Marsh Soils in the United States and in the Netherlands

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At the invitation of the Soil Conservation Service the authors toured the Gulf Coast between Houston, Texas, and Pascagoula, Mississippi, and the Atlantic Coast between Brunswick, Georgia, and Toms River, New Jersey. The object was to look at the marsh soils and to assess—in the light of Dutch experience—the possibility of reclaiming them. However, it was not the purpose of the tour to give any advice on changes in present land use under present economic conditions.

In every state visited they made field trips with officials of the Soil Conservation Service, including soil scientists and drainage engineers, and this arrangement provided them with an excellent opportunity of seeing and discussing some of the problems of the various areas visited.

The authors wish to thank Dr. Charles E. Kellogg, Assistant Administrator, S.C.S., and a great friend of the Netherlands, whose idea it was to invite them. They would also like to thank the many officials of the S.C.S. who prepared the field trips so well and explained the local conditions so ably.

This paper is divided into two parts; I deals with soils, and II deals with water management questions. Each of the authors is responsible for his own section. Part II is by Dr. van Staveren.

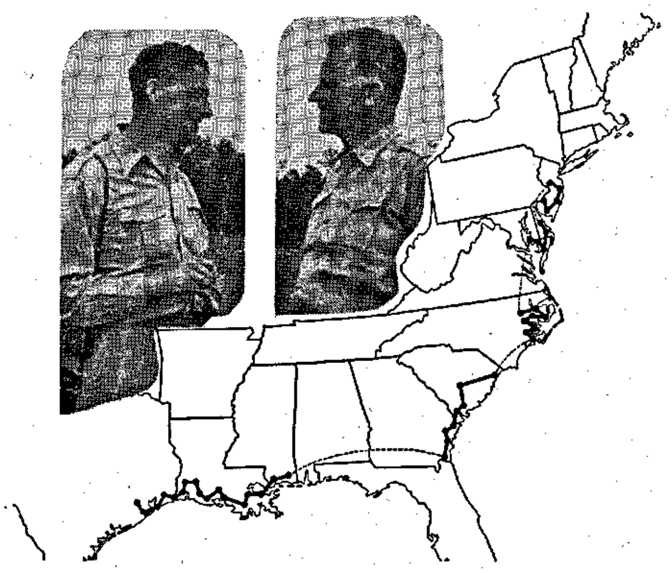
When writing in the Netherlands on the conditions seen, both authors felt how much they had benefited from the tour. Numerous observations carried out in the United States have been very useful for a better understanding of Dutch conditions. This is one more reason why the authors are so grateful for having been enabled to make a most interesting tour of which this report is a result.

PART I

SOIL CONDITIONS

Definition: "Marsh soils" is not the name of a clearly defined group of soils.

In the U. S. the term applies to surfaces covered with grasses, sedges or more or less natural swamp vegetations, on which movements of the sea level have had an influence. This broad definition would also hold good for the Netherlands if soils reclaimed from marsh were included.



J. M. VAN STAVEREN (left), engineer and director, International Institute for Land Reclamation and Improvement, and C. H. EDELMAN (right), professor of soil science at the Agricultural University, traveled the route shown by solid lines. Both men are located in Wageningen, Holland. (Photograph and map courtesy of the U. S. A. Soil Conservation Service.)

←**OLD-FASHIONED DUTCH POLDER LANDSCAPE with trenches and ditches to discharge superfluous water. WATER MILLS keep level at a fixed height.** ***(K.L.M. Aerocarto Ltd.)***

Marsh soils in the U. S. may be mineral or organic. The mineral soils may be deposited by salt or by brackish water, or they may be older mineral soils, which are now affected by marshy conditions. The organic marsh soils in the U. S. are formed in fresh, in brackish and even in rather saline water.

In the Netherlands the natural condition of the mineral marsh soils also ranges from quite salty to fresh, but the organic soils are only found in fresh to slightly brackish surroundings. This difference is due to the much richer natural vegetation in the U. S. as compared with the Netherlands.

Lime in Mineral Marsh Soils

The major difference between the mineral marsh soils in the U. S. and in the Netherlands is in the lime ($CaCO_3$) content. During our long trip from Houston, Texas to New Jersey we did not visit one spot where mineral marsh soils contain lime. In the Netherlands most marsh soils contain lime, or did contain it when they were reclaimed. However, there are a number of other marsh soils which do not contain lime: these will be discussed later in comparison with American marsh soils.

The presence of lime in marsh soils is of very great importance for their potential value as agricultural soils. During the process of oxidation of the virgin marsh soil, a part of the lime serves to neutralize the sulphuric acid formed during the oxidation of sulphides which always occur in marine deposits. Moreover, it produces the calcium ions necessary to replace adsorbed sodium and magnesium and to build up good soil structure.

In the moist and cool climate of the Netherlands reclaimed marsh soils lose 1 per cent of lime in a century. Marsh soils reclaimed during the early Middle Ages have lost their lime in the first 1 to 2 feet, but those reclaimed during the later Middle Ages still contain lime in the top soil. A mineral marsh soil with 10 per cent of lime will retain its favorable properties for 1,000 years and even after that will retain a reasonable degree of base saturation for several centuries under Dutch climatic conditions.

These favorable properties must be taken into consideration in any appraisal of the efforts of the Netherlands to reclaim land from the sea at a cost of $1,200 per acre. If the new land had not been calcareous, the sacrifices to reclaim it would not have been made.

Most of the calcareous mineral marsh soils in the Netherlands are mixtures of fine sand, silt and clay. Some of the best land would be called fine sandy loam in the U. S.

ONCE THE SEA FLOOR. The large lime-content brought about by shells and other animal remains is a most IMPORTANT FACTOR on reclaimed lands in the Netherlands. *(A. Roelofs van Goor, Publishers, the Netherlands)*

Non-calcareous Mineral Marsh Soils with a Solonetz Tendency

Like those in the U. S. the non-calcareous or lime-free mineral marsh soils in the Netherlands are nearly all in the clay to heavy-clay range. There are various kinds. Quite a few of them, formed in brackish and swampy conditions, contain more sodium and magnesium in their adsorbtion complexes than average soils, and in some cases even have the characteristics of Solonetz. They are called *"knik"* or *"knip"* soils. Other non-calcareous mineral marsh soils, deposited in fresh water, have more average adsorbtion complexes. They show transitions to the back-swamp river soils, known as *"kom"* or *basin* soils in the Netherlands.

All these heavy non-calcareous clay soils, with their difficult internal drainage, are used as permanent improved pasture. Some of them are well managed, like the knik soils in Friesland, where the famous Frisian cattle originated. This district exports pedigree bulls all over the world and has the lowest cost price for milk in western Europe and perhaps in the whole world. This shows that these non-calcareous, heavy marsh soils can be successfully used under good management. It must be admitted, however, that the grassland section of Friesland also includes some better soils, although these are likewise non-calcareous heavy clay soils.

Some of the Gulf of Mexico coastal marshes are similar to these non-calcareous Dutch heavy clay soils with a weak Solonetz tendency. To explain the similarity it must be borne in mind that all these Texas and west Louisiana marshes are of marine origin. They were formed as soft salt-water marshes. With continuing sedimentation they became higher and more compact. Finally they became so high that only the highest floods could influence them. At the same time the salt was washed out by the rains. They are so compact that it looks as if they contain much adsorbed magnesium. The few analyses available support this theory.

Land use on the fresh firm mineral marshes in Texas and western Louisiana is related to that on the bordering coastal prairie. It includes range grazing and rice cultivation. As far as the range grazing is concerned, the situation on the Gulf coast is comparable to that in parts of the Netherlands in the early Middle Ages. With flood protection and some drainage, part of this marsh land would change quickly into relatively good pasture, which under good management would support an excellent livestock industry. Under present economic conditions, such development is not recommended.

This discussion could lead to a misunderstanding with regard to the present classification of the coastal marshes in the U. S. The present environment and land-use possibilities are characterized by such terms as *fresh, brackish* and *salt.* But this does not mean that the marshes in question were formed in the same environment. In terms of sediment history, the fresh marshes of Texas are salt marshes.

Mud Clay and Cat Clay

Another non-calcareous, heavy-clay marsh soil in the Netherlands is the soft *mud clay,* which in its oxidized form has acquired a very bad reputation under the name *"cat clay."*

The soft muds in question are brackish deposits formed under the influence of a very dense vegetation, often the reed, *Phragmites.*

In these surroundings the sulphates of the sea water are deoxidized and precipitated as sulphides. In this process the decaying organic material derived from the vegetation plays an important part. The black, soft muds, full of rootstocks of *Phragmites,* may contain as much as 3 per cent sulphur in the form of iron bisulphides.

Under these natural conditions the soil is about neutral. If this mud clay oxidizes, the sulphides are transformed into sulphates and sulphuric acid, a process which in a simplified form can be represented by the formula:

$$4\,FeS_2 + 6\,H_2O + 15\,O_2 \rightarrow 4\,FeSO_4(OH) + 4\,H_2SO_4.$$

The sulphuric acid causes extremely low pH-values (down to 2.5 and lower), precluding plant growth. The basic iron sulphate is very conspicuous by its straw-like yellow color, which no other soil component displays.

The basic ferric sulphate $FeSO_4(OH)$ is unstable and slowly hydrolizes to the compound $Fe_3(SO_4)_2(OH)_5\ 2H_2O$, known from investigations by Posnjak and Mervin (1922) on the $Fe_2O_3 - SO_3 - H_2O$ system. During this hydrolysis more H_2SO_4 is formed, in accordance with the formula:

$$3FeSO_4(OH) + 4\,H_2O \rightarrow Fe_3(SO_4)_2(OH)_5\ 2\,H_2O + H_2SO_4.$$

According to Van der Spek (1950) this compound still has a light yellowish color and gives a neutral reaction in pure water, though it can exist in a quite acid soil. Some examples have been found in the Netherlands of soils with a neutral reaction and light yellow mottles of basic iron sulphate, but this is not the rule. More frequent are soils in which iron hydroxides have been formed as the final product of the hydrolysis of the basic iron sulphates. Such soils are grey acid clays with brown or orange mottles of iron hydroxides.

Van der Spek also pointed out that the mono-sulphide FeS oxidizes to iron hydroxide without an intermediate yellow basic ferric sulphate.

Easy as it is to recognize cat clay after oxidation and drainage, this recognition is too late. The problem is how to identify the cat clay in its natural mud-clay form. Not every black mud clay has the same sulphur content (Bennema, 1953). Dutch soil scientists have made themselves familiar with important visual differences between various mud-clays in their own country, but it is by no means sure that these differences will have the same meaning in another continent. The establishment of the connection between visual differences in mud-clays and important differences in sulphur contents will constitute a subject of research for American soil chemists. It is probable that such differences exist. According to Van der Spek the salt environment produces more FeS and less FeS_2 than brackish conditions, because less organic material accumulates in a salt environment than in a brackish one. If this also turns out to be the rule in the coastal marshes of the U. S., the marshes of saline origin will have a higher potential value for agriculture than the brackish ones.

One of the peculiarities of the transformation of mud-clay into cat-clay is the difficulty of measuring a correct pH. A fresh sample of a black brackish mud, immediately analyzed, has pH of between 7 and 8. Slow drying in the laboratory decreases the pH to 5 or less. Careful oxidation in the laboratory under controlled conditions may bring out a pH of 2.5 or less. Random handling in a routine laboratory may give anything between pH 8 and 3.

The characteristics of the cat clay—*viz.,* extremely high acidity and the straw-yellow color of the fresh oxidation product—were not observed in Texas and Western Louisiana during our recent trip. We were indeed shown very acid soils with a pH near 4, but not cat clays. It is probable, however, that real cat clay occurs in the brackish environment of the Mississippi delta, where sea water mixes with the large amounts of fresh water discharged by this river.

Cat clay was repeatedly observed in Georgia, South Carolina, Delaware and New Jersey. In Georgia and South Carolina the mud clay and cat clay soils were found in wide river estuaries. Much of this land produced rice in the 18th and 19th Centuries and has even done so in the 20th Century. Rice is the only crop not affected by the acidity of the cat clay, because the soil is kept under water and remains de-oxidized for most of the year. Its acidity is potential, not real. In this connection it should be borne in mind that rice grows on similar soils in parts of Burma and Thailand.

Since modern rice-farming requires the use of heavy machinery, only firm soils can be used for it. The soft mud clays only change into firm soils after they have been dried out, but this would activate the acidity. Consequently, it is improbable that the soft old rice fields of

Georgia and South Carolina will be used again for rice cultivation. Since cat clay soils are not suitable for any other crop, reservation for wildlife is the only feasible land use.

In Delaware cat clay was observed in a bird refuge, under conditions similar to those in the southeastern states.

The cat clay in New Jersey was found in ancient riparian meadows along some of the river estuaries in conjunction with organic soils. These fields have been used as meadows for centuries. Dikes broke down during the great depression and were not repaired. The old meadows are now filling with recent mud clay (and cat clay).

Non-calcareous Marine-Clay Subsoils of the Bladen Group

It may be useful to point out that very acid subsoils, related to cat clay, occur in recently drained soils of the Bladen group in Mississippi, Georgia and the Carolinas. These soils occur on a raised marine terrace, supposed to date from the last interglacial period. Many of them must have been black soft muds after deposition. The poor natural drainage has preserved a de-oxidized condition in the subsoil. Drainage activates the acidity of the subsoil. We heard about analyses of Bladen subsoils indicating pH-value ranging between 8.2 and 3.8, and it should perhaps be reiterated that the two figures may be correct even for the same sample. As far as can be ascertained from our casual observations, the subsoils of the Bladen group are not uniform in their potential or real acidity. This gives rise to a very difficult problem of classification and correlation, because small differences in the origin of the parent material might be associated with very great differences in soil conditions, at least temporarily. The classification experts of the U. S. might find it convenient to define an acid or very acid subsoil phase of the Bladen soils; this would constitute an unusual approach.

Further north the associates of the Bladen, such as Othello and Portsmouth, are found on different substrata with no potential acidity, yet the names of these soils were selected from places in this coastal region. Thus we may say that parts of Bladen soil and its associates have potential acidity in their subsoil, and other parts with the same series name do not. This is not satisfactory from a classification point of view.

The consequences of the potential acidity of the subsoils of some soils of the Bladen group are much less important than those of cat clay near the surface. It has been found in the Netherlands[4] that cat clay at a depth of 16 inches no longer influences yields of a crop like sugar beet. Such a soil would not, however, permit the growth of fruit trees. Experience in the U. S. is similar. On Weston soils, the subsoil of which had a pH of 3.8, truck crops are raised near Charleston, South Carolina. Nevertheless, the low pH of the subsoil mobilizes Al and Fe, which may precipitate in the pores of tile drains and thus make field drainage difficult.

Organic Marsh Soils

The organic marsh soils in the U. S. vary greatly. In Texas they fill up pockets enclosed between older marshes and "cheniers" (ancient coastal sand bars). Their thickness is greatest around certain lakes. Their formation indicates a minimal influence of marine sedimentation, which also means that they are mainly fresh-water formations. Since there is little or no flood protection, they are sometimes flooded with salt or brackish water. In this way some sulphur compounds are trapped in these organic deposits, thereby giving them a certain potential acidity and relating them to mud clay and cat clay.

Under natural conditions the organic soils of Texas and western Louisiana are too soft for grazing. In that case they are only good for wildlife. When the organic layer is less than 8 inches thick it does not affect land-use potentialities.

Some shallow organic marshland in the Mississippi delta has been drained in the same way as the Dutch polders. After subsidence, pumping is necessary. The land has become very (though not excessively) acid, but liming has controlled this. Some of the best pastures of Louisiana are on such soils and support excellent cattle. The financial results of these reclamations, however, are said to be unsatisfactory compared with the use of the land in its natural state for wildlife. The soils in question are less attractive than similar organic soils in the Netherlands, which have much less potential acidity or none at all. Most of the latter are used as improved permanent pastures and support a prosperous dairy industry.

Summarizing the properties of the organic soils of the U. S. Gulf Coast area, it is evident that some of the thick peat soils with trapped sulphur compounds have no future as agricultural land. If necessary, large acreages of other organic soils could be transformed into good pastures, but the development of this land would be costly. Drainage by pumping would be necessary.

Many organic soils in Georgia and South Carolina are found in river estuaries, in the lowest part of the fresh-water zone. Some of them have been cypress swamps and their depth may go to 15 feet or more. Some may have been farmed in the past and have subsided because of drainage. Since there is no flood protection these swamps are now influenced by brackish water and are sometimes covered with mud clay and cat clay. Such land is very difficult to reclaim and the present use as a reservation for wildlife is correct.

Movements of the Sea Level and the Future of the American Coast

It is interesting to note that some of these peat deposits of coastal eastern U. S. have a subsoil of mud clay and cat clay. This indicates an alternation of marine and continental influences, similar to that in Europe. In the Netherlands the movements of the sea level relative to the land have been very carefully studied, since both the history and the future of the country are very closely connected with these changes. To explain the situation it should perhaps be observed that three processes are going on at the same time: movements of the sea level (all over the world); movements of the earth's crust (regional); and subsidence resulting from the compression of soft formations (local).

The first is of world-wide interest. According to most experts the general sea level has been rising since 1850. The coast of the U. S., as far as examined during our tour, everywhere shows examples of this movement of the sea level.

It is possible that there are also regions where the earth's crust is subsiding, but our program was not intended to include a study of this problem. According to most geologists the Mississippi delta is such a subsiding region. It should, however, be understood, that this delta is very typical of the compaction of soft sediments. Other river estuaries also show this kind of movement.

Although the interest of the U. S. in this question is less than that of a low-lying country like the Netherlands, it should be borne in mind that the fate of the coastal parts of the U. S. is inseparably bound up with the behavior of the coast. Very little has been done about flood hazards despite the fact that the encroachment of the sea over the land is evident in many places. Flood protection has been a private affair till quite recently. In Dutch eyes it is almost incredible that whole towns are unprotected against not infrequent floods. The situation is comparable to that in the Low Countries in Europe before 1000 A.D., when the first important dikes were being planned. It is true that the Low Countries at that time were already densely populated, but this only illustrates how rich the U. S. is with its immense land reserves and relatively sparse population. Good dikes are being constructed to ameliorate conditions for wildlife, but not to improve human living standards, agriculture or forestry.

Specific Problems of Organic Marsh Soils

To return to the subject of the organic marsh soils of the U. S., we saw thin organic soils overlying older soils in North Carolina and Maryland. The subsoils were mostly connected with the youngest marine terrace, as in North Carolina, but also with the young windblown silt cover in Maryland.

In North Carolina the organic soils in question are related to the poorly drained soils of the Bladen group, with a peat layer on top instead of a dark-colored A-horizon. There are districts where such soils have been drained; sometimes the land is used for row crops and sometimes as pasture. According to Dutch experience three points are important in draining such lands:

The deeper the drainage the faster the subsidence. The impression exists that American farmers try to get rid of the organic layer as soon as possible by deep drainage, sometimes even by burning as much of it as possible during reclamation from the forest stage. This looks to a Dutchman like mining the land. The organic layer has potentialities that are being destroyed. Moreover, the subsoils with their high potential acidity are not always good as future topsoils. Some of the organic soils have subsoils of sand. Contrary to the usual American point of view, we would prefer sandy subsoil to the acid clay subsoils.

Without any intention of recommending a practice, we should like to point out that such soils in the Netherlands would be drained carefully, with a high water table, and covered with sand from the subsoil about 2 to 3 inches thick. This sand layer would be mixed with the top of the organic layer and the soil would then become very productive pasture. With the high water table subsidence would be slow and the land would still be firm enough for the use of modern farm machinery.

The organic soils in question are excessively drained by Dutch standards. Their topsoil is irreversibly dried out to fragments of fine gravel size which can no longer be wetted. This is the well-known reaction of acid peat soils to drying-out. In Holland this drying-out does not occur when the soils are drained to less than 18 inches, but the soils very often dry out when the ground water is at 22 inches. The irreversibly dried-out organic soils or "dead" soils are much less productive than well-managed organic soils, especially under pasture. Since the tendency to dry out is a property of acid organic soils, liming is essential to good management.

The acid organic soils are normally subject to copper deficiency. This is well known in the Middle West, but not—apparently—in the Eastern coastal regions with organic soils. Copper deficiency was discovered in Holland in 1924 on black acid soils similar to the organic topsoils of the Atlantic coastal plain in America. A plant disease, known as "reclamation disease", has been and still is controlled by copper sulphate. No good crops could be produced on such land before the discovery of the influence of copper. This discovery gave rise to the modern reclamation of the low-lying acid organic soils in the former heath area. It is considered part of the task of modern land development to cure such deficiencies *because the cost of drainage can only be justified if the crops are first-class.*

Magnesium, too, is deficient on such soils, and this likewise requires attention. Over-liming causes manganese deficiency. These are well-known facts with respect to soil fertility, but they should be equally well known for drainage operations in acid organic soils or black acid topsoils.

Organic soils with a reasonable mineral subsoil (not cat clay!) should be considered as valuable for future times. They are too promising to be kept for wildlife. [*Editor's Note:* If the esthetic, educational and economic values of wildlife in America are considered, this conclusion is debatable. At least until U. S. population pressures become much greater.]

Various Poorly Drained Soils

In North Carolina, Maryland and Delaware we saw mineral soils, which are covered with a little water and a marsh vegetation, but which genetically have very little to do with marsh conditions. The flooding and the marsh vegetation are apparently due to the recent rise of the sea level. The most striking examples are among such soils as Elkton. The physical properties of the profiles of these soils may be excellent. With flood protection and some drainage such land would become quite productive.

This observation brings us to the large acreage of poorly drained, but physically good soils, which occur in the coastal plains of the U. S. outside the marsh area proper. Most of this land is under forest and we even saw successful attempts to drain such land for forestry purposes.

Recent advances in agricultural science and technology have entirely changed the prospects of such soils. If the physical properties of these soils are suitable, drainage is fairly simple. Lack of chemical fertility can be offset by the use of fertilizers. Under modern conditions such land can be made very productive, and it may even surpass land with a much higher reputation in the past.

Productivity is not constant property of the soil; it changes with the state of technology. Sooner or later land use will adjust itself to changing conditions. Predicting these unavoidable changes is one of the objects of soil science. These are the good reasons why soil scientists and engineers should study the poorly drained soils and their very different potentialities.

PART II

DRAINAGE AND RECLAMATION

Introduction

With regard to their possibilities for agricultural use the areas we visited are characterized by their low situation in relation to sea level. Not only has this essentially influenced the nature and structure of the soil profile, as discussed under *Soil Conditions*, but it is also of great importance for an assessment of the possibilities of later reclamation.

In reality the question is whether the soil can be given such water management as is necessary for agricultural use. From a technical point of view this can be answered quite simply: the drainage of nearly all the marshes we visited will not entail any considerable technical difficulties.

It may be asked whether such works would prove to be economically worth while. For the present the answer to that will often remain in doubt; to answer it fully each area will have to be studied separately from the point of view of the feasibility of the economic development of the whole region.

The great increase of population both in the U. S. and all over the world justifies the opinion that the economics of land use will change continually. A scheme which at present is not economically attractive may well turn out to be so in the future.

That is ample justification for carrying out studies now which may indicate what prospects exist for reclamation; the results thereof can be taken into account in making decisions about the use of the individual areas for specific purposes (*e.g.*, forest culture and wildlife reservations).

Climatic Conditions and Drainage

The coastal area under review has practically the ideal climatic conditions prevailing in the eastern states of America, *viz.*, a rather high rainfall which is fairly evenly spread over the whole year, and a temperature which especially in spring is very favorable to the crops. The very rapidly growing woods and the luxuriant natural vegetation show the influence of this favorable climate. That is why the soils should yield heavily under good management.

The total annual rainfall averages approximately 40 inches on the coast of New Jersey; it increases towards the south to about 60 inches in Florida and near the Mississippi delta; then it rapidly decreases westwards along the Gulf coast. (In the Netherlands the rainfall averages approximately 25 inches a year.)

As mentioned above, the rainfall is very evenly distributed throughout the year; consequently the average amount of precipitation in the warm summer months is adequate to permit non-irrigated agriculture. Since the whole rainfall does not always benefit the soil and the crop, a high-value crop will be served by supplementary irrigation so as to avoid particular risks in dry periods. Under good management the row crops and pastures can usually do without irrigation.

With regard to the rainfall it must be pointed out that the high intensity with which the rainshowers sometimes come down should be considered as a less favorable factor. Intensities of 1 inch in 10 minutes, for instance, occur with a frequency of once in 5 years. It is obvious that such storms (to say nothing of less violent ones) will give rise to all sorts of flooding and erosion difficulties, since even the best soils cannot absorb such quantities of water in a short time.

Accordingly, the daily rainfall is also very high. Along the Gulf Coast, for instance, a rainfall of 6 inches a day once every 5 years must be taken into account; further north, in New Jersey, the figure amounts to 4 inches a day. For the Netherlands the corresponding figure is only 1.7 inches a day. The daily rainfall can therefore be more than three times as much as in the countries of Western Europe.

We were informed that for drainage design in this region it is customary to reckon with discharges of between 2 inches a day for improved pasture and 4 inches a day for truck crops.

In the Netherlands it is not usual to allow for more than 0.3 inch a day for gravity-flow systems and about 0.4 inch for discharge by pumping (without seepage). It can be seen from these figures that whereas the rainfall intensities in America are two or three times as high as in the Netherlands, the discharge of the drainage system is necessarily more than 7 to 10 times as large.

This needs further explanation. We assume that one of the reasons is that with the more intensive rainfall a greater part of it will tend to be surface run off; consequently, it will come in less time to the drain system to be evacuated. Another reason is that the water-storing capacity is much smaller in America because there is less open water and the ground cannot store so much. We did not have time on our trip to investigate this point further; however, we suppose that these high rain intensities are a reason for some limitation in the choice of crops and for a lower valuation of the soils with unstable surfaces.

Drainage Conditions and Soil Classification

If no drainage system has been laid out, the land will have a continuous water disposal problem under normal circumstances. According to the topographical situation and the structure of the soil profile, the ground-water level will be fairly high and will reach the surface almost throughout the year.

In the American system of capability classification the present or natural soil drainage in coastal marshes may determine the capability class. [*Generally on the coastal plains, the soils which are permanently wet are not studied in the same detail as other soils, and classification units (soil and capability) are broader.*] To anyone who is familiar with the circumstances in the Netherlands such a classification system seems unusual; for there it is well-known that a poorly-drained soil may become productive after improvement of drainage. [*In the Netherlands, drained soils may continue, however, to be subject to certain limitations and hazards. In the Netherlands the degree of drainage is indicated in land capability classification by means of a "subordinate indication," viz., as "phase".*]

To the Dutch reclamation engineer the "phase" indication is important. He is going to change the present or natural drainage radically. Therefore, the engineer in the Netherlands is interested in "capability maps" that show what the soil potentials are for agricultural use after drainage has been completed.

Thus we approach the idea of basing either soil or capability classifications on a supposedly efficient drainage system. The factor of ground-water table can be a predominant influence in such a capability classification system. Ground water can affect the productivity of the soil to a great extent. Undoubtedly as wet soils are studied in more detail in the United States, their soil and capability classification will become more precise. It seems important that soil conservation and land management workers in the U. S. should have at their disposal maps on which the classification conveys an idea of the potentials of soils under normal management. It seems that failure to study wet soils in detail has given rise to some confusion. (This applies particularly in areas that are under development; there the drainage situation will be altered with every new opening-up. The soil profile, however, will remain unchanged in texture and make-up, except from superficial tillage. The indication of the drainage conditions is only of value in as much as it is an observation at the time of surveying.)

On the other hand it cannot be denied that a modified ground-water table may bring about changes in the soil profile, such as the transformation of a mud clay into a cat clay or the oxidation and drying-out of a peat layer, both due to excessively deep drainage. In these instances the water table is indeed inherent in the value of the soil profile, yet the term "well drained" would no doubt be irrelevant here.

Another objection to classification by drainage is that the situation can alter owing to natural (geological) changes. The relative sinking of the land which is noticeable along the U. S. coast gradually transforms a large area from a poorly drained into a non-drained one, whereas with comparatively simple technical works it would in fact be possible to turn it into a well-drained area.

Principles of Water Management

We were struck by the fact that in the reclamation areas we visited the design and operation of the drainage systems usually differ from those in the Netherlands. It is a logical economic principle that when a drainage system is laid out endeavors are made to limit the number and size of the ditches and canals to the minimum. Nevertheless, when a comparison is made it is a striking fact that the ditch intervals in the U. S. are generally considerably greater than in the Netherlands (not taking into account that a substantial acreage of the flat Dutch districts is provided with a sub-drainage system in between these ditches).

This observation is not in accordance with expectations based on the rainfall. The difference may be accounted for as follows:

1/Withstanding a high water table for some time may be less harmful for crops in the American climate. (This does not seem very probable to us)

2/It is more economical to have lower yields than optimum; optimum could only be obtained by means of intensified drainage systems and would therefore demand higher investment

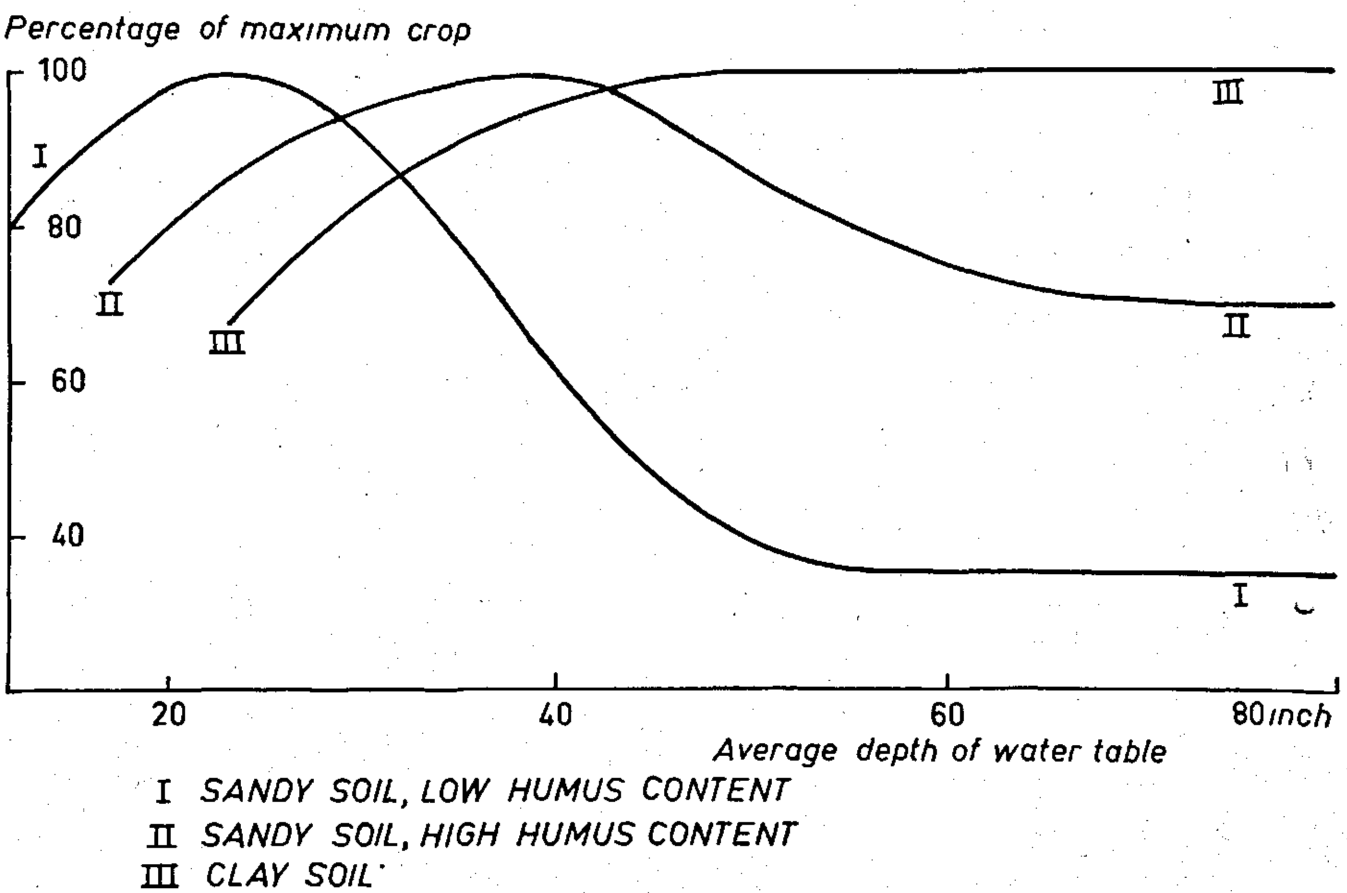
3/The ditches are sometimes fairly deep and they are allowed to dry up completely; this results in a greater water storage

4/A very considerable part of the rainfall is not discharged through the ground (internal drainage), but is drained off over the surface to the ditches.

We suppose that the considerations mentioned under 2 and 3 apply to soils of good permeability; in the coastal area this group of soils is not very large. The consideration under 4 applies especially to the frequently occurring soils of a finer texture. Particularly under the row-crop system the impression is gained that the furrows between the rows can play an important part in distributing the rain along the surface to the ditches.

In the Netherlands, because of lower rain intensities, the surface run-off is less important. In earlier times this means of drainage was frequently and systematically used in the form of "beddings." These beddings were 25 to 60 feet broad; they were chiefly applied in slowly permeable clayey soils, but also in soils of better permeability coupled with a shallow water table. (Since the main discharging system for these soils of better permeability has been greatly improved during the last fifty years, the bedding system is no longer necessary, consequently further upkeep was stopped. In some cases the furrows have been replaced by tile drains.)

In various places in the U. S., fine-textured soils with



a low infiltration rate were examined. In our opinion the use of the bedding-system on these fine-textured soils was fully justified.

The principle of drainage science as developed in the Netherlands during the last fifty years is to maintain as far as possible for every soil type a water table conducive to an optimum agricultural production.

By way of explanation, the statistically empirical graph (page 12) represents the relation between the crop (expressed as a percentage of the maximum crop) and the average water table in various soil profiles.

From this figure the following conclusions are illustrated with regard to the water management of the Dutch soils:

1/The left-hand part of the curves shows that too shallow a water table results in crop depression; this is accounted for by lack of air in the ground

2/For every soil profile a definite optimum can be established for the crop with a given average water table. Naturally, the absolute value of this optimum is closely related to the remaining fertility factors of the ground

3/The depth of the water table at which the best crop is obtained increases with the fineness of the soil and the content of organic material or clay

4/The right-hand part of the curves shows that too deep a water table gives rise to crop depressions owing to parching especially in the case of lighter soils. Below a certain depth the water table no longer influences the crops, since the plant roots are out of range of the capillary rise.

Keeping this figure in mind it is possible to obtain quantitatively a better idea of the meaning of water control systems. The word "control" is used expressly, since it is not only a question of water discharge (left-hand part of the curves) but also of *maintaining* the water table at a certain depth. This means that we should not drain too deep. In practice it is usually impossible to prevent the water table from sinking below the bottom of the ditches in dry periods if nothing is done; if, however, it is preferred to approximate the optimum, then irrigation will have to be considered in due course. Under favorable circumstances, especially in the case of a flat landscape and a reasonably permeable subsoil, it is possible to apply sub-irrigation from the ditches, and raise the water level again. In various areas visited in the U. S. this was considered possible. In other cases irrigation will have to be effected via surface systems.

The foregoing remarks also make it obvious that if the maximum yield from the whole surface is required, it is desirable that the depth of the water table should not differ too much at various distances from the ditches. This means that the intervals between the drains (or sub-drains) should not be too wide.

The basic principles of the drainage have now been explained. In the Netherlands there are certain practical results:

The slowly-permeable good soils are provided with tile drainage systems with spacings varying according to the hydraulic conductivity, from 25 to 100 feet; these clayey soils do not need irrigation.

For the more permeable sandy soils with their undulating topography it is sufficient to have shallow ditches with greater spacings; a considerable proportion of these would benefit greatly from supplementary irrigation. In recent years sprinkler irrigation has been much in favor.

A number of sandy soils in the flat new polder areas are provided with a sub-drainage system; in summer this system is made subservient to sub-irrigation by letting in water.

It is by no means our contention that similar refined water-control systems will pay under the economic circumstances of American agriculture. However, it is our impression that we have seen a number of situations where locally favorable circumstances would permit simple application of the above-mentioned results and would merely call for improved management.

In particular, the great importance of maintaining the exact water level in peat soils must again be stressed. The unfavorable effect which too deep a water level may have in this type of soil, not only with respect to the crop but also as regards the nature of the soil profile, has already been emphasized in the section on soil conditions.

Drainage Design

We have pointed out that the lay-out design of sub-drainage systems in the Netherlands takes account of the hydraulic conductivity of the soil profile.

We think that it will suffice here to refer to the formulas which have been developed by various authors and in which *the relation is established between the discharge and the spacing of the drains; the hydraulic conductivity of the soil profile; and the hydraulic head (height of the water table above the drains).*

During our trip, we had the opportunity to demonstrate a simple apparatus with which the **hydraulic conductivity** can be determined according to the principle of the auger hole method; this calculation takes little time and trouble, while with the use of some nomograms it is very easy to work out the observations.

In our opinion it may be of importance when designing drain systems to be better informed on the permeability of the soil, and to achieve a better basis for the design, at least where internal drainage is concerned.

Undoubtedly, in the U. S. supplementary studies will have to be made to show how to handle the formulas. Thus criteria will have to be sought in order to establish the characteristic discharge per day in relation to the depth and the movement of the water table. Here, too, the problem will arise that the amount of rainfall which is discharged through surface run-off must be known. This is naturally connected with the soil profile and the condition of the surface (vegetation, tillage, slope, etc.). There is no disguising the fact that the application of formulas for the calculation of drain systems under American conditions still presents many difficulties; on the other hand we believe that drainage practice can be greatly improved through application of knowledge of hydraulic conductivity.

Major Reclamation Constructions

The most important works for the reclamation of marshes are the building of dikes, the digging of the main ditches and the construction of water outlets.

Dikes serve to retain high water levels outside the "polder" and should, therefore, be built high enough to prevent the risk of flooding. In this respect it makes a difference for economic reasons whether the area protected is inhabited or is used solely as agricultural land. In Holland practically all polders are inhabited; many villages and towns are situated in them. In these cases efforts must be made to build dikes which give protection against tides of any height. Much to our surprise we found villages along the coast of Maryland which were exposed to every high tide.

For exclusively agricultural land, less effective protection may suffice where occasional flooding is acceptable. There is no serious objection to this if the flood water is fresh. It is most unwise to accept the risk of regular salt-water inundations; there is grave danger of serious salt damage to soils and crops, in which case production would be badly affected.

For calculating the crest height of dikes it will be necessary to use on-the-spot observations of the water heights, preferably taken over a long period. The tidal ranges along the U. S. coast are much less (4 to 5 feet) than along the Dutch coast (5 to 13 feet on the average). Consequently, for normal high-water levels there is no need for the dikes in the U. S. to be as high as those in the Netherlands; in fact they can be much lower. However, wave action and wind-blown spray will have to be reckoned with, especially if there is shallow water in front of the dike. For these reasons there are dikes in the Netherlands with a height of 20 feet or more above the average sea level.

We do not know to what extent the occurrence of hurricanes has to be taken into account in the U. S. On the one hand there is little chance of wind-damage to dikes; on the other hand more information is necessary on hurricane influence on high-water levels and water damage to dikes.

This is not the place for a detailed discussion on the construction of dikes. Construction depends largely on the materials available at the site. It should be mentioned that great care must be taken in using peat, either as a material of the dike proper or as a foundation. In both cases serious subsidence and settlement problems may be expected. Even if the body of such a dike is covered with a layer of, say, 1½ to 2 feet of mineral soil, these problems will not be avoided, and for a long time to come costly maintenance of the dike will have to be faced.

The principles of the dimensions and intervals of the water mains system have been discussed in *Principles of Water Management and Drainage Design.*

For the outlet, two systems can be distinguished:

A/ If the area is not too low with respect to the normal low-water levels, **gravity flow through sluices** is possible. This has the advantage that the installation requires little supervision. A careful study is needed which takes full account of the frequency of higher-than-usual low tides, the duration of the ebb tides which are available for discharging and the possible subsidence of the area after draining. The watercourses will often have to be very large owing to the limited time available for discharging the water. This will be most uneconomical; consequently the use of a pump can be cheaper.

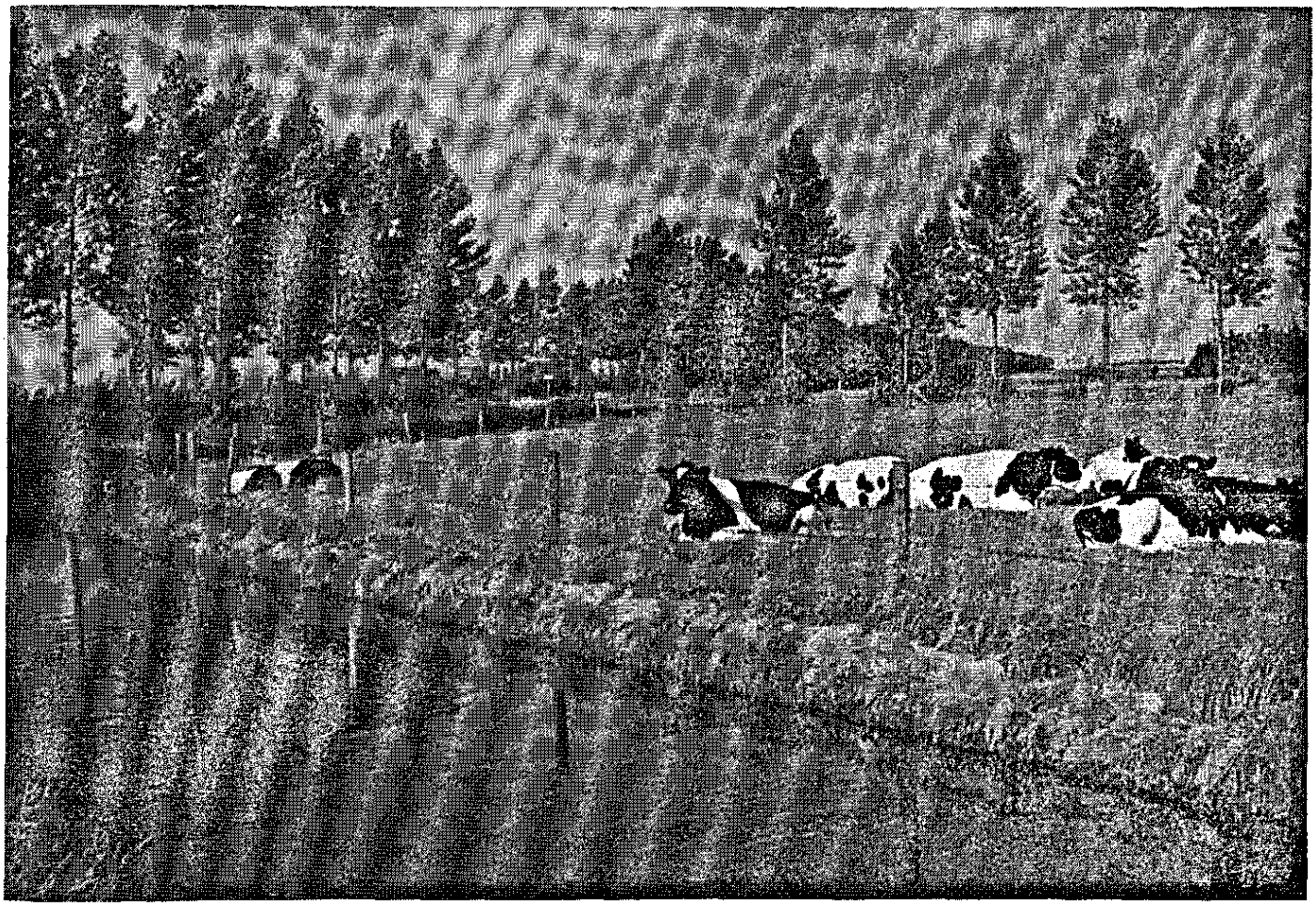
B/ **Pumping.** The principle and practice can be assumed to be known. Undoubtedly, the pumping costs will have to be carefully considered beforehand. (The annual cost for pumping and maintenance of the dikes and main canals in the Netherlands does not exceed 4 dollars per acre under conditions similar to those along the U. S. A. coast.)

Desalinisation of Salt Marshes

Part of the marsh land which can be considered potentially suitable for reclamation was originally deposited in, or subsequently flooded by sea water. Consequently, reclamation also implies the need for desalting the soil.

As is known, Dutch experience shows that it is quite possible to desalt soils that are saturated with sea water. The principle is that the salt is leached out of the soil by the rainfall; the essence of this process is that the water is discharged through the soil, *i.e.*, through internal discharge.

In the Netherlands the water surplus of one winter (only about 8 inches or 200 mm.) already suffices to



MODERN LANDSCAPE IN THE ZUIDERZEE POLDERS.
Ground water level, through the infiltration system, is kept optimal for the growth of crops. The water mains have been cleaned recently and barbed-wire prevents the cattle from treading down the ditchsides.
(Zuiderzee Polders Authority photograph)

bring about a shallow desalting which permits the growing of a first crop. Complete desalting takes several years. For the discharge of the salt water an intensive drainage system is necessary, for which trenches or tile drains are used at intervals of 25 to 75 feet, depending on the permeability of the soil.

In addition the adsorption-complex of the soil, which contains partly sodium ions, must be regenerated by interchange with calcium ions. In this process gypsum ($CaSO_4$) can play an important part. In Dutch marine soils this component is originally present in adequate quantities to bring about the reaction. In view of the absence of lime ($CaCO_3$) in the American soils it cannot be said with certainty whether these soils will also contain enough gypsum; this will have to be ascertained. If there is a lack of gypsum, its application will probably be necessary; the quantities required can be estimated from analyses.

In order to prevent renewed salinisation in a later stage due to a capillary rise from the subsoil, it is essential to maintain a good drainage system permanently. Salt water should not be allowed to enter the ditches if permanent good results are desired.

Caving Problems in Canals

Although it has little to do with the preceding considerations, a few remarks should be made on a problem which is more in the province of soil-mechanics, that is the occurrence of slides in the slopes of water mains.

In South Carolina we were shown examples of this unpleasant phenomenon. The soil concerned was of a very fine texture; through it a deep canal (about 20 feet) had been dug for the drainage of a low-lying area behind. The probable reason for this caving is that in this very fine soil, which was waterlogged during excavation, the internal slide-resistance in moist conditions was too low to maintain the soil-mechanical equilibrium. Generally speaking, the more simple method of preventing such a situation is:

1/Enlarge the slide-resistance; this is achieved when the water is sucked off from the soil pores; drainage will therefore be very useful.

2/Lessen the one-sided weight or exert back-pressure; in practice this means: dig the main less deep and/or make the slopes less steep; drain the slope beforehand and/or choose a higher water table in the main, for example by employing a weir.

In difficult situations it will sometimes be necessary to switch over to stabilization of the soil. The most simple solution (which, as we have already explained, works out favorably for two reasons) is to apply an improved drainage. A recommended method is to lay out a tile drain on each side of the main, parallel to it at a distance of, say, 15 to 20 feet, which can discharge at fixed distances into the existing main, or elsewhere if this main has yet to be dug.

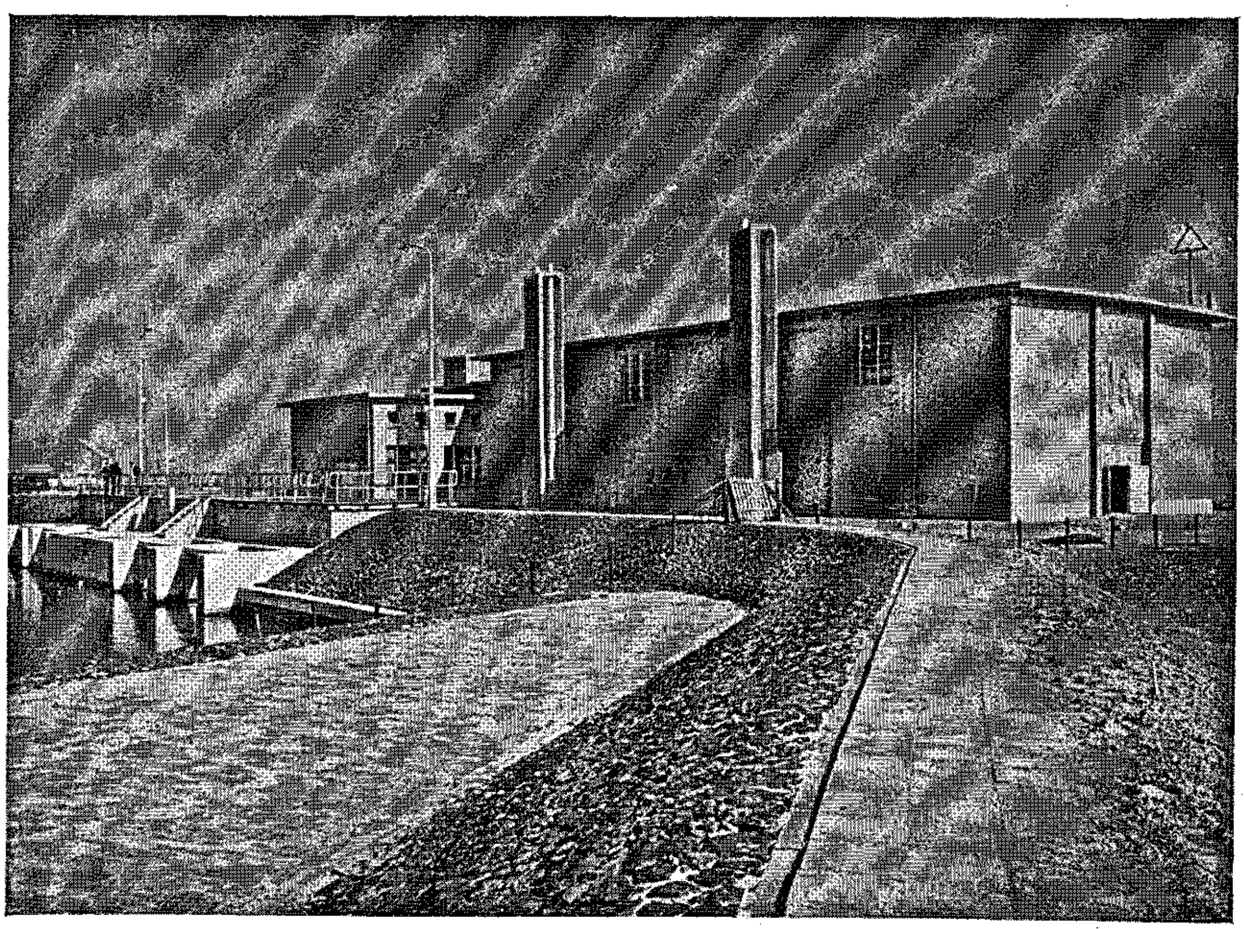
It is difficult to recommend a general solution; the situation will differ from place to place.

In the South Carolina case the difficulties could perhaps have been avoided if the deepening of the main had been done not in one, but in two or three stages at intervals of a few weeks, so that the water had time to drain from the slopes.

The Administration and Upkeep of Water-Management Systems

It seems appropriate, in this brief study, to include a few remarks on the necessity of setting up administrative bodies to assume the responsibility of the management and maintenance of the works carried out. The importance of such bodies cannot be over-emphasized. Nevertheless, in many countries examples can be found of previously constructed expensive drainage systems which have fallen into disuse and decay merely for want of an efficient local, administrative apparatus.

In the Netherlands legislation in this respect has been in existence since the early Middle Ages. The scope and character of the regulations and forms of administration have naturally undergone frequent changes in the course of time, but the principle of collective responsibility for this administration has always been adhered to. The form of administration which has evolved for this purpose in the Netherlands is the **waterschap** or local conservancy board, an institution which can best be compared to the **water district** in the United States. A "waterschap" is a public corporation whose function it is to attend to



THE WORTMAN PUMPING STATION at Lelystad can handle 110,000 gallons per minute. On the 133,000-acre Eastern Flevoland polder, there are three of these stations.
(A. Roelofs van Goor, Publishers, the Netherlands)

all matters of water control in a particular area which constitutes a "conservancy unit" (*e.g.*, the area drained by a watercourse, or a newly reclaimed polder) and to promote the interests of the area in this respect. The implementation of this task is entrusted to an Executive Committee elected by the local landowners from among their own number. The Committee acts by virtue of by-laws, naturally with the approval of higher authorities.

The costs incurred are recovered from the landowners in proportion to the size of their holdings. The Committee has regulatory powers over the landowners.

Since under this system the responsibility for the interests of the district always rests with the local farmers themselves, it is found in practice that the management is generally carried out in a very efficient manner.

There is a regular check on the condition of dikes, canals and hydraulic engineering works. The large works are maintained under the supervision of the Committee, but the smaller drains have to be kept up by the landowners whose property they adjoin. In the event of failure to discharge this obligation satisfactorily the Committee can order the necessary work to be carried out at the expense of the farmers concerned. This system of administration has fully proved its worth over a period of centuries and must be regarded as the basis which has made it possible to achieve success in the face of the complicated hydrological conditions prevailing in the Netherlands. There is a deep feeling of common responsibility, and the duty to cooperate in this respect is considered one of man's moral obligations.

In return the Dutch farmer feels justified in expecting his "waterschap" and the public authorities to see to it that the drainage system around his land is kept in good repair. This feeling of entitlement is based on a longstanding tradition.

As far as we were able to ascertain, the American state governments have clearly recognized the need for legislation on matters of water management and have already enacted necessary laws. With regard, however, to the rights and obligations arising from this legislation, it seems that more experience is required on the part of all concerned.

CONCLUSIONS

We have indicated and discussed briefly some major points in the problem of the reclamation of coastal marshes.

The impression we acquired during our journey along the coast of the U.S.A. is that a number of areas are undoubtedly suitable for reclamation. No sufficiently clear survey has yet been made. For that purpose further soil reconnaissances will first be necessary. A comparison of the most important groups of soils leads to the following conclusions:

1/There are large complexes of humic-sandy and loamy-sandy profiles, sometimes with a wild vegetation but mostly covered with trees, which would be very suitable for use as improved pasture and also for truck crops, provided that there is properly controlled water management. These reclamations should not be expensive, due to the higher elevation above mean sea level.

2/In our opinion the peat soils should be considered secondarily attractive, with preference for those with a sandy subsoil. Careful water control is essential for the conservation and continued good productivity of these soils. This is even more important here than in the case of the first group. For various reasons the reclamation will turn out a little more expensive than for those in group 1.

3/Vast areas of low-lying loamy-clay and clay soils occur. Insofar as these do not possess the unfavorable properties of group 4, reclamation must be considered quite possible. This land is suitable for row cropping as well as pasture. Owing to the lower situation, resulting in more expensive dike construction, and to the intensive drainage and desalting which are necessary, the reclamation costs are fairly high for this group.

4/On various occasions clay soils were observed which, because of their high content of sulphides, showed the unfavorable pattern of cat clays. No attempt should be made to reclaim these soils. Cultivation would be too expensive. Cat clay can be allocated as wildlife refuges.

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