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Lessons from 1200 years' impoldering in the Netherlands

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ABSTRACT: Polder development faced many problems in the past, but most of these problems were solved by many studies and research activities during the recent reclamation of the IJsselmeer polders, such as: design of the drainage system, "soil-ripening" of the soft mud, management of the land reclamation through state farms.

1. INTRODUCTION

The Netherlands is a small country (34,000 km2) located in the delta and the former flood plains of the Rhine (160,000 km²), Meuse (33,000 km²) and Scheldt rivers.

A quarter of the land is situated below the mean sea level, with elevations to about 5 m below mean sea level. In absence of dikes, 65% of the country would be flooded at high sea and river levels.

The country has almost 15 million inhabitants (450 per km²), with most of the population in the low-lying western part (900 inhabitants per km²).

The Netherlands has a cool maritime climate with a mean annual rainfall of 775 mm and a mean annual (open-water) evaporation of 700 mm.

The rainfall is evenly distributed over the year, but the open-water evaporation varies from 0 mm/day in the winter, upto 5 mm/day in the summer. Generally, there is a rainfall surplus of some 300 mm in the winter, and an average deficit of 120 mm in the summer.

The average temperature in the summer months reaches upto 17 °C, in the winter months around 2 °C.

The sea tide in the North Sea differs in amplitude along the coast, with the maximum average tide in the Southern part of +2.00 m and -2.00 m around mean sea level. However, the maximum sea levels during storms are much higher and the sea dikes are presently designed for sea levels of +5.00 m (return period of 1:10,000 years) and an additional 10.00 m for wave run-up.

The geological profile in the lower part of the Netherlands is formed of a 20 m toplayer of clay and/or peat on a thick sand layer. The groundwater is brackish or saline, so seepage water is often brackish. Normally seepage amounts to less than 1 mm/day, but there are exceptions of upto 20 mm/day.

2. HISTORY OF POLDER DEVELOPMENT

2.1 Early development

Some two thousand years ago, the major part (20,000 km2) of the Netherlands consisted of lagoon and delta type areas, and flooded during high water levels of the North Sea and of the rivers, see also Figure 1.

Behind the coastal dunes, large areas with peat-forming vegetations existed together with reedmarshes and marsh forests. Along the rivers, forests on nutrient rich alluvial soils existed, as well as marsh forests and reed marshes downstream.

The people, mainly fishermen and hunters, lived on the natural levees of the rivers.

Protection works against the water started around 300 BC by constructing artificial dwelling mounds.

Construction of small dikes along rivers was started around 100 BC under influence of the technical and organizatorial power of the Romans.

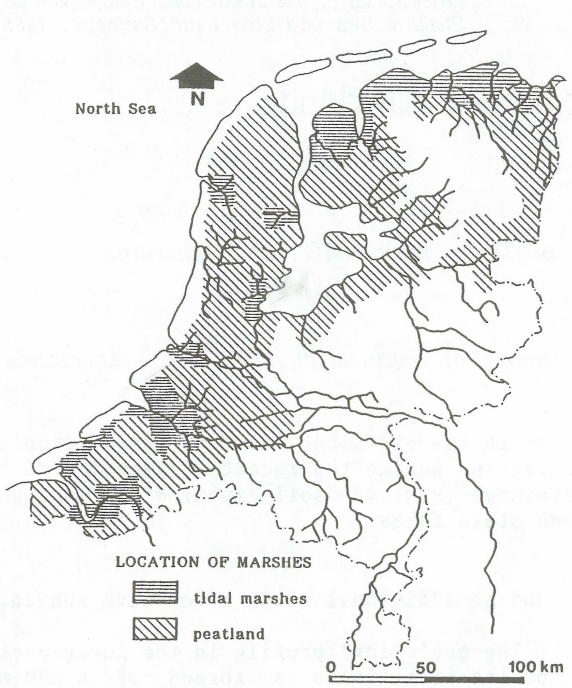

Figure 1. The Netherlands 2000 years ago

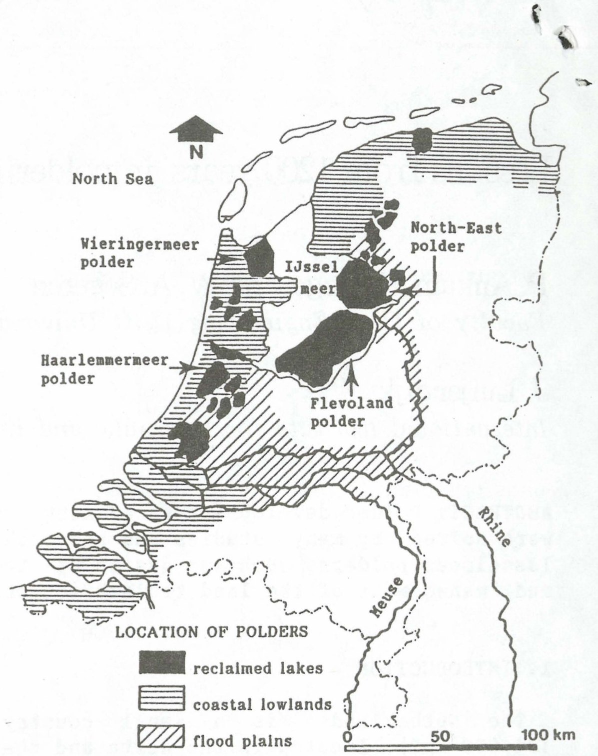

Figure 2. The Netherlands at present

2.2 Empoldering of "old land"

It is estimated that the first polders were constructed in the eighth century. These polders were remnants of old land lost to the sea in historical times.
The polders had elevations at around mean high-tide level and were originally used for the growth of cereals at a low groundwater table.
However, the major part of the first polders were "peat" polders, consisting of peat soils overlaying mainly loamy or clayey soils. Reclaimed peat soils oxydate and shrink after the groundwater table was lowered. The terrain subsided gradually and the water management conditions in the polders deteriorated. Therefore, the groundwater table was kept as high as possible, thus allowing only grass cultivation for cattle.

These first polders drained their water by gravity through simple sluices into an internal channel system with a water level of ± 0.50 m below mean sea level. The channel system discharged also by gravity into the sea during low tide.

2.3 Empoldering of coastal areas

The reclamation of coastal areas started around 1200 AD. Tidal forelands and islands, silted up to about high tide level were reclaimed from the sea.
Generally, the soils are loamy and have groundwater levels of 1 - 2 m below surface. The land use is predominantly arable, with potatoes and sugarbeet as main crop.

2.4 Empoldering of lakes

The Netherlands in its early days was not only characterized by land of just above sea level, but also by numerous lakes. These lakes were some 4 m deep and extended gradually because the soft banks of peat were either excavated by the population for their fuel, or were eroded by the attack of the waves on the lakes.

The application of the windmills made it possible to reclaim the land in these lakes and to use the fertile clay soils suitable for cereal production.

The first lake (Achtermeer, 35 ha, near Alkmaar) was successfully empoldered in

1532 and was followed by the empoldering of many other lakes: 3,000 ha during the 16th century, 28,000 ha during 17th century, 25,000 ha during the 18th century, 52,000 ha during 19th century, and 2,000 ha in the 20th century.

The empoldering of the Haarlemmermeer (18,000 ha, see also Figure 2) in 1852 was a break-through towards modern empoldering techniques to be used for the IJsselmeer polders. Here, the 4 m deep polder was reclaimed by using steam engine driven pumping stations.

2.5 Empoldering of IJsselmeer polders

The IJssel lake ("IJsselmeer") polders are located in a shallow inlet of the North Sea, and was formerly called "Zuider Sea", see also Figure 2.
First plans of closing the Zuider Sea from the North Sea dates back to 1667. It would eliminate stormfloods and salinization of the heart of the country. The first plan for reclaiming parts of the Zuider Sea dates from 1849 and was followed by many other plans.

The first IJsselmeer polder, Andijk polder of 30 ha, was constructed as an experimental polder to gain experience with the land reclamation techniques on the Zuider Sea bed deposits.

The Wieringermeer polder became dry in 1930 and its land development was completed by 1940. The reclamation of the 20,000 ha of salty saturated sediments learned much on the ripening process of soft muds.

With the construction of a 30 km long barrier dam with sluices in 1932, the IJsselmeer was formed by closing off salt water entrance from the North Sea. Within a few years the IJsselmeer became a fresh water lake.

The North-East polder (48,000 ha) was reclaimed from 1942 to 1962.
The Flevoland polder was split for development into two sub-polders: the Eastern Flevoland polder (54,000 ha) was reclaimed from 1957 to 1976, and the Southern Flevoland polder (43,000 ha) from 1968 to date.

The Markerwaard (41,000 ha) is awaiting financing of around one billion US dollars in 1988-prices.

Agricultural development was of prime importance in the first polders, but changed to other land uses: in the Flevoland polders even good soils were allocated for recreation and urban development (Lelystad and Almere for at least 100,000 inhabitants each).

3. EXPERIENCES IN THE NETHERLANDS

3.1 Introduction

The polder development in the Netherlands started as private initiatives in the early days when no government organization existed. Later in the 16th and 17th century, the polder development was undertaken by merchants on a commercial basis.

The polder development of the Haarlemmermeer in 1852 was undertaken with the main purpose to protect Amsterdam against bank erosion by waves. Its agricultural development was not very successful during the first generations, because was it done by individual farmers without support on technical know-how, research, finance and organization by the government.

The polder development in the 20th century was undertaken by the government, who set up the IJsselmeer Development Authority ("RIJP") in 1930. About one fourth of the employees of the IJsselmeer Development Authority are working in the research divisions.
Initially, the research was limited to soils, water management and agriculture, but was gradually extended to a wider scope, including research on biology, environment, rural and urban development, archeology, economy.

Sub-surface drainage machines, such as trench cutters, trench ploughs, wheel and chain diggers for sub-surface drains were developed during the reclamation of the IJsselmeer polders.
The Wieringermeer polder was developed by manual hand labour, which involved 200 manhour per km for trenches and 180 manhour per km for subsurface drains. This was reduced for the Flevoland polders to 3 manhour per km for trenches and 12 manhour per km for subsurface drains due to the machines.

Besides the mechanization, there was also a development in subsurface drainage pipes: from clay pipes with straw envelopes, to corrugated pvc pipes with cocos envelopes or even without any envelopes.

The scope of the IJsselmeer Development

Authority was extended from the original area of the IJsselmeer polders only, towards general polder development in the whole of the Netherlands, and even to polder development outside the Netherlands.

3.2 Present approach on polder development

At present, the development of a new polder in the Netherlands is more or less fixed and follows specific steps:

1. construct the enclosing dike with outlets (pumping stations, sluices);
2. dredge main drainage canals when the polder is still submerged;
3. evacuate the water from the polder during 6 to 12 months;
4. sow reed-seeds on the (soft) mud surface by airplanes. This is to promote the drying process ("soil-ripening") and to prevent other weeds;
5. construct of the drainage network of main drainage canals, main ditches and plot ditches, as well as the construction of the road system;
6. develop the land by (i) burning the reed vegetation, (ii) construction of the open field drains;
7. farm the land for about 5 years with government funds, very often with oilseed in 1st year, wheat in 2nd year, barley in 3rd year, oilseed in 4th year, wheat in 5th year;
8. replace the open field drains by a subsurface drainage system (pipes) after the soil has ripened and the land subsidence has halted, e.g. after the 5th year;
9. construct farm buildings and villages, and lay telephone and electricity supply cables and the water mains;
10. allocate land to private individuals on the basis of one to four workers per farm-holding;
11. landscape, afforest and construct recreation areas;
12. when the polder is ready: transfer of the administration and maintenance functions to e.g. a Polder Board.

3.3 Drainage System of the Polder

The drainage system in a polder exists of (see Figure 3):

i field drainage system, to maintain the groundwater table under the root zone;
ii main drainage system, to divert the drainage water from the field drainage system to the outlet;
iii sluices and/or pumping stations, to evacuate the water from the main drainage system to the bordering canals;
iv storage canals ("boezem") surrounding the polder.

The water management in a polder is mainly determined by "water level control" and to a lesser extent by capacities or "volume control".
Therefore, the determination of the stagnant water level ("polder level") and the amount of water storage in the polder, i.e. the percentage of open water in the polder, is most important.

The "polder level" is the target level of the open water to be maintained in a polder.
The polder level is established on the basis of mainly agricultural considerations, such as:
- the functioning of the field drainage system,
- to prevent or reduce the (irreversible) subsidence of the soil,
- to prevent the oxidation of wooden pile foundations,
- to meet interests of navigation, recreation and nature preservation.

The actual determination of the polder level is based on an experimental basis: the optimum polder level gives the highest crop yields.

Polders may be divided into sections having different polder levels, depending on the topography as to limit the variation in groundwater depth to e.g. 0.50 m.
Different polder levels are also applied when soil conditions differ, e.g. peat soils with high polder levels ± 0.50 m below terrain, clay soils with deep polder levels at ± 1.50 m below terrain.
Very often a "summer" polder level and a deeper "winter" polder level is applied, as to provide for more drainage in the winter season.

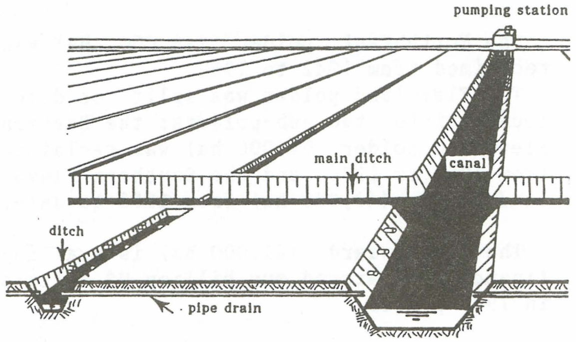

Figure 3. Drainage system in polder

3.4 Field drainage system

The function of the field drainage system is two-fold: (i) during the reclamation period is to speed up the soil-ripening process, inwhich the very soft and wet soils are transformed into normal soils, and (ii) to maintain adequate drainage conditions during after reclamation.

Preparation of new clay-polders (see Figure 4) starts with the digging of trenches of ± 0.60 m deep at intervals of some 50 m, to promote the de-watering process.
One year before cultivation, other trenches at intervals of some 10 m are dug between the existing trenches.
After a few years of farming, the trenche drainage system is replaced by subsurface drainage pipes, e.g. 1.20 m depth and at interval of 50 m for a design discharge of 10 mm/day. The interval of the drainage pipes for sandy soils is usually less (e.g. 10 m), because the permeability of ripened soft clays appears to be higher.

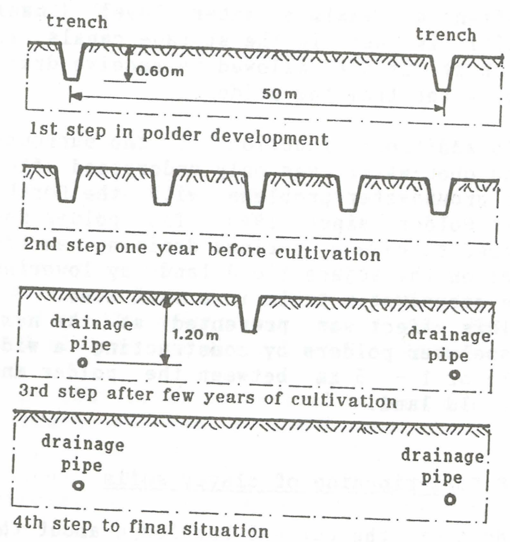

Figure 4. Drainage during reclamation

The design of the field drainage system in a polder is now almost at its optimum. Modern criteria for polders are related to the groundwater level, which may reach upto e.g. 1.00 m below terrain level during 2 days with a frequency of once per year, and upto e.g. 0.75 m during one day with a frequency once per 10 years.

3.5 Main drainage system

The main drainage system of a polder consists of (see Figure 5 and Table 1):

i Canals, which are often navigable and have (stagnant) water depths of some 1.50 - 2.50 m. The gradient of the canal bed is normally horizontal;
ii Main ditches; and
iii Ditches, which run along the long sides of the plots, i.e. the rectangular fields of about 500 m x 1200 m.

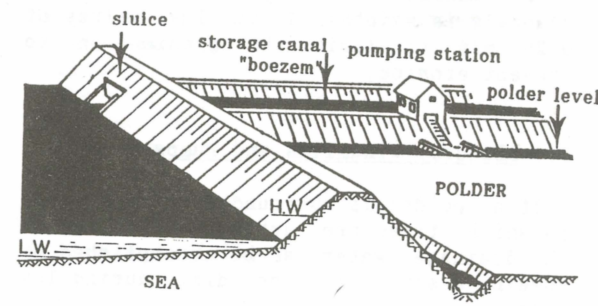

Figure 5. Relation Polder-Boezem-Sea level

The present design procedure of the main drainage system is still rather empirical and based on steady flow.

The required capacity of the drainage system depends not only on the rainfall but also on the seepage (often 0.7 - 1.0 mm/day) and on water from polder shiplocks (1 - 2 mm/day).
This leads for the IJsselmeer polders to discharges in the main drainage system in the order of 13 mm/day for the ditches and of 11 mm/day for the canals.
For urban polder areas, values for the main system of 20 mm/day and more are often applied.

Table 1. Type of polders.

polder type	land use	open water %	polder level m÷terrain	pumping capacity mm/day
peat	grass	5 - 10	0.20 - 0.50	8 - 12
old-clay	grass	3 - 10	0.40 - 0.70	8 - 12
old-clay	crops	5 - 10	0.80 - 1.00	8 - 12
new-clay	crops	1 - 2	1.40 - 1.50	11 - 14
urban	- -	3 - 8	1.50 - 1.80	15 - 30

The above criteria depend also on the percentage of open-water, which is kept low in the modern polders (1 - 2%), but is much higher in older peat polders (5-15%).

Water management in the polders is based on "water level" control to keep the polder level constant. However, a water gradient will be needed during discharges.
During periods of discharge, actual canal levels in the upper part of the polder will generally exceed the polder level (+0.10 to +0.20 m), while near the outlet the water level may be lowered well below the polder level (-0.30 to -0.40 m)

The maximum velocity in the drainage channels is maintained at low values of 0.25 m/s to limit the gradient and to prevent erosion.

3.6 Sluices, Windmills and Pumps

If a polder is surrounded by open water in which tides are active, evacuation of the drainage water can be accomplished by opening a sluice in the dike during low tide.

In the early days, the discharge modulus was lower than presently applied. So was assumed that winter rainfall of 260 mm should be evacuated between 1 February and 15 April, when 50 - 70 days are available for sluicing. This means a drainage capacity of 3.7 to 5.2 mm/day.
Another old rule-of-thumb prescribed 2-4 m sluice width per 1000 ha polder.

However, gradually the polders subsided so that pumping became more and more necessary.
The first windmills for water evacuation, were constructed around 1400. An improvement of the efficiency of the windmill followed in the sixteenth century with the invention of the revolving cap of the mill bywhich a changing wind direction could be followed.

The first windmills used the paddle-wheel for raising the water, to a maximum head of 2 m.
The technique of placing several windmills in a series to overcome more head was developed in the seventeenth century and could reach a head of a multiple of 2 m.
The open "Archimedes" screw pump to lift upto 4 m was invented in 1634.

Generally, one windmill could cover around 600 ha polder, from where some 300 mm per year was pumped at a head of 1 m, during some 30 - 60 days of sufficient wind.

In the past, the estimation of the pumping capacities of windmills was rather experimental set at 8 mm/day, which referred to the criterium that the rainfall during five consecutive days (40 mm) should be discharged within the same period.

The steam engine for pumping was applied from 1770. The application of diesel and electrical driven pumps followed in the beginning of the 20th century.

3.7 Surrounding Open-Water

The polders evacuate the drainage water from the polder canals to the surrounding open-water, sse also Figure 3.
This is a system of higher-lying canals, lakes or former rivers, usually at some 0.50 m below mean sea level and serves as a temporary water storage.

The storage system ("boezem") is actually not a part of the polder and is drained independently into the sea by means of a sluice or by a pumping station.
Often a maximum water level ("maal peil") is set in the storage canals, at which it is not allowed to receive drainage water from the polder.

An additional function of the surrounding open-water was only understood after the groundwater problems with the North-East Polder since 1940. The polder appeared to have a serious draining an effect on the adjacent old-land, by lowering the groundwater table in a vast area.
This effect was prevented at the next IJsselmeer polders by constructing a wide lake of 1 - 5 km between the polder and the old land.

3.8 Soil-ripening of clayey soils

Much of the current knowledge about the reclamation of unripened soils have been gained during the impoldering of the IJsselmeer polders and has been applied in many other parts of the world.

The physical soil-ripening process starts as soon as a polder falls dry and is a process of de-watering. Full ripening of a soil profile to 1.00 - 1.50 m depth may take centuries. Good drainage is most essential for ripening.

Parallel with the physical ripening, various chemical and biological changes occur in the soil.

At the beginning of the reclamation, the clay soils have a very high pore volume (70 - 80%) and are almost impermeable (K = 10^{-3} to 10^{-4} m/day). Thus, subsurface drainage is not feasible and is done by the evapotranspiration of pioneer-vegetation such as by reed.
This drying of the mud is irreversible and the rewetting of the ripened clay does not bring back the soft original mud.

The physical soil-ripening process causes a considerable shrinkage of the soil. The vertical component leads to a subsidence of 0.5 to 1.5 m. The horizontal component causes soil cracks. These cracks are irreversable and are very important for the drainage of the soils.

Prediction of subsidence is often calculated with Terzaghi formula. The disadvantage of the use of this formula is that the relative subsidence ($\delta z/z$) can reach impossible values above 1 for soft soils and for large values of the grain pressures after and before loading.
A new set of formulae has been developed in the Netherlands.

4. THE POLDER BOARD

4.1 Water Board system

The origin of polder development in the Netherlands is to be found in protection of land against flooding. Initially, these activities were carried out by individual farmers and by private corporations. Gradually, the maintenance of the embankments and sluices was controlled by regulations.

At that time, no central or regional government existed, so local communities had to play an important role. Thus, the Water Boards ("waterschap") were formed, being special corporations on polder management.

The Water Boards are one of the earliest forms of government administration in the Netherlands.
Since the 15th century, the Water Boards have a clear management and juridical identity.

Since the early 19th century the Water Boards are supervised by the provincial governments, but they have retained a high degree of independence with regard to finance and to issuing regulations concerning water control in their areas.

The management of the Water Board is carried out by: (i) the general assembly, (ii) the council, and (iii) the dike-reeve ("dijkgraaf").
The general assembly is composed on a functional basis and represent different interest groups, mainly land owners, on an election basis. The general assembly elects the council, who does the day-to-day management of the Water Board.
The dike-reeve is the chairman of the council and is employed by the assembly.

The costs of the water management in a polder is paid by the interested parties, mainly land owners and domestic/industrial polluters.
The Water Boards have no fixed financial relationship with the central government, unlike the provincial and the municipal governments.

4.2 Water legislation

By public law, the Water Board and the Municipalities belong to the lower (third level) administrative level. The Province is the second management level, and the State is the first.

The Water Board is a form of functional decentralisation within the Netherlands State and has responsibilities on water management matters, such as:
- operation and maintenance of hydraulic structures along coast and rivers,
- control of water quantities (mainly drainage, but also supply of water),
- control of water quality,
- control of polder dikes and roads.

The Water Board, as a functional body, is not responsible for public administrative matters. This is left to the Municipality which is the general administrative body.

The provincial government is responsible for the organization and operation of the Water Boards in its Province, by giving them authority and controlling their duties.

The central government and the Provinces have also management responsibilities on water control in addition to their tasks on Water Boards: (i) the central government manages the large waterways, such as IJsselmeer, river Rhine, and (ii) the Provinces manage certain rivers on e.g. navigation and main dike system.

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