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Draining the Peat Fens south of the Wash, England: A Cautionary Tale

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From 1649, the peat Fens were drained by gravity and the project was declared successful early in the 1650s. A decade later the lands had become wetter and the project was in trouble. Vermuyden, and everyone else involved was surprised. The easy modern explanation is that Vermuyden, whose scheme it was, would have been experienced in taming the sea and marine and fluvial sediments, coming, as he did, from the Netherlands, the leading nation for land reclamation and drainage. It is generally accepted that he and his contemporaries could not have been expected to know that drained peat degrades and gravity drainage ceases to work. However, a fact that has generally been overlooked in the relevant literature is that large areas of peat in the Netherlands had been drained over centuries from around AD 800. The Dutch experience was complex, including land drained but then lost to the sea by AD 1250 and then drained again, from about 1450. By the seventeenth century, any memory there may have been of peat wastage had been lost. The paper begins with a brief account of seventeenth-century peat drainage in England, followed by the Dutch experience, including the use of drainage windmills from about 1450. This leads to a discussion of the time taken for windmills to become common in England as an example of technology transfer and the need for appropriate administrative arrangements. There is an appendix on peat.

Introduction

For the purpose of this paper, the Fens denotes the area south of the Wash comprising the peat and silt fens east of the river Welland traversed by two main rivers, the Great Ouse and the Nene (Fig. 1). Much has been written about Vermuyden's project, following a 1649 Act of Parliament, to drain the peat lands. This literature includes major overview volumes, notably by Darby (1940), Summers (1976) and Ash (2017). The 1649 project aimed to convert fen into arable farmland. By the early 1650s, the project had officially been accepted as successful but 'What had seemed a promising enterprise in 1652 had, by 1700, become a tragedy' (Darby 1940, 113). What had happened was not immediately understood but is explained very simply. With drainage, the peat soils had first compacted somewhat and then begun to degrade under aerobic conditions, lowering the land surface, rendering gravity drainage inoperable to the standard needed for arable cultivation and to be safe for dwellings. This surprised Vermuyden, his backers and apparently everyone else.

The tacitly accepted explanation for this surprise is that Vermuyden was a Dutchman. The Dutch were the leading hydraulic engineers but their experience was with reclamation from the sea and thereby with sand, silt and salt marshes and therefore Vermuyden could not have been expected to know drained peat degrades. It is true that in the seventeenth century there were few if any new peatland drainage schemes in the Netherlands, but the Dutch history of drainage goes back to about AD 800. So the present purpose is to explore the relevant histories of peat drainage in England and the Netherlands the better to understand why in 1649 Vermuyden was presented with a novel problem.

The English story

The two English projects prior to 1649 were the draining of Hatfield Chase from 1626 and then, from 1630, a project for the whole of the peat fens, basically the same area that was tackled again from 1649.

Hatfield Chase

It is generally accepted that the first major peat-fen drainage scheme in Britain was Hatfield Chase, an area of about 110 square miles in North Lincolnshire and South Yorkshire. By agreement between Charles I and Vermuyden in 1626, the latter was to drain this land so that grazing would be improved and at least some land made suitable for arable farming. The enterprise was supposedly completed and declared a success in 1628. Three sets of circumstances conspired to mask any impact of peat shrinkage there may have been: technical aspects of the scheme, legal disputes and deliberate disruption, and the broader political situation in England leading up to the Civil War (1642–1651) and the Republic.

The project is described in some detail by Harris (1953, 41–58). He does not mention that the scheme relied upon gravity drainage and gives no hint of

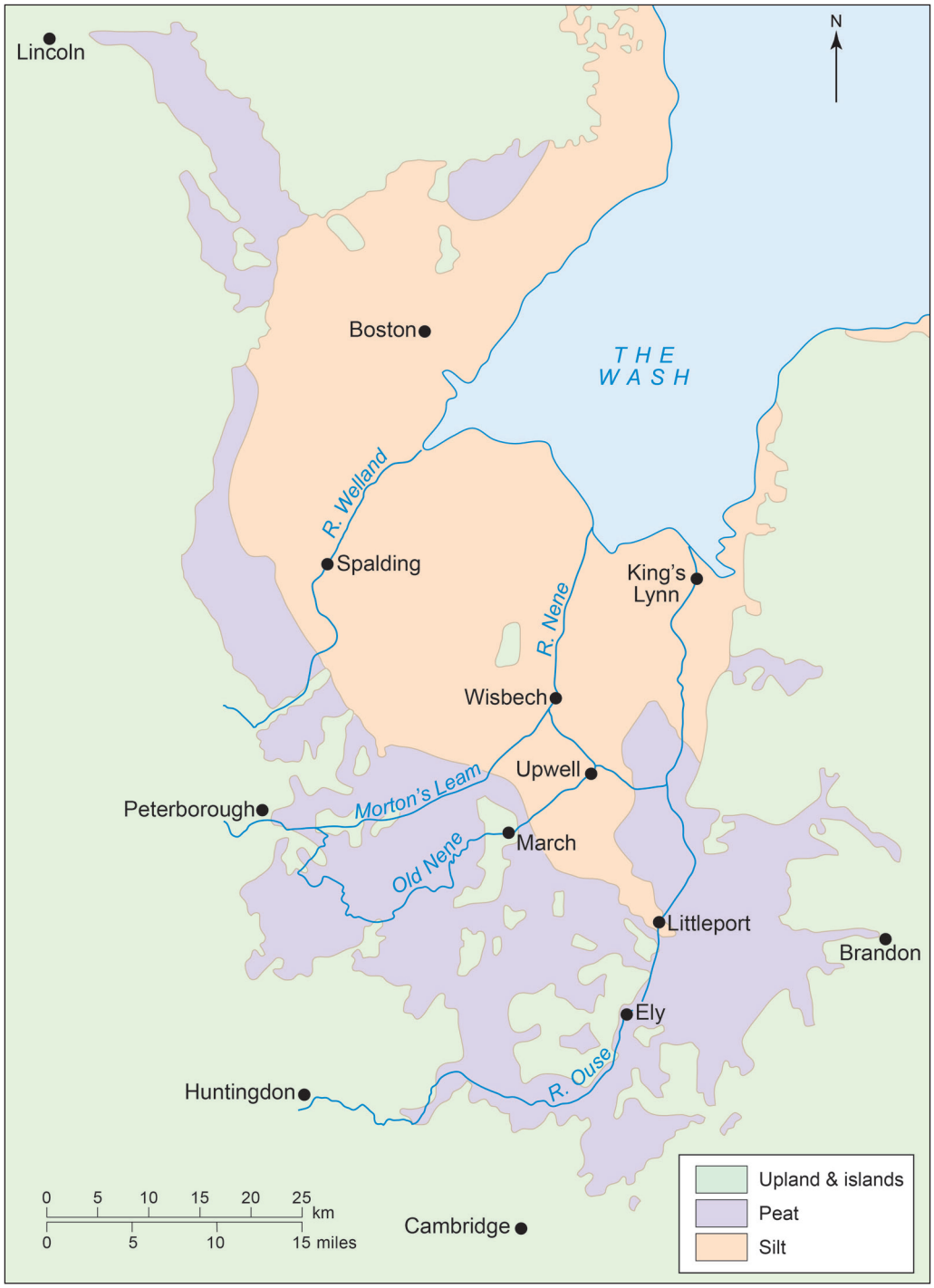

Figure 1. *Nineteenth century peat fens around the Wash. Re-drawn from Darby 1940, figure 6.*

peat wastage problems. The primary concepts were: realign rivers so that their waters did not enter the area to be drained; new channels to be constructed within the area and naturally winding courses to be straightened; and provision for the temporary storage of seasonal river flood water. New and improved embankments were also needed. However, the technical problem was judgement about the precise specifications for the works, and in this respect it quickly became apparent that further engineering was required. Although mistakes might be understandable for a major pioneering project unlike anything else in England, some do seem difficult to comprehend. For example, the re-direction of rivers had the unintended result of flooding land and communities that previously had been relatively dry (Ash 2017, 156). This issue was but one of several problems:

> The Commoners brought various petitions and lawsuits against the Participants from the 1630s onwards. The people of the Isle of Axholme took

> advantage of the confused situation of the Civil War and Interregnum in the 1640s and 1650s to take revenge on the Participants. They deliberately flooded Hatfield Chase in 1643 … and destroyed sluices and banks. It took until the 1650s, and the appointment of an agent called Nathaniel Reading, for the unrest to die down … [but] it was not until 1719, when the Commoners' latest Bill against the Participants was dismissed, that unrest around Hatfield Chase finally ceased' (Nottingham University 2017, 2).

Notwithstanding the difficulties, it seems that in the early years after 1628 the venture had achieved a good deal: 'The whole face of the Level had been changed from continuous swamp to arable and grazing lands, subject, it is true, in some cases to periodic flooding, but, generally speaking, land fit for tillage and pasture' (Harris 1953, 54). This assessment is consistent with the information recorded in William Dugdale's compendium of flood protection and drainage works, first published in 1662 and re-issued in 1772, with amendments. He claims the project was completed in five years, with Huguenot refugees settled who were building houses and farming the land, 'All of which they enjoyed till about the month of June, in the year of 1642' (Dugdale 1772, 145). However, trouble had become apparent as early as 1627 and from that point on 'Opposition to the Hatfield Level drainage was thus every bit as complicated as the drainage work itself' (Ash 2017, 157).

The long-term rate at which the surface of peat becomes lower with drainage and cultivation may be in the order of one to two inches annually, and more rapidly in the early years. However, the rate is affected by the depth to which the water table is lowered and the way the land is used (see the Appendix). Had events been peaceful on Hatfield Chase from 1628, the drained land's surface would have fallen quite quickly to the point at which arable farming would not have been possible. There are no reports in the literature that peat shrinkage did occur and opponents of the scheme did not express fears that shrinkage would happen (Ash 2017, Chap 5; Harris 1953, Chap 5). Any problems from the lowering of the land surface were masked by other concerns.

The 1630s project for the peat Fens south of the Wash

The same conclusion is true of the 1630s project for roughly the same area that Vermuyden drained from 1649, more than four times the area of Hatfield Chase. As with the Chase, this enterprise was initially regarded as successful. Vermuyden seems to have had no role in the 1630s' scheme (Ash 2017, 184–194). This enterprise encountered many problems similar to those experienced in the Chase, including local opposition and the exigencies leading up to the Civil War and thereafter. But there was a critical difference from the 1626 venture, namely, that the principal aim was to obtain 'summer ground'. In other words, the intention was to improve pasture and livestock management, in the expectation that there would be periodic floods but that these would be less frequent and of shorter duration than hitherto (Darby 1940, 44). This aim is explicitly formulated in the Lynn Law of 1631 under which the project proceeded, that the lands 'shall be fit for meadow or pasture, or arable … but that a great part of the said now surrounded lands will be overflown with sudden waters' (Wells 1828, 102). This was not full drainage for arable farming and the construction of dwellings. The environmental circumstances created would have caused little lowering of the land surface but in any case the project was only a partial success and turbulent times leading to the Civil War overtook other considerations.

Vermuyden's 1642 Discourse on the Fens

Sometime in the years 1637 and 1638, Vermuyden prepared a *Discourse* for draining the peat fens, presented to king Charles I in 1639 and then published in 1642 (Wells 1828, 339–366). This treatise shows considerable first-hand knowledge of the Fens but acknowledgement of the documents he saw and the individuals he consulted is sparse. In large measure, the proposals published in 1642, and the modified version implemented from 1649, embodied many features local landed interests had been proposing (Knittl 2007).

In the present context, there are two key facts to note about this document. First, the drainage arrangements proposed relied on gravity drainage. Second, it reveals his lack of awareness that peat degrades when drained:

> 'The soyl of this vast country is moorish, gathered and grown up higher by the weeds and ooze of the waters; many of them are rich grounds, and all would (if they were well drained) be very profitable and become good grounds, especially after they be burned, manured, and husbanded as such grounds should be' (Wells 1828, 343).

There is no hint in the text about shrinkage of the peat with drainage. Furthermore, Vermuyden visualised the need to construct embankments to control waterways and provide flood storage but did not realise that peat and peaty materials are not suitable for this purpose, saying: 'That the banks (so much as may be) be laid out from moorish grounds' (Wells 1828, 346). Such material does not provide strong embankments; the material is porous, resulting in significant seepage; and the organic materials degrade on exposure to air.

The 1649 drainage project for the peat Fens south of the Wash

Early in the 1650s, the 1649 project was officially declared a success but by 1661 it was in trouble. Land that had been dry enough for arable farming was getting too wet and a committee was established by the Company to consider solutions:

> 'The [management] company struggled to cope with the worsening situation, but it did not understand the nature of the challenge. Its officials failed to recognise the fundamental problem of land subsidence, which would remain a mystery until

> well into the eighteenth century, and they mistook the silting up of the fenland rivers as the root cause of the trouble, rather than a symptom of it' (Ash 2017, 304).

There seems to have been an equivalent failure to realise that peaty materials are not suitable for embankments.

Conclusion

Nobody in England and the Netherlands in the seventeenth century with an audible voice seems to have known peat would degrade with drainage for arable purposes. This is curious because, as shown below, there was, and still is, much drained peat in the Netherlands. As Stephen Rippon points out in *The Transformation of Coastal Wetlands* (2000, figs. 3 and 4, 179–182), there have been projects to drain smaller or larger peat areas in the Netherlands since the ninth century, but his maps of coastal wetlands in England and north-west Europe do not distinguish between peat and silt areas. He does not show the extent of the Dutch peat areas, despite citing Audrey Lambert's *The Making of the Dutch Landscape*, published in 1971, wherein she has a generalised geological map for the country showing the then contemporary distribution of peat lands. With such a long history of peat reclamation, why were Vermuyden and his contemporaries in the mid-seventeenth century not aware that gravity drainage for arable farming would be problematic?

The Dutch story

A major source for the history of water management in the Netherlands is the book *Manmade Lowlands* by the Dutch historical-geographer Gerard van de Ven, published in 1993 in Dutch and English, revised and extended in 2004 (see also Vos *et al.* 2020). Van de Ven compiles and integrates the many geological, historical and archaeological studies that have been conducted on the history of the Dutch landscape and Dutch water management, focusing on the period after AD 800. As shown in Fig. 2, large parts of the Netherlands were covered with peat at the beginning of the ninth century. Some modern towns have been added on this and subsequent maps to aid orientation. The peat existing in 800 included both low-lying fens of reed, sedge and swamp trees on the one hand, and also extensive raised bogs, domes or ridges of *Sphagnum* moss, reliant on precipitation for water and able to cope with a nutrient-poor environment. The largest domes were fifteen kilometres (nine miles) in diameter (van de Ven 2004, 44). Since 800, most peat land has been drained or cut. North of Amsterdam, drainage started in the late eighth century and was completed by 1200 while south of Amsterdam drainage started in the late tenth century and was completed by 1300 (Besteman 1997).

The early drainage was effected by gravity drains into natural channels. As the drained land subsided, the drains on *Sphagnum* peat were extended toward the centre of the dome or ridge. The drains were complemented by suitable embankments. There was no pre-determined extent for drainage projects but later schemes were more strictly controlled, either by the Count of Holland or the Bishop of Utrecht, often having the extent from tidal waters set at the beginning (van der Linden 1955). Fig. 3 shows where most of the peat drainage occurred in the period from 800 to 1250.

There is ample archaeological and historical evidence that these drainage activities resulted in significant peat shrinkage. In some areas, such as the West-Friesland area, peat has disappeared completely, apart from some remnants under churches and other old buildings. While some arable farming remained possible into the early sixteenth century, most arable land was replaced by grassland; specialised dairy farming developed (Besteman 1997; Ettema 2005. In addition, peat mining became important. According to a survey from 1514, the main profession in many villages in Holland province was not agriculture, but peat cutting, creating many lakes, most of which have since been reclaimed (Bos 1988, 40).

In coastal areas, much land was lost to marine flooding between 800 and 1250 (compare Figs. 2 and 4). For a long time, this was attributed to rising sea-level and/or greater storminess but 'it has become clear that human occupation has been the main cause for this loss of land. The accompanying subsidence of the ground level has been the primary cause of the increased influence of the sea' (van de Ven 2004, 100). In addition, especially when agricultural prices were low, the land was not profitable enough to support the increasing costs of flood protection (van Dam, 2003). This process of land loss is recorded in many local studies, of which three additional to those noted above may be mentioned – for Jsselmonde near Rotterdam, the south of Holland more generally and Amsterdam further north (Mostert 2012; Leenders 2004; Abrahamse *et al.* 2012).

By 1600, the extant peat drainage schemes were already at least 100 years old. There were drainage problems and these were attributed to rising river levels caused by sedimentation, obstructions in the river beds, land reclamation of the floodplains, and a wetter climate (van Oudenhoven 1654). Locally, there were major silting problems, as with the estuary of the Old Rhine in the eleventh century (Tielhof and van Dam 2006). But more generally, most of the peat land was in pasture, with the land surface subsiding very slowly, at millimetres annually. The cumulative effect of subsidence probably outweighed other effects but was overlooked. Indeed, it was not until the twentieth century that the nature of peat was well understood in the Netherlands. There were times when it was thought that peat was the compressed bark and twigs of a large forest blown down sometime in the ninth century; or it had drifted in the form of islands from northern countries; or a kind of sediment; or it had existed in its present form since the creation of the world (van Oudenhoven 1654; Le Franq 1769; Kampinga 1917).

Sphagnum moss peat was identified in the province of Holland in 1729 (Degner 1729), but these observations were challenged forty years later because

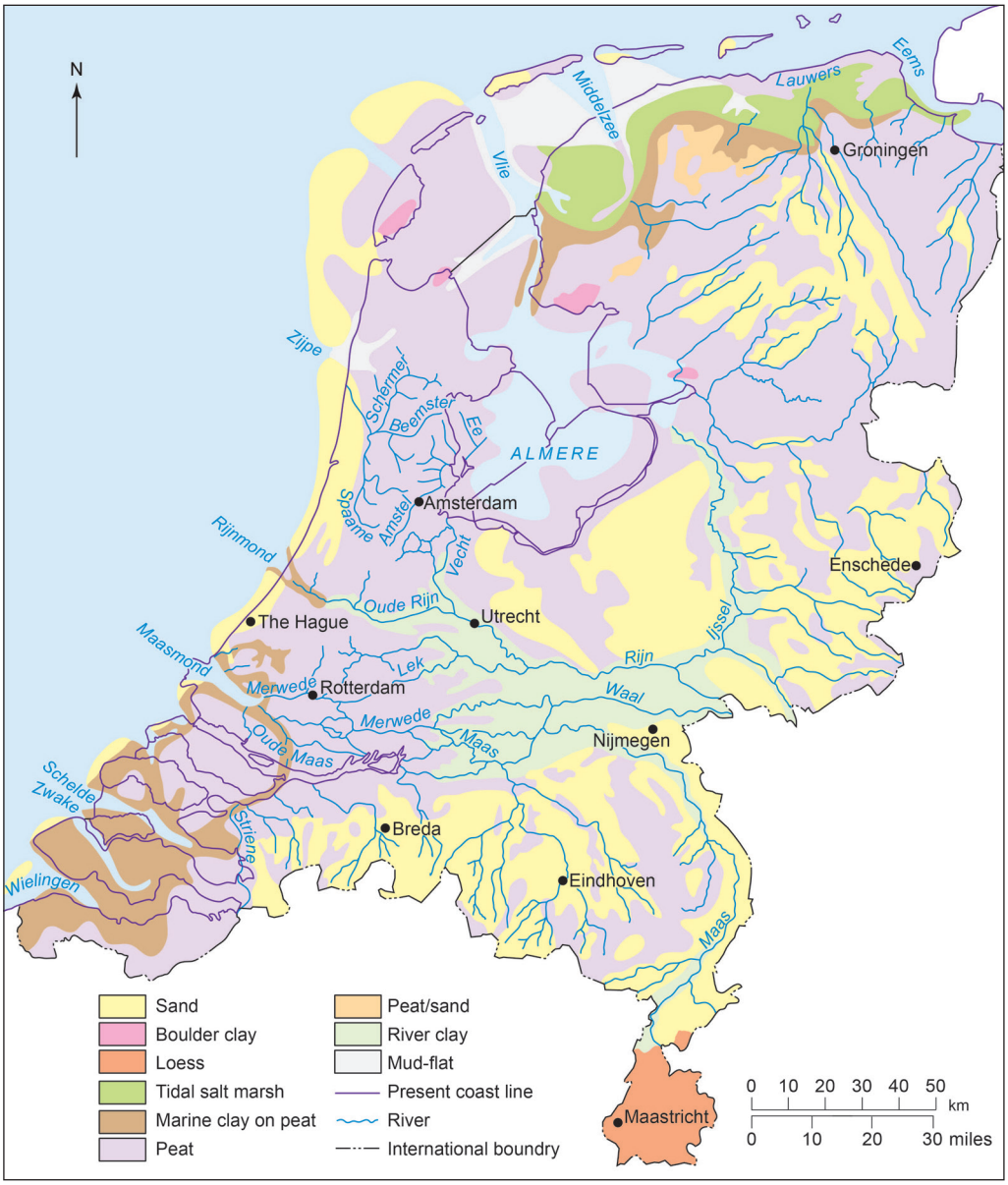

Figure 2. *Distribution of peat in the Netherlands around AD 800. Re-drawn from* Man-made lowlands *van de Ven 2004, 40.*

Sphagnum was then very rare in lowland areas (Le Franq 1769). *Sphagnum* was again identified in lowland peat areas in 1910 but the critical study was published in 1929. It examines the stratification of peat layers at several locations near Amsterdam, showing a succession of deposits first formed by fen vegetation, overlain by swampy forests and on top peat containing *Sphagnum*, indicative of raised bogs that had shrunk (Polak 1929). For these former raised bogs Polak used the term *verdronken hoogveen* (literally: drowned high peat), but she did not offer an explanation for the shrinkage. By 1940, however, the cause was widely known: (improved) drainage. According to the journal *De Boerderij* (*The Farm*) of 13 August 1941, twenty years previously the dominant idea had been that 'good drainage is deep drainage, and that's it', but it had been recognised that draining too deeply was the problem. Since then, knowledge of the peat areas has been increased significantly by soil scientists, historians, historical geographers and archaeologists (de Bont 2008 Chap.7).

Over the period 800 to 1250 there was a complex history of land drainage and land lost to the sea, with a significant bearing on what then happened up to 1600. Three developments are critical for our understanding. First, peat was a valuable commodity as fuel:

> 'In the peat reclamation areas where the surface level was higher than the water level outside, farmers cut peat to turn it into fuel. After 1350, when the towns grew larger, a start was made with the commercial exploitation of peat. The fuel was not only important for households but also the emerging industries

Figure 3. *The Netherlands AD 800–1250, water management regions. Re-drawn from* Man-made lowlands *van de Ven 2004, 51.*

> – such as breweries – needed peat. The peat winning and trade in peat were in the hands of wealthy townsmen, who acquired lands and received the count's permission to dig a certain amount of peat. … After 1450, nearly all the peat had been dug away in a number of places. The peat diggers now started to use watermills to lower the ground water level' (van de Ven 2004, 125).

The mills were driven either by wind or by horse. Roughly a century later, in 1540, the 'hand drag' (baggerbeugel) was introduced, allowing peat to be retrieved in several metres of water, obviating the need for drainage. The peat was laid on dry ground, tamped down and, when suitably dry, cut to size and stacked for further drying. The result was the creation of substantial areas of water with residual baulks of peat, a landscape with little or no economic value. The hand drag can best be likened to a stout version of a child's seaside fishing net – a metal ring with a bag to hold the peat as it was scooped out. Peat mining had a major impact upon the Dutch landscape.

The second major process was the impact of tidal waters on land that had previously been reclaimed. Where there was residual peat, this was covered with marine clay, creating conditions equivalent to the natural circumstances in the south-west recorded in Figure 2 for *c.* AD 800, clay on peat. The depth of this new accumulation would have varied considerably. For peat lands that had been drained and then lost to the sea, the accumulation of marine clay was particularly important. In the ninth century, most of the peat areas that were drained had peat formed from *Sphagnum* moss (Fig. 5), lacking plant nutrients. Consequently, when drained from about 800, the peat soil had limited value for arable farming and much was in fact used for pasture. When this land was managed for the second time, the superimposed clay had created conditions for highly productive farming – both arable and pasture.

From the thirteenth century, waterways were created or improved with the aim of maintaining gravity drainage but this was a difficult battle because of

Figure 4. *The Netherlands around 1250. Re-drawn from* Man-made lowlands *van de Ven, 2004, 104.*

the inevitable lowering of the peat surface (Hendrikx 2001). So the third development to note was the introduction of windmills driving scoop wheels to pump water off the land. The first documented successful mill was erected in 1408 and the innovation spread rapidly (van de Ven 2004, 122). By about 1450, windmills were making a significant impact on the Dutch landscape, in complex water management regimes. For example, summer drainage of pasture that had been deliberately flooded by fresh water in the winter, something that provided thermal protection for the soil and simultaneously introduced new nutrients.

Events between *circa* 800 and *circa* 1250 had created a very complicated set of circumstances for reclamation work thereafter. The over-riding need was the maintenance of protective banks. The land so protected could be drained by gravity but wetness of the land so managed would occur for multiple reasons: particularly in the winter, excess rainfall; to some degree the seepage of water through the protective embankments; and the subsidence of drained peat. It would not have been easy to distinguish the impact of these three processes. However, from about 1450 it did not much matter because there was a solution to hand – windmills. If a single lift proved to be inadequate, a second, third or even a fourth mill could be installed in series to achieve the necessary lift in stages. This would have increased the on-going management costs but was evidently regarded as worthwhile expenditure. Much of the land that had been drained and then lost to the sea had been reclaimed for a second time by about 1600 under very different circumstances and the focus had turned to reclaiming new land from the sea and draining lakes and meres:

Figure 5. *The Netherlands* Sphagnum *moss peat distribution around AD 800. Re-drawn from van de Ven* Man-made lowlands, *2004, 44.*

> 'In the period between 1600 and 1800 huge areas of land were reclaimed by coastal and lake reclamations in particular. More than a hundred lakes and broad meres with a joint surface of about 600 km^2 were transformed into land. A considerable part, 230 km^2, consisted of lakes, which had been created by man … After 1650 people started to reclaim them once more' (van de Ven 2004, 191).

Conclusion

By1600, most of the land that had been lost by 1250 had been recovered and the task thereafter was to maintain the sea defences, judicially to win more land from the sea and to convert man-made lakes to more profitable uses. In addition, and probably much more important in the present context, the shrinkage rate of the remaining peat was very slow and difficult to identify, and the technology was available to counter the consequences. In the Dutch context, draining peat lands was not a problem at the dawn of the seventeenth century.

Sir Cornelius Vermuyden

That is the context into which Vermuyden was born about 1595 in Sint-Maartensdijk, on the western edge of the island of Tholen, located in the extreme south-west of the country (Zeeland), facing the North Sea. As the British *Dictionary of National Biography* (1885–1900) observes 'His native place afforded him exceptional facilities for studying the principles and practice of embanking and reclaiming lands from the sea'. His parents and their immediate forebears were prominent in the locality as embankers and drainers, and also in civic affairs (van Cruyningen 2016, 17–37). We do not know what formal training Vermuyden received but it seems clear that, as a young man, the general circumstances in the Netherlands and his family background provided no clues that peat drained for the first time initially degrades rapidly if the water table is low enough for arable farming. Any such knowledge there may have been had been lost.

Windmills in England

It is now well-known that the solution for land subsidence was the introduction of windmills to lift water and that in England this began to happen late in the seventeenth century, ushering in the eighteenth century as the 'age of the windmill' (Darby 1940, Chap. 4). Darby cites a handful of windmills in operation in the second half of the seventeenth century but gives no figures for the rate of installation; the clear impression is that the examples cited were regarded as exciting curiosities. Furthermore, he confuses the issue by referring to a 1662 map showing 'the large number of windmills' in the silt fens, noting they 'were hardly drainage mills' (Darby 1940, 115 fn 1). The 1662 map in question depicts South Holland in Lincolnshire, the whole area lying within the silt fens (Dugdale 1772, 218–219). In any case, we can be sure that in 1658 there were no windmills for land drainage in the peat fens. Jonas Moore was the surveyor for the 1649 project, compiling a map in 1658 as the official record, at a scale of two inches to the mile. It shows some windmills, all of which are situated on 'dry' land above flood level within the fens, or on the uplands surrounding the Fen basin; no windmill is shown where it could have drained peat fens (Willmoth and Staziker 2016). They would all have been corn mills, consistent with the fact that the silt fens had been protected from floods for centuries before the seventeenth century, drained by gravity and used for arable farming (Hallam 1965; Neilson 1920; Chisholm 2021; Silvester 1988). Nevertheless, in a publication dated 1983, Darby removes the caveat about windmills in the silt fens not being drainage mills and observes: 'During the latter half of the [seventeenth] century windmills were increasingly used for drainage purposes. Many are shown (mostly on the siltlands) on Dugdale's map of South Holland in 1662' (Darby 1983, 107).

Writing in 2017, Ash (2017, 305–307) avoids Darby's mistake but, for want of data, does not fully address the rate of windmill take-up. However, he does note that the Bedford Level Corporation, in conflict with private owners, ordered dozens of drainage mills to be dismantled but then had their surveyors build four in 1678. As late as 1703, the Corporation succeeded in a lawsuit to pull down two privately built drainage windmills (Wheeler 1896, 379).

There is no doubt that that by the end of the seventeenth century the drainage project was in serious trouble and that, though there were some windmills for drainage purposes, they were not in general use. It was not until the third decade of the eighteenth century that the construction of windmills to drain land really got going. In other words, there was something like half a century from the time it was realised all was not well with Vermuyden's drainage scheme for the solution to be taken up in earnest. So far as the present authors are aware, there has been no detailed overall study of the rate at which drainage windmills were installed in the late seventeenth century and into the succeeding one, and the factors inhibiting their use.

Continental engineers attempted to gain windmill technology monopoly rights in England (Ash 2017, 305–306). There seems to be no record of any such patent being awarded, which is not surprising. Windmills had been common in the Netherlands from about 1450 and any visitor seeing them in action would have readily understood the principle by which the well-known technology of grain windmills could be modified to lift water. One must look to other matters to understand what was going on.

The realisation that drained peat lands were becoming wetter obviously meant that gravity drainage arrangements were ceasing to operate effectively. Unaware that the surface level of drained peat becomes lower, the widespread view was that the beds of rivers were being raised as a consequence of the drainage works. In this respect, William Dodson in 1664 was correct to observe:

> 'Observation and experience will teach you that the bottom of your dikes [watercourses] grow not up, nor rise as you say, but it is your ground lying dry, the moor earth groweth solid … it is not your dikes bottoms which rise, but your grounds which sink' (Wells 1828, 446).

It is true that there were problems with the river outfalls through the silt fens but these were long-standing. With the accumulation of marine and river sediments, the coastline is steadily advancing into the Wash. To maintain their gradients, the rivers have to build up their beds, creating problems for sea-going vessels and for land drainage. That process presents problems for gravity drainage but this is independent of the impact of peat shrinkage arising from land drainage.

The belief that drainage works caused the beds of waterways to rise persisted in some quarters into the eighteenth century, as shown by Thomas Badeslade's well-known 1725 treatise. This book was occasioned by the collapse of the major sluice on the Great Ouse at Denver, a little upstream from King's Lynn. This treatise is an extended argument that the sluice should not be re-built, in the belief that the sorry state of the peat fens after drainage arose because of problems with the main streams 'which have grown up for want of Dyking and Scouring' (Badeslade 1725, 17). But by this time changes were afoot to achieve better integration of main drain management with local land drainage, paving the way for a rapid increase in windmills.

The solution that evolved was the establishment of drainage boards within the area controlled by the Bedford Level Corporation. Each such drainage board required an Act of Parliament. The first of these, achieved in 1726–27, was for Haddenham, a village located between Cambridge and Ely, in the south-east corner of the peat fens (James 2009). Then:

> 'After the success of the Haddenham petition, many more soon followed … The company opposed such bills as a threat to its ability to maintain the central drainage network, but its failure to offer any workable alternative solution ensured that several bills were passed into law … Over time they constructed an elaborate, decentralised network

> of subsidiary drains throughout the level, as well as hundreds of drainage windmills that became a defining feature of the landscape' (Ash 2017, 308).

In other words, the introduction of windmill drainage technology required some radical changes in administrative arrangements for which the 1649 Act of Parliament had made no provision because the need had not at that time been foreseen. The full story of this halting process of windmill adoption remains to be told, to complement the recent study of the way the 'age of the windmill' ended (James and Finney 2023).

Conclusion

The central question posed at the beginning of this paper is why it was a surprise to find that Vermuyden's 1649 gravity drainage scheme did not work. The Dutch had long been actively involved with peat landscapes so one might think they would have known the land surface would become lower with drainage. The first step was to confirm the reality of the surprise. The second step was an examination of experience in England prior to 1649 with the drainage of substantial peat fens, specifically Hatfield Chase in the 1620s and the Fens in the 1630s. Neither of these projects yielded recognised warnings that drained peat degrades. The third matter was to understand the outlines of Dutch experience with draining peat lands.

By the dawn of the seventeenth century, existing drained peat lands in the Netherlands had such a long history of drainage and management that the rate of surface subsidence was so slow it did not register as a problem. So far as subsidence did continue, windmill technology was able to compensate. Any memory there may have been that pristine peat degrades rapidly in the first few years after drainage had been lost. In addition, the natural environment of the Holland and Zeeland provinces is very dynamic, sensitive to climate change, changes in sea level and the frequency and severity of storm surges. One may readily understand that identification of the impact of peat shrinkage with drainage would have been difficult if not impossible.

While this answers the question posed at the beginning, it raises other questions that deserve more detailed examination than has hitherto been undertaken. It is well known that, for a considerable time after trouble became apparent for the 1649 drainage scheme, opinion was divided over whether it was land subsidence or the raising of riverbeds that was the cause of increasing wetness on the drained land. The issue was not finally resolved until well into the eighteenth century but the full story of this debate has not been written. The other issue to note is more general. Although the basic drainage ideas were known in England, the 1649 project should be regarded as a major transfer of technology, implemented by means of a radically new administrative structure bolted onto long-established arrangements. The Dutch had evolved technology and also management structures, but the latter were not exported. England then had to learn the hard way how to adapt the social means to manage water in the Fens.

Appendix

On peat

The International Union for the Conservation of Nature reckons that the accumulation layer of peat is usually between 10 and 20cms thick, which will quickly disappear with compaction and oxidation. Thereafter, undisturbed peat will subside by 1–2cms annually (IUCN 2014). With cultivation, the rate of loss is accelerated. However, the rate of loss is also dependent upon the depth to which the land is drained. In the Netherlands, records show that if the average lowest ground water level is 1.5m below the land surface, the subsidence is 2.86cms annually. Should the water level be just 0.25m below the land surface, the rate of loss is virtually zero. The same study showed that, with grassland farming, surface subsidence is just a few millimetres each year (van Asselen *et al*. 2020). This finding confirms Dorothy Summers' observation that 'grass is the only crop that can be grown on peat without ultimately destroying it … the solution most generally favoured in the Netherlands' (Summers 1976, 253). An extreme English example of early lowering is provided by the post at Holme Fen, originally set in 1848 into 22 feet of peat near Peterborough when Whittlesey Mere was drained. Initially, the land surface subsided nine inches annually. The Fen was designated as a nature reserve in 1985 and the overall rate of surface subsidence there has averaged about one inch annually.

Peat in the Fens

The Holme Fen record might suggest that a very thick layer of peat once covered the entire peat fens. This was the opinion of four authors writing at various dates from 1589 to 1664 about the circumstances at the time they wrote. They asserted that the peat fens stood higher than the silt fens by some four to seven feet. These assessments were accepted by two twentieth-century authors, namely Darby (1940, 107–108) and Summers (1976, 16). However, as Darby notes (1940, 108), in the modern landscape, the silt fens stand ten feet or more above the peat fens; this would imply a blanket of peat up to seventeen feet deep once covered the peat fens. The manner in which peats accumulate makes this impossible, and the weight of evidence is that in the seventeenth century and previously the peat fens were subject to periodic riverine inundations, ruling out the possibility of a peat surface above the silt fens. To clarify the matter, a brief discussion is warranted.

The domes of peat formed in the Netherlands were created by *Sphagnum* moss and associated plant species, accustomed to acidic conditions and able to thrive reliant for water solely upon precipitation. The plants

are nutrient-poor, so creating peat that is also lacking in nutrients. The river waters entering the Fens are mildly alkaline and therefore inimical for *Sphagnum* moss but fine for fen peat vegetation – rushes, sedges and the like. If fen peat accumulates to a sufficient depth above the water table, carr vegetation of shrubs and small trees can become established, paving the way for *Sphagnum* moss to take over and continue the upward accumulation of peat. In the Fens, this happened only in isolated places around the fringes of the Fens, where localised basins were deprived of river water because of a temporary drop in sea level. Holme Fen is almost certainly the site of the largest such raised bog (Godwin 1978; Waller 1994, 105). Note that the depth of peat there depended not just on the upward height of accumulation but also upon the height of the land surface below the peat left behind by the last glacial period (Gibbard *et al.* 2018).

The peat drained in the seventeenth century was fen peat, now known as Nordelph Peat. The water table controlled the depth to which this peat could develop and that was determined by the level of rivers draining to the sea. From the time when the Romans withdrew and into the Anglo-Saxon period, sea level rose somewhat but the silt fens were not inundated. By about 970, they were defended against the sea by embankments and some land was in arable farming. There is no evidence that rivers were flowing to a sea level significantly higher than we know today.

This is confirmed by records going back to the eighth century. Felix, writing between 730 and 740 about the life of St Guthlac of Crowland, identifies a 'fen of immense size' that begins with the river Cam and Cambridge and stretches north to the sea, saying that: 'It is a very long tract, now consisting of marshes, now of bogs, sometimes of black waters overhung by fog, sometimes studded with wooded islands and traversed by the windings of tortuous streams' (Colgrave 1956, para. 24: Roberts and Thacker 2020, xviii, 316). Bede's *Historia Ecclesiatica* (*c.* 731) confirms this description, noting that "the district of Ely is surrounded on all sides by waters and marshes" (Colgrave and Mynors 1969,395, Bk.IV,19).

About a millennium later, the same general area was described by Vermuyden in his 1642 *Discourse*. He notes that the rivers:

> '… lye common with the land, without separation by banks …The level is broad, and of great extent, and flat, with little or no descent of its own, and grown full of hassacks, sedge and reed … and the waters go slowly away from the lands' (Wells 1828, 342).

Less than two decades previously, in 1618, Mr Atkyn was asked to tour the peat fens with a view to formulating a drainage scheme. His report notes that the silt fens at that time stood higher than the peat fens that were regularly subject to long-lasting freshwater floods (Wells 1828, 71). Three well-known maps were published between 1636 and 1646, J. Blaeu, H. Hondius and J, Jansson. These are all at a scale of about one inch to 2.5 miles, showing the whole of the peat fens as 'surrounded' or 'inundated', subject to periodic flooding, with 'islands' of solid ground above the flood level. All three maps must have been based on the remarkably accurate 1604 MS survey of the Fens at a scale of one inch to the mile undertaken by William Hayward for the purpose of devising a drainage project (Chisholm and Stickler 2012; Chisholm 2018). There is no suggestion in the literature about draining the peat fens that any projects essayed were designed for lands standing higher than the silt fens, a fact consistent with the widely used descriptive term for the peat fens – the 'great level' – grading to the Wash through the outfalls of the Nene and Great Ouse in particular, and the Welland to a lesser degree.

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