, which consists of movable sand over the whole area, are seriously affected by the currents.

Owing to modern methods, however, research by means of models can show just how the work already finished and the neighbouring sea-bottom are attacked during certain current situations; and on the basis of those studies it is possible to determine which is the most suitable form of construction, what will be the best order in which to carry out the work, and how far the sea-bed will have to be protected. The scouring danger to which the sea-bottom will be exposed generally makes it necessary to protect the edges of the shallows, the bottom of the channels – possibly even over great lengths – and that part of the shallows on which the foot of the future dyke will rest, against being scoured out before the current increases to great force. In this way dangerous crumbling away of the ground can be prevented.

During the past few years two systems have been generally applied to close up the large gaps in dykes. In one of these systems a closing dam made of resistant material (such as specially made concrete blocks, large stones poured in, sandbags and boulder clay) was thrown in the closing gap. In the other system, the closure was obtained by sinking one or more sealed caissons in the open gap.

Because of the large tidal volume the use of the second system, that of closed caissons, is not considered advisable for the sea-arms, as a great number of these caissons would have to be placed in exact position at the same time. As a result of the unfavourable current situation, this would lead to risks that dare not be taken, while it is also quite probable that the system would not work.

To meet such objections as these, De Booy (Bibliography 2), even during the designs for closing the Zuyder Zee, put forward the idea of using caissons with large openings by means of which a great length of the profile to be closed remains open for the time being. Then at the last moment all these openings can be closed simultaneously, the closing being carefully worked out in relationship to all conditions and circumstances. With this system it is possible, as has now been demonstrated, to put each caisson into position individually without the great current speeds hampering the operation too much. This system was applied in the closing of the Braakman in 1952, when one of the two caissons placed there was provided with gates that could finally be closed. As to the construction of the closing dam there are principally two systems to be considered. One for closing the sea-arms by means of a gradual building up by pouring water-resistant material into the gap to be closed off and the other by using caissons with closable gates.

In the closing of the sea-arms the first method which entails the use of boulder clay could not be used, as it was in the Zuyder Zee works, because this material is not found in the vicinity of the Delta. Moreover, the current speeds will run too high in the Delta area, as a result of the greater tidal differences, to make it possible to close the gaps by using this boulder clay.

It is true that as far as the current velocities permit, the function of the boulder clay could possibly be taken over by the rock and stones excavated from the Limburg coal mines which are available in great quantities. In addition, pouring stone could be used, while in the sections with the greatest current speeds specially constructed concrete blocks could be used either separately or linked together. Yet the huge size of the gaps to be closed and the strong currents that are present there would require a very great mobilisation of men, equipment and materials, which in their turn would produce many problems that would still have to be solved. However, in principle, the closing of the gaps by the system of gradual pouring in of material is at least considered possible for the sea-arms of the Eastern Scheldt and the Brouwershavense Gat.

By the second method, using open caissons, advantage can be taken of the experience which has been gained with the placing of closed caissons in previous closings. The open caissons will naturally be kept closed during the work of placing them in position.

Both in the reclamation of Walcheren in 1945–1946 and in the repairs to the dykes in 1953 the engineers were called on to close dyke gaps which were from day to day being made wider by the scouring of the tidal currents in the unprotected sandy bottom. So the work had to be completed as quickly as possible. Most of the available caissons for those operations were actually made for a totally different purpose; but to save time, risks were accepted with open eyes, even though the caissons were not too suitable for blocking breaches in the dykes. But by careful preparation and with the aid of experience gained, many of the risks which had to be accepted in those two earlier closings (1945–1946 and 1953) can now be avoided. With the correct determination of the dimensions of the closing gaps, it will be possible to place every caisson in position in such a way that at the placing of the last one the tidal currents will not rise to an inadmissibly great height.

The studies that have been made already about the best ways to close the sea-arms of the Brouwershavense Gat and the Eastern Scheldt indicated that it will probably be practicable to achieve the closing of each of these dams in one season. Nevertheless, it will be desirable to take into account that this may not, for one reason or another, to be successfully done in that time, so that arrangements will have to be made for the placed caissons to be protected for the winter. It is, indeed, very essential that every effort be made to see that in each of the sea-arms where work is in progress all the elements can be closed at the same time, as otherwise a dangerous current situation could arise.

In the construction of the caissons, the means by which to close them and their method of transport, very high requirements must, therefore, be met. Apart from the caissons themselves, the mutual links, the placing of them at the right spot, the construction and finishing of the restraining dam, and finally the closing between the top of the dam and the bottom of the caisson will all have to be given much attention, because every effort must be made to ensure that after the openings in the caissons are closed there will be no strong currents leaking through under and between the caissons. For safety considerations it will be necessary to design the construction in such a way that the closed openings in the caissons can be re-opened again if one of them or even a few of the closing elements would fail or if unacceptably strong currents should leak through.

If these factors just mentioned are all taken into account, the Committee thinks it possible in principle also to close the Brouwershavense Gat and the Eastern Scheldt by means of caissons.

The Committee does not intend to deal further with the details of the construction of the big closing dams. Although in his installation speech the Minister of Waterways put the question as to how these dams were to be made, it appeared from a later explanation he gave to the Chairman of the Committee that by his reference he did not mean the study of a detailed plan for the construction of these dams for which the Committee certainly has not the requisite information or function.

Of course, the Committee has naturally devoted a good deal of attention to this point, and much information has reached it from the Government Waterways Department. This has reinforced the Committee's view – already outlined – that the closing of the sea-arms is technically possible, so that it can recommend that the work be executed. However, it was not the Committee's task to go into further details of the exact method of carrying out the work. This is left to the responsible service.

Nevertheless, the Committee wishes to point out that it considers that a full study is necessary of the two methods of construction of the dams mentioned in the previous paragraphes, namely, the gradual building up by pouring water-resistant material onto the site, and the use of caissons with closable gates. Only after such a careful investigation can a justified choice be made between the two systems of closure.

But whichever method is chosen, it will always be necessary to give as complete consideration as possible to the current pictures in each of the stages into which the work will be divided, so that every conceivable precaution can be taken to prevent undermining which is both harmful and even dangerous for the whole work. The great extent of protection needed for the sea-bed necessary for this, and the very long period for which it will have to exist, makes this one of the most difficult operations of the whole project. The usual brushwood or reed mattresses will probably not be used here, not only because the available quantities are insufficient for this huge job but also because deterioration as a result of the ship-worm must be allowed for in this area. So it will be necessary later to study any different ways, apart from the use of brushwood, how the protecting bottom constructions can be supplied. Here the possibility of using reeds, mine stone, asphalt and plastic materials seem indicated. However, it may be accepted that a solution of the problem of sea-bed protection will be solved.

But to matter which of the two methods of closing the sea-arms is finally selected, it must be taken for granted that very large quantities of equipment and material, as well as a very varied and experienced and skilled staff, will be needed. But care will have to be taken that these heavy requirements which will have to be made at a certain moment do not lead to unacceptable price increases, or even make the execution of the project impossible.

As soon as a definite choice about the closure method has been made, therefore, a detailed and exact working programme must be drawn up in which every care must be exercised to ensure that the objections just mentioned are prevented.

It will be necessary, moreover, to have this working plan available quickly because the various sections of the huge closing operations can be started at an early stage, and will thus promote speedy achievement of the whole closing project.

Although further study and experience are necessary on many points, the Committee believes that the present knowledge of the Dutch engineers, along with the means that are now available, make it possible to draw up the extensive scheme, based on the development of modern technique, which will enable the huge closing work to be carried out. Undoubtedly many difficulties and possibly even setbacks will occur, especially in the great closings of the Brouwershavense Gat and the Eastern Scheldt, but the Committee is convinced that all obstacles will be overcome.

In the Fourth Interim Report attention was drawn to the importance of the experience which will be gained with the closing of the Veerse Gat. Similarly, the opportunity must be seized to get still more experience with the other closings, which will precede the final very large dammings, which have to be carried out within the framework of the Delta Plan.

6.0 SIGNIFICANCE AND RESULTS OF THE WORKS IN THE DELTA AREA

6.1 Safeguarding against storm floods during normal and large river discharges

6.1.1 *Introduction*

As after the execution of the works proposed in 5.2. the storm floods can only penetrate into the closed waters of South Holland and Zeeland via the Hook of Holland, high storm-tide levels in the Delta area north of the Western Scheldt – except in the vicinity of the Hook of Holland – will be a thing of the past.

During any discussion about the safety of this area, however, a distinction must be made between storm tides at normal river discharges and those with large river discharges.

The Committee has, in fact, not included in its discussions the area in which the storm floods no longer have any influence on the raising of the water levels.

6.1.2. *Protection against storm floods at normal river discharges*

The tidal wave which enters the Rotterdam Waterway during a storm will rapidly decrease in height towards the inside as a result of the strong suctioning-off effect of the Haringvliet basin, including the Haringvliet and the Hollands Diep with their connecting waters. As a result of this sucking-off effect of the Haringvliet basin an important decrease in the water levels in the Rotterdam Waterway is already to be expected, especially when the dam to be constructed in the Oude Maas in connection with the fresh water economy is open at storm tide.

Although the chance of one of the closing dams of the main water protection chain being breached is considered as very slight, this possibility should nevertheless be taken permanently into account. In such a case, however, it is only in a very protracted stage of the storm flood that there can originate a flooding breach, and even that will be of limited size. As a result the water protections maintained behind the dams offer a great reserve of safety. Yet in this respect it will be desirable to maintain that protective capacity of the second line of defence behind the dams by means of a logically connected system.

With normal river discharges the water levels in the Haringvliet basin will be increased only a little during the time when the discharge of the feeding river water is stopped. In these areas, therefore, the direct effect of the storm flood will be much lower. Moreover, the water levels in the Haringvliet basin can be somewhat further decreased by the discharge of water on the Zealand Lake through a gate in the Volkerak Dam. The water levels in this lake, where the direct influence of the storm tide is excluded, will here be raised very slightly.

The top levels which will be reached in the Haringvliet basin with a storm flood will be greatly dependent on the form of the storm-tide curve, because this influences the time during which the discharge of the surface water is being stopped. However, other factors also play a role. According to how the profiles of the Noord, Dordtse Kil, Oude Maas and Spui are made more extensive, so will the storm-flood water be able to penetrate more easily the Haringvliet basin, which will in turn lead to higher water levels in this basin. As to the water storage in the Haringvliet basin and the Zealand Lake it is not only the surface of each basin which is of importance but also the level that was there before the beginning of the storm flood and the stopping of the surface water discharge. This level will have a relationship with the height of the tide in the sea, especially the ebb tide, before the storm, the discharge programme of the Haringvliet locks, and the way in which the water discharge of the Zealand Lake is regulated. The influence which the aforementioned low water has on the water levels in the Haringvliet basin plays a smaller role in proportion to how the river discharges are smaller.

To give an idea of the lowering influence of the Delta Works on the storm-tide levels in the Haringvliet basin and on a few of the connecting waters, Fig. 6.1.2 shows the water levels which, at present and after the closing is completed, are to be expected under certain circumstances. This diagram starts with a storm flood with a top level of N.A.P. +5 m at the tide gauge at the Hook of Holland, and gives the form of the curve of the storm tide and of the preceding tide, as indicated in Curve 1 of Figure 6.1.1 (see also Contribution IV.3), of river discharges (Rhine discharge of 3,000 m^3/sec and Meuse discharge of 500 m^3/sec) [1]) which are admittedly rather large but which in the stormy season must certainly not be considered as rare, of a normal discharge programme, and of the existing river profiles. The storm-flood levels to be expected in the case mentioned in the present situation in the Haringvliet and connecting waters are indicated by Curve III, and that for the situation after the full completion of the Delta Works by Curves IV and V of Figure 6.1.2. The information on which this figure is based comes from model tests in the Hydraulic Laboratory at Delft and has been tested by calculations.

In connection with this Fig. 6.1.2, the following must be added. In determining the storm-tide levels it is presumed – so far as the existing situation differs from what could eventually happen in reality – that no dykes are breached or are badly overflowed. And except in Curve VI as is mentioned in 6.1.3 it is accepted that no poldering has been carried out.

The situation after the execution of the Delta Plan is based on the supposition that the Haringvliet sluices are closed on the arrival of the flood current of the tide preceding the real storm flood, and that they remain closed to the end of the storm flood. The total time for which the discharge was stopped amounted to about 18 hours in the case under investigation. It has also been accepted that when the Delta Plan is finished no water is discharged through the lock in the Volkerak Dam to the south.

From Curves III and IV on Fig. 6.1.2, it appears that as a result of the carrying out of the Delta Works and of the suppositions made, the storm-flood levels are going to be decreased by 0.50 to 0.60 m in the Rotterdam Waterway and the Nieuwe Maas between Vlaardingen and Rotterdam, by 0.80 m at Krimpen aan de Lek, by 1.60 m at Dordrecht, and by 3 m or more in the Haringvliet basin.

As Curves IV and V show, the closing of the Oude Maas during a storm will result in the storm-flood levels in the Rotterdam Waterway being higher than with the Oude Maas open. The lowering of those levels which the closing of the Oude Maas will have on the remaining waters appears, on the contrary, to have hardly any significance, even as with an open Oude Maas there will not be any danger for the existing main water protections along these waters when the Delta Plan is completed. To demonstrate this, in Fig. 6.1.2. both the highest and the next highest observed levels in this area of the Lower Rivers are shown (see Curves II and I). On the occurrence of the last-mentioned ones, no serious dyke damage

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[1]) According to observations in the period 1911/1950, the Rhine discharge during 20 to 25 days per month was smaller than 3,000 m^3/sec in the storm season. See 6.1.1. in Contribution IV.4. The average discharge over the winter period is 1,900 m^3/sec. For the Meuse this is 365 m^3/sec. See also Note on page 52.

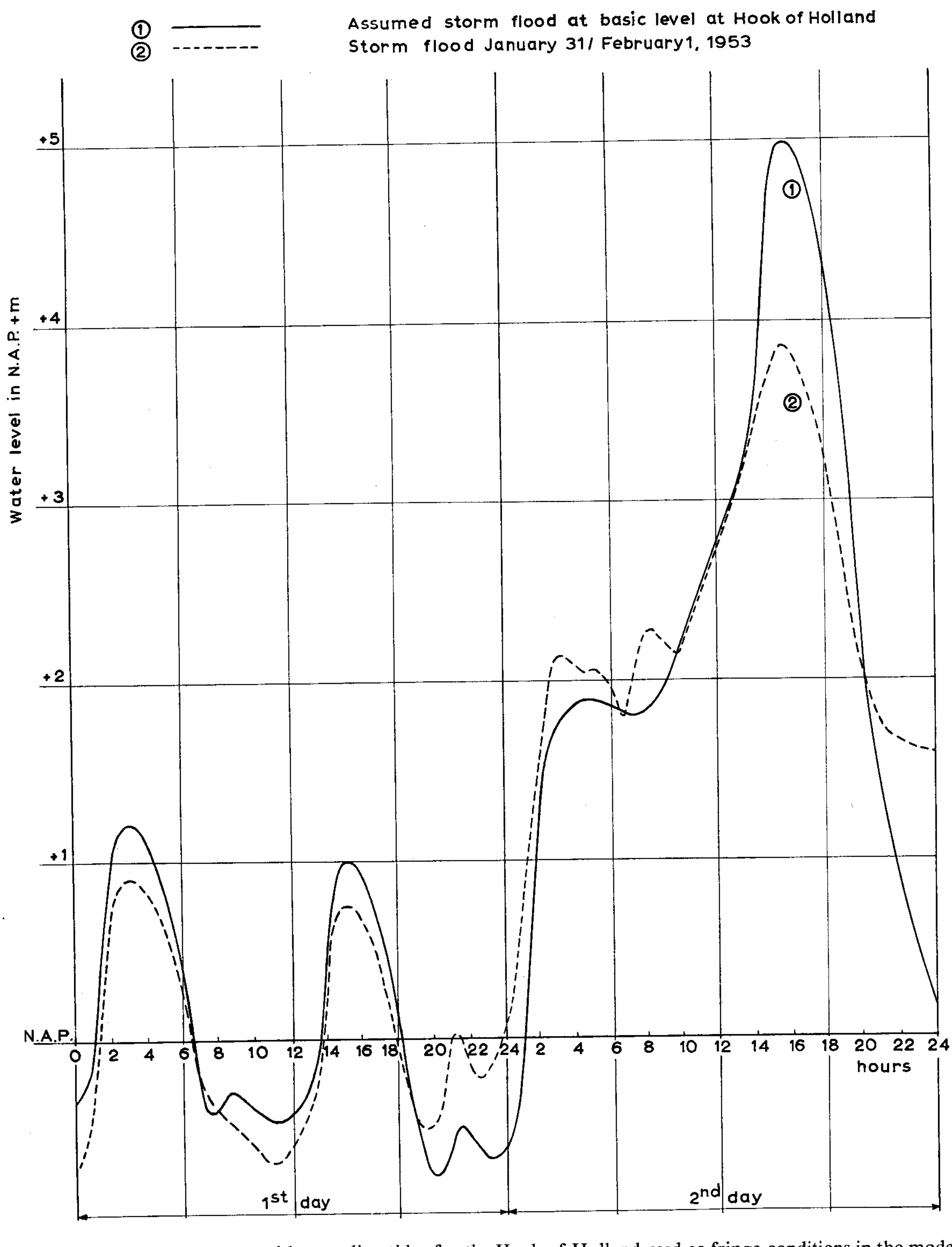

Figure 6.1.1. Storm-flood curves with preceding tides for the Hook of Holland used as fringe conditions in the model at the Delft Hydraulic Laboratory

With the assumed storm flood which reaches the level of N.A.P. + 5 m at the Hook of Holland, it naturally started from the spring tide. For the first day a spring tide that actually occurred has been taken (August 6, 1948); for the second day this has been combined with a storm effect which increased from zero to 1½ m at 6.0 p.m., to 3 m at 12 noon and which was a little higher than 4 m between 3.30 p.m. and 6.30 p.m.

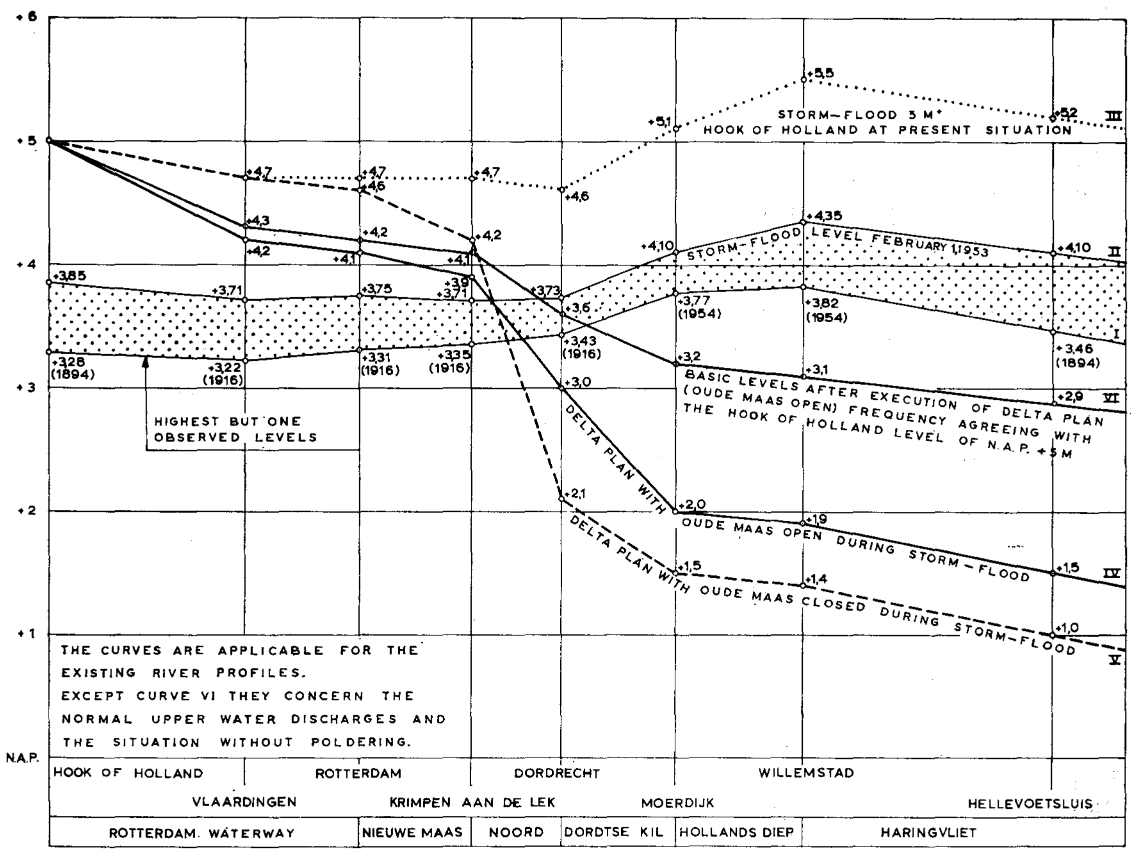

Figure 6.1.2. Storm-flood levels in the northern Delta area before and after the execution of the Delta Plan

resulted, while it may be expected that as a result of the strengthening of a number of weak spots in the main water protection network, generally higher levels can be sustained and held (see note on page 30). The intersection of these curves appears to lie in such a way for the open and closed Oude Maas (Curves IV and V on Figure 6.1.2) that in the area where the situation with the open Oude Maas is less favourable than with the closed river, the levels almost everywhere lie below the line of the highest-but-one observed levels (Curve I). In the interests of safety, therefore, the dam to be built in the Oude Maas must be able to let storm floods pass through.

This must be taken into consideration when determining the length, within the framework of the Delta Plan, over which the strengthening of the dykes on the Lower Rivers will be necessary, as well as when deciding on the size of such strengthenings. The combination of storm floods and large river discharges must also be noted, and in this the location of Curve VI on Fig. 6.1.2 plays a role. This will be further discussed in 6.1.3.

6.1.3 *Protection against storm floods with large river discharges. Basic levels and design levels along the Lower Rivers*

In the preceding section 6.1.2. the course of the high water levels has been discussed, setting out from a storm flood with a top level of N.A.P. + 5 m at Hook of Holland in combination with the discharges of the Rivers Rhine and Meuse which are a little higher than the normal discharges in the stormy season. As in the Lower Rivers the surface water discharge also influences the height of the water levels, various combinations of storm floods and river discharges are also discussed for the determination of the basic levels along those Lower Rivers.

In connection with determining the dyke heights along the big rivers, the Government Waterways Department has been investigating extremely high discharges of the Rhine and its branches. With the help of this information and for a number of combinations of various storm floods and surface water discharges, the high water levels to be expected along the Lower Rivers have been studied, both for the existing situation and for that which will result when the Delta Works are completed, in the Hydraulic Laboratory in Delft and also calculated by the Government Waterways Department in respect of the chances of their occurrence. This study was made because of the absence of correlation shown by the Mathematical Centre between the storm-flood tides and the large river discharges. See Contribution II.3.

The water level information about a number of the combinations investigated has been outlined in Table 6.1.1; the combinations chosen being those which have about the same chance of occurrence as the basic levels along the coast.

Depending on the course and duration of the storm flood as well as of the preceding storm-flood tide, higher and lower water levels can occur inwards, as shown in the table. The general tendencies, however, as seen from a comparison of the water levels remain the same.

Table 6.1.1

High water levels in the Lower Rivers at the occurrence of combinations of various storm-flood tides and upper water discharges with equal excess frequencies for the existing situation and for that which will arise after the execution of the Delta Works with the Oude Maas open. Taken from model tests in the Delft Hydraulic Laboratory. In order to have a possibility for a mutual comparison it was granted for both cases that no dykes in the area of the Biesbos have been completed nor any dykes were broken.

		High water levels in m over N.A.P.					
		Existing Situation			After the Delta Works are completed, and with the Oude Maas open		
Fringe conditions	Hook of Holland	+5.0 m	+4.0 m	+3.0 m	+5.0 m	+4.0 m	+3.0 m
	Rhine discharge [1]) in m³/sec	3000	8000	13000	3000	8000	13000
	Meuse discharge in m³/sec	500	1700	2900	500	1700	2900
Vlaardingen		**4.7**	4.1	3.4	**4.2**	3.8	3.2
Rotterdam		**4.7**	4.2	3.6	**4.2**	3.8	3.3
Krimpen aan de Lek		**4.7**	4.3	3.8	**3.9**	3.8	3.5
Schoonhoven		**4.7**	4.6	4.2	3.9	4.0	4.0
Spijkenisse		**4.7**	4.1	3.4	**3.8**	3.5	3.1
Goidschalxoord		**4.9**	4.3	3.6	**3.4**	3.3	3.1
Alblasserdam		**4.7**	4.3	3.8	3.3	3.3	**3.4**
Dordrecht		**4.6**	4.4	3.9	3.0	3.2	**3.3**
Werkendam		**4.6**	4.4	4.2	2.7	3.4	**3.9**
Hellevoetsluis		**5.2**	4.1	3.1	1.5	1.8	**2.1**
Willemstad		**5.5**	4.6	3.7	1.9	2.3	**2.6**
Moerdijk		**5.1**	4.5	3.9	2.0	2.5	**2.8**
Mond der Donge		**4.4**	4.0	3.4	2.1	2.5	**2.8**

[1]) According to the Ten Years' Survey of Water Heights (1941–1950) of the General Service of the Government Waterways Department, the Rhine discharges at Lobith from 2,380 to 4,370 m³/sec are regarded as "moderately high discharges"; over 4,370 to 9,400 m³/sec as "high discharges"; and over 9,400 m³/sec as "very high discharges." The highest known discharge of the Rhine was about 13,000 m³/sec in January 1926. In the same period the discharge of the Meuse was about 2,900 m³/sec.

It is clear from the table that in the existing situation the top levels in the whole of the area of the Lower Rivers, with storm-flood tides of for example N.A.P. + 3 m and + 4 m at the Hook of Holland combined with a large river discharge, are lower than when there is a level of N.A.P. + 5 m in combination with a normal water discharge. In this area, therefore, the influence of the sea tides is more dominant than that of the discharge of the rivers.

This will change when the Delta Works are completed, as will the points where the influence of the large rivers begins to operate, on the Lek between Krimpen aan de Lek and Schoonhoven, on the

Noord near Alblasserdam, and on the Oude Maas between Goidschalxoord and Dordrecht. Near Dordrecht and Werkendam, and in a greater measure in the Haringvliet basin, the influence of the storm floods as a result of the closing works will have decreased to the extent that, in contrast to the present situation, the influence of the upper waters will be dominant. Nevertheless, the closing off of the high tide from the sea will also result in the high water levels in this area dropping more considerably than can at present be expected with combinations having the same chances of occurrence. Then, too, the possibilities of the occurrence of high water levels in the neighbourhood of Dordrecht and farther south will also be greatly diminished by the execution of the Delta Plan.

From the statistical material provided it is obvious that a certain high water level can originate as the result of various combinations. For example, according to Table 6.1.1 there will be reached, when the Delta Works are finished, the level of N.A.P. + 3.3 m at Alblasserdam when there are combinations of Hook of Holland N.A.P. + 5 m and Rhine discharge of 3,000 m^3/sec, and of N.A.P. + 4 m and 8,000 m^3/sec respectively. Each of these combinations has an occurrence chance of about 1 in 10,000. However, other combinations can also be thought of at which the level of N.A.P. + 3.3 m is reached at Alblasserdam. From this it becomes evident that the chance of occurrence of the level N.A.P. + 3.3 m at Alblasserdam in the situation after the Delta Works are completed will be much greater than 1 in 10,000. To learn the chance of reaching or exceeding a certain water level, all possible combinations leading to it will have to be considered. Then by adding the chances of occurrence attached to each of the combinations (and because of the very great number of combination such an addition means integration), the total chance of reaching or exceeding the water level concerned is obtained. Through this channel it will be possible to find a water level which has a certain excess frequency. The method has, however, been worked out in a practical way and fully explained in Contribution IV.3. This has been applied to a number of stations along the Lower Rivers for the determination of basic levels (see 3.0) namely, the high water levels which have the same excess chance as the level of N.A.P. + 5 m at the Hook of Holland. This study has been made for both the existing situation and that which will function after the execution of the Delta Works. For the first-mentioned situation it was assumed that the dam in the Oude Maas could let storm floods pass through; but discharging water into the Zealand Lake has not been accounted for. It was, however, allowed for that the whole of the South Holland Biesbos and a greater part of the Brabant Biesbos are dyked, and that the areas of the Donge and the Oude Maasje have been made free of high water, thereby increasing the water levels on the Lower Rivers in this area. The levels obtained in this study are given in Table 6.1.2, and they apply to the existing profiles in the Lower Rivers.

Comparison of the water levels in Columns 1 and 2 of the Table 6.1.2 shows that as a result of the Delta Works the decrease will not extend upstream to Vreeswijk and Werkendam.

The basic levels mentioned in Column 1 of Table 6.1.2 are also depicted in Fig. 6.1.2 (Curve VI). Comparing Curves VI and IV of this diagram it is seen that with large upper water discharges, and on the starting assumption that no water is discharged into the Zealand Lake, higher levels will occur over a vast area than with high storm floods in combination with normal upper water discharges in the storm season.

The basic levels indicated by Curve VI certainly do not forecast a dangerous situation for the greater part of the area concerned with the present state of the main water protection and the existing river profiles, so that here no strengthenings of the dykes are required.

Seawards from Dordrecht, however, the basic levels are higher than the second highest observed levels (Curve I of Fig. 6.1.2), by which the main water protections here may still be regarded as safe. So in this case consideration must be given to a study of how far dyke strengthenings will be necessary in connection with the design levels to be adopted.

For the southern side of Central Holland the basic level must be kept as the design level, which means that strengthening of the dykes will be necessary in that region. Less important interests, however, are protected by the remaining water protection works, so that the design levels there can be lower than the basic levels. But before the actual design levels for this area can be determined, further study must show what reduction can be applied to the basic level in each separate case.

For the island of Dordrecht the Committee believes that this reduction can certainly be put at about 20 cms (8 inches). As the basic level here is N.A.P. + 3.60 m, a design level of N.A.P. + 3.40 m is needed. The relevant level here on Curve I of Fig. 6.1.2 is N.A.P. + 3.43 m. The lowest point of the

Table 6.1.2

High water levels in the Lower Rivers with excess frequency of 1/10,000 for the existing situation and for that after the execution of the Delta Works

River	Station	High water levels in m + N.A.P.	
		Basic levels after the execution of the Delta Plan (with polderings)	High water levels with an excess frequency of 1 in 10,000 in the present situation (without polderings)
		1	2
Rotterdam Waterway	Hook of Holland (tide gauge)	5.0	5.0
	Vlaardingen	4.3	4.8
	Rotterdam	4.2	4.8
Lek	Krimpen aan de Lek	4.1	4.8
	Schoonhoven	4.2	4.8
	Vreeswijk	7.0	7.0
Oude Maas	Spijkenisse	3.9	4.7
	Goidschalxoord	3.6	5.0
Noord	Alblasserdam	3.7	4.8
Merwede	Dordrecht	3.6	4.9
	Werkendam	5.1	5.1
Haringvliet	Hellevoetsluis	2.9	5.2
Hollands Diep	Willemstad	3.1	5.6
	Moerdijk	3.2	5.3
Amer	Mond der Donge (Mouth of the Donge)	3.4	4.4

main water protection in the town of Dordrecht lies at N.A.P. + 3.80 m, so that there is an excess height of 40 cms in respect of the design level. And as the latest improvements in the main water protection plan have aimed at making the town safe even with a water level of N.A.P. + 3.60 m, the situation here is considered adequate by the Committee, particularly in view of the presence of paving and the absence of on-coming waves.

With an equal chance of occurrence, however, higher levels are possible than those on which the preceding basis was calculated. These could originate by another form of storm-flood curve, as well as by another starting level in the Haringvliet basin as the result of a higher middle level in the sea and an altered discharge programme in the period before the storm-flood tide. In this connection it should be noticed that in the investigations that have been carried out other storm-flood tide curves than those in Fig. 6.1.1 have been used as the fringe condition, so that the conclusions drawn to in the preceding remarks can be considered as having been based on all the observation material available. The observations made so far, however, cover too short a period to determine the most unfavourable form of the storm-tide curve. This means that study into this problem must be continued.

Furthermore, the storm-flood levels in the Haringvliet basin and the waters directly connected with it will increase when the feeder channels, especially of the Noord, will be enlarged in the interests of shipping. This would also reduce the basin storage capacity of the Haringvliet, especially if this river is normalised and if there is any land reclamation.

If it would appear in the future that such factors as these would lead to more unfavourable combinations as outlined in Contribution IV.3, then the basic levels, and with them of course the design levels, along the Lower Rivers must be reviewed.

In determining the design levels of the Lower Rivers, account must be taken of the fact that there must remain some reserve in the water storage capacity of this area to give more freedom for the operation of the Haringvliet locks in time of storm, especially as just in that period a strong wave attack can be expected against the lock-gates. In addition, the accelerated discharge of the water from the current area of the Rhine must be considered.

As a completely new permanent situation is to be created, it is recommended, in connection with the possibility of the stopping of the discharge of the large rivers into the sea via the Haringvliet, to keep the opportunity open of making the discharge of water possible into the Zealand Lake. If this is found necessary, then the current locks being built in the Volkerak Dam in the interests of the fresh water economy must be of good size, while at the same time for the water storage capacity of the Zealand Lake, and especially the northern part of it, a minimum must be set. In this way some compensation can be obtained for the separation of the Zealand Lake by which the water storage capacity for the discharge of the upper rivers will be greatly limited and the high water levels in the Haringvliet basin will be heightened to a considerable degree.

Thus, in the case to which Curve IV in Fig. 6.1.2 applies, the water levels in the Haringvliet will be about 80 cm lower than is there indicated if, on completion of the Delta Works, the Haringvliet basin stands in open connection with the Zealand Lake.

From Fig. 9.6.1 of Contribution IV.3 it is seen that the influence of the water discharge into the Zealand Lake during large river discharges into the Haringvliet basin is indeed rather large, but that as a result of the water resistance mainly of the Dordtse Kil this has already been considerably decreased.

6.1.4 *Current velocities at storm flood and large river discharges*

In regard to the current velocities which will occur, at the end of the Delta Works construction, during and directly after a storm flood and during high river discharges, it appears from tests with models that, generally speaking, they will be no greater, or only a little greater, than those which now originate in a similar situation in the rivers. See Contribution IV.3.

Only the velocity of high tides which, with storm tides, can occur in the downstream section of the open Oude Maas and in the Noord, and in the ebb tide speeds with large river discharges on the Dordtse Kil, are an exception here. According to model tests, they do not become higher with storm floods of the type just mentioned than the velocities which also occur elsewhere under occasional special circumstances. As high storm tides occur only seldom, and the above-mentioned maximum velocity currents will moreover be of short duration, these are considered permissible, the more so as shipping is then for the greater part still. However, it could appear necessary to protect the bed and banks of the rivers just mentioned against scouring over certain lengths. This will probably be the case eventually on the Noord, as here the daily current speeds will increase. See under 6.3.2.

6.2 Improvement of the fresh water household

6.2.1 *The existing situation*

In the situation as it is at present the sea water penetrates into the Delta area through the open sea-arms and river mouths. The distance over which this occurs results much more from a number of mixing movements than from the actual high tide stream or current. In opposition to the transport in an upstream direction, there is the transport of water towards the sea as the upper water discharge carries the salt back again. According to the size of the upper water discharge, a situation is created in this salt and fresh water movement in the rivers and sea-arms in which the salt content gradually decreases as it goes inland and is also lower as more upper water streams down along the river.

The upper waters of the Rivers Lek, Waal and Meuse mainly flow along the Rotterdam Waterway and the Haringvliet to the sea. Only at very high upper discharges is some river water discharged via the Brouwershavense Gat and the Eastern Scheldt.

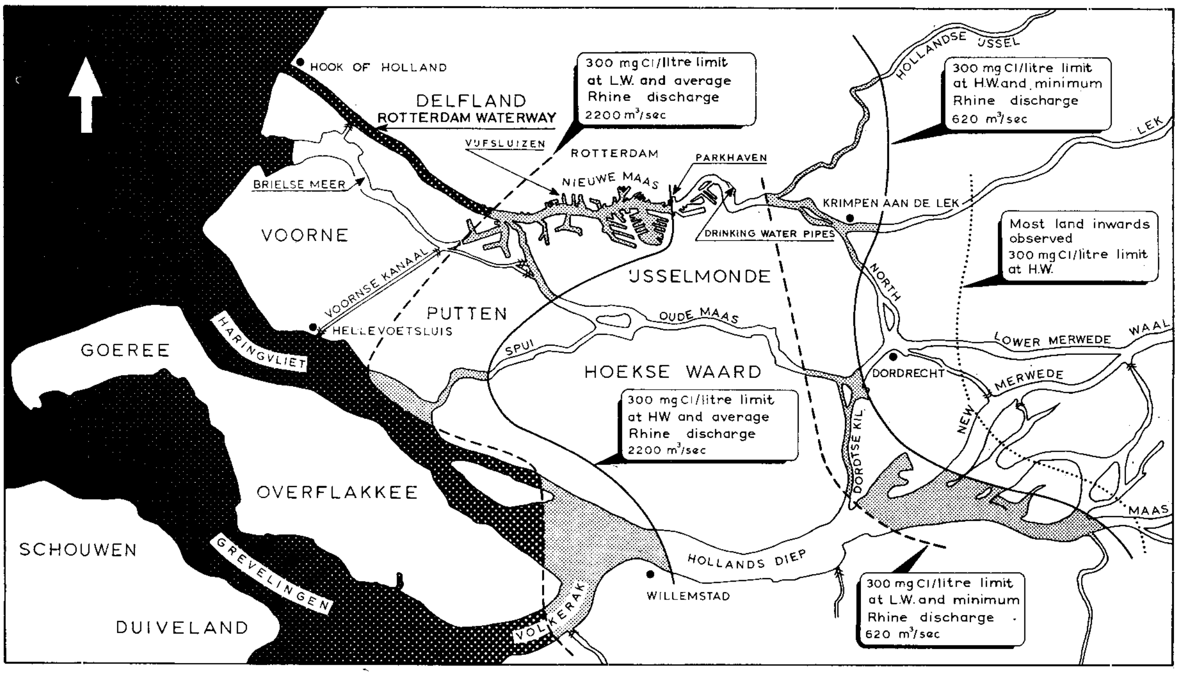

Figure 6.2.1. Rough survey of the 300 mg Cl/litres limits at high and low water changes of tide in the Lower Rivers for normal and very small upper water discharges

The general situation in the Delta area is that the Zeeland streams are almost entirely salt, while the salt content in the Haringvliet, partly because of the salt injections via the Volkerak, is usually reduced to a sufficiently low value first in the neighbourhood of Willemstad. On the Rotterdam Waterway the upper water discharge is proportionately rather large, but the salt transport in an upstream direction is also larger, as among other things a result of the strongly mixing influence of the different harbours.

The Rotterdam Waterway and Nieuwe Maas are of great importance as a supply stream of fresh water in connection with the water withdrawal for Delfland, the drinking water supply for Rotterdam, and the water supplies for the industries located in the region.

The most important points for the direct inlet of river water into the Delfland area are near the Vijfsluizen between Vlaardingen and Schiedam and near the Parkhaven locks in Rotterdam. The inlet near the Vijfsluizen, however, cannot be used every year over a long period because of the strong chloride content of the river water.

It can be generally said that Delfland preferably does not let in water with a chloride content of more than 300 mg Cl/litre. Experience has shown that in the present circumstances, with a Rhine discharge of about 2,000 m³/sec, the critical point for the inlet of water in the Parksluizen is reached. This Rhine discharge, however, is not reached during about averagely six months of the year.

The dry summer of 1947 led to the building of a pumping station at Leidsendam, so that Delfland can now be provided with fresh water through the Rhineland basin that in Gouda withdraws water from the Hollandse IJssel. As a result of the buffer effect on the Hollandse IJssel, this inlet of fresh water at Gouda has so far been possible. But as the fresh water supply of Delfland along such a byway cannot in the long run be regarded as satisfactory, it is especially important that the river water at the Parkhaven inlet point has as low a salt content as possible.

With the present distribution of the upper water discharge, in very dry years the salt can go upstream as far as Krimpen aan de Lek. In those circumstances, the inlet of usable water at Parkhaven for Delfland becomes impossible, while the withdrawal of drinking water for the Rotterdam Municipality is also greatly hampered. The *prise d'eau* of this drinking water pipeline lies in an upstream direction only a few miles from the Parkhaven. Moreover, the water withdrawal from the Hollandse IJssel is being seriously endangered in other ways, notably the Water Management Boards of Rhineland and Schieland will be still more affected when these are expanded.

While the polder and basin waters in the low-lying parts of this country are already exposed to silting up as a result of seepage and diffusion from salt-containing layers in the subsoil, the high chloride content of the water in the Lower Rivers and the sea-arms is also the cause of much hindrance, experienced from the salt which gets through in various ways, such as when the water passes through the lock gates, leakage through the sides and bottom of the closing apparatus of the locks and the discharge gates, and seepage under the main water protection works. Moreover, the high chloride content of the outside water is an objection to using it for rinsing or flushing to combat the silting up or other pollution of the polders and the basin waters, as well as in connection with controlling the level of those waters and in arranging the water supply for the crops during the growing period. The drinking water supply also suffers considerable hampering from it.

Although the supply of fresh water in the Netherlands would be adequate, if there were no silting up or other pollution, to meet the needs of household, industrial and agrarian purposes, the situation just described produces salt difficulties and water shortages, especially in dry periods, which in their turn cause trouble and damage in a number of other places.

As for the supply of fresh water in the Netherlands, the following general picture can be given. The Rhine supplied on an average during the period 1911–1950 about 70 milliard m^3 a year, the Meuse about 8 milliard m^3, the Overijssel Vecht near Gramsbergen, the Roer, the Niers and a few other small rivers about 1 milliard m^3 from outside Dutch frontiers. Thus there is a total supply of 80 millard m^3 in an average year being imported from outside our country frontiers. In addition, Holland's "own" water coming from rain falling over a surface of about 8,750,000 acres, at an average of 76 cms (31 inches), a year amounts to 25 milliard m^3 annually. This, however, is not such a boon as it looks, because evaporation must be taken into account, and during the summer this is, indeed, even greater than the rain. From this it is clear that the Netherlands are mainly dependent on a supply of fresh water from abroad, and mainly on the River Rhine.

To summarise this section, it is evident that a great amount of salt is entering into a large part of the country as a result of the low location of the land and of the sea-arms that penetrate so deeply into it. And this, to the disadvantage of the country's economy, makes the fresh water household periodically unsatisfactory.

6.2.2 *Possibilities of improving the fresh water economy*

A very valuable and important improvement in the fresh water household will be obtained by closing the sea-arms in the south-west, because by this project the primary source of the salt coming in from the sea will be cut off over a large area of the Delta area. When the Delta Works are completed, running from the Hook of Holland to the Western Scheldt – except when the Haringvliet sluices are opened during heavy ice formation and high tides – sea water will be able to enter the Delta area only through the Rotterdam Waterway. Yet this shows that even after this there will remain a considerable salt objection which will have to be combatted as much as possible by obstructing salt entrance, especially from the Rotterdam Waterway, with fresh water and then flushing the inner waters. For this large quantities will still be needed.

In addition to the actual quantity of fresh water which is available for the country's fresh water economy, the quality of the water of the Rhine also naturally plays an important part, as the Rhine is the main supplier of Holland's fresh water. In this respect there is cause for serious anxiety, as the Rhine water has become very badly polluted near the Netherlands frontier, not only with organic materials but also with inorganic matter. This is causing more and more difficulties for the Netherlands; indeed, the pollution with chlorides has gradually produced what might be called an emergency situation.

The cause of the great chloride discharge of the Rhine is to be found in the increasing discharge of salt-containing waste water from the Ruhr area and Alsace. In the past few years this chloride discharge has considerably increased, as can be seen from Fig. 6.2.2. While, taking an average over the year, it amounted in 1935 to about 110 kg Cl/sec, it has now gone upto about 250 kg Cl/sec. It is obvious, too, that the chloride content of the Rhine water increases in proportion to the extent to which the discharge is lowered. In Fig. 6.2.3 the relation between the size of the Rhine discharge near

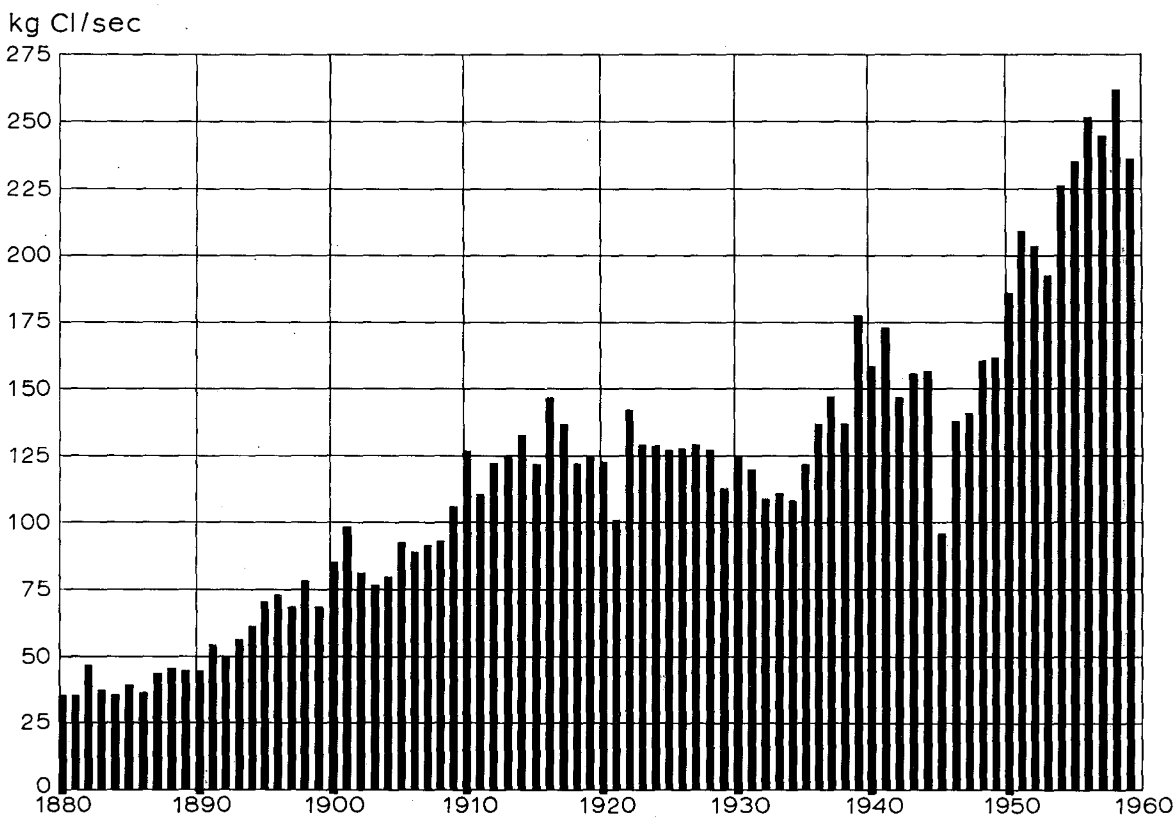

Figure 6.2.2. Chloride discharge of the Rhine since 1880 in kg Cl/sec averaged over the year, according to information of the International Commission for Protection of the Rhine against Pollution

Lobith and the chloride content has been shown in curves at a value of a chloride discharge of 225 kg Cl/sec, which is considered from the Netherlands' side as the outside limit acceptable for the annual average. From this diagram it appears that with small river discharges a concentration of 250 Cl/L can already be reached or exceeded at the Netherlands frontier.

The increase in the chloride content of the water at a decreasing discharge of the Rhine results in a situation that to combat the salt in the coastal areas the greatest quantity of upper water will be required just at the time when the water supply from the upper rivers is smallest. This means that, as shown in Contribution IV.4, after the Delta Works will be finished, with a closed Oude Maas 210 m^3/sec more upper water will be needed if the chloride content of the upper water increases from 100 to 250 mg Cl/litre in order to push back the salt content to 300 mg Cl/litre at the turn of high tide near the Parkhaven in Rotterdam, a situation which is taken as a standard for the reasonable combat of salt in the Rotterdam Waterway. When the Oude Maas is open, there will be needed even 360 m^3/sec more upper water.

As the chloride content of the Rhine water gets higher, the quantity of water needed to keep up the desired situation in the Rotterdam Waterway–Nieuwe Maas will increase, as well as the number of days in which such a situation cannot be reached. The cause of the harmful and deeply penetrating unacceptable chloride content in the Nieuwe Maas after the Delta Works will be finished will no longer be the thrusting sea water but the polluted quality of the Rhine upper water which will also have a decreased discharge.

Any further salting or polluting of the Rhine water, which would be a serious threat to the whole fresh water economy of the Netherlands, is in the opinion of the Committee absolutely inadmissible in view of the necessity of continuing to combat the salt in the coastal areas.

For this reason the members have learned with great interest that efforts are being made to bring about international talks to agree on measures which will improve the quality of the Rhine water. The

International Commission for the Protection of the Rhine against Pollution is now considering the whole problem of the decline in quality according to objective norms determined along the whole course of the river, and also the limits which have laid down to govern the various pollutions. From the Dutch side one line of approach is to strive for a decrease in the very high salt content during small river discharges. This can be obtained by limiting the discharge of salt into the river, or by regulating the quantity in proportion to the size of the discharge. This Delta Committee thinks it is of the utmost importance that the Dutch authorities should continue their strong pleas during this international discussion to ensure an improvement in the quality of the water and the prevention of actions which would reduce the quality of the river water before it reaches the Netherlands.

This underlines what has already been said about the great dependence of the Netherlands fresh water economy on the regime of the Rhine. Not only does the discharge continually change but also the quality of the water, which in its turn means that it is of vital interest for this country to use the Rhine water as effectively as possible. There are several ways in which this is possible: the river water can be prevented from directly pouring into the sea when some of it could have been useful elsewhere; water storage can be carried out in open reservoirs and underground during ample discharge of good water; and works can be carried out which enable the distribution of the excess water to be changed in more favourable directions, especially during times of limited river discharge. One more point: the possible radio-active pollution of the Rhine water during certain periods is also of considerable significance, and needs much attention during periods of water scarcity.

As a result of the closing of the sea-arms and the closing of the Oude Maas the wasteful streaming of the river water into the sea will be prevented. This is an example of the first method just mentioned.

As for reservoirs, it should be recalled that by the closing of the Zuyder Zee and the creation of the IJsselmeer Holland's first large reservoir was created for storage of the upper waters. The Brielse Maas reservoir, too, though of a much more limited size, is another example of how this method has been very useful.

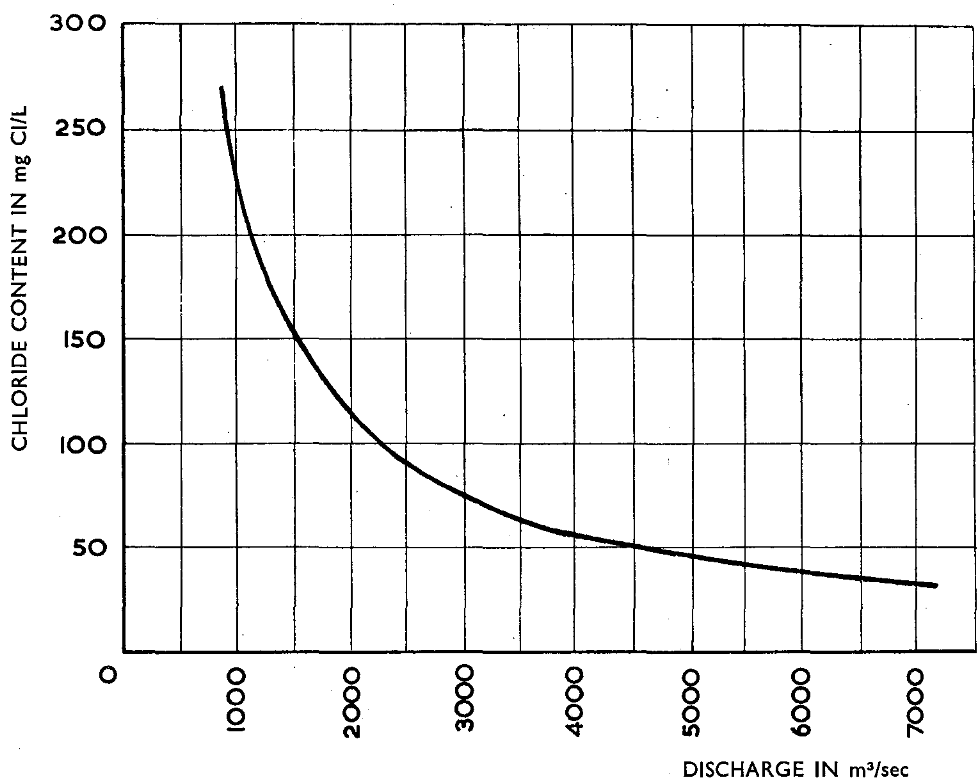

Figure 6.2.3. Connection between the chloride content of the Rhine water and the discharge of the Rhine at Lobith with a chloride discharge of 225 kg Cl/sec

By the anticipated damming of the Volkerak within the schema of the Delta Works, the closed Zealand Lake will be formed. In this lake a quantity of fresh water can be stored which can be used in dry periods to irrigate the surrounding land. No demand will be made on the limited quantity of running-off upper water which will then be wholly available in the dry weather for the areas north of the Volkerak Dam.

As the filling of the Zealand Lake will take place when the Rhine discharge is large, the water stored there will be of good quality.

But in addition there must be storage of water of good quality in the subsoil during times of ample river discharge, and in this connection reference can be made to the water supply works of Amsterdam and North Holland and of The Hague where the water is stored under the dunes.

As a measure for the favourable changing of the distribution of the running-off water, the Neder-Rijn/Lek canalization can first be mentioned. With the aid of the dam near Driel a change in the distribution of the Rhine water along the Neder-Rijn and the IJssel will in the future be made. [1] Then more water than now will run along the IJssel to the IJsselmeer, thus simultaneously serving the interests of both shipping and the fresh water economy in the eastern and northern parts of the country.

The putting into operation of the Neder-Rijn/Lek canalization will result in a decreased supply of river water in the Delta area in those periods of the year in which it is already small. This would be inadmissible, however, without making further provisions, because then the fresh water supply of Delfland, Rijnland and Schieland, the drinking water supply of Rotterdam, and the provision of water for industries, would be hampered. The execution of the Delta Plan, however, makes it possible, even when the Neder-Rijn/Lek canal project has been completed, to meet this objection.

In addition to decreasing the amount of salt water by the closing of the sea-arms as one great advantage, the Delta Plan also creates the possibility of distributing the running-down water of the Rhine and the Meuse in the area of the Lower Rivers.

After the completion of the closings of the Haringvliet, Volkerak and Oude Maas, during dry periods almost all the water from the Lek, the Waal and the Meuse will be discharged via the Nieuwe Maas and the Rotterdam Waterway to the sea, thus compensating for the falling discharge of this branch of the Rhine as a result of the canalization of the Neder-Rijn and the Lek, while the entering salt can be obstructed with more success. The supply of fresh water from this river for Delfland and the Rotterdam drinking water needs will also be better ensured.

The closing of the Volkerak, moreover, gives the advantage that the surface of the waters standing in contact with the rivers and with the Rotterdam Waterway will be made smaller. As a result of this, the levels of those waters and of the amount of river water discharged by the Rotterdam Waterway will react more rapidly to the changes of the area of the flow surface at the Haringvliet sluices and to the changes in the river area.

When, after the damming of the sea-arms, the Zealand Lake and the Haringvliet basin will have been de-salted, the serious effects of the salt in the water passing through the locks and of the sea water leaking through the sides and bottom of the gates will be ended. With the fresh water then present it will be possible to maintain the polder waters at the right levels and by replacing them combat the salt damage in the polders. The salt water in the subsoil will, of course, for a considerable time give rise to salty

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[1]) The storage programme made for the dam near Driel is based on one hand on obtaining sufficient sailing draught on the IJssel by which at least 250 m^3/sec will be led along that river, and on the other hand by limiting the IJssel discharges greater than 350 m^3/sec in connection with the flooding of the forelands and the scouring of the river bed. For this latter purpose, in the future water will be withdrawn at the Neder-Rijn if possible at all discharges of the Rhine which are lying just under the average discharge (2000 m^3/sec) on behalf of the IJssel, because first by this Rhine discharge the required quantity of water will be running off through the IJssel without any damming up. For the time being, however, it has been accepted that such a regulating of the discharge distribution will be made in such a way that the discharge of the Neder-Rijn, at the cost of which the increase in the IJssel discharge will be obtained, below Driel will amount to at least 50 m^3/sec. In determining this quantity it has been assumed that possibly via the Betuwe area of the Amsterdam-Rhine Canal about 40 m^3/sec maximum can be taken away from the Waal to the Lek to supply the Lek area, so that by also using a rather large sideway water withdrawal from the Neder-Rijn and Lek, which is put at 65 m^3/sec, for flushing through the downstream course of this Rhine branch, the minimum quantity necessary of about an average of 25 m^3/sec will remain. These discharges must be considered as the averages over a number of days. In this discharge distribution the water withdrawal of the Hollandse IJssel has been omitted because the water needed for this is supplied by the Noord.

springs, as it can only be gradually replaced by the fresh water penetrating from the surrounding waters. But this objection will steadily disappear, especially after it is counteracted by flushing. See Fig. 11.5.1 of Contribution IV.4.

The presence of fresh water in the Zealand Lake and the Haringvliet basin will open the opportunity, especially during the growing period of the crops, to lead needed water to the drought-sensitive land in the Delta area and in North Brabant, and thus either prevent crop failures or at least limit them.

In addition to increasing the safety of the southwestern part of the country the Delta Works, along with the works on the Rhine and the Lek canalization, therefore offer the possibility of achieving an important improvement in the fresh water economy over a very large part of the country, even in the north.

When the work has been finished, the disadvantages now experienced, resulting from the presence of salt water and the shortage of fresh water, will be considerably limited. Especially in long periods of drought, and particularly when these are coincident with small river discharges, as occurred in the years 1921, 1934, 1947, 1949, and 1959, the improvement of the fresh water household, represents an important economic interest, notably in the sphere of agrarian activity, where much is at stake.

6.2.3 *Realisation of the possibilities of improving the fresh water economy*

There must now be studied the ways by which it is possible to realise the various improvements that can be obtained in the fresh water supply after the closing of the sea-arms.

As has been already delineated, three areas must be considered: the Zealand Lake, the Haringvliet basin with its connecting rivers, and the Rotterdam Waterway–Nieuwe Maas.

The de-salting of the Zealand Lake will be carried out – after the de-salting of the Haringvliet – by letting in river water through the current sluices in the Volkerak Dam and by discharging water through the appropriate means in and near the dammings of the Brouwershavense Gat, the Eastern Scheldt and the Veerse Gat. The desirability of discharge from the Western Scheldt requires still further investigation.

It seems possible that the Zealand Lake can obtain a rather low chloride content in this way within a few years of the completion of the Delta Works. Of course, salt will remain in the deepest parts of the channels for a long time, but this will not lead to serious difficulties.

However, as has already been pointed out, as a result of salty springs from the subsoil there will be a serious salt problem in the Zealand Lake at the beginning. To combat this, flushing with river water will be necessary by letting such water in through the transit locks in the Volkerak Dam, although for the time being it must be taken into account that with small river discharges an average chloride content lower than 300 mg Cl/litre probably cannot always be maintained. In this connection it is clear that it will be important not to build locks in the dams of the Brouwershavense Gat, the Eastern Scheldt and the Veerse Gat, as much salt water would enter through them. It is also desirable to take measures to prevent the penetration of salt when locking at Hansweert and Flushing. If such steps were not taken, a great deal of fresh water would be needed to push back the salt water, which would mean that the effective water stock in the Zealand Lake would then be made appreciably smaller. See 11.1 of Contribution IV.4.

The Zealand Lake will be of greater value to agriculture when, in times of drought, larger quantities of water can be withdrawn, so that it will be necessary to collect as large a water storage as possible before the dry period starts. With an adequate storage capacity, the lake will be able to cope for a rather long time with the comparatively large differences between the water supplied to it and that taken from it. In times of water scarcity a great deal of water will be available to be drawn from it not only to supply the surrounding arable land but also to help combat the salt water without the necessity of a new supply. This water withdrawal in this case, moreover, will not be at the expense of the water consumption in fighting the salt penetration in the Rotterdam Waterway or elsewhere in the Delta area.

It is to be expected that at about the same time as the Zealand Lake begins to act as a water reservoir, the discharge forecasts over a long period will be sufficiently reliable to make the effective management of this lake possible. But it is obvious from what has been said here that in the complete interests of the fresh water supply, it is very important that the Zealand Lake is given the largest water storage capacity possible. As shown in 6.1.2, indeed, there must be a minimum standard set for this capacity also in the interests of safety.

Moreover, because of the other interests linked up with the Zealand Lake, more especially those of water discharge and shipping, there must generally be both a maximum and minimum level on the lake, although perhaps exceptions can be permitted for short periods. The limits between which level exchange is permissible determine also the minimum surface of the Zealand Lake which will still guarantee to an adequate degree both the general safety and the water economy. Because a permanent situation is being created here, it is also obvious that this minimum surface area must be fixed with abundant reserve, a reserve, moreover, which must not be made subservient to any other interests.

There is no doubt that from various sides efforts will be made to use parts of the Zealand Lake, as well as of the Haringvliet basin, for the realisation of plans which in themselves will be attractive. These will mainly be in the interests of land reclamation, the construction of water-free areas, recreation facilities and provisions, and perhaps the institution of salt water basins for shell fish culture. That is to say, certain interests will seek to limit the area or level of the Zealand Lake which, if agreed to, will reduce the water storage capacity.

But to determine the final size of the Zealand Lake and the level changes permitted for it, the economic values of the various and often conflicting interests must be carefully weighed. Another balance to be drawn up is whether Holland's agrarian production is favoured more by an ample water supply or by the reclamation of new land.

In Contribution VI. under 4.1 a picture has been drawn of the economic value the water storage of the Zealand Lake can have if this is applied for helping in the reclamation of the surrounding land. From this it is clear that there are still great uncertainties present in the whole problem, so that to obtain a better insight into the real character of the factors still at stake, much more study in both the technical and economic fields is required.

Only after a very careful investigation, added to practical experience, will it be possible to weigh the various interests against each other in such a way that finally the general interests can best be served. The aspects connected with this problem, indeed, are far-reaching, even beyond the interests just mentioned connected with the immediate surroundings, for they touch, with the Rhine canalization as a linking element, the water economy of the whole of the Netherlands. All this means that in the construction and level regulation of the Zealand Lake great care will have to be taken and the final solution reached only step by step.

For all these reasons just outlined, the Delta Committe does not consider itself able at this stage to come to any conclusion on a definite level regulation. Nevertheless the Committee feels it is desirable to give at least some orientation about it, which will be found in 6.3.1.

Turning now to the *Haringvliet basin*, it can be said in the first place that when that basin is completed a quick de-salting can be expected, because during large discharges of the upper rivers an important part of the salt water will be let out through the discharge sluices to be built in the Haringvliet Dam.

In addition to discharging the superfluous upper water, the Haringvliet sluices will be used to flush off the salt that has penetrated and also, if necessary, to flush the outer channel.

As the Haringvliet basin with connecting streams will emerge on the open sea via the Rotterdam Waterway there will be no possibility to have a fresh water supply, as that of the Brielse Maas dammed up.

When in normal circumstances, as the result of leakage and flushing water through the Haringvliet locks, or by the percolation of salt springs in the polders, some salt penetrates into the Haringvliet basin, this can be easily removed again by the discharging river water. However, it must be taken into account that in the beginning this cannot always be prevented, so that also in the Haringvliet, that is, in the downstream current, an average chloride content of 300 mg Cl/litre can be exceeded during very small river discharges. It is therefore recommended to limit the salt charge of the Haringvliet as much as possible.

The surrounding polders will be able to withdraw water from the Haringvliet basin which will be replaced regularly by the discharge of the rivers.

It is, however, to be expected that in severe winters the Haringvliet sluices will have to be opened for some time during the tidal movement as part of the measures to deal with ice formation. As a result of this, a certain amount of re-salting of the basin will occur, especially in the lower part. This, however, need not lead to serious difficulties, because after the ice period has ended the penetrated salt, especially as far as this is in the upper layers of water, will as a rule be discharged fairly quickly by the normal river streaming to the sea.

As has been shown in 6.2.1, the *Rotterdam Waterway* and *Nieuwe Maas* are very important as a supply route for fresh water.

When the Delta Works are completed, the limiting of the discharge of the upper water via the Haringvliet basin will bring more water for discharge through the Rotterdam Waterway than is now discharged along this route in a natural way.

To push back the salt in the Rotterdam Waterway as much as possible, it will be necessary, because the upstream discharges are becoming smaller, to decrease the discharge of the Haringvliet more and more. Finally, with small to very small upper water discharges, the Haringvliet sluices will have to be kept completely closed, the more so as under these circumstances the discharge of the Lek is very small and a maximum supplement via the Noord is necessary. In the years with very small upstream discharges, such as 1947 and 1949, this proved to be the case over many months in succession. Here, too, will be seen the influence of the complete or partial closing of the Rhine dams. Account must also be taken of the fact that in the future it will be desired to withdraw more and more water from the Nieuwe Maas for agriculture, industry and drinking water supply. Nevertheless, even in times of great water scarcity in the Nieuwe Maas, there will be an improvement over the present situation.

The effect of the Delta Works on the fight against the salt in the Rotterdam Waterway will be determined to a great extent by the closing or not closing of the Oude Maas. The discharged upper water by the Oude Maas produces a freshening influence on the Rotterdam Waterway only mainly downstream of the Westgeul, while on the other side the upper water of the Nieuwe Maas exerts its salt-resisting capacity over the full length of the river. For combatting the salt in the Nieuwe Maas, the discharge of river water along the Oude Maas has, indeed, small significance. The closing of the Oude Maas will, therefore, result in making the situation in the Nieuwe Maas considerably more favourable.

As shown in Table 6.2.1, when the Delta Works are ready, the chance of exceeding the chloride content standard of 300 mg Cl/litre near the Parkhaven will be less than a half with a closed Oude Maas than with an open Oude Maas.

In the summer half year for which Delfland has the most urgent need of fresh water, the chance will even be reduced to less than one-third, 12 days instead of 39 days.

Table 6.2.1

Rhine discharges with their excess frequencies in which a chloride content of 300 mg Cl/litre during high water turn of tide will be exceeded near the Parkhaven, estimated for the existing situation and for the situation after the execution of the Rhine canalization and the Delta Works with an open and a closed Oude Maas, at a chloride discharge of the Rhine of 225 kg Cl/sec at Lobith.
The feeding of the Zealand Lake in the situations B, C and D starts with Rhine discharges higher than the indicated value.

Situation	Summer half year	(April–Sept.)	Winter half year	(Oct.–March)	Year
	Discharge m^3/sec	Days/year	Discharge m^3/sec	Days/year	Days/year
A. Existing situation . . .	1995	96	1915	93	189
B. Delta Works with open Oude Maas	1500	39	1360	47	86
C. Delta Works with closed Oude Maas	1160	12	1120	23	35
D. Situation C with Rhine canal dams open . . .	1095	9	1080	19	28

In determining the Rhine discharges mentioned for the situations B, C and D, there has been set out in the first place that the water needed for the agrarian, domestic and industrial purposes is fully met, as well as the necessity for salt combat, flushing, leakage and well water, while the water needs around the Zealand Lake are provided for by withdrawal of the water storage present there.

The influence of the closing of the Oude Maas on the fresh water consumption for fighting salting in the Nieuwe Maas is so great that the difference in itself would be sufficient to provide for the average water needs in the south and west of the country.

The influence of the Rhine canalization appears, according to Table 6.2.1, much less than that of whether the Oude Maas is open or closed.

When the Rhine discharge becomes greater than is required for the maintaining of the 300 mg Cl/litre limit near the Parkhaven, it will be important to prevent the discharge of the surplus through the Oude Maas, because this surplus can be usefully used for the flushing of the Haringvliet basin and of the Zealand Lake in order to decrease the chloride content which will rise with small discharges, and also to replenish the water stock of the Zealand Lake.

As the closing of the Oude Maas will also result, when inlets are included in the Volkerak Dam, in a similar upper water discharge, a higher entry level can be obtained than would be possible with open Oude Maas, thus enabling more water to be let in and stored in the Zealand Lake. This shows that the closing of the Oude Maas in this connection also is important for the water management of the Delta area.

However, it is clear from the foregoing that even after the execution of the Delta Works, during small discharges of the Rhine there will occur periods in which too little fresh water will be available to meet all the requirements of the fresh water economy. These periods, nevertheless, will be considerably shortened if the Oude Maas is closed.

In view of all these considerations, the Committee therefore believes that to obtain a good fresh water household it will be necessary that the Oude Maas can be closed in times of water scarcity. In this way more water will be available to prevent or limit crop failures during dry periods.

To be able to make as economical use as possible of fresh water on the completion of the Delta Works, including the closing of the Oude Maas, a good distribution of the available upper water is necessary. The opportunity for this will exist because it will be possible to regulate the discharge distribution over the IJssel and the Neder-Rijn by means of the upper dam in the last-mentioned river, and the discharge distribution in the Lower Rivers by means of discharge sluices in the Haringvliet, the current sluices in the Volkerak Dam, and the dam in the Oude Maas. In regulating the discharge distribution, it is necessary to allow not only for the direct water needs of agriculture and the desirability of storage but also especially for the combat against salt water which is so necessary for the obtaining of a good quality of fresh water.

In this respect the fight against the salt in the Rotterdam Waterway, especially with a high chloride content of the Rhine at Lobith of 250 mg Cl/litre, requires a great amount of water, while the salt combat in the Haringvliet basin and the Zealand Lake, after those basins have become fresh, will proportionally require less water. Even seen against the combined water needs of agriculture, polder flushing and basin flushing and water replacement, the quantity of fresh water necessary to push back the sea water in the Rotterdam Waterway will still appear very large.

But after the execution of the Delta Works, and without considering the Meuse, a satisfactory situation will exist, as long as there is sufficient water available for the IJssel (vessel depth and water supply of the IJssel Meer), and for the canalized Neder-Rijn and Lek, to enable the salt water to be pushed back in the Nieuwe Maas, the Oude Maas, and the Haringvliet, and for the Zealand Lake (pushing back the salt, the water supply for the surrounding land and the level control).

In fact, provided in the future situation the upper water can be regulated with the aid of the upper dam on the Neder-Rijn and the locks and sluices in the Haringvliet, Volkerak and Oude Maas, it will be possible always to achieve such a distribution of the upper waters that an optimum situation can be obtained. But for this there must be determined in advance to which interests priority must be given at a certain moment.

Taking into account the interests that are now concerned with the fresh water household, an example has been given by Fig. 6.2.4 and Table 6.2.2 of the possible distribution of the upper water. In this example a four-phased distribution is given based on various and increasing Rhine discharges.

Figure 6.2.4. Diagrammatic survey of the course of:
a. the chloride content in various places at high water turn of tide;
b. the upper water distribution along the Rotterdam Waterway, the Haringvliet and the Zealand Lake; and
c. the average high and low water levels at Willemstad after the introduction of the Rhine canalization and the execution of the Delta Works with closed Oude Maas, for the average summer half year (April—September inclusive), and average tide at sea, as function of the Rhine discharge and its surpassing frequency.

→

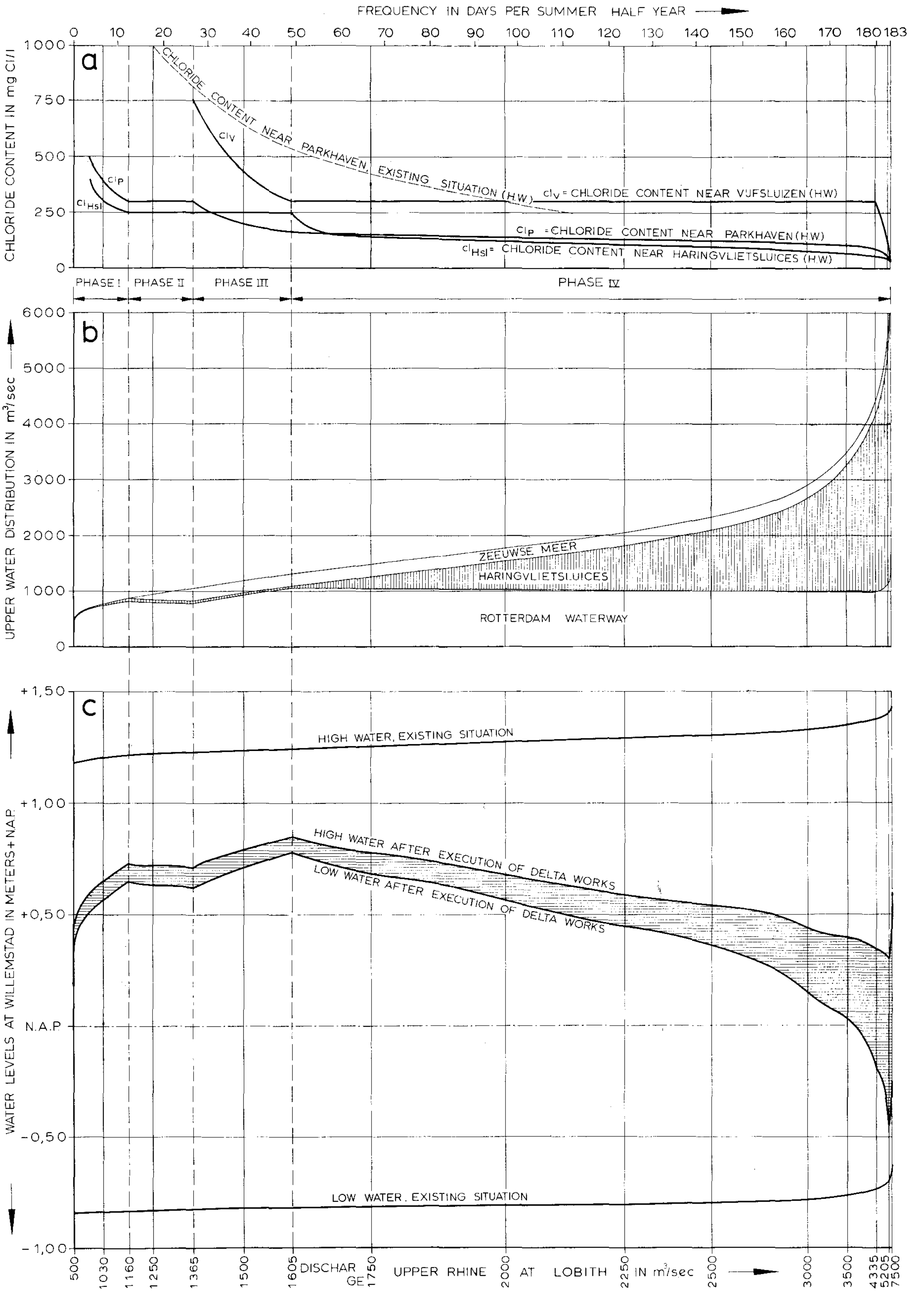
FREQUENCY IN DAYS PER SUMMER HALF YEAR
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 183
CHLORIDE CONTENT IN mg Cl/l
1000
750
500
250
0
a
CHLORIDE CONTENT NEAR PARKHAVEN, EXISTING SITUATION (H.W.)
clv
clP
clHsl
clv = CHLORIDE CONTENT NEAR VIJFSLUIZEN (HW)
clP = CHLORIDE CONTENT NEAR PARKHAVEN (HW)
clHsl = CHLORIDE CONTENT NEAR HARINGVLIETSLUICES (H.W)
PHASE I
PHASE II
PHASE III
PHASE IV
UPPER WATER DISTRIBUTION IN m³/sec
6000
5000
4000
3000
2000
1000
0
b
ZEEUWSE MEER
HARINGVLIETSLUICES
ROTTERDAM WATERWAY
WATER LEVELS AT WILLEMSTAD IN METERS + N.A.P.
+1,50
+1,00
+0,50
N.A.P.
-0,50
-1,00
c
HIGH WATER, EXISTING SITUATION
HIGH WATER AFTER EXECUTION OF DELTA WORKS
LOW WATER AFTER EXECUTION OF DELTA WORKS
LOW WATER, EXISTING SITUATION
500 1030 1160 1250 1365 1500 1605 1750 2000 2250 2500 3000 3500 4335 5205 7500
DISCHARGE UPPER RHINE AT LOBITH IN m³/sec

Table 6.2.2
Possible phase classification for the future distribution of the upper water in the Delta area

Phase	Limit of the phase	Rhine discharge in m³/sec at Lobith	
		Summer	Winter
I	Rhine discharges smaller than those at which the chloride content at Parkhaven at high water turn of tide has reached the limit of 300 mg Cl/litre with a dammed discharge of the Neder-Rijn	<1160	<1120
II	Rhine discharges larger than those in Phase I but smaller than those at which – maintaining the 300 mg Cl/litre limit at Parkhaven – it is possible to deliver the maximum needed quantity of water to the Zealand Lake	1160—1365	1120—1190
III	Rhine discharges larger than those in Phase II, but smaller than those at which – maintaining the feeding of the Zealand Lake – the chloride content is decreasing at Vijfsluizen to 300 mg Cl/litre	1365—1605	1190—1380
IV	Larger Rhine discharges than those in Phase III	>1605	>1380

The four phases given in Table 6.2.2 will now be examined more closely.

Phase I

With these small river discharges the IJssel at the present time has little depth, while the Nieuwe Maas is silted up over a long distance. By the execution of the Rhine canalization and the Delta Works there will, indeed, be a considerable improvement made, although even if the Oude Maas is closed the situation will still be unsatisfactory. Along the IJssel the desirable supply of 250 m³/sec for ship draught (see note on page 64) will not yet have been reached, while the chloride content at Parkhaven at high water turn of tide will be higher than the acceptable figure of 300 mg Cl/litre. In view of the interests involved in having a good water household, it is clear that during this phase the regulating programme of the dam in the Neder-Rijn near Driel and the sluices in the Haringvliet Dam should be based on such a distribution of the available upper water that, in the first place ,– as far as possible, – the water needs are met for the agrarian, domestic and industrial purposes, as well as the primary necessity of combatting salt leakage and providing flushing water in the Oude Maas and the Haringvliet.

The sluices in the Haringvliet remain closed, except for flushing back salt leakage and other flushing water, which is also the case for the closings in the Oude Maas and the outlet sluices in the Volkerak Dam. So the Zealand Lake is completely independent. The quantities of water that will have to be drawn off from this lake will come from its own water storage. In addition, by careful investigation of all interests concerned, it will be regularly studied whether, and if so by what dam programme, the Rhine canalization can be put into operation. Only when the Rhine discharge has increased to about 1150 m³/sec will there be sufficient water available to operate the Rhine canalization fully so as to reduce the chloride content near the Parkhaven to the acceptable limit of 300 mg Cl/litre at high water turn of tide. During the remaining phases of the tide the chloride concentration is lower, as well as further upstream of the river.

Phase II

As soon as more upper water becomes available, other interests can also be served. Possibly the surplus water will not at once be used to push the salt limit farther back on the Rotterdam Waterway, but that in the beginning it will be preferred to discharge a supplementary amount of water through the Haringvliet sluices, not only to combat the salt leakage and provide flushing water, but also to flush away the percolating salty water from the polders which will discharge into the Haringvliet basin. It seems sufficient to strive first for a chloride content of 250 mg Cl/litre in the Haringvliet basin, for which in most cases rather small quantities of river water will be needed.

If after this has been done upper water is still left, this should not be discharged through the Oude Maas but be used to control the level in the Zealand Lake as well as for the flushing of this lake to eliminate the effects of the percolating salt water of the polders. Only when the Rhine discharges have increased to about 1200 m³/sec (winter) or about 1350 m³/sec (summer) can the maximum quantity of water needed be fed to the Zealand Lake with which a satisfactory situation of the fresh water economy will be obtained.

Phase III

When the Rhine discharge increases above 1200 m³/sec (winter) or 1300 m³/sec (summer) respectively a start can be made on trying to reduce the salt limit of 300 mg Cl/litre in the Rotterdam Waterway unto Vijfsluizen, which is of so much importance for the Westland horticultural area. This point is reached with Rhine discharges of about 1400 m³/sec (winter) and 1600 m³/sec (summer) respectively, unless it must be delayed because of too high a rise of the ebb velocity in the Noord. (See also under 6.3.2 and, in connection with this Table, 16.1.5 of Contribution IV.4).

Phase IV

After the salt limit in the Rotterdam Waterway has been pushed back to Vijfsluizen, the remaining upper water, being superfluous, can be discharged through the Haringvliet sluices.

With increasing Rhine discharges the area of the Lek also becomes greater. Along the Noord less water has to be sent into the Rotterdam Waterway. And finally the Lek discharge alone is sufficient, or even more than sufficient, to combat the salt in the Rotterdam Waterway. But in connection with the flushing, care must be taken to see that the Noord continues to contain some upper water. On this basis, the Haringvliet sluices can only be fully opened at ebb tide when there are very large upper water discharges, which on an average occur only a few days in the year.

If the upper discharges are further increasing, a situation arises in which the upper water distribution for the Lower Rivers is no longer under control. The measurements of the Haringvliet sluices, however, have been chosen on such an ample scale that it will not be their flushing profile that would cause such a situation but rather the natural discharge capacity of the Lower Rivers themselves.

Table 6.2.3 contains the four phases just discussed differentiating between the summer and the winter half-yearly periods and joining up with the Rhine discharges, while also giving the chances of the occurrence of these phases during an average number of days. It is not possible without more information to set up a comparative classification in phases, because at present there are no regulating possibilities available, and also because no water withdrawal and storage takes place as will be the case when the Delta Plan is in operation. Moreover, there are now no limit criteria between Phases II and III (feeding of the Zealand Lake). For further information by which to judge the improvements to be provided by the Delta Works in respect of the distribution of the upper water over the existing situation, see Contribution IV.4.

Table 6.2.3

Possible phase classification for the future distribution of the upper water in the Delta area for the situation after the execution of the Delta Works (Oude Maas closed and the Rhine canalization in operation)

Rhine discharge in m³/sec			Chance of occurence in days per		
Phase	Summer	winter	summer	winter	year
I	<1160	<1120	12	23	35
II	1160—1365	1120—1190	15	7	22
III	1365—1605	1190—1380	22	19	41
IV	>1605	>1380	134	133	267
		Total	183	182	365

The regulation of the water distribution will not, however, in the meantime always be able to be exclusively attuned to the interests of the fresh water economy and of the shipping on the IJssel.

In view of the possible necessity of keeping the outlet channel on the sea side of the Haringvliet locks on depth, the discharge through these gates will occasionally have to be increased at the expense of the discharge along the Rotterdam Waterway, although any excess of chloride content of 300 mg Cl/litre during high water turn of tide near Parkhaven will have to be avoided as much as possible. The opposite will also have to take place by temporarily increasing the water discharge along the Rotterdam Waterway so as to retain as great a depth as possible along that important shipping route. It is also possible that the movable dam in the Oude Maas will have to open fully with normal and large Rhine discharges, or only at ebb tide. These possibilities, however, must be given further extensive study.

Further important differences in the preliminary distribution programme will originate as a result of the influences of the wind, especially at times of rising and falling of the average sea level. When the sea level rises such an increase will not at first be followed in the Haringvliet basin. There will thus be a difference of level between this basin and the sea so that the discharge of upper water via the Noord and the Rotterdam Waterway will strongly decrease.

In view of the battle against the salt in the Nieuwe Maas it may then appear necessary to put the Haringvliet basin at a temporary higher level by limiting the discharge through the Haringvliet sluices. Conversely, it can also be necessary with a lowering of the sea level to increase the discharge through the Haringvliet locks to prevent too great velocities originating in the Noord. The smaller the buffer effect of the Haringvliet basin, the more rapidly will it be possible to apply it to the other sea levels, while other water discharges will also be possible. In this connection, the importance should be indicated of the dam through the Volkerak which prevents the very great buffer effect of the Zealand Lake from playing a direct role. The satisfactory regulation of the upper water discharge would make this impossible.

When a storm flood tide is approaching, of course, it may well be that a different discharge programme will be followed. It is thinkable that in such circumstances, and putting aside the interests of the fresh water household, as much water as possible will be discharged, probably through the Volkerak sluices, to give this basin as large a storage as possible by decreasing the level.

Differences in the normal distribution programme can also be expected during times of heavy ice when it will be necessary to have the Haringvliet sluices open during both ebb and high tides.

It has appeared from the foregoing that the execution of the Delta Works will make a very important improvement in the fresh water economy of the country. It is also clear, however, that even with the carrying out of this great plan it will not yet have been possible to meet all that was desired in this respect, while for the future it must be calculated that more and more water will be wanted from the rivers for agriculture, industry and the drinking supply, as well as a better quality of the water.

It is obvious, of course, that works which would result in increasing the quantity of salt water admitted to the fresh water area or reducing that area in the Delta region would damage the fresh water economy seriously, and add to the difficulties caused by the fact that it was not even then entirely satisfactory.

This means that it will always be necessary to keep the fresh water household of the country under strict observation and to do everything possible to prevent the working of disadvantageous influences and, moreover, to compensate them in every way practicable.

This includes arranging for the correct distribution of the upper water, as well as keeping the quality as high as possible, while at the same time reaping all the benefits that can be achieved in the various fields affected.

The Committee feels it necessary in this connection that in the future a Central Managing Board be instituted for the fresh water economy of the Netherlands. It will be the task of this authority to keep itself fully informed about all the existing and changing circumstances and situations occurring in respect of the quantity and quality of the water being supplied, and also of the needs that are arising, thus ensuring that the distribution of the upper water will be made in such a way that it achieves the maximum economic effects.

6.3 The hydraulic situation with normal sea levels

6.3.1 *Normal water levels*

The water levels in the Lower Rivers depend on the sea tides, the discharges of the upper rivers and the distribution of this upper water over the Lower Rivers. In the present situation the dominating influence is that of the sea. Thus it is, for example, that the high water at Willemstad lies on an average at almost N.A.P. + 1.3 m while the low water stands at N.A.P. — 0.8 m.

The difference in the tides, therefore, amounts to more than two metres (over six feet), while there is only a difference of a few decimetres whether the Rhine discharge is 10,000 m^3/sec or only 1,000 m^3/sec.

All this, of course, will change considerably after the finishing of the Delta Works. With small water discharges when the Haringvliet sluices are closed, the tidal movement will then be able to enter only through the Rotterdam Waterway upto the Haringvliet basin. Under those circumstances the water levels in the Rotterdam Waterway itself will undergo little change, but further upstream, in the direction of the basin, the tidal movement will be gradually lowered to an extent in which the tidal difference in the Haringvliet will amount to only one or two decimetres.

With larger river discharges as meant above, the tide will be increased when at ebb the superfluous water is let out by the Haringvliet sluices in the form of intermittent discharges from the basin at the rear. The tidal difference in the basin will increase as the Haringvliet sluices are opened wider and wider with growing upper water discharges. Finally, with large and very large discharges, which occur only a few times, the tidal difference on the inner side of the Haringvliet sluices will amount to about 8 to 9 dm (3 feet). This is less than half of the similar tidal difference under the present circumstances. In an upstream direction the tidal difference will decrease as a result of hydraulic resistance. Indeed, this difference will be hardly noticeable in the wide Haringvliet and Hollands Diep, but near Werkendam, for example, there will remain, as is now the case with high river discharges, only 4 to 5 decimetres of tidal movement.

Apart from the changes in the tidal difference already discussed, there are the changes in the half-tide levels which are characteristic of the influence which the Delta Works will exercise on the river levels in the area of the Lower Rivers.

In the Rotterdam Waterway these changes are of little significance. The half-levels admittedly get higher with increasing discharges, but this will occur in the future in almost the same measure as at present.

But the situation will be entirely different in the Haringvliet basin and the waters directly connected to it. There the half-tide levels mainly relate to the upper water distribution along the Haringvliet and the Rotterdam Waterway, which is mostly capable of regulation by limiting or not limiting the discharges of the Haringvliet sluices. The more water sent out in this way in the direction of the Rotterdam Waterway, the higher will the half-tide levels rise as a result of the rather small outlet capacity of the rivers lying in between. This rise will be smaller if the Oude Maas is open than if it is closed and the same quantity of water must be discharged only via the Noord. The difference between both half-tide levels on the Haringvliet is a few decimetres with normal and small river discharges, a point which is of interest in connection with producing and maintaining the level in the Zealand Lake via the Volkerak sluices.

When during a large discharge of the rivers the Haringvliet sluices are partly opened at ebb, the mid-levels will drop in the Haringvliet basin.

Finally, with very high upper discharges the water resistances in the Haringvliet, Hollands Diep, etc. will exercise an important influence on the water movement. By this the mid-levels will again rise. However, the water levels near Werkendam and the mouth of the Donge will differ only a little, while further upstream there will be no difference at all from similar levels in the present situation.

As can be seen from the preceding remarks, the tidal and the half-tidal differences, and thus also the high and low water levels, in the Haringvliet basin will be linked up closely with the size of the upper water discharge and the discharge programme followed in the Haringvliet sluices. As an illustration of this, Fig. 6.2.4 gives the water levels at Willemstad as a function of the Rhine discharge. The connection shown, however, gives only a rough and simplified survey based on a regulation programme of the Haringvliet sluices which is also the foundation of the preliminary classification in the four phases already dealt with. From this diagram, therefore, no information should be taken for detail designs of adjustment works. The main thing is that in the diagram the Rhine discharges are shown in such a way as to give an idea of the frequency with which they occur.

Concerning the level regulation of the Zealand Lake, a few remarks now follow for orientation, based on Contribution IV.4.

In those parts of the Zealand Lake intended to be used as a water reservoir there will usually be, as in the IJssel Meer, two different levels to take into consideration, namely, a summer level and a winter level.

To form a water storage in the Zealand Lake, the level will move gradually during March and April into a summer level of about N.A.P. + 0.5 m. A much higher one cannot apparently be reckoned with through the natural entry from the Haringvliet basin.

As long as the upper rivers supply sufficient water, the summer level will be maintained, as far as is possible, by supplying the loss through evaporation and through the withdrawal of water by bringing in additional water through the Volkerak sluices.

With small Rhine discharges, as mentioned in 6.2.3, no water, or at best insufficient water, will be available to keep the Zealand Lake at level and to flush it. Then the letting in through the Volkerak sluices will have to be stopped or limited, and reliance for the water supply and for the fight against salt be placed on the water store of the Zealand Lake itself. The summer level of the lake can by this gradually fall to N.A.P. – 0.5 m or lower. As a very low level which during a few months could occur in very dry years, 1947 and 1949 may be mentioned when at the end of the growing season for a few months it was down to N.A.P. – 1.0 m to N.A.P. – 1.25 m.

During the winter season the level aimed at in the Zealand Lake will probably be N.A.P. or lower. To attain this, the summer level will be lowered in September (or earlier if the season is wet) by temporarily limiting the entry of water through the Volkerak sluices and by discharging as much as possible through the different discharge facilities. If the summer level had already been falling considerably during the growing season, it is possible that water would then have to be added to the lake to reach the winter level. For further discussion on the level regulation of the Zealand Lake, reference is made to Contribution IV.4.

Although a number of uncertainties exist about the normal water levels of the Zealand Lake and the Haringvliet basin, one thing at least is certain: that the removal of the low water levels will necessitate a number of provisions to maintain good water discharge for the polders and high ground. These adaptation works will vary strongly from polder to polder and will have to be examined for each area separately. Moreover, it is recommended to combine the water discharge areas and then design the systems by which the water can be admitted and used as flushing.

6.3.2 *Normal current velocities*

In the Rotterdam Waterway, downstream from the intersection with the Oude Maas, the tidal volume, as a result of the Delta Works completion, will decrease by 20% to 30% with average Rhine discharges. See Contribution IV.3. The 20% decrease is for a situation in which the Oude Maas remains open, while the 30% is for when it is closed off. It may be expected that the ebb and high water velocities, averaged over the cross-section, will be lowered by about the same percentage, which will be an advantage for shipping on the Waterway. But against this advantage it is to be expected that both inside and outside the mouth of the Waterway more maintenance dredging works will have to be carried out than at present.

In the upstream course of the Rotterdam Waterway, in the Nieuwe Maas and in the Lek the current velocities will not materially change to the advantage or detriment of shipping.

To the Noord, however, much attention will have to be given in the future, especially if, within the scope of the Delta Works, the Oude Maas has been closed and the Noord has to cope with a great quantity of upper water.

It has been calculated by the Rijkswaterstaat (Government Waterways Department) that the average discharge of the Noord during the period 1946–1959 inclusive was about 260 m^3/sec in the existing natural distribution of the upper water. When the Delta Works will be completed, with the Oude Maas closed, this quantity will run upto an estimated 660 m^3/sec, while the discharge with an open Oude Maas can be put at about 320 m^3/sec. In the first case peaks will even occur of from 800 to 1,000 m^3/sec.

However, by the regulating programme chosen for the Haringvliet sluices the increase of the ebb discharge along the Noord can be kept well in hand. See what has been said on this point in dealing with Phases III and IV under 6.2.3.

The current velocities of the various discharges of the Noord are summarised in Table 6.3.1 taken from Contribution IV.4.

Table 6.3.1

Maximum ebb and high tide velocities in the Noord with average and maximum upper water discharge along this river and an average tidal movement at sea

	Present situation	Delta Plan		
		Oude Maas open	Oude Maas closed	
Discharge	Average 260 m³/sec	Average 320 m³/sec	Average 660 m³/sec	Maximum 900 m³/sec
Maximum speed high tide . .	0.25 m/sec	0.45 m/sec	0.60 m/sec	0.40 m/sec
Maximum speed ebb tide . .	0.60 m/sec	0.85 m/sec	1.15 m/sec	1.25 m/sec

The speeds indicated are averages counted over the whole of the present cross-profile. The greatest speed, which occurs near the surface in the middle of the river, is about 20% to 30% greater.

According to Table 6.3.1, the accelerated velocities remain within the limits admissible for shipping but they make it probable that the Noord will scour out, even if the Nieuwe Maas as part of the Delta Works remained open. As the widening of the Noord would scarcely, or not at all, contribute to a reduction of the current speeds – the tidal movement would then get stronger – it seems probable that in the future it will be impossible to avoid the making of a bottom protection here.

Although the mid-levels in the Haringvliet basin would be lowered by the widening of the Noord, such a widening is nevertheless not attractive in the interests of the formation and maintenance of the water reserve in the Zealand Lake. The widening of the Noord, therefore, can only be considered if this would be necessary for safety reasons during storm-flood tides or very large river discharges, or for shipping. In connection with the latter reason, the intersecting points near Dordrecht and Krimpen aan de Lek also require special attention.

In the Dordtse Kil the situation will be more favourable than in the Noord. The velocities generally do not there become great, or at least will not when the Oude Maas is closed. Yet in the upstream course of the Kil some scouring can be expected. Moreover, as the current speeds in the Kil will increase if the Noord is widened, the two rivers cannot be taken into consideration independently.

In the Oude Maas the current velocities will not become significantly greater than at present when the Delta Works are completed. If the river is to be closed, then of course the speeds will be very small.

In the upper mouth of the Spui, near Oud-Beijerland, an improvement in the streaming seems desirable.

In the Haringvliet, the Hollands Diep and the Merwede rivers, as well as in the downstream course and the connecting upper rivers, the current velocities generally will greatly decline. See also Contribution IV.3.

6.3.3 *Situation during ice drift*

In the Zealand Lake, in addition to the absence of tidal movement, one of the most important changes will be the obtaining of fresh water. In severe winters, however, this will promote the formation of a solid crust of ice.

As fresh water has its greatest density at 4° C, during any cooling off all the water down to the bottom must be reduced to 4° C before the temperature of the water on the surface can drop still further until the formation of ice can occur. This effect, of course, is delayed by the great amount of water exchange that takes place as a result of the turbulence caused by currents or winds.

With sea water, the formation of ice follows a completely different pattern. When the salt content is 24.7 $^0/_{00}$ or more, the water becomes heavier and heavier when cooling down. The temperature of the surface water, therefore, will not fall to or below freezing point until all the water has been cooled down. Moreover, the freezing point here becomes lower in proportion as the salt content is higher.

As a result of this, ice formation only takes place when the whole of the water contents has cooled down to around –1.5° C in the Zeeland waters where the salt content almost everywhere is more than 24.7 ‰.

Then, too, there will also be changes in the existing circumstances in the water of the estuaries concerned which now mixes with the North Sea water which has a higher salt content. This North Sea water, moreover, is somewhat warmer in cold periods than the water in the sea-arms. This exchange of warmer and colder water naturally hampers the formation of ice, a situation that will not exist when the sea-arms are closed. See Contribution IV.5. With these favourable influences no longer operating, ice formation will occur in the fresh water lakes when the water has a surface temperature of just onder 0° C, while at the bottom, or at least in places where mixing as a result of the wave effects can be neglected, the temperature can still amount to 4° C.

Because of this, ice formation on the Zealand Lake must be expected earlier than at present on the open waters. The amount of ice, however, which will be formed in a severe winter need not be very much more than at present because of the insulating effect of a permanent ice cover. The new formation on the Zealand Lake will be less than that on the IJssel Meer (Zuyder Zee) and the Frisian lakes because of the climatological differences of those areas.

The formation of ice on the Zealand Lake can hamper shipping transit only when it lasts for as long a period as it often does on the sailing channels of the Rhine. But as this is not expected to be the case, especially when ice-breakers are operating, it will produce no difficulties.

However, measures must be taken during thaws caused by westerly winds to prevent the broken ice cover being forced up in such a way that it would clog up the shipping channel from Wemeldinge to the Hollands Diep. This can be avoided by constructing screen dams to keep the floating ice from the channel, and in several places the existing sand shallows can perform this function.

As for combatting the ice in the area north of the Volkerak Dam, a few points should be recorded.

One of the most important points of difference here from the more southerly situated waters is that the Nieuwe Merwede, the Hollands Diep and the Haringvliet are the main discharge channels of the floating ice coming from the upstream rivers.

With the existing situation the problem can be solved by breaking the river ice cover upstream of the bridges near Moerdijk, while downstream of the bridges the ice can be kept loose by the tidal movement and then be discharged along the Hollands Diep and the Haringvliet without further artificial interference.

If it should appear, however, after the completion of the closing works that the ice of the upstream rivers can be discharged through the Haringvliet gates by maintaining the normal discharge programme, by which the sluices are closed at high tide, then such a discharge programme must naturally be followed. The vertical tidal movement and the tidal currents in the Haringvliet and the Hollands Diep will not be large, and so will promote ice formation and fixing by the freezing of the ice fields. A further contribution to this will be that the closing of the sea-arms will be keeping out the usually warmer sea water with its low freezing point.

The question will, therefore, be whether with the normal discharge programme of the Haringvliet sluices it will be possible to keep the ice cover open with the aid of ice-breakers in severe winters. As it is not possible to make any predictions in this point, allowance must be made for the possibility that in severe winters, which may be expected on an average every five years, the Haringvliet sluices will have to be kept open at both ebb tide and high tide to let as strong a tidal movement as possible into the Haringvliet basin. The weakening of the tide by the quenching effect of the Zealand Lake will be prevented by the closing of the Volkerak.

In addition, if it appears necessary, ice-breakers might be put into operation downstream of the Moerdijk bridges to ensure the discharge of the ice in the interests not only of shipping but also of safety.

Finally, the Committee recommends that the promotion of the development of new methods of combatting ice be undertaken as much as possible.

6.4 Sand movement in the sea-arms and along the coast

6.4 Under the influence of the governing currents and the wave movements in the sea-arms and on the coast a great deal of sand is set in motion. The currents can be tidal currents, wind-drift, currents aroused by waves, or currents resulting from density differences in the water. Although the currents and the waves can each separately transport a lot of sand, the actual sand transport in the sea-arms and the coastal waters is finally governed by the combined effect of both.

As along the coast the current resulting from the tidal movement is directed northwards, and as the wave energy running towards the coast also has a resulting northward component, a continuous sand transport in that direction has to be accepted. However, it should be noticed that this transport seems to be usually only a small fraction of the total quantity of sand which comes into motion through the currents and the waves.

Between the sea-arms and the neighbouring sea area there is a strong exchange of water, which means that the influence of the sea-arms can therefore be seen to a considerable distance from the coast where during a great part of the tide the currents are more or less vertically directed to or off the coast. In the south, at the height of the mouths of the Scheldts, this effect is much stronger than more northerly, for the Brouwershavense Gat and the Zeegat van Goeree. Moreover, not only does the difference in capacity of the sea-arms mentioned play a role, but also the phase differences between the currents in the sea-arms and those in the sea, which are greatest in the south. In the sea-arms, deep channels are usually found between the shallows, in which the larger part of the current is concentrated. Farther from the shore in the deeper sea area, the current is directed more parallel to the coast, while the shallows also are more orientated in this parallel direction. Between the two areas just mentioned lies the so-called under-water delta. In this rather shallow region the channels coming out of the sea-arms end in a more or less fan-shaped form where the difference between channels and shallows becomes less marked. The current does not show turns of the tide in this area, but turns round during one tide without appreciably changing in strength.

The building up of this under-water delta is mainly the result of the more or less vertically directed coastal currents to and from the sea-arms. The sand which is taken by the ebb currents out of the sea-arms, and the sand moving along the coast, is therefore taken by this ebb current to places where the wave movement affects it less. As the under-water delta is built up further, more sand is transported to the coast and in a northerly direction by the wave movement and flood current where, in the long run, a sort of possibly dynamic balance can be formed for the under-water delta and the sea-arms, and around which fluctuations of importance can occur which may be of very long duration.

Calculated over the period 1872–1952, the Eastern Scheldt scoured out, while the Brouwershavense Gat and the Zeegat van Goeree showed some sanding-up. See Contribution IV.6. The quantity of sand which is now heaped up in the under-water deltas amounts to several milliards of cubic metres.

When the sea-arms are closed, the vertical currents along the coast will largely disappear, so that then there will only remain mainly a current directed parallel to the coast. What effects this change of the current picture will have on the sand movement in this part of the coastline cannot yet be predicted with certainty.

The observations made since the closing of the Brielse Maas in the mouth area of this sea-arm show that after that closure a strong although somewhat irregular sanding up has been taking place. The sanding is strongest in the channels running almost vertically to the coast, while the under-water delta is subject to erosion on the sea side. Roughly speaking, the changes observed here indicate sand replacements in the direction of the coast.

On the basis of the experience in the Brielse Maas mouth, a similar development can probably also be expected for the more southerly located sea-arms when these have been closed. In addition to strong similarities between the first-mentioned mouth and the other sea-arms, there are also, however, important differences which, as far as any predictions are concerned, are grounds for caution. In this connection attention is drawn to the fact that the Brielse Maas mouth is somewhat protected by the protruding causeways at the sea end of the Rotterdam Waterway, and this is not so easily influenced by the current directed along the coast. On the other hand, the more southerly sea-arms will certainly be sensitive to that effect.

There is no doubt that the deep channels which cross the under-water deltas will sand up considerably. In addition to the degeneration of the channel system directed more or less vertically to the coast there will, however, be the inclination or tendency to a formation of other channels running parallel to the coast, although these will probably be less strongly developed. It is not unlikely, too, that by such a channel formation the protruding undefended heads of the islands will be threatened, which would then necessitate the construction of coastal protection works.

It may be accepted that after the completion of the closings the outside section of the under-water deltas will decrease in size, and that in front of these a formation of dams will arise in the course of time, or perhaps a continuing beach with a row of dunes will originate.

The disturbance of the existing relative balance in the Delta area can also possibly have far-reaching results for the whole mouth area of the Rotterdam Waterway and the level coast lying north of it.

Furthermore, it is almost certain that in the very long run – a matter of decades or even centuries rather than of years – the under-water deltas will be entirely removed and that in front of the Delta area a more or less level coastline will result.

In the interests of protection against the sea as well as of shipping, it is desirable to watch the sand movements in the coastal waters after the completion of the whole Delta project. The Committee therefore recommends that this huge area be carefully sounded in front of the coast regularly before and during the closing works and also for a long time afterwards, if possible every year. In this way even in an early stage an idea will be obtained of the speed and nature of the various causes and effects and symptoms that have been outlined above. It is also recommended that a study be made of the sand replacements by all available means before the closing works are actually started, and then to continue this study during the execution of the works and for a long period after.

Shipping interests also make it necessary to give special attention to the mouth of the Western Scheldt and that of the Rotterdam Waterway. The Committee closes this section by again emphasizing the great value of a continuation of the study of these coastal problems just mentioned and of the necessity of making available for it all the means called for.

6.5 Possibilities of land reclamation, recreation, etc.

The proposed Delta Works open up attractive perspectives for land reclamation as well as for the creation of new possibilities of recreation, for both of which there is a great need in the Netherlands. The construction of residential centres and industrial areas must also be considered.

As the tidal movement and the storm tides penetrate only to a limited scale in one portion of the area concerned, and not at all in the remaining part, the possibilities for the reclaiming of land are considerably increased. These same circumstances, and also the facts that many shallows and shorelands will lie partly dry when the level can be kept low and that the connections with the important population centres will be greatly improved, means that there will also be the possibility of producing new recreation areas.

It has already been pointed out, however, in an earlier section that this sort of use of the Delta project is justified only on a limited scale, as there can be none too great a sacrifice of the required water storage capacity by which it is intended to obtain safety and a satisfactory national water economy, even though the side-advantages may be important in themselves. Land reclamation would result in the water storage becoming smaller and the amount of fresh water less. Then, too, this could only be regarded as permissible if, compared with the demands of safety, the agrarian production would thereby increase more than it would if given a better water supply. In this respect there must also be taken into consideration in a national sphere the question of how far the possible improvement under the Delta Works of the fresh water household could perhaps be achieved in other ways. Finally, social considerations must also play a part in this problem.

Somewhat similar considerations arise when the point is raised whether some parts of the new fresh water surface area should be seized in the interests of fisheries, recreation, town expansion and even possibly harbours.

At this stage also the possibilities might be indicated of how the execution of the Delta Plan could fit in with the development of what is called Randstad Holland (or the great conglomeration of urban interests lying in the heavily populated area between places like Rotterdam, The Hague, Gouda and Dordrecht). The Delta scheme might also help in solving the problems arising from the harbour extensions along the Rotterdam Waterway. In other words, by the execution of the Delta Works space is being created which can lead the planological development in good channels.

Although national interests are at stake in each of the areas mentioned, it is only after the careful study already outlined in 6.2.3 that a decision can be arrived at as to how far it is permissible to withdraw a certain area from the natural waters and make them available for other purposes.

It is, of course, of the greatest interest and importance that the Delta Works – seen from a national viewpoint – will give as great a yield as possible. For more about this, see the Committee's Interim Reports Nos. 2 and 3 mentioned in Bibliography (12, 13, and 14). The various interests related to the Delta Plan have already been given great attention to by those concerned, but it would be wrong if those interests would be looked at only one-sidedly or from a particular angle. They already demand opposite requirements. So to reach the right and best decision, the Delta Committee recommends that a further study be urgently made in the course of which the representatives of the varying interests must try to solve their problems in mutual cooperation.

7.0 LOCATION OF THE CLOSURES AND THE ORDER OF PREPARATION AND EXECUTION OF THE DELTA WORKS

The Committee has given general consideration to the places at which the closing dams should be constructed as well as to the order in which the different works should first be prepared and then executed. In this respect the model of the Lower Rivers and sea-arms studied in the Hydraulic Laboratory and the measurements and calculations made by the Rijkswaterstaat (Government Waterways Department) have supplied important and useful information. See Contributions IV.1 and IV.3.

7.1 The location of the closing dams

In determining the exact spots at which the closing dams should be built, it is necessary first to take into account the existing situation and the changes that will result there from the construction of the dams.

The choice of the closures near the sea is in the first instance indicated by the necessity of increasing the safety. From the viewpoint of storm-flood protection it is desirable to have a coastline as short as possible, which means that there is an inclination to project the dykes between the islands at the extremity near the sea. In this way also there is a limit put to the length of the dams outside the existing main water protections which have to be strengthened.

Location as far as possible outside also promotes the interests of safety, the fresh water economy and the land reclamation, because such a location provides a maximum area of possible water basin inside the dams.

However, the many difficulties and risks connected with the execution of works – most of which cannot be precisely seen in advance – put limits to the seaward location of the dams. Very close to the sea means interference by strong wave movement, and consequent danger of damage to the construction works and equipment, accompanied by great delays in the work as a result of unfavourable weather. These factors, of course, will be present throughout the whole area to a certain extent, but they will be most strongly detrimental near the sea. Moreover, there is not much actual information on these factors available for this area. That is why, as far as is still possible, it is desirable to make wave measurements, supplemented by laboratory investigations, so that a better view can be obtained of the working possibilities in the sea-arms.

As has already been pointed out in 5.6, there is no doubt at all about the technical possibility of executing these closings of the sea-arms, but it would nevertheless be unjustified to carry out the works in such a way that the difficulties to be mastered would become disproportionately large.

Finally, it should be indicated that the further seawards the sites for the proposed dams are chosen, the more will the tidal volumes and the throughpassing currents increase, which in their turn would increase the size and the cost of the closing works.

But as the advantages and disadvantages of putting the dams closer to the sea at the mouth of the sea-arms cannot be put into a concrete form to create a balance-sheet at the moment, it is not possible for the Committee to come to a general decision on the choice of the plan that would be best for these closings. This must be left to the results of the detailed study which will be made of the different designs for the dammings, so that those who finally decide will be able to take the responsibility for the execution. It is the final arbiters who alone will be able to judge which risks may be regarded as acceptable and which are not.

In determining the actual sites of the dams, of course, an important role is played by the choice of the connecting points with the existing main water protection network. In this the general interests of the neighbouring land must as much as possible be taken into consideration. See also Bibliography (14b).

Although the interests of traffic are not of primary importance in selecting the sites of the dams, these also will have to be taken into consideration as far as possible.

All these factors show that the choice of the dam sites and of the general plan of their construction must take into account a number of different interests which are of such importance that they should be further dealt with here, even though only partially. In this connection the Committee felt that a diagrammatic picture of these plans would suffice, although the members know that the sites have already been wholly or for the greater part decided on for some of the closings. See also Enclosure 5.0.1.

Concerning the factors which are of influence for the choice of the site of each of the dams, the following remarks might be made.

Because of the situation of the neighbouring dykes, the site of the closing of the *Hollandse IJssel* had to be chosen very close to the mouth. In this choice, too, the actual construction of the closing was of influence. In the opinion of the Committee, this choice has meanwhile proved satisfactory.

When selecting the site for the damming in the *Haringvliet*, the circumstance had to be taken into account that a large complex of sluices was essential, in addition to the requirements of the dam itself. In this project full consideration had to be given to the facts that during the construction of the sluices there would be strong tidal currents to contend with, that the sluices would be exposed to heavy wave attack after the work was completed, and that the works themselves would exercise considerable influence on the movement of sand and mud. In this case also the Committee agrees fully with the choice of site and plan.

As far as the choice of location for the damming of the *Brouwershavense Gat* and the *Eastern Scheldt* are concerned, the Committee has no special comments to make, apart from those already mentioned as having been located near the sea.

In determining the plan for the closing of the *Veerse Gat*, it was recommended to project it as much seawards as possible in order to meet circumstances similar to those to be later expected in the Eastern Scheldt and the Brouwershavense Gat. In this way the carrying out of that work will supply experience which can be very important and valuable for the closing of the two last-mentioned sea-arms. In this case as well the Committee agrees with the project that has in the meantime been determined on.

The dam in the upper mouth of the *Grevelingen* mainly has the function of separating the storage basin areas of the Brouwershavense Gat and the Eastern Scheldt. The site of this dam will be determined above all by the requirement that in no single intermediate stage will an inadmissible current arise in or near the Zijpe. Traffic also plays a part here, but this can only be dealt with within the hydraulic limits.

The site of the damming of the *Zandkreek* is in principle tied to the area in which the tidal currents in the channel are weakest, that is, near Katse Veer. In the choice of location, which is right in the opinion of the Committee, local interests have also played a role.

In chosing the trace for the closing of the *Volkerak*, notice had to taken of the difficulties which can arise with ice drift, both for shipping and for the penetration of salt in the Zealand Lake. In the case the closure will be achieved farther south of the junction point of the Volkerak, Haringvliet and the Hollands Diep there will originate a larger area of water north of the dam in which floating ice can pile up and hinder shipping. When the Haringvliet gates are opened to discharge the ice, salt will also penetrate into this dead arm which would be difficult to remove and which could penetrate into the Zealand Lake in the following inlet period. Because of this, the location here should be as far northwards as possible.

Moreover, account must be taken of the fact that the closing of the Volkerak Dam can be executed in the stage when the Eastern Scheldt is still open. The plan had, therefore, to be chosen by which a complex of large locks can be made without creating a current stream that would hamper shipping or cause danger to the neighbouring shores.

Finally, the interests of traffic entered into the picture when determining the plan for the Volkerak Dam, including the bridging of the Haringvliet.

All these interests that have been mentioned can be combined in a satisfactory way by closing the Volkerak according to a line running from the Brabant shore just south-west of Willemstad to the Hellegat dam, and through the Ventjagersgaatje to complete connection with the shore of Overflakkee. In this way the Committee feels a satisfactory solution will be obtained to cater for the final situation.

The site of the dam designed for the *Oude Maas* is to a great degreee dependent on space which is needed for the construction of the required locks with their feeder canals, as well as on the existing works and those still to be carried out.

7.2 The order of completion and execution of the works

Because of the nature and great size of the Delta Works it will not be possible for them all to be ready at the same time.

In the first place, the main effort must be to strive to complete those parts of the whole project which will provide the greatest and earliest possible improvement in security. In addition, the execution of the work must be planned so that advantage can be taken in carrying out the more difficult sections of the experience gained with the less difficult sections, not only in respect of equipment and materials but also of personnel, and in the light of what has been proved technically possible. This will ensure that in the interests of economic soundness no unnecessarily difficult, or even inadmissible, situations arise in the field of hydraulics which are not really justified.

Among the *closing works* the construction of the storm-flood weir in the *Hollandse IJssel*, which has been accomplished in the meantime, took a special place. This was because such a project, independent of the other dammings, could be carried out at any time. Moreover, this work was of a character and size of works that had been done before in Holland, so that no special investigations were necessary before actually starting on the project. Further, as this storm-flood protection provided a safeguard in behalf of a great length of dykes of the Hollandse IJssel, which in themselves protect an important part of the western area of the country and which were anything but reliable, there was every reason to complete that work in the first stage. The Delta Committee, therefore, proposed in its second Interim Report of May 26, 1953, that a start on that work be made as quickly as possible.

The Committee, moreover, is very pleased that this was done with great speed, even to the degree that such a storm-flood security could have been put into service, had it been necessary, in the winter of 1957–58.

As has already been explained in detail in the fourth Interim Report, the Committee thought it desirable to obtain experience with the damming of the Veerse Gat – which is of moderate size by comparison with the closing of the other sea-arms – and to use that experience for the preparation and execution of the succeeding closing works. This meant that the damming of the Veerse Gat had to precede the other closings as much as possible, and had to be tackled in the very first stage. As pointed out in 5.2.2, it was necessary to link up the closing of the *Zandkreek* with the closing of the Veerse Gat. This has led to the so-called Three-Islands Plan, with the execution of which considerable progress has already been made. With the carrying out of this plan, not only will the required experience and insight be obtained but here, too, as with the Hollandse IJssel, the security of the surrounding areas will be increased. Moreover, permanent connections will be established between North Beveland on the one side and with Walcheren and South Beveland on the other.

To determine the order of execution of the large closings in the Haringvliet, the Brouwershavense Gat and the Eastern Scheldt, it is important to investigate which of these dammings, in itself, will give the largest direct improvement in safety.

In this connection it can be indicated that the closing of the *Haringvliet* will lower the storm-tide levels along the main water protections in a vulnerable area along a greater length than either of the other two great dams. When the sluice-gates designed in this dam are closed at storm-flood tide, then the high water levels in the Haringvliet, the Hollands Diep and the directly connected waters will be lowered to the second highest level with a storm-flood tide such as that of February 1, 1953, and the river discharges that then occurred (Fig. 7.2.1, line I). At Willemstad, this fall amounts to about 0.55 metres, and in a southerly direction it drops gradually to nothing through the connecting waters to the Eastern Scheldt. On the Noord, the Nieuwe Maas, the Rotterdam Waterway and the Oude Maas the tide levels will already be somewhat lower also. In addition to this advantage, there is the fact that of the three large closings just mentioned (Haringvliet, Brouwershavense Gat and Eastern Scheldt), that of the Haringvliet will cause the least technical trouble. The discharge sluices to be built in advance can, for example, be open during the actual closing, enabling the currents in the closing gap to remain limited. Yet another advantage is that also with this closing a good deal of experience will be gained in working in open places which will be of the utmost use in the construction of the other two, and much more difficult, big dammings.

By giving priority to the closing of the Haringvliet the interests of the fresh water economy can also best be served, provided that the Volkerak Dam is also closed at about the same time. This is necessary so that it can be of considerable use even when the Haringvliet is not yet fresh. So also the Zealand Lake if formed earlier, could not be de-salted with an open Haringvliet.

Based on these previous considerations, it is clear that the Haringvliet is first singled out for completion. With it, indeed, important progress has already been made.

As explained in 5.2.2, an enclosing dam will be constructed in the eastern part of the *Grevelingen* before there can be any important decrease in the cross-profile of the Brouwershavense Gat or the Eastern Scheldt. But it is not necessary to wait with the closing of the Grevelingen until that of the Haringvliet is completed. Neither of the two closings can be expected to present serious difficulties, while the size of the works is not so great that they could not be done at the same time. So to ensure regular progress in the works, therefore, the Committee recommends that the damming of the Grevelingen be started at such a time that it will be ready to operate by the time the damming of the Haringvliet is completed.

The dam in the Grevelingen keeps the tide from penetrating the Brouwershavense Gat. This means that the storm-tide levels west of the dam will be increased, so in this area strengthening of the dykes much be carried out for the transitional period.

As long as the Volkerak has not yet been closed, east of the dam in the Grevelingen, especially also when the Haringvliet is closed, the storm-flood levels on Zijpe, Krammer and Volkerak will be lowered compared with the present situation. These lowerings appear for the area north of the Volkerak in Line II of Fig. 7.2.1. After the closing of the Grevelingen and the Haringvliet, therefore, security will be consideratelyincreased over a very large area. The construction of the dam in the Grevelingen will in

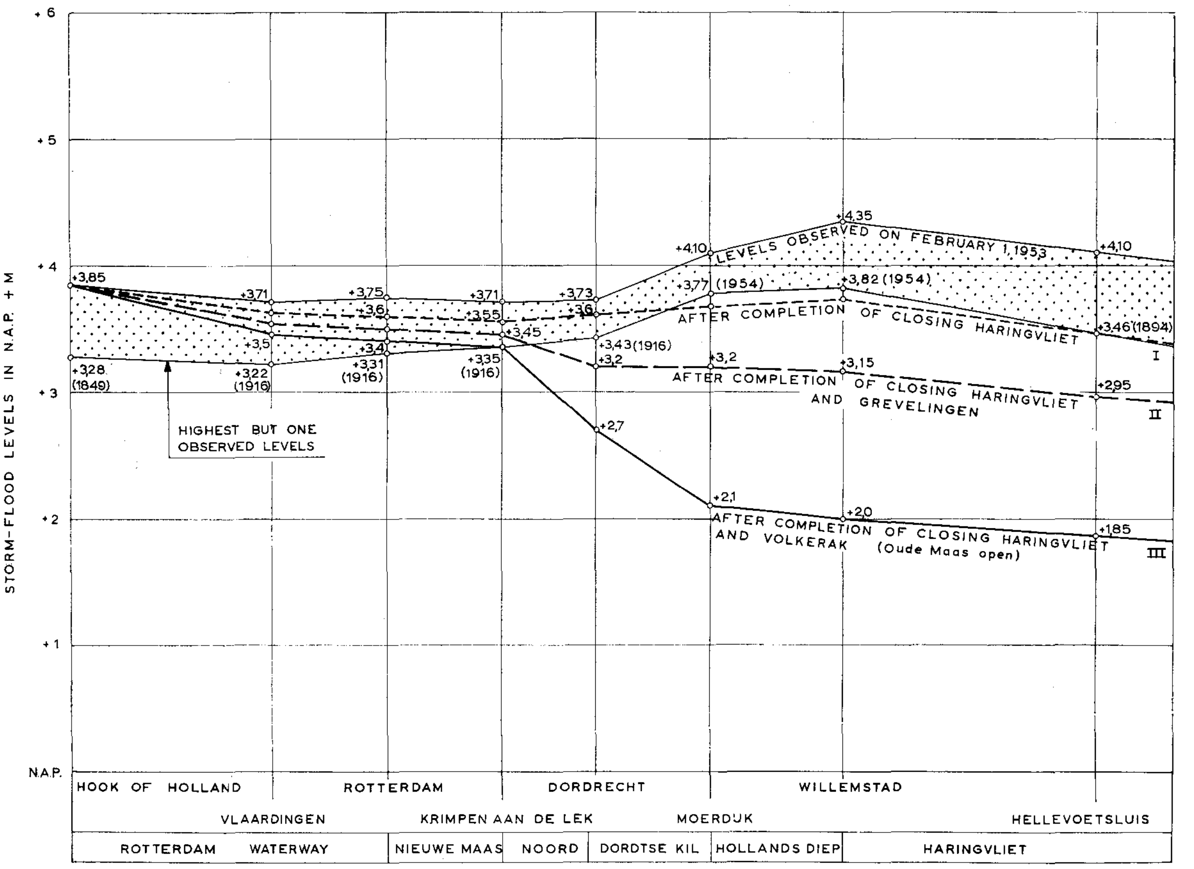

Figure 7.2.1. Course of the high water levels in the Lower Rivers during storm flood as that of February 1, 1953, with the then occuring Rhine discharge of 1,600 m^3/sec and a Meuse discharge of 210 m^3/sec for the situation on that date and for a few assumed situations, deduced from model tests of the Hydraulic Laboratory at Delft. The Biesbos, Donge and Oude Maasje are supposed not to be closed.

the meantime also be of influence on the normal tidal movement east of the dam, and the results of this, along with the measures possibly to be taken in connection with them, will still require further study.

As the horizontal and vertical tidal movements in the area east of the dams in the Haringvliet and Grevelingen are greatly dependent on an open or closed *Volkerak*, for hydrological reasons the closing of the Volkerak at about the same time as that of the Haringvliet could be necessary. But in addition to the advantages of this, the possible disadvantages will also have to be accepted.

For the situation in which such a necessity did not arise, the Committee had to consider the question at what stage of the execution of the Delta Works the closing of the Volkerak is then the most desirable. With this closing there are a number of factors which all influence the economic balance of the Delta Works and although most of them exercise repercussions too far outside the scope of the Committee, some of them must be mentioned. They include the improvement of the safety of the whole Delta area, the fresh water household of the Netherlands (this in connection with the canalization of the Neder-Rijn and Lek now under construction) even upto the north-east of the country, international shipping interests, the national roads policy, the threatened oyster and mussel culture, and the increase in the cost of the Delta Works.

The Comittee, therefore, is not able to form a complete judgment on the most desirable time for the work on closing the Volkerak, and thinks that this decision can only be taken by the Government after obtaining all the essential information from the various interests concerned.

When the closings of the Grevelingen, the Haringvliet and the Volkerak are completed, the decreases in the storm-flood levels caused by the Delta Works in the northern Delta area will have obtained their definite size. (see Line III in Figure 7.2.1).

South of the Volkerak Dam, however, as long as the Eastern Scheldt has not been closed, the storm-flood tides will increase. So in this connection strengthening of the main water protections will be necessary.

After the closing of the Haringvliet, Grevelingen and Volkerak, the closing of the Biesbos, the Donge and the Oude Maasje can be considered. How far these closings would be justified in view of the storm-tide increases they would cause in the situation of the open Volkerak should be given further investigation.

The question must now be answered as to which of the two remaining large dams, that in the Brouwershavense Gat or that in the Eastern Scheldt, should be the next to be completed after the closings in the Haringvliet and the Grevelingen.

In continuation of the works in the Veerse Gat, the Haringvliet and the Grevelingen just mentioned, the closing of the Eastern Scheldt, with the exception only of the area west of the Grevelingen Dam, gives the whole Delta area the safety aimed at as well as the desired improvement in the fresh water economy. In connection with traffic, too, both on land and water, the damming of the Eastern Scheldt has greater significance than the closing of the Brouwershavense Gat. In view, therefore, of the adopted principle of trying to obtain the greatest possible advantages as quickly as possible, it might seem advisable to give priority to the damming of the Eastern Scheldt.

The damming of the Brouwershavense Gat, however, is considerably smaller and will have fewer risks than the closing of the Eastern Scheldt. So technically it would seem that the order should be Brouwershavense Gat first and then the Eastern Scheldt. A gradual increase in the size of each successive project, with the accompanying cumulative collection of information and experience, should be of benefit to the favourable course of the carrying out of the work. In addition, the preference for the closing of the Brouwershavense Gat has another advantage that the interests of the shell-fish culture would only be damaged at a later stage, and so it might well be of use in view of the possible continuation of the oyster cultivation.

But there are other considerations still. In view of the preparations which have to be made in hydrological and other fields many years before actual work on the closings can start, and in view also of the fact that the dyke strengthenings along the Grevelingen necessitate well in advance the knowledge of the order in which the sea-arms are to be closed, it is evident that the choice between these two dams cannot wait for further experience to be gained from the closing of the Veerse Gat and the Haringvliet.

The studies made during the past few years have convinced the Committee that the arguments which support the preference for the closing of the Brouwershavense Gat weigh more heavily than those for the Eastern Scheldt; and so in the opinion of the Committee priority must be given to the closing of the Brouwershavense Gat sea-arm over that of the Eastern Scheldt.

The closing of the downstream mouth of the *Oude Maas* in the interests of the fresh water economy only obtains its full significance when the connection of the Haringvliet with the sea in the south (by damming the Volkerak or the Eastern Scheldt) has been closed. It does not seem justifiable in an early stage to close the Oude Maas on behalf of the improvement of the fresh water household, as this in itself would provide only a very small advantage in that respect. It is true that the salting of the Oude Maas would then be limited, while also in the Spui there would come a better situation; but in the Nieuwe Maas, where the improvement is most needed, the salt border, according to calculations made by the Government Waterways Department, would not be pushed back as long as the Volkerak and Eastern Scheldt were not also closed.

The current sluices to be built in the Volkerak Dam, and possibly also in the Grevelingen and Zandkreek dams, can only be of use after the Zealand Lake has been formed, which will not be until after the closing of the Eastern Scheldt.

The construction of these sluices, therefore, can be postponed for many years, which will mean not only a considerable saving in interest on capital outlay but also that much more information will then be available to determine the measurements of those sluices.

Summarizing, this is the position as the Committee sees it in connection with the order of finishing the closing works:

First, the Hollandse IJssel had to be closed, followed in succession by the closing of the Zandkreek and the Veerse Gat. Then the dam at Grevelingen and the closing of the Haringvliet will have to become ready.

As for the two large closings, namely, the Brouwershavense Gat and the Eastern Scheldt, the Committee recommends giving preference to the closing of the Brouwershavense Gat.

When the connection of the Haringvliet with the sea, also in the south, has been broken by the damming of the Volkerak or by the damming of the Eastern Scheldt, then the Oude Maas must also be closed.

Regarding the time when the Volkerak should be closed, the Committee decided to give no advice.

The current sluices to be constructed in the Volkerak Dam, and possibly also those in the Grevelingen Dam and the Zandkreek Dam, should only be constructed at about the time when the Eastern Scheldt is to be closed.

Finally, the Committee would again point out the desirability of starting as quickly as possible with the closings of the Brouwershavense Gat and the Eastern Scheldt. In this connection work can already be commenced during the execution of the northerly works, because the construction of dyke sections on the shallows of the deeper parts of the restraining dams in the channels will exercise only slight influence on the state of the current. The Committee emphasizes, however, that the safety of the south-west of the country will be very greatly served by the quickest possible termination of the closing of the Eastern Scheldt.

The strengthening of the main water protection and the construction works connected with it is a project of a completely different character from the closings of the sea-arms. This type of work does not produce the technical difficulties which are generally met with in projects like damming the sea-arms. But, on the other hand, much time will probably be lost with negotiations about the purchase of land which has been damaged or is needed for the strengthening work and which locally can be a fairly important part of the total cost. Then, too, the form of the organisation, the quantities of materials and the nature of the equipment can all be very different from those needed by the Delta Works.

The Delta Committee thinks, therefore, that the strengthening of the existing main water protection network must be carried out independently of the closings, and that it must start soon. This is quite possible, however, because this work can be distributed in smaller contracts, so that it is probable that it will be carried out by a different set of contractors from those dealing with the huge damming projects.

As for the order in which the strenthenings must be carried out, emphasis is placed at once on the main water protection works along the northern bank of the Rotterdam Waterway, the Nieuwe Maas and the rivers in open connection with them during storm-flood tide, as well as to the North Sea coast between the Hook of Holland and IJmuiden, as these must be considered first because the security of the centre of the country depends on them.

7.2

The strengthening of the sea-walls which in the future will lie outside the dammings must also be tackled immediately.

The execution of the remaining provisions in connection with the proposed dammings mentioned in 5.4 and which are needed for adaptation to the changed situation in the area of the Lower Rivers and sea-arms will have to keep pace with the progress of the actual closing works as well as of the dyke strengthenings.

In fixing the order and the speed in which the various sections of the works have to be carried out, attention will first have to be directed to the desired order in which they have to be actually completed, as already indicated here. As far as this order permits, every effort must be made to ensure as equal as possible a spreading of the work during the period of execution, as this materially benefits the economic side of the project. Finally, the work plans of the various groups must be in agreement or coordinated. By good planning of the different sections, the purchase of special equipment possibly wanted for one particular activity can be limited to a minimum and also enable such equipment to be used with marked and maximum efficiency.

8.0 STRENGTHENING OF EXISTING AND CONSTRUCTION OF NEW MAIN WATER PROTECTIONS

8.1 Introduction

The strengthening of the existing protective works, and the construction of new ones, must be carried out on the basis of the design levels and indications outlined in 3.0 and 6.1.2.

For the design of these works a few recommendations and directives will, however, be given in this section.

The Committee believes that there should be a break from the system whereby dyke-building and dyke-improvement is made according to plans based on varying ideas and coming from various sources. In the past this system has led to a situation in which ideas have originated in different parts of the country – not in logical agreement with each other – about the requirements which have to be met to ensure safety, so that various water protections which together give security to a particular area do not always provide the same measure of safety. To bring about unity in this important respect, the Committee thinks it necessary that when making plans for future construction or improvement of main water protections, the directives given under 8.2 should be followed.

For a main water protection the required top height is found by adding the design level to the watch height as can be determined by the directives given in 8.2. If in an existing main water protection this level appears higher than the present top height, then this water protection may be considered as needing strengthening. The height of the design levels appears to be such that, with the exception of the greater part of the dune coast, almost all existing main water protections in the area investigated by the Committee will have to be enlarged, apart, of course, from those which will be superseded sufficiently by the Delta Works.

8.2 Recommendations and directives for the construction and improvement of the main water protections

The dyke construction designs applied until fairly recently have in many cases appeared unable to withstand much overflowing water. This means that to be efficacious the dykes must be given a top height so that with water levels equal to the design level, comparatively little water can be expected to pour over them.

By providing the top and the inner slope with a watertight covering it is possible, in principle, to make a dyke resistant to overflowing water, although even then the top height would have to be determined on the basis of the amount of such water which can be regarded as admissible for the land lying behind it. However, it is not recommended that this criteria be introduced before it is proved that the covering remains watertight, even without frequent maintenance. Moreover, an investigation should also be made into whether no other – and so far unknown – dangers to the stability of the dyke are introduced by such coverings.

To determine the top height, the watch height must be added to the design level. See 8.2.4. This watch height consists of a number of components which are dealt with separately later.

8.2.1 *Run-up of waves*

With dykes attacked by water the run-up of waves is the most important factor in deciding the watch height.

Before being able to determine the main measurements of such a water protection, as good an insight as possible must be obtained into the wave movement in a storm-flood tide of the force that can be expected.

Factors which further determine the wave movement immediately in front of the water protection include the direction from which the waves must be expected during a storm, the form and width of the river bed or sea bottom in front of the dyke, and the height and width of any land lying in front. It must be noticed, too, that at very high storm levels taken with the design levels, there will occur in front of the main water protections a greater depth of water than before, and that the storm-flood levels are possibly the result of stronger winds than those which had previously been experienced. This means that waves of greater height can be expected than any previously registered.

When the right idea has been obtained about the wave movement(s) for which the dyke will have to be calculated – divided into wave height, wave period, wave length and wave direction – and also about the frequency with which these various factors can occur, then an investigation must be made into the force of the waves that will surge up against the dyke to be designed. As the height of the uprunning wave is greatly dependent on the profile and, to a lesser degree, on the roughness of the outside surface, a preliminary supposition must first be made about the way in which it is thought desirable to construct this outside layer.

As with the wave movement in front of the dyke, so does the run-up of the wave against the outside slope continually change. Here, too, there can be a sort of frequency division, so that for the run-up of the waves it is impossible to give a practical and usable value which it is certain will never be exceeded. In dyke building, the standard usually adopted for the wave run-up is that which is passed by 2% of the number of waves.

The Committee recommends that this criterium be maintained if no overflowing water worth mentioning is to be permitted. From the studies that have been available in this investigation, however, the Committee has had to conclude that knowledge of wave movement and of the onrush of waves is certainly by no means complete (see Contribution V.1). It therefore recommends also that research into wave movement and the onslaught of waves be vigorously continued both theoretically and experimentally, and then the results tested as rigorously as possible. In this connection it is also recommended that as many of these observations as possible be made during storm-floods.

To obtain the desired information in this field, the most modern means should be used, including photographic observation from the air, radar, and wave-measuring and wave-registering instruments. The Committee thinks that the registration of wave heights must most preferably be carried out by means of instruments than visually, and so urges that registering wave-measuring equipment be placed outside the coast in the open sea-arms as well as in the harbours.

In this connection the Committee would record that it has heard with interest about the plans for the building of a permanent observation tower on the Dogger Shallows (Bank) in the North Sea.

In a few instances the height of the flood marks is shown on the dykes themselves. These observations, too, give useful indication of the size of the wave run-ups. In the opinion of the Committee, this system should be continued regularly and the results studied carefully in combination with registered wave heights, water levels, wind speeds and wind directions.

8.2.2 *Squall oscillations and gust bumps*

By the term squall oscillations are meant the irregular fluctuations of the water level which are usually observed over a period of many minutes (15 to 45 minutes), especially during extra hard wind gusts in a storm.

In gust bumps the water level rises occur apartly in a very pronounced manner.

The oscillations and bumps have the character of long waves, so that they are also felt in full strength in sheltered places and in the harbours. Their intensity varies from place to place, and as a rule their height in line of the coast in showery storms is usually a few decimetres, sometimes even half a metre or more. It is possible for oscillations coming from the sea to be strengthened by the resonance of the harbours. This actually occurs in IJmuiden, where the harbour basin between the ends of the harbour breakwaters and the locks can come to resonance with the oscillations from the sea within a period of from 30 to 40 minutes. A water level was observed there recently which was more than one metre higher than was registered at the same time by the tide-gauge on the southern pier. It is obvious that such values should be taken into account at the very places at which they occur. See also Contribution III. 5.

The secondary water movements just mentioned are not shown in the list of water levels because the information about the water levels is the basis of the calculation about the transmission of the tide and in which the additional symptoms do not play any significant part. Nor in determining the storm-flood heights have they been included, nor are they incorporated in the basic and design levels. However, definite recognition should be given to the fact that they can be dangerous by reason of the fact that their rather long duration can cause a breach. Especially where there is little or no wave movement and the dykes will be constructed with a small watch height above the design level, must these shower oscillations and shower pushes be taken into account when determining the final details of the main water protection.

Where wave attack is to be expected, the full amount of squall oscillations or gust bumps need not be fully included. This is because they are of short duration in respect of the tidal movement, and so only a temporary increase in the frequency with which waves go over the dyke is to be noticed there.

For practical application (see 8.2.4), the additions recommended in Table 5.3.1 in Contribution III.5 can for the time being be adhered to for squall oscillations and gust bumps. For basins, the required additions must be separately determined based on the period of their own individual vibrations.

Because of the importance of these symptoms the Committee urges that the study of the size of the squall oscillations and gust bumps along the coast and in the harbours be continued. It also recommends, however, that the usual method of registering the average storm-flood tide levels in the Year Books of the Water Heights issued by the Ministry of Transport and Waterways be continued, so that no changes can come in the registration of the basic material for the excess curves of the high water levels, nor in the basis for the determination of the design levels.

8.2.3 *Subsidence of the soil, etc.*

In the improving of existing dykes or in constructing new ones, as well as in the construction of all protective works, as a rule it is intended that they possess the required safety factors for a long period. Full account must therefore be taken of the so-called relative subsidence of the bottom in the Netherlands, and of the subsidence of the dyke tops as a result of subsiding of the subsoil and also of the shrinking of the body of the dyke. See Contribution V.3.

By *relative bottom subsidence* is meant here the rate of the general drop of the no longer exposed subsoil of this country (the pleistocene) in respect of the average sea level, so that according to this definition it is not determined whether the bottom is sinking, the sea level is rising, or both are occurring.

The extent of this change in level cannot be exactly determined. It is true that tide-gauge observations and levelling measurements covering many decades, are available, but in such observations the relative bottom subsidence cannot be separated from the local sinking as a result of the shrinking or compacting of the alluvial layer between the bench-mark on which the zero of the tide-gauge has been based and the solid subsoil.

Though most bench-marks are in or on well-established objects, it is also even in these cases not certain that the effects of local subsidence are totally excluded.

The location of the zero point on the tide-gauges is occasionally corrected for a difference in respect of the N.A.P. level, by which is meant the imaginary horizontal level determined in relation to the main level mark in Amsterdam. If the corrections had always been made without mistakes, the variation of the N.A.P. level in respect of the average sea level height would, of course, have been known in a number of places. But as the result of mistakes made in the past in the transmission of the N.A.P. and the corrections of the zero points of the tide-gauges, however, the drop of the N.A.P. level in respect of the average sea level, – to be called further the *N.A.P. subsidence,* – cannot now be exactly determined. On the basis of the figures registered at the most reliable tide-gauges, it may be accepted that the N.A.P. subsidence in the past century has amounted to from 15 to 20 cms (6 to 8 inches). According to investigations (see Contribution V.3), the relative bottom subsidence does not appear to be much smaller.

During the past few years a method has been developed (the C^{14}-method) which makes it possible to determine the age of peat layers which are now occurring deep in the soil but which long ago were at sea level. The results of this research indicate that the relative bottom subsidence of the Netherlands compared with the preceding period of 10,000 years is declining. See Bibliography (7).

Apart from the relative bottom subsidence, considerable attention should be given to the subsidence of the dyke tops as the result of the shrinking of the alluvial layer under the dyke and of the body of the dyke itself. These lowerings will in many cases amount to a good deal more than the N.A.P.-subsidence, and they determine the so-called *top subsidence* of the dykes, which is the decrease in the height of the dyke top in relation to N.A.P. With a soft subsoil, dyke top lowerings of more than one metre per century have been observed, without counting the shrinking of fresh dyke specie after construction. The top subsidence is so dependent on local circumstances, however, that no definite value or formula for it can be given. In each separate case the excess height to be allowed for the top subsidence must be largely based on the results of soil mechanics research. For the exact levelling in respect of N.A.P., a survey must be made on a constructed dyke.

However, correct knowledge of the sinking symptoms is very important in connection with the water-defying capacity of the main water protections.

It must be expected that both symptoms, relative bottom subsidence or N.A.P. and top subsidence will continue for a long time. The consolidation or pressing together of thick soft soil patches can take centuries. Indeed, based on the geological explanation of the subsidence of the subsoil in the Netherlands, it may be accepted that the rate will actually decline in the future, although that, of couse, will happen very slowly.

When preparing a design for the construction or improvement of a main water protection work, therefore, a certain amount will have to be allowed for in the watch height for the subsidence to be expected upto the following repair of the dyke top in respect of the average sea level. See 8.2.4.

8.2.4 *Watch height, dyke table height and construction height*

By *watch height*, in contrast to other definitions, this Report means the height of the top of the main water protection above the design level.

It is striking that during the disaster of 1953 it was particularly the water protections located away from the storm area that collapsed. Their watch height, which apparently was small compared with the heights of those lying in the storm area, quickly became too small when the storm-flood level rose above the level for which the dyke was calculated at the time of its construction. On this occasion it appeared that in many cases the great watch height of the strongly attacked dyke sections showed an important reserve in respect of the excess over the design level. It is recommended, therefore, that special attention be paid to the watch height of the main water protections along the harbours and waters where little dash of the waves is to be expected.

Because only a very few wave tops may be permitted to stream over the dyke during a heavy storm tide, the watch height of a main water protection must never be smaller than the sum of the run-up of the waves and part of the squall oscillations and gust bumps to be expected and to be calculated according to Table 5.3.1 of Contribution III.5. This sum is called the minimum watch height, and with main water protection which is either not exposed or only lightly exposed to wave movement, this minimum watch height must be at least a few decimetres.

The top height must never drop below the level which is obtained by adding the minimum watch height to the design level. Because the minimum top height which is permissible is a relic of the old days, the so-called dyke tables mention *dyke-table height* in this connection.

By *construction height* is meant the height of the top of a water protection immediately after its construction is finished.

This height is obtained by adding to the dyke-table height (design level plus minimum watch height), the N.A.P. subsidence and the top subsidence which are to be anticipated during the period of the next repair.

The over-height destined for the lowering of the dyke top is dependent on the period which expires between two successive heightenings. The Committee recommends – insofar as the construction of the dyke permits – that this addition be based on a period of at least 20 to 30 years and that the amount allowed for top sinking is to be generally not less than ½ metre, and in which the over-height allowed for shrinking during construction must not be included.

This addition of minimum watch height provides, as a result of the N.A.P. subsidence and the top subsidence, a gradually diminishing margin of safety. This forms a certain compensation against the usually smaller resistance capacity of the still fresh dyke.

When the part of the total watch height reserved for the subsidence of the top of the dyke has disappeared, which means that the minimum watch height has again been reached and which must be determined by levelling, then a complete heightening must be made along with the repair of the required profile of the dyke. The grass mat or other covering must be removed, the slopes must be given the right angle, and a good connection must be made between the new layers and the old ones.

If the nature of the subsoil justifies the expectation that the dyke will soon have to be again heightened, then consideration can be given to giving the top a greater width immediately, so that in later heightening work the slopes can remain unchanged.

The Committee points out that full account must be taken, when constructing or improving main water connections, of the different values each of the above-mentioned factors possess.

In certain places, too, consideration must also be given to the blowing up to be expected by shallow waters, the changes in water levels as a result of the execution of the work, and similar circumstances insofar as they have not been allowed for in determining the design level. See also 3.0.

A dyke which has not been made resistant to the force of the overflowing of a lot of water can, even when it is in good condition, only meet the requirements of safety as long as it has the pre-determined minimum watch height. Therefore much is generally dependent on the precision and the frequency of levelling for dykes not exposed to waves, where the watch height is usually small.

Those responsible for the water protections must regard it as their task to have levelling done systematically according to a fixed time-table. Although the time elapsing between two successive levellings could be dependent on the circumstances surrounding each particular water protection, the periods must not be very long. The Committee thinks in this connection of at least one levelling every five to ten years.

The top subsidence of each dyke section must be known not as an average but as a maximum amount of a number of points. Care should be taken to see that no point at the top of a dyke section falls below the minimum level determined in advance. Considerable attention will also have to be given to the so-called permanent level marks which are the basis for levelling. It must be reckoned with that these marks repeatedly sink more than the N.A.P. level; there are cases known of sinking of more than ½ metre per century in relation to N.A.P. (see Contribution 4.3).

8.2.5 *Directives concerning dyke construction*

It is important that not only consideration is given to the factors which work on the main water protections but also that as much information as possible should be obtained about the factors which determine the strength of the main water protection works themselves.

In Contribution V.2 a summary is given of an investigation concerning the stability of dykes which has already been partly made and which is still being continued. In addition, research is being carried out into the problems of dyke coverings. In this connection also reference can be made to the final report of the work-group "Grass mats on dykes" instituted in 1953 by the Land Improvement Association (Bibliography 21), and to the published results of the research into the asphalt covering of dykes (Bibliography 3).

The grass mat or "lawn" is still extensively used as covering material for dykes, especially for the inside slopes. In extreme cases these are periodically exposed to the effects of the over-pouring wave peaks, but it must be admitted that the factors which determine the resistance of the grass covering of the inside slopes against over-pouring water present a problem which has not yet been solved. As dyke-breaches are almost always introduced by damage to the inside slopes (this also was the case in 1953), it is very important that the study of these factors be continued.

There is not yet the lengthy experience with asphalt coverage that has been obtained with other materials. So here too it is extremely important that the behaviour of the existing asphalt coverage is continually checked with great care, and that the study of the composition and method of using the bituminous mixtures be continued.

The Committee recommends that dyke managers be informed as much as possible of the results of such investigations as just mentioned, and that as far as it is practicable they themselves participate in the investigations, or at least promote these by supplying information about their own dykes and areas.

A few remarks will now be made on general dyke construction, based on the results of the investigation into the causes of the dyke damage during the 1953 floods (Bibliography 10 and 21) and on the investigations mentioned in the previous paragraphs.

The principal requirement in the construction of dykes, the centre of which consists of sand and is either insufficiently drained or not at all, is that there must be made a thick covering layer not affected by cracks and which will prevent splash-water, rain-water and over-pouring water from penetrating into the centre of the dyke. With the present constructions this layer can be clay with a cover of natural stone or concrete blocks in the area of the wave attack, connected with – possibly by means of a clay-sandwiched brick layer – a strong thick grass mat or a bituminous construction, possibly outside the zone of the wave attack, along with a clay layer with grass mat.

The danger of a breach in an attacked dyke can be reduced by artificially decreasing the wave approach, which will already be less as the cover of the outside slope is rougher. The attack can also be made smaller by putting obstacles in the cover of the outside slope when under construction or by adding them later. Generally these will have to be put rather high up on the outside slope so that they can be specially effective during high storm-flood levels.

Another way to decrease the wave run-up is the application of an outside berm. As a general rule such a berm has its maximum effect if it is located near the storm-flood level. In any case, the berm is better if lying over that level than below it, and so any outside berm must not be lower than the design level which, as has already been described, is the storm-flood level, at which the dyke is dimensioned. If the flood rises higher than de berm, then the effect of this device is naturally decreased. A berm at 1 to 2 metres under the design level will be of little value for a stormflood which reaches that level. From this it follows that a dyke with an outside berm called on to face more unfavourable circumstances than had been allowed for has less reserve strength than a dyke without an outside berm. The width of the berm will have to be decided case by case according to the wave attack. See also Contribution V.1.

Apart from the foregoing, however, an outside berm can be important as a road for the inspection and possible repair of damage to the dyke.

In general each dyke section will have to be studied separately to decide whether the application of an outside berm is desirable or not.

If the cover of the outside slope is of natural stone or concrete blocks, for dykes that are moderately or severely attacked by waves this cover will have to be made to above the design level or, if there is an outside berm, to above the berm. Over that there can possibly be a lighter stone covering. For dykes with a less heavy wave attack there can be a lower termination and/or a lighter construction of the stone covering. When determining the strength of the covering of dykes heavily attacked by waves, the place or places where the attack is strongest must be taken into account. This lies between the storm-tide livel and the wave trough. See Contribution V.1. As for the height of the transition of the covered slope to the grass mat, consideration must be given to the requirements of the grass mat so that, for example, it is planted not too close to the salt water area. If a bituminous construction is used, there may be reason in a few cases for continuing that covering right over the top.

When applying the watertight covering particular attention must be paid to the construction of the foot of the outside slope, as wrong application can easily led to strong water tensions under the covering, resulting in this being lifted up and damage being caused. It is, therefore, very important that a thorough study be made of the design of the foot of the dyke and of the required thickness of the cover in the area where the water tensions can be expected. In this respect the Committee draws attention to the recently-developed research method using a plate-formed electric conductor. See Bibliography (11) and (15).

The angle of the slopes must be made according to the water pressure on the dyke body, especially in the interests of stability. See Contribution V.2. Grass coverings, according to the quality of the mat, must not be steeper than 1 : 3.

Because of the possibility of the occurrence of somewhat stronger wave movement than that which is the basis of the design, allowance must be made, especially for dykes which have not been designed for the over-pouring of a good deal of water, for a few high waves streaming over it during a heavy stormflood. These dykes must be strong enough to withstand those rare occurrences. Even if the cover has not been made especially resistant to erosion, it must still be so solid that local scouring is not easy during exceptionally large streams of overflowing water. In this respect a top width that is by no means small is of great importance.

A sufficiently wide inside berm, located at a height of about 1 m + H.W. (=High Water), on which is a hardened road surface at least 3 m wide, will in more than one respect provide an important contribution to the safety of the dyke.

Depending on the nature of the dyke material and the covering, as well as on the subsoil and the contribution width, the drainage of the body of the dyke may be desirable. All angles of the dyke profile must be rounded on a wide scale.

In special cases the local situation may, of course, make it practically impossible to comply with all the rules and suggestions given here. This will be the case, for example, with the Netherlands beach resorts along the sea-coast, where the local main water protection is the promenade. So where local circumstances make it essential to accept a solution in which heavy waves will break over the protection, it will be necessary for an entirely different method of construction to be used from that discussed here.

8.2.6 *Directives about strengthening the dunes*

Along a sandy coast the protection against the sea is usually formed by beach and dunes in mutual cooperation. The slightly sloping beach is the daily water protection, while the foot of the dunes is reached by the water only during high storm tides.

Retrogression of the beach, which is shown in the first place by the landwards withdrawal of the low water line, has the unavoidable result of the recession of the undefended base of the dunes. This means that primarily every effort must be made to produce a situation of balance on the beach (Bibliography 9).

A balanced situation formed naturally will generally be there if and so long as there is balance between the supply and removal of sand which moves vertically on and along the coast. The transport of the sand takes place under the influence of currents, waves and wind. As these elements are continually changing in strength and direction, the idea of balance is significant only when the result of the development is observed over a longish period. A heavy storm along with a high water level can affect the foot of the dunes greatly. The stormflood of February 1, 1953, for example, caused in some places a crumbling of the foot of the dunes of from 20 to 30 metres (65 to 100 feet). Such a loss can be repaired again within a number of years through sand-drifts in quiet winters, so that calculated over a period of some years a balanced situation can also be spoken of in this case provided that there is sufficient width of dunes so that the crumbling caused by the flood does not meanwhile led to direct danger and damage.

Moreover, apart from an adequate period of time, the maintenance of balance also demands a sufficient quantity of sand from which Nature can operate. When making protective works along the coast, the engineers must avoid above everything else any activities or works which would hamper the supply of sand for the building up and maintenance of the coast itself. If this – for example, during the expansion of harbour dams – cannot be prevented, it is preferable for steps to be taken to compensate for the sand supply by artificial means. It is clear, therefore, that when permanent works are to be made for the maintenance of the coast, these must be so designed that they fulfil their purpose without producing harmful additional effects. For this a precise study of the vertical sand movement along as well as on the coast will be necessary, and care should be taken to see that interference with the natural course is not caused by too great a haste (Bibliography 16).

If a balanced situation is present, the beach is lying under the balance-slope. This is determined by the size of the tidal difference, the depth in front of the beach, the currents along the coast, the composition of the grain material, the situation in respect of the direction of the governing wind, and the wave attack. When the beach is in this balanced situation, then generally in the Dutch beaches the low water and the high water lines lie so far apart that they can be connected by a slope of the order of 1 : 50, while the high water line is about 50 metres away from the foot of the dunes.

In the coastal sections where there is a certain amount of crumbling away, a little retrogression of the coast can be permitted where there is adequate dune width in the expectation that a balanced situation of the beach will later be obtained. Where the dune width is not large, however, it may be necessary to fix the low water line of the beach of such a coastal section by building low breakwaters or groynes out into the sea. The length and in-between distances of these breakwaters will depend on local circumstances.

When the beach is in balance, a strip of dunes with no other defence than a well-kept strip of beach grass or planted tufted grass can only be considered a safe storm-flood protection at a strongly-attacked coastal strip when along an adequate width there is an average land height of N.A.P.+8 to 10 metres. This width must be such that even after there has been a regular crumbling away a few times during heavy storm-tides, there still remains an adequate buffer strip. The presence of a high drift head along the outside of the dunes will be of much help in limiting the crumbling of the dune. The crumbled sand namely remains for the greater part at the foot of the dyke where it undergoes further limited crumbling. If the beach is not so wide as the balanced width, the missing width must not be reckoned as dune terrain.

If the above-mentioned requirements are not met, then a start must be made to defend the foot of the dunes, while in addition a well-covered sand dyke must possibly be made as a lay-in dyke.

The defence of the foot of the dunes and the measurements of the lay-in dyke must be based on the design level valid for that spot.

Much attention must be given to the connection of the lay-in dyke and of the dune foot defence with the undefended neighbouring areas, as well as to obstacles lying in or near the dune edge to whose removal there are valid objections.

The defence of the dune foot must be adapted to the natural dune slope and be given such a shape that extra turbulence is prevented. It must be constructed from such a low level, and the slope must be so slight on the ground side, that with the natural sand movement the complete covering of the beach can always be reckoned on. Moreover, the construction must be such that onrushing water does not endanger the stability of the defence. With the presence of a high drift head the dune foot defence is protected in a natural way against water pouring in behind.

Along the coastal sections where the defence of the foot of the dunes is a necessity, the decrease of the beach must be especially watched, and if necessary a breakwater will have to be built out into the sea.

Where no dune defence is necessary, care must be taken to see that after every crumbling of the dunes the loss is made up as soon as possible by the artificial promotion of the drifting process.

Finally, it must be understood that the considerations outlined above refer to a smooth coast. With a broken or interrupted coastline, where strong currents sometimes run close to the shore, special measures might have to be taken.

8.2.7 *Directives on the construction of engineering works in a main water protection*

In the disaster of 1953 one of the factors causing the dyke breaks was the collapse of construction works which were not suitable for their task. Sometimes these are so old that nothing is known of their underneath construction or of their connection with the dyke. The Committee feels that a careful and thorough study of these construction works is necessary and that in doubtful cases there should be new dykes built.

It struck the Committee that, according to the area concerned, the number of valves in the sluices varies from one to four, whereas the Committee thinks that two strong ones would be preferable. The height of these will have to be determined from case to case in respect of the water level and of the wave attack that is to be anticipated, as well as of the interests that lie behind. Usually a little overstreaming water will not be a serious objection, provided this is planned for in the construction. The protecting height will generally have to lie above the design level at that spot.

Special attention must be paid to the connection of the construction works with the main water protection, because experience has shown that many cases of serious damage or breaches find their origin in this factor.

If a complex of construction works (such as a few sluices) is part of a main water protection, those construction works must also be mutually connected in such a way that any danger of a breach is impossible.

In constructing the water discharge sluices in the dams of the sea-arms, care must be taken to see that the closing elements are so constructed in connection with their exposed location that the required discharge of the inland water is ensured.

The foregoing remarks about construction works apply equally in a general way to the so-called coupures or trenches in the main water protections. In principle these are not desirable, but as in some local circumstances they cannot be avoided, the sole or bottom must be located at the height of the design level for that place unless there are very serious reasons against it. Moreover, at strongly attacked places a double protection is needed, with each part sufficiently strong to resist the heaviest wave attack. If the sole of the coupure is lying fairly high, then it can be considered that a little overflowing of the waves is permissible.

There must, however, be guarantees that the coupures are closed in ample time when necessary.

8.2.8 *Preventing building on and planting in the main water protection works*

The ideal protective works must be free of any form of construction such as houses, poles, railings, trees, bushes and other impediments. Particularly must the laying of pipes and, wherever possible, cables, be prevented.

The Committee recommends that to limit the constructional works in the main water protections as much as possible, discharge sluices and shipping locks should be concentrated wherever practicable, while where possible siphon locks should be considered.

As already pointed out in 8.2.7, coupures or trenches should only be admitted when absolutely necessary.

One of the faults in many of the old dykes was the building construction, including the necessity of digging into the dykes for foundations. It is now clear, however, that serious efforts must be made to have a system of main water protection without any buildings on it. If for good reasons some of the present buildings on the dykes must be retained, the security of the dykes as protection at those sites must be ensured as much as possible. Nor must the possibility be excluded of gradually freeing the dykes of such buildings as the result of disuse, insofar as these dykes retain their protective functions in the future. In any case, this should be aimed at in the greatest degree.

During the 1953 disaster the damage wrought on some of the dykes was largely caused by trees and bushes having been planted on them. For this reason the Committee recommends that all main water protections should be kept free of such vegetation.

9.0 MEASURES FOR INCREASING SAFETY INSIDE THE MAIN WATER PROTECTION

In the preceding sections attention has been drawn exclusively, in indicating the measures necessary to increase safety against floods, to the damming of the sea-arms and to the strengthening of the main water protections, as the Committee feels that money which can be made available for the increase of general safety can best be used for the construction or strengthening of the main water protections. On whatever basis of design level the water protection works are dimensioned, it will always have to be kept in mind that the possibility is still present that such a high water level will occur that the main water protection will collapse. With the strengthening of the existing dykes it is, moreover, possible that unknown weak spots will remain in them. It is therefore recommended that a few measures be taken to increase the safety inside the main water protections as well, and which can be made without too great a financial expenditure. These can, however, only be of a secondary nature.

In this connection two types of measures can be taken into consideration, namely:

1. construction and maintenance of second water protections to limit inundation;
2. measures to limit the danger of drowning to the minimum:
   a. by drawing up advance regulations as to what to do in time of floods, thus providing timely warning against threatening danger and thereby preventing any fatal atmosphere of panic as well as of unnecessary drowning; and
   b. by the provision of temporary safe accommodation in the inundated area.

9.1 Construction and maintenance of second water protections to limit inundations

With the growth of the Netherlands many inside dykes have originated in the western and northern parts of the country. At first these were outside dykes, but by further reclamation they have become second or even lower rated dykes. In addition, second water protections have sometimes been made especially to increase safety in certain areas. In the construction of some of these dykes, however, sufficient care has not always been taken, and in other cases digging through them or lowering the tops has decreased their value as protection against the water. However, for the greater part these inside dykes are still there, although they have not everywhere been linked up to form a closing unit of second or lower rated dykes. In those areas where this has not been done, there is still in many cases the possibility of achieving a system of second-line water protections without taking measures that would create too many difficulties or too great an interference.

It has already been pointed out that inside the closing dams in the sea-arms the existing main water protections can form a reliable second-line water protection. And as only small expense is needed for their maintenance, this reserve safety measure must certainly be implemented.

In special cases, in fact, even larger expenditure can be justified. That is why in its First Interim Report the Delta Committee advised the heightening of the Schouwen dyke between Schouwen and Duiveland to a top height of N.A.P.+5 m. In the first place, there was taken into account the circumstance that at that time Schouwen and a large part of Duiveland were still flooded and that it was possible that the sea could not be expelled before the winter. Therefore it was of the greatest importance to prevent the two flooded areas from joining up, as that would have endangered the existence of the whole island. In the second place, it was realised that although the Schouwen dyke would possibly be taking on a permanent function as a link in the second-line water protection behind the future main water protection, part of this dyke would actually remain a main water protection when the sea-arms were closed.

It must be remembered that when a flood occurs as a result of a break in the main water protection, it is important to limit the damage as much as possible by reducing both the size and the duration of the inundation. In addition, too, the drowning risks of the population demand attention.

During a flood the second-line water protection limits the size of the area flooded. In the tidal area the limitation of the inundation area usually results in the tidal currents in the breached dyke remaining smaller, so that the gap does not become enormous and can be closed more rapidly and easily, thereby also reducing the duration of the flooding. On the other hand, however, account must be taken of the fact that, especially when the area between the first and second water protections is small, the level of the flood waters will rapidly rise, thereby creating considerable risk of drowning for the inhabitants of the land between the two protection lines. If also the second water protection is breached, as is always possible, then the people living behind it, who had previously considered themselves safe, come into danger, especially if the second protection line is breached near a large population centre. The confusion that would thus be caused can obviously have disastrous results, so measures must be taken to prevent a possible breach in the second water protection near a largely-populated area.

When a second-line protection is breached, however, there is always the chance that it can be quickly repaired, thus restoring the advantages of a second water protection.

The requirements to be met by such a second-line defence must be determined separately in each case according to local circumstances. In this connection important factors are the size of the area that would be flooded after a breach in the main water protection, the altitude of the area, and the location of the second water protection in respect of the wind, for all these things determine the duration of the inundation and the strength of the wave attack on the second-line defence. If a start is made from certain suppositions in regard to the breaking of a main water protection, the information mentioned in the preceding paragraph about the chief factors governing the safety of the area can give an idea of the measures which could be taken concerning the second-line protection. Once again, the risks that can be accepted depend on each individual case.

As a rule, the second water protections will be so-called green dykes. It is important therefore that the slopes are by no means steep so that the turf can be kept in good condition. In general, also on the inside dykes – and certainly on the top and slopes – any planting should be avoided. Attention must also be given to the removal of buildings on the dykes as well as to limiting the number of coupures or draining trenches to the minimum.

If it does not appear justified to make a second water protection at any place because of local circumstances, clearing can be considered as a helpful measure. But before starting on this, however, a study must be made into the extent to which during a sudden inundation this form of protection can provide possibilities of escape for the population and cattle, and also into the way in which, after damage has been caused, it can serve as a foundation for the rapid separation of a part of the flooded area.

In short, it is stressed that a thorough study is required in every case as to the desirability and nature of a second protective line. This must include the cost of making it, the course which a possible flood would take both in the speed of expansion and in the depth of the water, the water levels to be expected immediately after the breach and the risk of drowning resulting from this factor, the damage likely to be caused by flooding, and the possibility of a speedy repair of the breach.

Testing the all-round situation in the Netherlands by the factors just mentioned, it would seem that it can be called generally satisfactory in the north of the country, in North Holland north of the North Sea Canal, and – after the completion of the Delta Plan – also in the south-west, because the areas behind the main water protection has a rather high elevation (for the Netherlands) and in many places second protections are present.

The Zuyder Zee reclamation is an example of the division of a low area into mutually separated areas or compartments by which the safety standard is greatly increased. In this connection Overflakkee can also be mentioned, where a second-line closing water protection has already been constructed.

However, the Delta Committee thinks that special attention must be paid to the safety of the Holland-Utrecht lowlands, which are so important for the economy of the country, but which have so many deeply-located reclamation works. The security of this area comes next to that of the Zuyder Zee area which, while being of about the same size, has at least two good water protections and a considerably less density of population than the Holland-Utrecht region.

In the south-east of this area security will be fully ensured after the completion of the double storm-flood protection in the mouth of the Hollandse IJssel and of the dyke strengthenings that are necessary.

But here thought must be given to the fact that one of the weakest links in the defence line in this area is now to be found in the north Lek dyke west of Vreeswijk, as here the size of the river discharge also determines the high water levels. See also Table 6.1.1.

In the heavily built-up area of Rotterdam, Schiedam, Vlaardingen and Maassluis great safety will have been obtained after the execution of the local works owing to the presence of wide and well elevated terrains. Between Maassluis and the Hook of Holland a new main water protection is being built, and the Delta Committee thinks it necessary that the Hoge Maas dyke, which is now operating as a main water protection, should be kept as a second-line protection. If this is done, the Committee believes that the safety along the southern side of this area will be adequately ensured.

To the west of this area complete protection is already afforded by the presence of the dunes, although those between Kijkduin and the Hook of Holland are locally limited in size. By the improvement of the existing barrier or the construction of new back dykes, however, a reliable second water protection can here be formed.

As for the north side of this area, the Committee draws special attention to the existence of the Spaarndammer dyke between Santpoort and Amsterdam, the top of which now lies for a great part over N.A.P.+2.50 m.

The great extent of a possible inundation of the Holland-Utrecht lowland makes it desirable to divide this area if possible. In this connection the Committee points to the presence of the Hoge Rijn dyke between Katwijk and Bodegraven, now lying at about N.A.P. which – because of the method of construction of its closing locks – is only able to protect the land to the north, the western dyke further on of the Enkele Wiericke (the so-called Prinsendijk) now lying at about N.A.P.+0.70 m, and finally the dykes along the Hollandse IJssel. Because of the possibility of flooding from the north as well as from the south, it is recommended to investigate the way in which the Hoge Rijn dyke can be made protective on both sides.

It is considered important that all the inside dykes mentioned remain, but also that they be brought into such a condition that in connection with a possible breach in the main dyke they are able, or at least can be made able within a short time, to withstand any inundation water and so limit the flooding. Only in that way can the possibility exist of taking advantage when necessary of these dykes. In this connection the Delta Committee points out that with the execution of the new works on or near the inner dykes mentioned, not only should the water protecting capacity be retained but also that it is important, where it can be done without incurring large expenditure such as road deviation around built-op areas, to make local improvements as well.

9.2 Measures for limiting the danger of drowning

To prevent, or at least to minimize, the danger of drowning which arises from the breaching of a dyke, it is important in the first place for the measures to be taken to be settled in advance. This especially concerns the organisation of first aid and other assistance services and, as far as is necessary, the evacuation of inhabitants.

When any threatened danger arises, it will be essential for there to be as many helping hands available locally as possible. In the first place, the waterways organisation known as the Dyke Army will have to jump into action. But in addition, other citizens will have to be ready to render services of many kinds. Where there are well-organised municipal services, these will have to be mobilised and coordinated with the other relief sections. But to ensure the smooth running of the assistance services, almost certainly under very difficult and perplexing conditions, the necessary measures and regulations will have to be prepared well in advance, which means that good cooperation between the administrators of the water councils and the municipalities is indispensable. The provision of help from the military authorities must also be regulated in advance. So the Delta Committee has heard with considerable pleasure that legal regulations in this connection are already being prepared.

It is also of considerable importance that warning of any threatening danger is given in time. This will protect the population from falling into a disastrous panic at a time of unexpected terror, and also give the authorities the opportunity of preparing the aid services and making preliminary plans to safeguard the population, especially by removing them to safe places.

Then, too, it is essential for there to be as many places as possible to which the population can be quickly moved. It is no longer possible to follow the example of olden times by taking the population to the "terpen" or safety mounds, as this measure is excluded by its impracticability, apart from the question as to whether sufficient accommodation could be provided. However, the experience of the 1953 flood showed that generally the number of people drowned, when moving to a safe place, by water was rather small (just over 10%). The greater part of the victims came from those not in houses standing adjacent to or near the dyke breaches (60%). These figures indicate the importance of having and using well constructed buildings as places of refuge. The Delta Committee therefore thinks it very important that in the population centres large buildings are equipped for people to be able to stay there safely at least in the upper floors. Furthermore, when constructing new buildings in areas liable to inundation care should be taken to ensure that they will last out for a long time should the floods come.

To be able to make a decision during a flood whether or not to evacuate the inhabitants either inside or outside the inundation area, it is essential to have some knowledge of the course of such a flooding, which means that there must be a picture of what the water is doing after the breach, in respect both of its gradual extension and its depth of water. Time also plays an important role in connection with the possibilities of evacuation.

In the immediate surroundings of the breach the water rises so quickly that it is impossible for the population at that spot to flee elsewhere. So especially in this area every effort must be made to have every building, or at least part of it, able to resist the invading water.

On the other side, along the inner fringe of the flooded area the water will probably rise so slowly that the people there have a reasonable chance of escaping to safer regions in the vicinity.

In the intervening area between these two extremes the people will have to be directed as much as possible to safe places. But as far as the agricultural population are concerned, consideration will have to be given to whether it will be advisable or possible, and to what extent, for them to stay in their houses.

Because of the many problems that arise, it is therefore desirable that the evacuation of the people and cattle be planned in advance, so that it can run smoothly and adequately. This means that every practical measure must be prepared to ensure as rapid a discharge as possible of the people caught in the flooded area, for it is generally felt that as few people as possible should remain behind in the inundated region where their situation would become steadily worse.

It is further recommended that all escape roads be planted with many trees and thus help the refugees and rescue workers to recognise and follow the best route.

Finally, investigations must be made in advance to find out what provisions can be made for the people who have temporarily fled from their homes.

The measures just outlined in the interests of evacuation and assistance certainly require a great deal of consultation and preparation, although they do not entail much expense. It is true, of course, that when the proposed works to increase the safety are completed, the chance of flooding will be small; but as this chance cannot be totally excluded, the Committee recommends that the suggested measures be taken nevertheless.

10.0 ADMINISTRATION AND MANAGEMENT OF THE WATER PROTECTIONS

The Delta Committee believes that in a report such as it has been asked to prepare it is not sufficient only to give recommendations about the construction or the improvement of the water protection works. These protective works must not only be given the safety considered desirable but such safety must be permanently ensured. Through the combined action of bottom subsidence, subsidence of subsoil, wear by the water, wind and sun, and by human alterations the dykes are continually changing. The construction works, too, become old and, like the dykes, are liable to sinking.

On those who are charged with the care and good maintenance of these water protectors, who may well be called the *administrators* [1]) of the water protections, there rests a great responsibility. It is this authority who must watch that the tops of the water protections never fall below the fixed minimum levels (see 8.2.4), that the construction works lying in them do not fail in any way, that any possible damage is immediately repaired, and that new constructions or changes in or to the water protections are always carried out in such a way that they do not interfere or reduce the water-resisting capacity.

As several hundred miles of dykes are covered with grass, it must be emphasized here once more that this must be well kept. In respect of maintenance, the quality of the grass is the principal factor. Especially on the inside slope must the turf be kept thick by suitable grazing. In fact, the Water Councils must become accustomed to the fact that the cost of maintaining these grass "lawns" will sometimes be higher than the proceeds of the grass crop. See also Bibliography (21).

The historical development of dyke-building in this country has led to the fact that the *administration* of the water protection works has been divided between a large number of authorities which, however, in view of the task they have to carry out, are in many cases too small in size and, because of this, also too small in capacity. It can be said generally that it is desirable, where the administration of sea and river protecting works is not the task of the Government or the provincial authorities, for Water Councils or Boards to be formed to cover the whole of the area protected by the respective water protective works. In an island area which is completely surrounded by water protection works, it is obvious that it is fairly easy to set up the so-called dyke rings. On the mainland, however, this will often not be possible. Yet efforts will have to be made to establish Water Councils charged with the care of works of rather large size and which, at the same time, as far as possible represent a more or less delineated area. It should be recognised that an economic system growing more and more complicated results in a considerable increase in the number of people and interests dependent on safety from flooding, and that this safety is no longer limited to the borders within which the direct effects of inundation are experienced.

In addition to the administration, however, there is the *maintenance of* the water protection works. Of course, the most simple and convenient solution is that the maintenance of the protective works is the responsibility of the administrating body itself. This, however, need not always be the case. Here and there government, provincial or municipal works can be so located that they are more or less part of the waterways network. It will also occur that construction works, such as sluices, quay walls, mooring berths, etc., and sometimes even roads and pavements, which are maintained by various bodies like municipalities or Water Councils, fall under the heading of water protection works and are an integral part of them. It is obvious that such works are always under the jurisdictional authority of the administrator who must determine not only the requirements of normal maintenance but also what improvements or even changes are necessary. In such cases where administration and maintenance are completely joined, it will generally be desirable also to bring the *ownership* of the property into the same hands.

When there are inner dykes which are or can be linked with a logically connected second water protection, it is recommended that these are brought under the same water control relation.

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[1]) By *administrator* is meant the authority or officials who, equipped with the requisite legal power, have the task of ensuring that the objectives of the Waterways administration meets the requirements necessary for good operation, independent of whoever is responsible for the maintenance.

There are many reasons which plead for a Water Council dealing with sea or river protecting works, being of a considerable size. In the first place, it must be such a capable body, and have such a large area, that it can not only effectively take regular care of the normal maintenance and necessary improvements, but also that on the sudden occurrence of a dangerous situation, or threat, or even a calamity, it will be able to take the required measures immediately. Then, too, the expansion of knowledge has put the construction and maintenance of the Dutch dykes on a more and more scientific basis, which incorporates not only the dyke body itself and the quality of the soil on which it rests, but also the currents along the coast or through the river bed, the wave attack, and many other factors. Whoever is charged with dyke administration must understand these things, which means that a sea or river protecting Water Council must have technically trained scientific people and a service well equipped administratively. This is only possible with large Water Councils.

In this connection the Committee would draw attention to the fact that although the waterworks departements in the various parts of the polder land of the Netherlands can be very different, so that no general rule can be given in this Report, the Committee recommends in the interests of good equipment and the desired size of the technical services that in many cases the Water Councils not only administer all parts of the water protection, but that at the same time they also take care of the basin waters and possibly also of the roads within the Council's territory. A joint dyke, basin and road administration can produce a strong and well-equipped Water Council.

Though it is not within the Committee's competence to give more detailed proposals about a better Water Council Division, its members think they must make a recommendation here in respect of the administration and maintenance of the coastal section between the dunes of Walcheren (Vrouwenpolder) and the Rotterdam Waterway. In this coastal section there are the five dams of the Veerse Gat, the Eastern Scheldt, the Brouwershavense Gat, the Haringvliet and the Brielse Maas, divided by short stretches of dunes or dykes. These closings and the construction works connected with them will exert a smaller or greater influence on the currents along the coast, and the coastal channels and shallows might change along with sand replacement. It will be necessary for regular observations to be made in this respect which may ultimately result in a few other works being necessary along the whole coastal section including the parts lying between the dams. As unity in tackling this problem and in maintenance, if necessary accompanied by changes or additions to the works, will be necessary, the Committee therefore thinks it advisable that the administration and maintenance of this coast section along the whole length be taken over by the Government.

Good maintenance of the main water protections, however, must not be considered only as the task of the administrators, who will normally be the Water Councils. It is national interests of particular importance that are at stake here. This, indeed, is already laid down in the Netherlands Constitution, which states that the "King" has the supervision of everything connected with waterways, while the Provincial Governments survey everything concerning waterworks within the provinces, including also – in fact particularly – the works of the Water Councils. Naturally – also according to the Constitution – the Provincial States establish the Water Councils, disband them and change them. It is therefore the task of these Provincial Colleges to provide the much-required strong Water Councils so that they can carry out their tasks in respect of the outside water protections. The Waterworks Act of 1900 with its subsequent supplements and amendments, as well as a few other laws, give all the rules governing this waterworks administration.

The Delta Committee understands that the execution of the Delta Works in general will follow lines adapted to this Waterworks law which has gradually been extended, to which the administrators have become accustomed, and which has proved its effectiveness in this country. Nevertheless, the Committee draws attention to one point: the Delta Works proposed by it, to provide a better safeguarding of the population and assets of a great part of the country, together with those works stretching along the whole Dutch coast, must be considered as one whole. Taking local circumstances into account, all these works must be constructed and improved according to the same directives. Here it is the task of the supervision of the Crown to ensure that these works are executed as one connecting chain without any weak links. The fact, too, that the greater part of the cost is to be paid by the Government indicates the desirability of this intervention.

Finally, insofar as the existing law and rules do not give adequate assurance of this unity, the Delta Committee recommends that the requisite steps be taken to provide legal supplementation to achieve it.

10.0

CONCLUSION

11.0 REVIEW OF THE COMMITTEE'S WORK AND ITS CONCLUSIONS

The catastrophic flood which occurred in the Netherlands in 1953 led the Minister of Roads and Waterways to form the Delta Committee to advise him concerning the hydrotechnical problem of the measures to be taken in the areas affected by the floods of February 1st of that year and whether such measures should include the closure of the estuaries. The Committee was later requested to estimate the water levels which could serve as the basis for improvement of the major sea-defence structures in the rest of the coastal region and to indicate the general lines on which such improvements should be made.

The emphasis of the Committee's study thus lay on increasing the protection against storm surges throughout the country and particularly in the southwestern Delta area. The problem presented still other important aspects, however, the most important of which was that the system chosen for damming the estuaries made it possible to effect a great improvement in the fresh-water supply. Many other factors were also at stake: land reclamation, navigation, overland traffic, fishery, and recreation. These factors were included by the Committee in its considerations.

In starting its work the Committee had at its immediate disposal a number of essential data collected by the so-called 1939 Storm-surge Commission and could also continue work on the extensive studies which had been undertaken by the Rijkswaterstaat (Governmental Service for Roads and Waterways) with the co-operation of the Delft Hydraulics Laboratory. Information was needed on other widely differing subjects, for which numerous specialized studies were indispensable. Many institutions extended their active co-operation to the Committee, which wishes to express here its great appreciation of the results of the many fundamental studies carried out on its behalf and the enormous amount of work which these investigations represent.

The Committee was aware from the very first that the scope of its task and the quality and range of the observations to be made and the data to be collected would necessitate the lapse of considerable time before the publication of its Final Report. The Minister, however, expressed the wish in his inaugural address that the Committee would within the shortest time possible suggest steps to be taken for the eventual prevention of a catastrophe such as occurred in 1953. In response to this request the Committee, as soon as it had informed itself on certain urgent points, submitted its advice in several interim reports. These reports are published in an appendix to the Final Report. They concern:

1. Raising the height of the Schouwen dyke;
2. Closing of the Hollandse IJssel;
3. Damming the sea-arms;
4. Damming the Veeregat and Zandkreek (Drie-Eilandenplan); and
5. Further considerations related to the damming-up of the sea-arms.

On several occasions after the publication of the interim reports the Committee supplied requested information and also advised the Minister of Roads and Waterways on a draft of the Delta Law.

This greatly simplified the preparation of the Final Report after the remaining data became available in their definitive form.

In order to form a general idea of the protective measures required, the Committee had first to take into account *the necessity for increasing the safety* of the southwestern, central, and northern regions of the country. The extent of the damage caused by previous storm surges, in particular that of 1953, not only emphasized this necessity but also made it quite clear that appreciable expenditures for increased protection were warranted.

One of the important causes of repeated dyke failures must be recognized in the fact that in general these dykes are continually liable to sinking. Where this was counteracted in the past by raising the height of the dyke, the design was based on the highest known local water-level.

Because of the catastrophes resulting from repeated storm-surge levels which were higher than those which had previously occurred, the Committee is of the opinion that this system does not give sufficient safety, and that an attempt must be made to take into account the chance of the occurrence of even higher storm-surge levels in order to provide a rational basis for dyke improvements by which an economically and socially acceptable degree of safety will be assured to each section of the country. A protective system based on well-founded norms and recommendations and tenable for the entire coastal area, cannot be dispensed with.

The Committee came to the conclusion that for the entire coast of the country the protection provided by the present defences is inadequate and that an immediate strengthening of a large proportion of the main sea-defence structures which protect the Netherlands against the storm surges was necessary and warranted (2.0).

Because the strengthening of the sea defences should be related not to the locally-recorded highest storm-surge level but to a level which will ensure an acceptable and economically sound protection for the future, the Committee's first task was to determine *basic and design levels along the coast, in the southwestern estuaries, and for the Wadden Sea.*

The studies which were carried out convinced the Committee that it was impossible to determine the highest storm-surge level which could occur. The higher the level which is considered, however, the smaller the chance that it will occur. The Committee came to the conclusion that along the whole coast the levels with the same chance of excess as the ordnance level N.A.P. + 5.0 m at Hook of Holland should be taken as the general standard for setting the requirements for the main coastal defence-structures taking into account the importance of the area lying behind them. These levels are called basic levels. Using the results of studies concerning the extrapolation of the frequency curve for the storm-surge levels at Hook of Holland, the frequency of excess of the ordnance level N.A.P. + 5.0 m at Hook of Holland was taken at 10^{-4}. This level lies more than a metre above the exceptional storm-surge level which occurred in 1953. The basic level was determined for a great number of stations along the coast, whose frequency of excess is per definition 10^{-4}.

Together with the basic level, those levels were determined which were needed to serve as criteria for the improvement of the coastal defences. In determining these levels, which are called design levels, the importance of the area to the rear was taken into consideration. For the coast between Hook of Holland and Den Helder, design levels were taken which have the same frequency of excess as the basic levels. For the south-west and north of the country and for the Wadden area, however, levels were chosen with a greater frequency of excess than that of the basic level because there the defence works must protect less impotant interests. In determining the design levels for the south-west, account was taken of the effect of the closure of the estuaries on the storm-surge levels in the neighbouring areas.

For the northern part of the country, a further distinction was made between design levels for situations considered permanent and those considered temporary, since the Committee assumed that in this area a temporary situation will be created by works of a more local nature which will increase the safety. It also takes into account, however, the probability that after the completion of the extensive constructions in the south-west, more definitive provisions for the north in the form of estuary closures between the Wadden Islands will be undertaken (3.0).

After having indicated for the entire country the water levels on which the improvements of the sea defences should be based, the Committee, as requested by the Minister, made its *choice between the strengthening of the structures of the existing protection and closure of the estuaries in the southwestern part of the country.*

For this part of the country the Committee came to the conclusion that closure of the estuaries on the broadest possible scale from the point of view of safety is greatly preferable to strengthening the existing structures. Such closure would result in a very desirable shortening of the coast-line while at the same time providing the advantage that within the enclosure the existing structures would form, in terms of safety, a very useful secondary retaining wall. Further, the closure of the estuaries would drastically limit the penetration of injurious salt sea-water and make it possible to greatly improve fresh-water conservancy.The interests of shipping, overland traffic, land reclamation, and recreation would also be served. Fishery interests would, however, suffer serious damage.

Along the Rotterdam Waterway and the Western Scheldt which are not, at least within the near future, under consideration for complete closure, the existing retaining structures will require strengthening (4.0).

Concerning *the provisions for the southwestern part of the country*, the Committee advised the closure of the Hollandse IJssel, the Haringvliet, the Brouwerhavense Gat, the Eastern Scheldt, and the

Veerse Gat. In order to make the realization of these closures technically efficient, the closure of the Grevelingen and of the Zandkreek was also considered essential, and the closure of the Volkerak may also be required.

The closure of the estuaries requires protective measures to provide for the discharge of water and ice. One of these is the building of ample discharge sluices in the dam in the Haringvliet. The efficient discharge of ice will be promoted by the closure of the Volkerak.

The Committee also decided that the parts of the coastal defences situated on the sea side of the closures would require re-inforcement on the basis of the proposed design levels.

After closure of the estuaries, sea-water will still penetrate through the Rotterdam Waterway. In the interest of fresh-water conservation it is therefore recommended that, especially after the canalization of the Lower Rhine and Lek rivers, the fresh-water discharge through these rivers be promoted. In this connection it is desirable to be able to close off the Oude Maas, particularly in periods with low Rhine discharge. In case of storm surges, however, it must be possible to open the barrier.

The closure of the Volkerak is also very important for fresh-water conservation: this closure will result in the formation of the so-called Zealand Lake which will be employed as a fresh-water reservoir.

In terms of the proposed closures there are further provisions to be realized in the interests of shipping, overland traffic, fishery and shellfish culture, the drainage of polder and waste water, and the condition of the river beds.

Because the closure of the large estuaries, with their strong tidal and wave motions and their sandy bottoms, will be a more difficult performance and one on a greater scale than any previously completed closure, the question has been raised whether it would actually be practicable. The Committee came to the conclusion that there are two methods of executing the closures: the gradual dropping of rather small elements and the formation of a barrier of caissons with closable gates. Its opinion, therefore, is that this question can be answered in the affirmative (5.0).

The Committee took under consideration *the significance and the consequences of the operations in the Delta area.* Since the high-water levels in the lower reaches of the rivers are caused by storm surges penetrating from the sea and by large upland discharge of the rivers, the Committee determined the high-water levels to be expected as a result of a conjunction of these two effects in the region of the river mouths. The studies carried out on this problem made it possible for the Committee to determine the basic level for a number of points on the lower river courses. They also determined design levels for several regions.

The Committee next turned its attention to improvement of the fresh-water conservancy. At present, salt-water penetrates inland through the various estuaries. After the proposed closure of these estuaries this will occur north of the Western Scheldt only via the Rotterdam Waterway. At present, too a large part of the water of the Rhine and the Meuse flows to the sea through the Haringvliet. By limiting the discharge through the Haringvliet sluices after the completion of the Delta Works, more river water will be discharged through the Rotterdam Waterway. In this way the salt-water can be forced back as much as possible and the salt effect appreciably limited. In spite of this improvement it will not always, even after the closure of the Oude Maas, be possible when the river discharges are low to repel the salt in such a way that the chloride content at the Parkhaven in Rotterdam will always remain below the preferred value of 300 mg Cl per litre. A low chloride content of the river water at this point is important because the horticultural district of Delfland has its fresh-water intake there and the *prise d'eau* of the Rotterdam Drinking-water Supply is situated not far away. The reduction of the 300 mg chloride level in the Rotterdam Waterway is hampered by the increasing salinity of the Rhine water, especially when discharge is low. The river water then becomes continually less efficient in removing the salt, so that increasing quantities of Rhine water are required which are simply not available at these low discharge levels. In this connection the attempts at the international level to improve the quality of the Rhine water, especially during periods of low discharge, are of eminent importance.

By draining off the salt-water via the discharge sluices in the dams, water in the Haringvliet basin and the Zealand Lake will be changed to fresh-water within a rather short time by the inflow of river water. The seepage of salt water from these sources to the neighbouring deep polders will thus be stopped. Nevertheless, in these polders the upward seepage of the salt-water already present underground will continue for a very long time and – after being flushed out – will cause an appreciable salinity in the Haringvliet basin and the Zealand Lake. Because an adequate flow of water into this lake for refreshing purposes will not always be available during the reduced river discharges, it will for the present be impossible to hold the chloride content of the water in the entire region below the level of 300 mg Cl per litre.

Although the average river discharge is sufficient to provide for all the requirements of agriculture, industry, and drinking-water, shortages will nevertheless continue to develop in periods of reduced river discharge even after completion of the Delta Works. It is therefore extremely important to be able to store a reserve supply during periods of sufficient river discharge. The Zealand Lake will provide this possibility: during increased river discharges the level of this lake can be raised so that water can be withdrawn in periods of greater demand. This supply will then be available for holding the polder waters at the proper level, the flushing of polders to counteract high chloride content, and for supplying dry areas.

As a result of the increasing demand for fresh water for agricultural, industrial, and drinking purposes, the problem of the fresh-water supply grows continually more pressing in the Netherlands. Even after the completion of the Delta Works it will still not be possible under all circumstances to satisfy the proposed standards. It is therefore essential that those possibilities which are offered by the Delta Plan for improving the fresh-water conservancy be exploited to the utmost. The Committee has added to its considerations concerning the fresh-water conservancy a discussion of a possible scheme for the distribution of the available river discharge.

This is followed by a discussion of the normal water levels and current velocities as well as the situation under ice conditions, and a number of relevant and indispensable provisions are indicated.

Finally, the expected sand movement in the bottoms of the estuaries and along the coast is examined; the places which must be kept under observation in the future are indicated; and the possibilities for land reclamation, recreation, etc. are pointed out (6.0).

In a general sense the Committee considered *the location of the closures and the order in which the works in the Delta area should be carried out.*

In chosing the closure sites a number of interests must be taken into account, some of which require further study. The Committee considered it sufficient to indicate schematically a plan for the closure (see Enclosure 2.0.1), although for a few cases this has already, with its agreement, been wholly or partially determined.

In determining the sequence of the execution of the works, hydraulic factors and requirements involved in the operation play a large part. The Committee, after weighing all these factors against each other, determined the most desirable order for the completion of the works.

The economically very important polder area of North Holland, South Holland and Utrecht lies behind the weak dyke of the Hollandse IJssel. During the 1953 storm surge this dyke showed the early signs of a breach. Had this dyke failed, which was only prevented by the most extreme efforts, the already catastrophic flood would have had even more serious consequences. In determining the order in which the closures were to be made, the Committee gave first place to the building of a movable storm-surge defence structure in the Hollandse IJssel, a contributory factor in this decision being the absence of unusual construction problems.

The closure of the estuaries is a large-scale and difficult problem. It was therefore important to obtain experience with a similar work of lesser proportions. On these grounds the Committee advised the immediate closure of the Veerse Gat and the related necessary closure of the Zandkreek. These operations could, after some preparatory measures had been taken, be carried out independently.

In determining the order of executing the three large-scale closures – of the Haringvliet, the Brouwershavense Gat, and the Eastern Scheldt –, the Committee gave priority to the first because it would immediately provide the greatest increase in safety and execution would present the fewest difficulties: during the closure the previously constructed sluices could be kept open, which would appreciably limit the current velocities during the real closure.

Before starting the closure of the Brouwershavense Gat or the Eastern Scheldt, the Grevelingen Dam would have to be built in order to prevent unacceptable currents in the connecting waters. This dam will also have to be completed before the closure of the Haringvliet can be executed. Since the two former dams have different types of construction, building them simultaneously offers no serious difficulties.

If the next closure were to be that of the Eastern Scheldt, the desired increase in safety would be fully attained and the advantages for the fresh-water conservancy would be fully effected, with the exception of these related to the Brouwershavense Gat. Nevertheless, in the Committee's opinion it is desirable to give priority to the closure of the Brouwershavense Gat because of the valuable experience it will provide for the most difficult closure, that of the Eastern Scheldt.

The closure of the Oude Maas should be carried out after the closure of the Eastern Scheldt or the Volkerak has formed a fresh-water area. To do so earlier would not be justified, because the closure would yield little advantage.

The Committee could not suggest a date for the closure of the Volkerak because various factors involved fall outside the scope of its work (7.0).

In the Committee's view it is essential that all the main coastal defence structures throughout the country satisfy safety norms which are logically related to each other. In order to achieve this, the Committee has made a number of recommendations for *the reinforcement of existing structures* and the construction of new ones (8.0).

The fact should not be lost sight of that the possibility of flooding can never be excluded with absolute certainty. The Committee therefore draws attention to *measures for increasing the safety at the rear of the main sea defences* which can limit the effect of possible floods. Since the increased protection must in the first place be seen in the reinforcement of the main structures, these measures should require relatively limited expenditures. What is involved here is the construction and maintenance of secondary retaining structures for the confinement of inundation and measures to limit the danger from drowning as much as possible (9.0).

Past experience has taught the crucial importance of constant vigilance that the installations which increase safety be maintained in good condition. With this in mind, a few remarks are made concerning *the supervision and the maintenance of the coastal defence* structures as will be required in the future (10.0).

The Committee has confined itself to suggesting the main outlines of the solution to the problem which had been laid before it: a detailed study does not lend itself to commissional treatment and should be put into the hands of a specialized body which can assume the responsibility and which is fully equipped to devote itself to the required studies.

Many of the Committee's conclusions are based on the data which are now available. Because of the great importance of the safety of the main coastal defences of the country, further observations, investigations, and studies must be carried out with the purpose of expanding these data to the utmost so that their validity can be continually re-examined and where necessary they can be further expanded or modified. The Committee wishes to stress forcefully the fact that in the future no effort should be spared in this direction.

In his inaugural address the Minister pointed out that the Committee was primarily a technical body and that the problems submitted to it form only one facet – however much an extremely important and, from the chronological point of view, primary facet – of the entire complex of measures required and concerning which further investigation must be made by other bodies at the appropriate time.

The Committee is also aware that its proposals form only the foundations for the Delta Plan, a plan whose primary object is to increase the protection against storm surges but which at the same time offers an opportunity for appreciable improvement in the fresh-water conservancy. The latter point is of equal importance in a country where an adequate supply of water for agriculture, industry, and drinking purposes is so seriously threatened by salt-water penetration.

Besides this, the Delta Plan offers an opportunity to promote navigation, overland traffic, recreation, and the expansion of population centres, harbours, and industrial zones. Further, the ending of the isolation of the South Holland and Zealand Islands can be expected to cause great changes of an economic, social, cultural and religious nature. It is essential that specialists in each of these fields give their ideas concerning the manner in which the interests involved can best be served in connection with the realisation of the Delta Plan and concerning the relative importance to be attached to these interests. Conflicting demands and expectations will arise which it will be impossible to satisfy completely. In order to arrive at the most effective solution to this complex problem, it will be essential to have a co-ordinated leadership which will give precedence to the interests of safety and fresh-water conservation for which the Delta Works were originally undertaken.

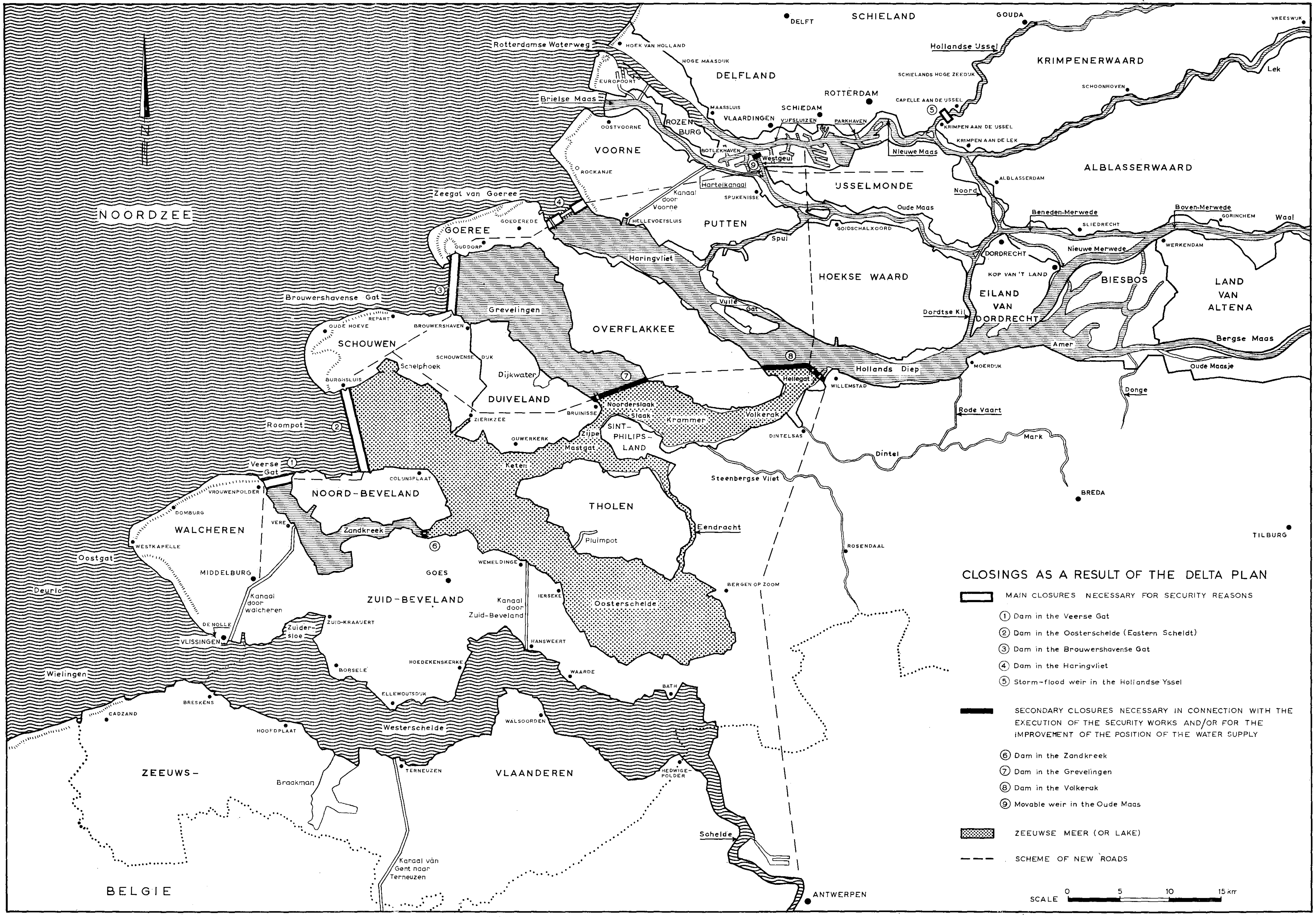
The Committee, in conclusion, expresses its hope that the Delta Plan for which it has provided the foundations will yield the greatest possible benefit to the people of the Netherlands.

As formulated by the meeting of the Delta Committee at The Hague, the 10th of December, 1960.

The Chairman:

The Members:

The Secretary:



Delta area with closings

Enclosure 5.0.1.

The Netherlands north of the great rivers

Enclosure 2.0.1