UNITED KINGDOM

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General

The United Kingdom - officially the United Kingdom of Great Britain and Northern Ireland - is located off the north-western coast of the European mainland. The United Kingdom consists of four constituent countries: England, Scotland, Wales and Northern Ireland. Northern Ireland is the only part of the United Kingdom that shares a land border with another State, the Republic of Ireland. Apart from this land border, the United Kingdom is surrounded by the Atlantic Ocean, with the North Sea in the East, the English Channel in the South and the Celtic Sea in the South-west. The country has an area of 24.2 Mha (million hectares) with, in 2022, a population of 67.5 million, or 2.79 persons per ha. England accounts for just over half of the total area of the United Kingdom and Scotland for just under a third, including nearly eight hundred islands, predominantly west and north of the mainland. Wales accounts for less than a tenth of the total area (Wikipedia and United Nations, 2022).

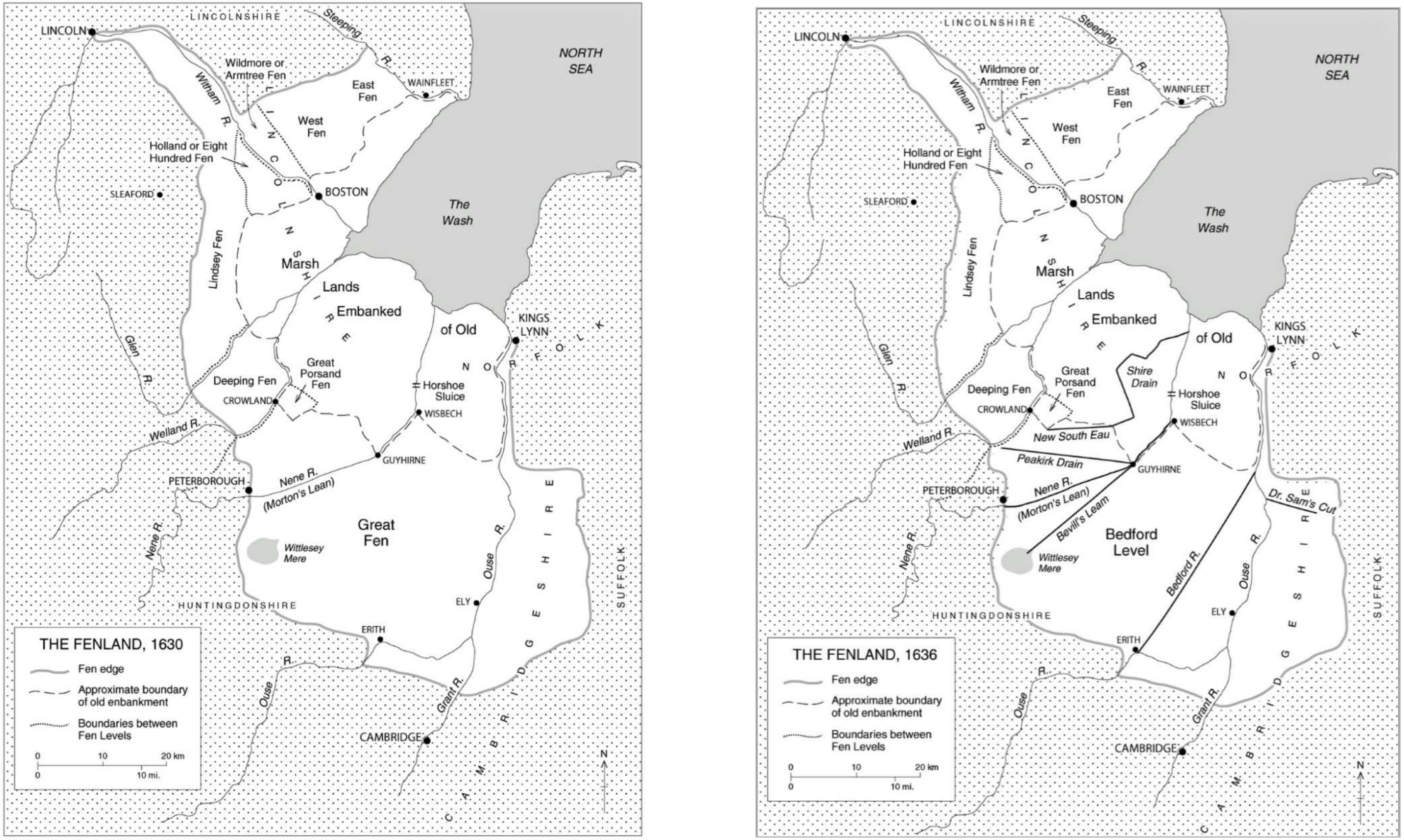
Climate and geography

The United Kingdom has a temperate climate, with plentiful rainfall all year round. The prevailing wind is from the Southwest and brings frequent spells of mild and wet weather from the Atlantic Ocean. The eastern parts are mostly sheltered from this wind. The majority of the rain falls over the western regions. The temperature varies with the seasons, seldom dropping below -11 °C or rising above 35 °C. Atlantic currents, warmed by the Gulf Stream, bring mild winters; especially in the West where winters are wet. Summers are warmest in the Southeast, being closest to the European mainland and coolest in the North. Heavy snowfall can occur in winter and early spring on high grounds, and occasionally settles to great depth away from the hills (source: Wikipedia).

Most of the country consists of lowlands. The main rivers are the Thames, Severn and Humber. Scotland is the most mountainous country. Its topography is distinguished by the Highland Boundary Fault, which traverses Scotland from Arran in the West to Stonehaven in the East. The fault separates two different regions; namely the Highlands in the North and West and the lowlands in the South and East. Lowlands - especially the narrow strip of land between the Firth of Clyde and the Firth of Forth, known as the Central Belt - are flatter and home to most of the population, including Glasgow. Northern Ireland is mostly hilly.

Williamson (2006) described the difference between marshes and fens in the United Kingdom. Marshes are areas of coastal silt and clay, usually located within former estuaries or behind sandbars and shingle. They were reclaimed from tidal salt marsh, usually in the early middle ages. Fens were areas with peat soil, which usually lay inland from the marshes. They were waterlogged for most of the time and generally did not contain any settlements. They were, for most parts, used as common land by the communities living around them, or on islands within them. Knittl (2007) showed the situation of the Fens at about 1630 (Figure 1a) and at about 1636 (Figure 1b).

Williamson (2006) also described the role of Dutch engineers in the draining of the Fens, especially of Cornelis Vermuyden who seems to have come to England, in 1621, to assist his brother-in-law, Joachim Liens, in his proposed reclamation project. When this failed Vermuyden was employed for repairing a breach in the banks of the river Thames at Dagenham. In 1626 he was commissioned to undertake the drainage of Hatfield Chase, an area of about 28,400 ha, and of the Isle of Axholme (Korthals Altes, 1924 and 1925). The project was initiated by King James I, who owned extensive properties at Hatfield Chase, and following both Dutch precedents and the new arrangements laid down in the General Drainage Act the investors - many of whom were Dutch - received 9,877 ha of the reclaimed lands, of which Vermuyden himself received 1,843 ha (Figure 2). The methods he employed were similar to those he later used in the Great Level. New canals were dug, and existing ones straightened in order to speed up the flow of the principal rivers - the Don, Idle, Aire and Went. In addition, washlands were endiked to prevent flooding during high discharges.



(a) (b)

Figure 1. The Fens about 1630 (a) and 1636 (b) (Knittl, 2007)

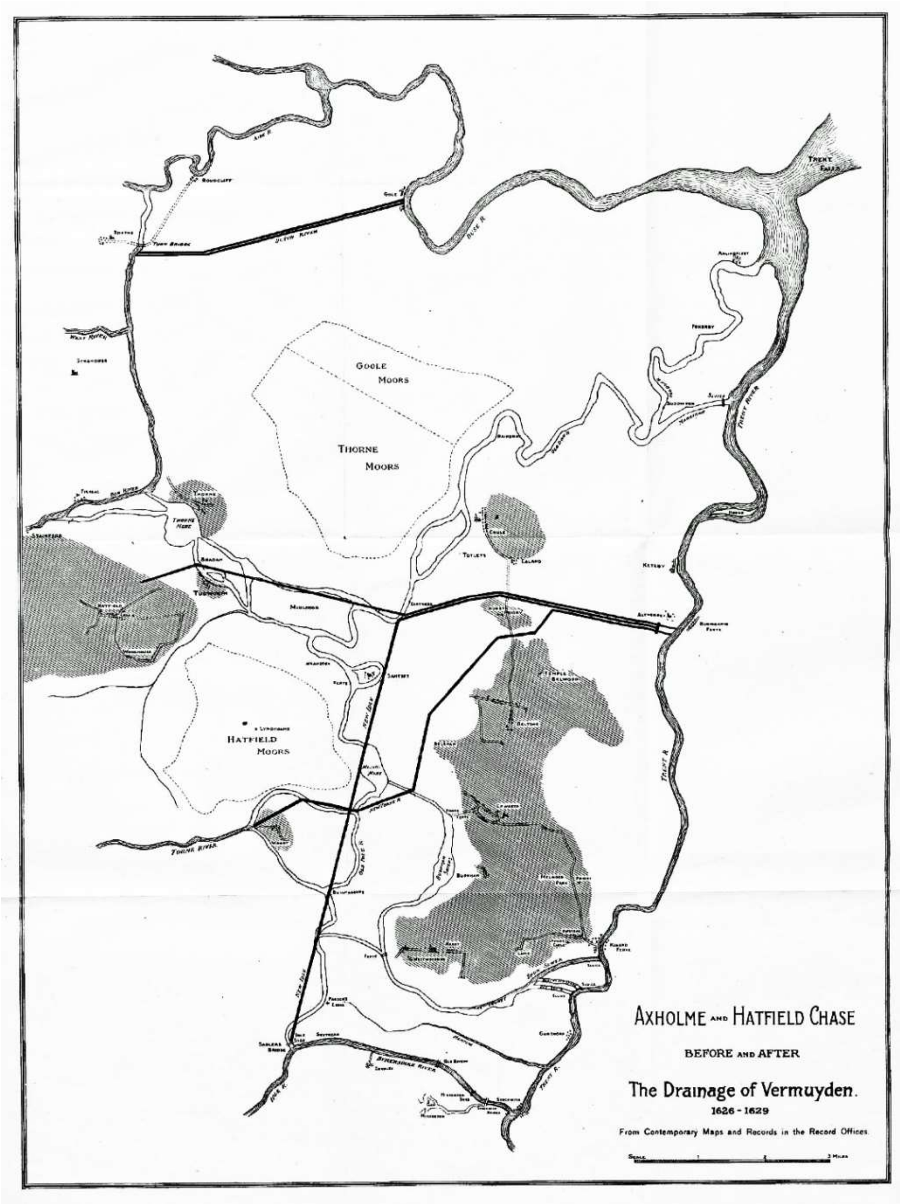


Figure 2. Isle of Axholme and Hatfield Chase before and after the drainage by Vermuyden (Korthals Altes, 1924 and 1925)

The scheme aroused considerable opposition from local people, and the engineering works – especially the creation of a new course for the Don River, in place of its several original channels, meandering through the fens - were expensive, so that in financial terms the project was not a success. However, it established Vermuyden's reputation in England as a drainage engineer, and earned him a knighthood from King Charles I, the successor of King James I. By 1634 new farmsteads were erected on the reclaimed lands. The settlers included Protestant families coming from the Netherlands as religious refugees.

In 1629 the Privy Council asked Vermuyden to prepare a scheme to drain the Great Level of the Fens (Williamson, 2006). It seems that they originally considered making a contract with Vermuyden himself, but eventually made one with Francis, the Fourth Earl of Bedford, who had considerable properties in the area. It was as a result of the Earl's involvement and that of his son, the first Duke of Bedford, that the Great Level gained in time its alternative name of the Bedford Level. Vermuyden was both director of the works, and an important investor. Work on the various components of the drainage system began in 1634. There were different opinions over the best way of improving the quality of drainage in the Fens. There was general agreement that the meandering character of the rivers made them liable to spill out across the surrounding land during winter floods, and that this problem was worsened by the fact that their outfalls into the sea were frequently clogged with sediment. Some, including the Dutch engineer Jan Barents Westerdyke, believed that a thorough cleaning and embanking of the main rivers would be a solution. This would ensure that the waters flowed at greater speed, thus keeping the channels and outfalls well scoured and open. At the same time the rivers would be restrained within their courses, even during the winter, by the construction of substantial dikes. Others advocated more radical improvements, based on the idea that increasing the velocity of the water flowing down the watercourses, by straightening them or amalgamating them or both, would reduce the risk of flooding and keep the outfalls well scoured. Vermuyden was of the latter opinion, and the principal feature of his scheme was the Seventy Foot or Bedford (later the 'Old Bedford') River that ran fully straight for some 32 km, was 21 m wide, and served to divert the waters of the meandering river Ouse from Earith, just inside Huntingdonshire, to Denver in Norfolk. It reduced the course of the river by some 20 km, and its old course was left as a minor drain. In addition, a number of new main drains were constructed, the longest being Bevill's Learn and the Peakirk Drain. There were innumerable smaller cuts, sluices and cut-off channels. The dikes bordering the major channels were initially constructed of peat, together with some of the clay which laid beneath it, but the banks often burst under pressure as the peat dried out, and extensive repairs had to be made later, using clay alone. In 1637 it was declared that the project was completed and that the Great Level was drained. But the new works were only partially successful. There was sustained opposition from the local people, involving riots and sabotage of the new works. Their objection was less to the drainage works per se than to the fact that the allotments made to the adventurers reduced the area of common land available to them. In 1638, for example, some forty or fifty men gathered in a fen called Whelpmoor, Common to Ely and Downham, to destroy the ditches, which had been made for enclosing their fen grounds from the common. Large areas continued to be liable to flooding, and in general the situation was deemed unsatisfactory. Charles I appointed a further Commission of Sewers to sit at Huntingdon in 1638. This ruled that the Earl of Bedford and his associates had not fulfilled their obligations: Charles himself took over as main undertaker of the scheme, and Vermuyden accepted office under him (Williamson, 2006 and Schouwenaars, 2019). Vermuyden prepared a *Discourse touching the draining of the great fennes*, which contained his ideas for further improving the situation in the Great Level, but the outbreak of the Civil War in England suspended all further work. Knittl (2007) described in detail the various decision making steps related to this project. She puts question marks at the role of Vermuyden in the draining of Bedford Level. However, it is difficult to see where she deviates from the description by Williamson (2006) as summarised above.

Korthals Altes (1924 and 1925) described that in 1630 Vermuyden obtained Malvern Chase and 1620 ha (4000 acres) in Sedgemoor. Both areas were reclaimed by him.

Williamson (2006) described that in 1649 attention turned once more to drainage matters. An act of Parliament was passed authorising William, Fifth Earl and First Duke of Bedford and his associates to resume the drainage work. The intention was to reclaim the land, not only for improved pasture, but also for arable land. The Level was divided into three parts, the North, Middle and South Levels, each of which was given its own Board of Commissioners. Vermuyden was once more in charge of the works, although he had to contend with an often hostile board of Adventurers and with the unwelcome interventions of his rival Jan Westerdyke. Vermuyden's main creation in this second phase of activity was the Hundred Foot Drain, or New Bedford River, which ran more or less parallel to the Old River. Substantial *barrier banks* were created on the outer edges of each, thus creating a vast washland which could store the waters of the Midland rivers in time of winter flood. Several other new watercourses were also created, especially within the area of the Middle Level, most notably the Forty Foot or Vermuyden's Drain and the Sixteen Foot or Thurlow's Drain. Improvements were also made to existing watercourses. A *barrier bank* was raised parallel to the old medieval drain, Mortons Leam, in order to create another washland; Denver sluice was built in 1653, to prevent tides reaching up the old course of the river Ouse; and many new roads were constructed. Less was done in the South Level, for Vermuyden's main proposal for this area was not carried out in his lifetime. This was for a cut-off channel running around the eastern margin of the Fens, preventing the waters of the rivers Little Ouse, Wissey and Lark reaching them. The idea was revived on a number of subsequent occasions, but only finally implemented in 1964. In 1653 the works were completed and the Great Level was again judged to be reclaimed. Following the Restoration of Charles I the 1649 Act, and the arrangements it had put in place, were confirmed by a fresh Act of Parliament. The agreed 38,445 ha were allotted to the

Adventurers in the form of blocks of land of various sizes scattered across the Fens. Many of these can still be seen on the map as distinct parcels of land with their drains orientated differently to those of the surrounding, later enclosures, and bearing the name Adventurer's Fen, Land, or Grounds (occasionally the name Undertaker's Fen appears. The undertakers were the men who undertook to carry out the work, rather than the adventurers who supplied the capital). Drainage work was not entirely completed. Some activity continued into the second half of the 17th century, with for example the drainage of Soham Mere in 1664.

Although the Great Level comprised the most extensive area of the Fens, it did not include the smaller areas of peat lying further north, the North Holland Fens around Boston, and Deeping Fen between Spalding and Stamford. Here, similar activities were taking place in the course of the 17th century, again under the direction of Dutch engineers. While some major drains were put in place, most notably the 38 km long South Forty Foot Drain, the engineering works here were on a less ambitious scale and the various schemes more fragmented in character.

Thanks to the achievement of Vermuyden and his fellow countrymen the condition of the Fens was, in agricultural terms, greatly improved, and although most of the land was still used for grazing some was exploited as arable land. However, the success of 17th century fen drainage should not be exaggerated. The kind of improvements and changes in land use were largely restricted to privately owned land. In fact only a minority of the Fens were actually impoldered, being the portions allotted to the undertakers and adventurers, and to a few leading landowners or divided into *severals* by the agreement of the local people. The majority remained as open common grazing ground, although now often allocated to specific parishes rather than shared between many and, as a result of the drainage works, less liable to serious inundation than before. Some areas were still not reclaimed. At a local level there were many problems with the drainage works, sometimes because of insufficient investment, sometimes because of continuing opposition from the local people and their sabotage of the drainage works. The North Holland fens thus remained imperfectly drained, while in Deeping Den a running fight between drainage projectors and local people lasted for over a century. All this encouraged landowners to keep even the enclosed parcels of land under pasture. The 17th century drainage left much of the Fens as common grazing, often only marginally improved, some parts completely undrained, and even within the enclosed and drained allotments, improved pasture seemed to have predominated over tillage.

Within these limits, the 17th century drainage schemes were initially successful. However, towards the end of the century the condition of the reclaimed lands deteriorated. Once water was removed from the peat, it shrank steadily; while on land that was ploughed and burnt the peat blew away, and the surface was constantly degraded by microbial action. With remarkable speed the land surface fell below that of the adjacent rivers and cuts, especially in the Great Level. The only solution was the use of horse mills or, more usually, windmills to lift water from the drains into the adjacent water courses.

The technology of drainage by windmills was first developed in the Netherlands, where windmills for drainage were introduced somewhere in the 14th century and widely established in the course of the 15th and 16th centuries (Schultz, 1992). They first appeared in the lowlands of eastern England in the 16th century. However, it was only with the drainage and subsequent shrinkage of the peat that windmills began to be erected on a large scale. References to the erection of windmills appear in records of the Bedford Level Corporation from 1663 (Williamson, 2006). There were frequent complaints about the inundations, which they caused to neighbouring land, and the deterioration of the dikes, which they allegedly brought about. However, as the peat continued to subside their numbers continued to increase. It were mainly smock mills, usually with vertical boarding, with a paddlewheel housed outside the body of the mill; but some smaller structures, resembling the spider head of the Netherlands, were also erected. Such simple windmills, with canvas sails and comparatively small paddle wheels, were insufficient to the task at hand, even though several might be placed in a series to raise water from the lowest land. Various improvements to these windmills were mooted, such as the use of the tilted paddle wheel invented by the Dutch engineer Anthoine Eckhardt, but little was actually done. Little remains of the fen windmills, although many survived in the Norfolk Broads, where they were erected on some scale in the 18th and 19th centuries. Most of the surviving windmills are brick tower windmills, but a good example of a wooden smock mill remained at Herringfleet, built about 1820.

Some improvements in the condition of the Fens were made in the middle of the 18th century. A series of Parliamentary Acts, beginning in 1727 with Haddenham in Cambridgeshire, established a number of Drainage Commissions, consisting of locally elected landowners who were responsible for the establishment, operation and maintenance of drainage works. These bodies were empowered to levy rates, borrow money, employ staff and to construct drains and windmills. Some attempts were also made to enclose the remaining fen commons, although these continued to meet with serious opposition from the local people and vast areas remained open and only minimally drained. No less than 16,000 ha (40,000 acres) in West, East and Wildmore Fens in Lincolnshire, for example, were not reclaimed and were largely under water in a wet winter (Williamson, 2006).

The final and complete drainage of the Fens - the creation of a productive and largely arable landscape - occurred in the course of the 19th century. Arable land use was increasing in Fenland by about 1800, as the recovery in agricultural prices, fuelled by rapid demographic growth from about 1760, was further stimulated by the blockade of the Napoleonic Wars.

The various common lands were mainly eradicated in a great wave of parliamentary enclosure, peaking during the Napoleonic War years. By the 1830s the Fens lay almost entirely in severalty. In addition there were major changes to the main drains, including the construction of the Eau Brink Cut in 1821, the Ouse Cut between Ely and Littleport in 1827, the North Level Main Drain between 1831and 1834 and the new outfall to the Nene in the late 1820s. Drainage was significantly improved through the installation of steam power pumping stations. The use of drainage by pumping had been mooted by the engineer John Rennie in 1803, but the first engine was installed - at Sutton St Edmund in Lincolnshire - in 1817. That at Ten Mile Bank, three miles south of Denver Sluice, was installed in 1819 followed by the engine at Borough Fen in the North Level in 1820, and by that at Upware, installed by the Swaflham and Bottisham Drainage Commissioners, in 1821. In 1825 the two great engines in Deeping Fen were installed - the 60 HP Kesteven, and the 80 HP Holland. Thereafter, during the 1830s and 1840s, drainage by pumping spread into all parts of the fens (Williamson, 2006). The new machines were a great improvement on the windmills. Their paddle wheels were larger, could rotate more quickly and through a greater vertical distance they could lift more water. Moreover, pumps were much more reliable than windmills, continuing to operate whatever the wind conditions. Clarke (1848) estimated that there had once been around 700 windmills for drainage between Cambridge and Lincoln, but the same area was by that time served by 17 steam power pumping stations, each lifting water up to 6 m (20 feet), which collectively drained more than 90,000 ha (222,000 acres).

According to the Tithe Files, by 1836 around 55% of the peat Fens were cultivated as arable land. In the course of Victoria's reign the last remaining areas of open water and wet fen were enclosed and drained, including the Holme Fen in Huntingdonshire in 1848 and the Grunty Fen in Cambridgeshire in 1857. The peat continued to shrink and erode. An iron column about 7 metres long was installed in the Holme Fen immediately after the drainage work began in 1851 (Ravensdale, 1982). Within twelve years, about 2 metres were exposed and by 1890 about 3 metres (Figure 3). Ravensdale (1982) Also showed a detailed lay out of the reclaimed Camdrigeshire Silt Fen (Figure 4). The Fens are nowadays located at on average below mean sea level (Wikipedia).

Figure 3. Holme Post installed in 1851 at surface level when Whittlesey Mere was drained (source: County Record Office, Huntingdon)

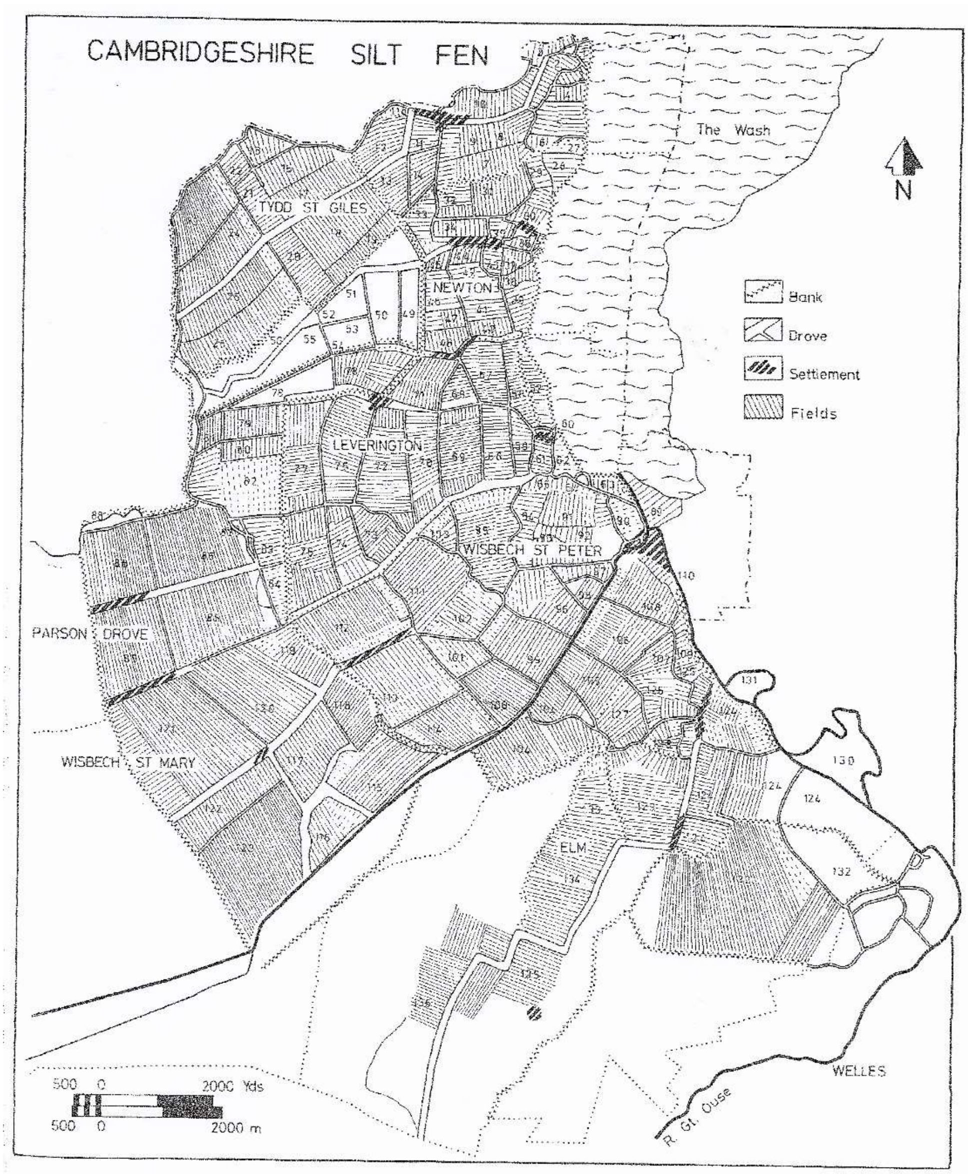


Figure 4. Detailed lay out of the reclaimed Camdrigeshire Silt Fen (Ravensdale, 1982)

The last phase of reclamation was accompanied by further refinements in drainage technology: the use from the 1840s of light grasshopper engines, and from the 1850s of centrifugal pumps. By the 1870s, around 75% of the peat soils were in use. This was the most productive arable land in England (Williamsn, 2006). The landscape of the Fens is a complex mosaic. Most of the main drains are of 17th century origin but the rectilinear fields, defined by straight field drains, are of varied dates, they form numerous different blocks, orientated in different directions. A few represent enclosures of fen ground dating to before the schemes of Vermuyden and his contemporaries; others are allotments given to adventurers, undertakers and wealthy landowners in the 17th century, but most are areas only enclosed and divided in the 18th and 19th centuries, usually by Parliamentary Act.

The present-day arable landscape of Fenland owes most to the developments of the 19th century. But these would not have been possible without the achievements of the 17th century reclamation projects, and in particular the structure of main drains, which were created. Particular indigenous circumstances, legal, political, and economic, encouraged the drive for lowland reclamation in the 17th century - a centralised state prepared to override local property rights, a rising population and a buoyant agricultural market. However, the technology and expertise employed in the drainage projects was, at least until the end of the 18th century, mainly derived from the Netherlands.

In addition to the above story about the Fens mainly based on Williamson (2006), Borrows (2006) described that in the United Kingdom a strategy *Making space for water* was developed (Department for Environment, Food & Rural Affairs (DEFRA), 2005) that advocated managing flood risk, rather than providing flood defences alone.

Existing polders

Gudgeon and Hannah (1983) described the history of the reclamation of Canvey Island, near the mouth of Thames River, that started in 1622 by building dikes (Figure 5). Initially the area was used for agriculture, but later on significant urbanisation and industrial expansion has taken place.

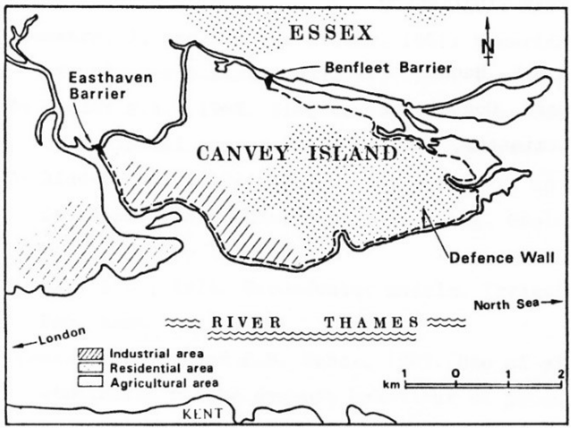


Figure 5. Canvey Island (Gudgeon and Hannah, 1983)

The Group Polder Development (1982) stated that in the Wash Bay in the 17th century about 11,500 ha of salt marshes were reclaimed, and in the last three centuries another 18,000 ha. Cook (1983) mentioned that the Wash had a surface level of 2 to 3 m+MSL (mean sea level). Land was reclaimed when the surface level reached the level of 3 m+MSL, which was about high tide level. The high spring tide level was 4.2 m+MSL (Figure 6). The Group Polder Development (1982) also mentioned that there was a plan to reclaim the Machair Lands. The polder area would be 450 ha. At Google Earth it can be observed that land has indeed been reclaimed.

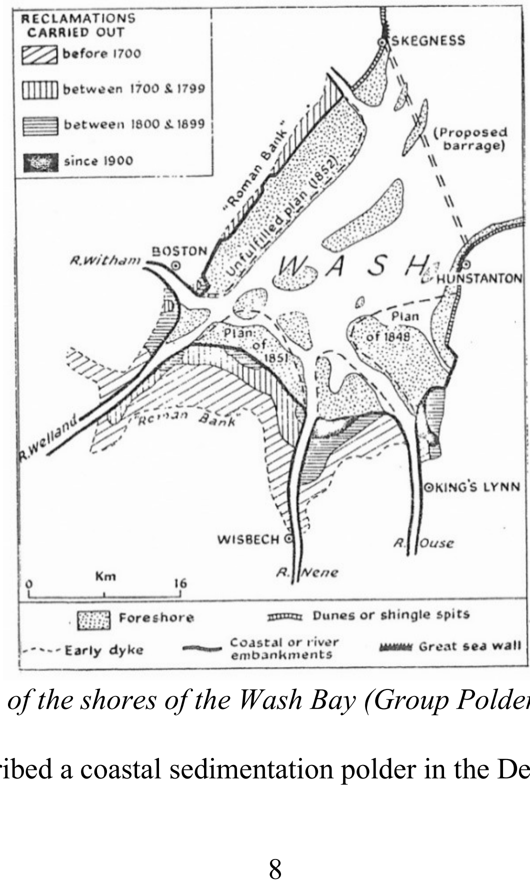


Figure 6. Evolution of the shores of the Wash Bay (Group Polder Development, 1982)

Colenutt (1999) described a coastal sedimentation polder in the Dengie Marsh (Figure 7).

Figure 7. Brushwood groyne perimeter fence enclosure to enhance natural sedimentation in the Dengie Flat, south-east Essex (Source: Colenutt, 1999, picture D. Carter).

Design, construction, operation and maintenance

Drainage

Rigby (1957) stated that there were about two hundred drainage pumping stations in East England, mostly either diesel engine or electrically driven (Figure 8). The pumping capacity of the largest pumping stations was based on 6.5 mm/day (quarter of an inch per acre per 24 hours) while the small stations might be based on 13 mm/day (half inch per acre per 24 hours).

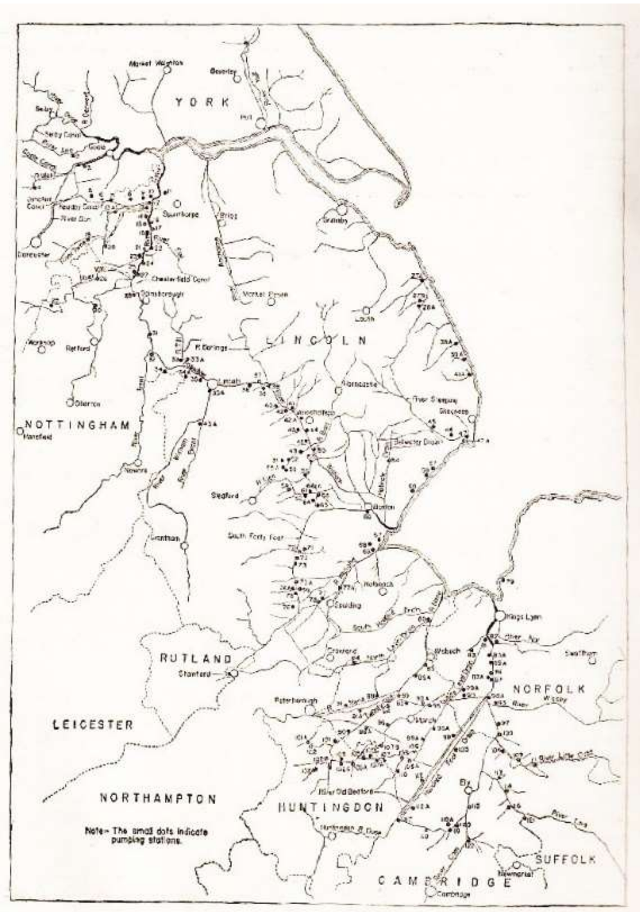


Figure 8. Drainage pumping stations in East England (Rigby, 1957)

Rigby (1957) also showed several pictures of a windmill and pumping stations. Two of these are shown in Figure 9. The windmill is a typical example dating back to about 1790, situated near Norwich. He stated that between Lincoln and Cambridge there were 700 of these windmills. The other picture shows an example of centrifugal pumps.

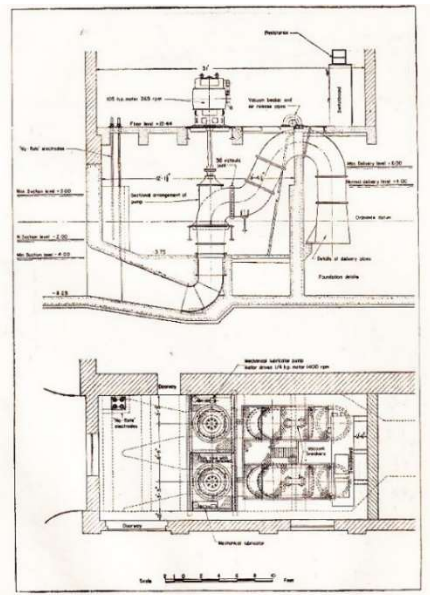


Figure 9. Typical windmill and example of centrifugal pumps in East England (Rigby, 1957)

Korthals Altes (1924 and 1925) described that by the end of the 19th century the drainage of Hatfield Chase was realised by a Bull Hassock steam power pumping station with 2 centrifugal pumps (Figure 10) for the southern part and the Dirtness pumping station for the northern part with 2 centrifugal pumps and a paddle wheel. In addition, there were:

- *in the South:*
  - River Idle of Bycarrs Dike with 1 pair automatic doors;
  - Snow Sewer of Old Warping Drain, 3 pair automatic doors;
- *in the North-east:*
  - River Torne. South outlet and North outlet, each 1 pair automatic doors;
  - New Idle River 2 pair automatic doors;
  - Dirtness outfall 1 pair automatic doors
  - North Doublé River 2 pair automatic doors.

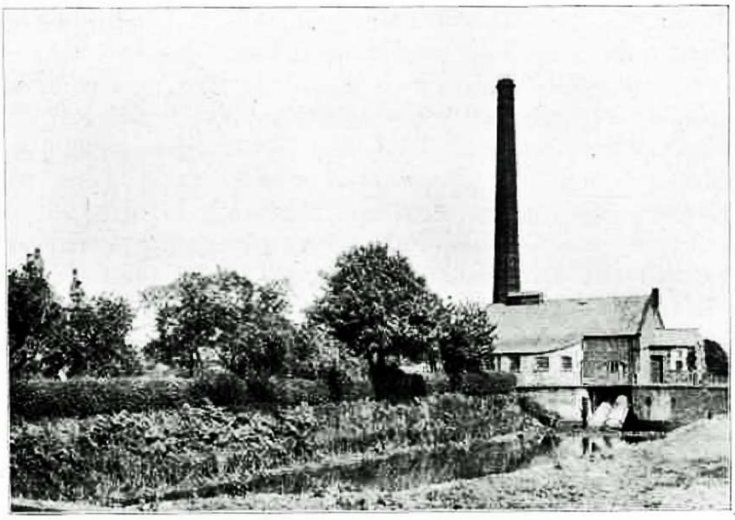


Figure 10. Bull Hassock steam power pumping station in the South part of Hatfield Chase (Korthals Altes, 1924 and 1925)

In addition he mentioned that for the Isle of Axholme there were several provisions for drainage to the River Trent, each under another Drainage Authority:

- through the Folly Drain at Derrythorpe 2 pair automatic doors;
- Haxey and Owston 1 pair automatic doors and 2 centrifugal pumps;
- Black Dikes 1 pair automatic doors and a pumping station;
- Newland a centrifugal pump aside of automatic drainage;
- South Common 1 automatic door;
- Rush Carr 1 automatic door and a pumping station;
- Althorpe 1 automatic door;
- South Soak Drain 1 pair automatic doors;
- North Soak Drain 1 pair automatic doors;
- Middle Common 1 automatic door and a pumping station.

Armstrong (1983) stated that the polders in the Fens reliedy on pumped drainage and also gave a general description of the design and maintenance of the field drainage systems. Beran (1983) stated that the total area with drainage by pumping in Britain was 900,000 ha and presented a map with the Fenlands (Figure 11). He also gave a schematic figure of the drainage network of the Newborough Fen (Figure 12) and Tables with the capacities of 15 pumping stations that are summarised in Table I. The capacities ranged from 4.3 mm/day to 19.0 mm/day. Finally he gave various computations for the situation under extreme conditions. Cook (1983) mentioned that in the Wash in 1977-1978 340 ha have been reclaimed (Figure 13).

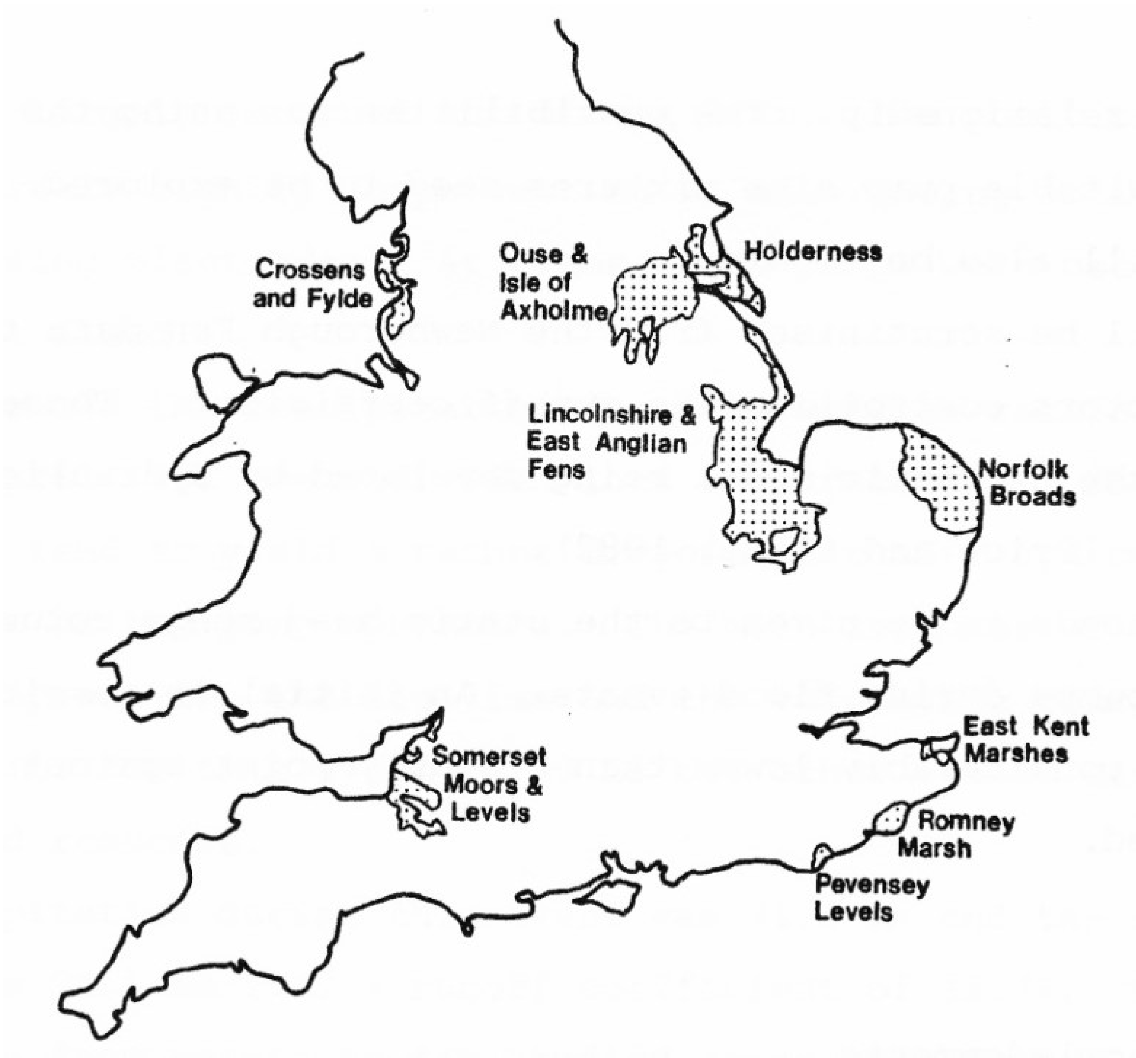


Figure 11. Location map of Fenland areas (Beran, 1983)

Figure 12. Drainage network of the Newborough Fen with location of water level recorders (Beran, 1983)

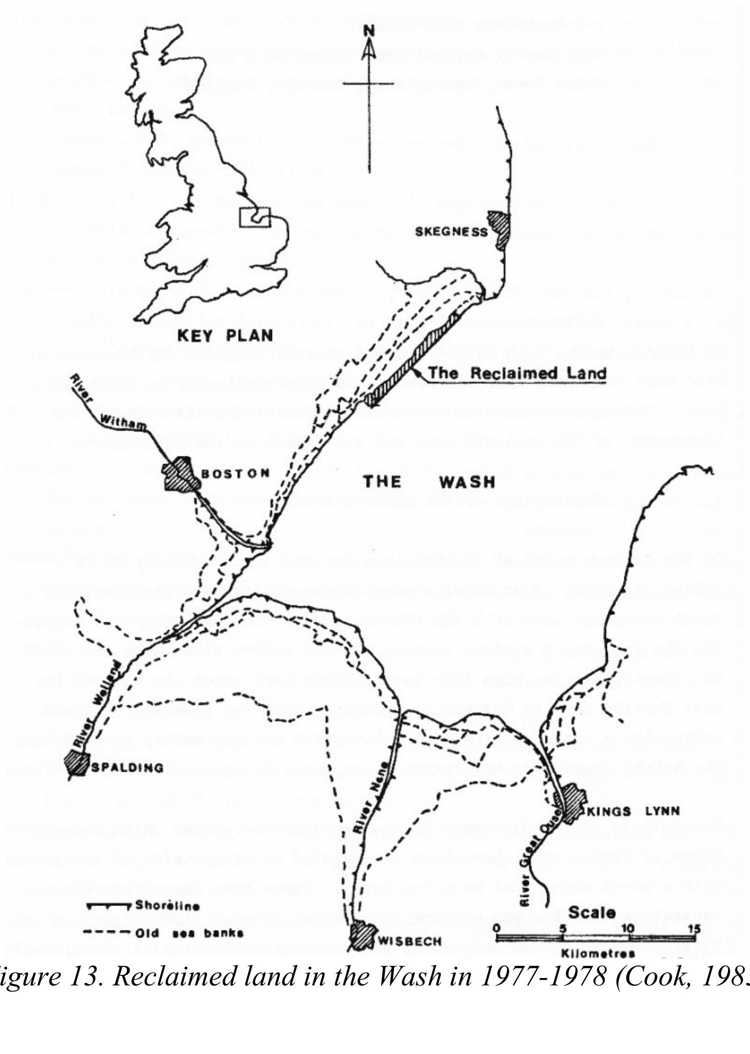


Figure 13. Reclaimed land in the Wash in 1977-1978 (Cook, 1983)

Table I. Pumping stations for which data on pumping capacity are available (Beran, 1983)

Pumping station	Drainage area	Water Authority	Drainage Board District	Period of record	Pumping capacity	
	ha				m^3/s **)	mm/day ***)
Fleet Haven	2400	Anglian	South Holland	1960-1978	1.8	6.4
Dawsmere	1000	Anglian	South Holland	1964-1978	1.0	9.1
Donningtons	700	Anglian	South Holland	1973-1979	1.0	12.2
Pear Tree Hil	1100	Anglian	South Holland	1973-1979	1.6	12.5
Fleet Fen	2600	Anglian	South Holland	1970-1979	2.8	9.2
Pode Hole	14,500	Anglian	Welland and Deeping	1964-1979	6.0	13.0 ****)
Fourth District	1100	Anglian	Welland and Deeping	1953-1979	1.5	11.8
Great Hale	2400	Anglian	Black Sluice	1968-1980	3.5	12.5
Black Hole Drove *)	4000	Anglian	Black sluice	1968-1979	5.8	13.0
West Sedgemoor	4500	Wessex	Sommerset Levels	1963-1980	4.4	8.2
Northmoor	2100	Wessex	Sommerset Levels	1963-1980	2.0	8.2
Weston Zoyland	1600	Wessex	Sommerset Levels	1963-1976	0.8	4.3
Stanmoor	410	Wessex	Sommerset Levels	1963-1980	0.9	19.0
Saltmoor	250	Wessex	Sommerset Levels	1963-1980	0.4	13.8
Bilsington	890	Southern	Romney Marsh	1975-1981	1.0	9.6

Notes:
*) isolated events only
**) obtained from MAFF returns
***) computed based on area and m^3/s
****) this value is given by Beran (1983) and not computed

Bateson and Jackson (2021) showed the area, the water courses and the pumping stations in the Fens (Figure 14).

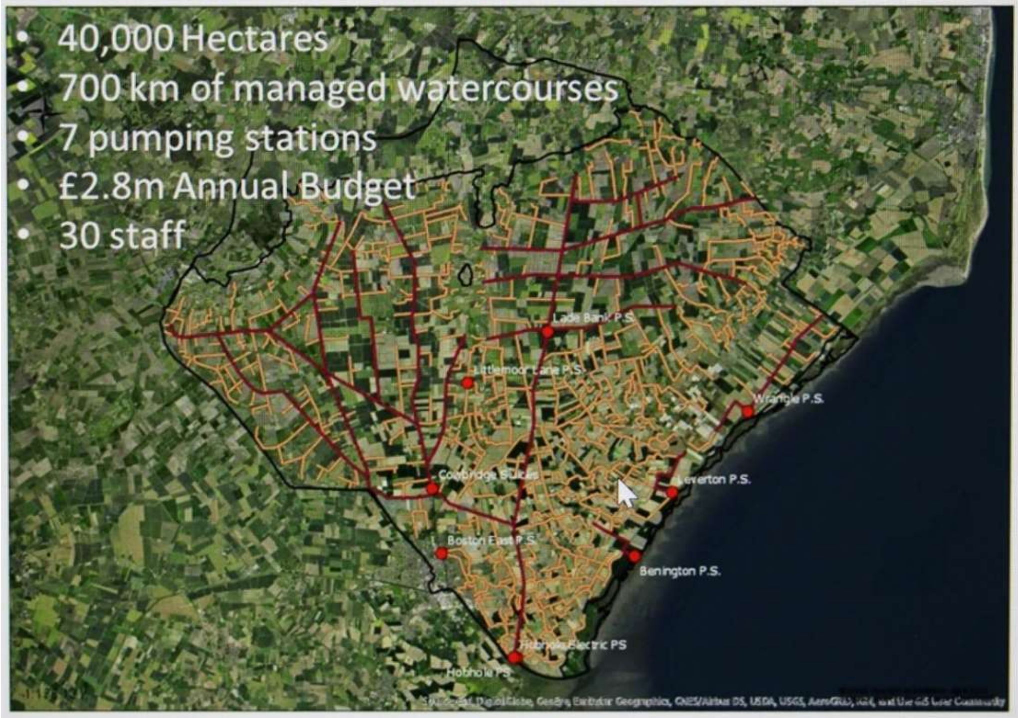


Figure 14. Lay out of the Fens (Bateson and Jackson, 2021)

Cook (1983) mentioned that the area in the Wash that was reclaimed in 1977-1978 was protected by dikes with a varying crest level between 5.8 and 7.5 m+MSL. The situation and a typical cross-section of the area is shown in Figure 15.

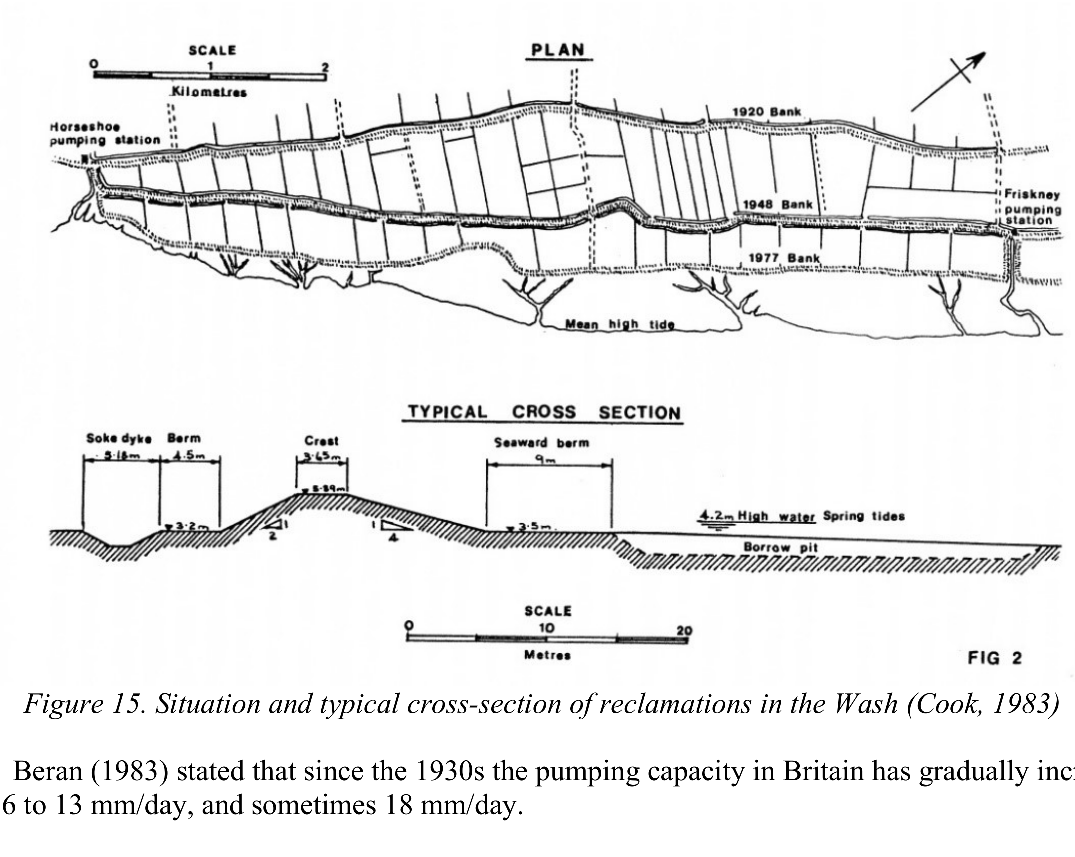


Figure 15. Situation and typical cross-section of reclamations in the Wash (Cook, 1983)

Beran (1983) stated that since the 1930s the pumping capacity in Britain has gradually increased from 6 to 13 mm/day, and sometimes 18 mm/day.

Protection against flooding

Gudgeon and Hannah (1983) described that in 1953 the whole Canvey Island was flooded. Thereafter a new standard for flood defence has been adopted, which implied raising of the dikes to a level of 0.90 m above the 1953 flood level. They also showed a typical cross-section of the improved dikes (Figure 16).

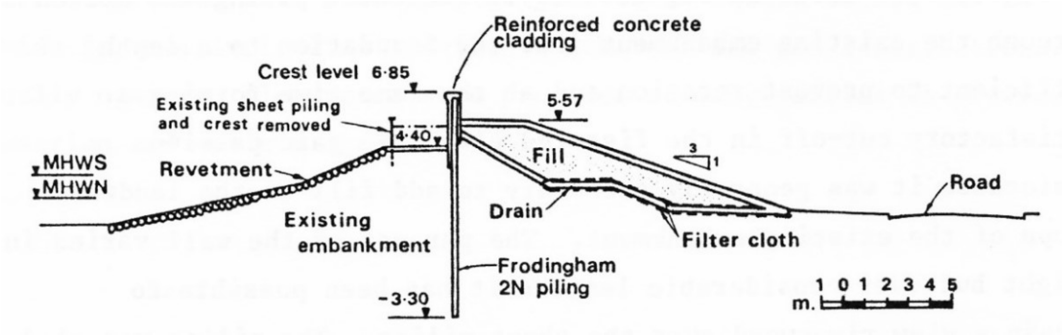


Figure 16. Raised dike using a sheet piling and fill (Gudgeon and Hannah, 1983)

Borrows (2006) described that in England and Wales development and flood risk were addressed in Planning Policy Guidance Note 25, known as PPG 25, and that different arrangements existed in Scotland. Measures to mitigate flood risk were called for where a flood risk existed. Three flood zones were identified:

- *low risk*, where the annual probability of flooding from rivers, estuaries or the sea was less than 0.1%;
- *low to medium risk*, where fluvial flooding was between 0.1 and 1% annual chance and where tidal and coastal flooding had a 0.1-0.5% annual chance;
- *high risk*, where the annual probability of flooding exceeded the above limits. Appropriate planning constraints were defined for each zone and it is required that the effects of climate change over a 50-year period will be taken into account when flood risk is considered. The need to provide for the consequences of flooding, despite the presence of defences, is also included.

Since then the planning note has been regularly updated. The last version was issued by the Ministry of Housing, Communities & Local Government at 1 October 2019.

General characteristics of existing polders in the United Kingdom are shown in Table II. Characteristics of the water management and flood protection systems are shown in Table III.

Proposed polders

The Group Polder Development (1982) mentioned that polders were proposed in Lough Foyle (Figure 17). While these polders would be developed on the east side of Lough Foyle, it would be in Northern Ireland, and therefore in the United Kingdom. As far as can be observed on Google Earth these polders have not been made.

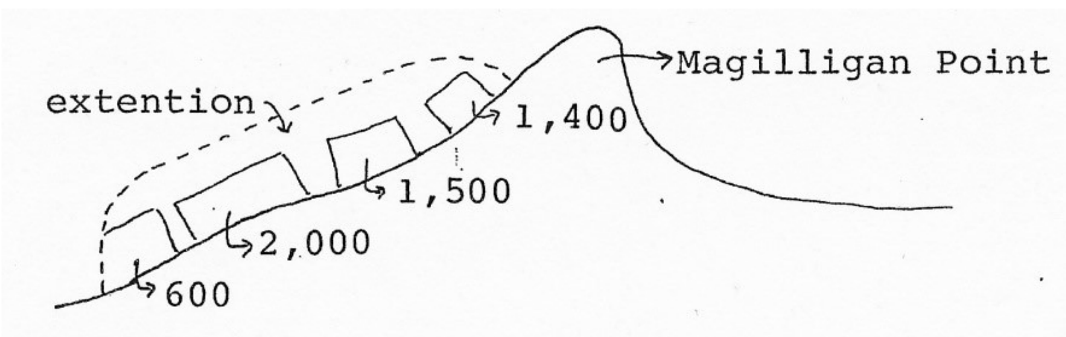


Figure 17. Proposed polders in Lough Foyle (Group Polder Development, 1982)

Location of the polders in United Kingdom as shown on the World polder map

The location of the polders in United Kingdom is shown in Figure 18.

Figure 18. Location of the polders in United Kingdom (source: esri – Batavialand)

The pictures by prof. Adriaan Volker are shown in Table IV. There are no pictures by Prof. Bart Schultz.

References

Airey, T., 2021. *COP26: Flooding lessons from Hull, a city below sea level*. BBC News. 12 November.

Alphen, J. van and Q. Lodder, 2006. Integrated flood management: experiences of 13 countries with their implementation and day-to-day management. *Irrigation and Drainage*. 55.S1. 159-171.

Armstrong, A.C., 1983. *The design of in-field drainage systems in the English Fenlands*. In: Proceedings International Symposium 'Polders of the World'. International Institute for Land Reclamation and Improvement, Wageningen, the Netherlands.

Armstrong, A.C., D.W. Rycroft and D.J. Welch, 1980. Modelling water table response to climatic inputs – its use in evaluating drainage designs in Britain. *J. Agric. Engng. Res*. 22: 311-323.

Ash, E.H., 2017. *The draining of the Fens. Projectors, politics, and state building in early modern England*. Johns Hopkins University Press, Baltimore, USA.

Barker, A. and D. Dawson, 1981. *Tetney outmarsh reclamation 1974-1980*.

Bateson, P. and A. Jackson, 2021. *Water management in the Fens*. Webinar presentation, 19 February. Institution of Civil Engineers, London, United Kingdom.

Beran, M.A., 1983. *Aspects of flood hydrology of the pumped fenland catchments of Britain*. In: Proceedings International Symposium 'Polders of the World'. International Institute for Land Reclamation and Improvement, Wageningen, the Netherlands.

Borrows, P., 2006. Living with flooding - Noah's legacy. *Irrigation and Drainage*. 55.S1. 133-140.

Brown, J.D. and S.L. Damery. 2002. Managing flood risk in the UK: towards an integration of social and technical perspectives. *Trans Inst Br Geogr* 27:412–426.

Clarke, J.A., 1848. On the Great Level of the Fens. *Journal of the Royal Agricultural Society of England* 8, pp. 80-133.

Colenutt, A.J., 1999. *Beneficial use of dredged material for inter-tidal recharge: management options for the Lymington Salt marshes*.

Cook, P.D., 1983. *Reclamation of land on the eastern coast of England*. In: Proceedings International Symposium 'Polders of the World'. International Institute for Land Reclamation and Improvement, Wageningen, the Netherlands.

Darby, H.C., 1956. *The draining of the Fens*. Cambridge University Press, Cambridge, United Kingdom.

Department for Environment, Food & Rural Affairs, 2005. *Securing the future: delivering UK sustainable development strategy*. TSO. London, United Kingdom.

Dugdale, W., 1662. *The history of imbanking and draining of diverse Fens and Marshes*. London. United Kingdom.

Group Polder Development, Department of Civil Engineering, Delft University of Technology, 1982. *Polders of the World. Compendium of polder projects*. Delft, the Netherlands.

Gudgeon, D.L. and M.E. Hannah, 1983. *The raising of the defences of Canvey Island to resist a 1 in 1,000 year tidal surge*. In: Proceedings International Symposium 'Polders of the World'. International Institute for Land Reclamation and Improvement, Wageningen, the Netherlands.

Harris, L.E. 1953. *Vermuyden and the Fens. A study of Sir Cornelius Vermuyden and the great level*. Cleaver-Hume Press Ltd., London, United Kingdom.

Hinde, K.S.G., 2006. *Fenland pumping engines*. Landmark Publishing Ltd. Ashbourne, United Kngdom.

Knittl, M.A., 2007. The design for the initial drainage of the Great Level of the Fens: an historical whodunit in three parts. *Agricultural History Review*, No. 55, I.

Korthals Altes, J. 1924. *Polderland in Engeland. De geschiedenis van een Zeeuwsch bedijker uit de gouden eeuw en zijne grootsche Hollandsch-Engelsche onderneming*. N.V. Boekhandel v.h. W.P. van Stockum & Zoon. the Hague, the Netherlands (in Dutch).

Korthals Altes, J., 1925. *Sir Cornelius Vermuyden. The lifework of a great anglo-dutchman in land-reclamation and drainage.* Williams & Norgate, London, United Kingdom.

Ministry of Housing, Communities & Local Government, 2019. *Planning practice guidance. The National Planning Policy Framework and relevant planning practice guidance*. Published 29 November 2016, last update 1 October 2019. London, United Kingdom

Ravensdale, J.R., 1982. *Review of Chapter 3: A comparative note on the exploitation and draining of the peat fens near the Wash*. In: H. de Bakker and M.W. van den Berg (eds). Proceedings of the symposium on peat lands below sea level. ILRI publication 30. International Institute for Land Reclamation and Improvement (ILRI). Wageningen, the Netherlands.

Rigby, W., 1957. *Land drainage pumping stations in England*. Third ICID Congress on Irrigation and Drainage. San Francisco, USA.

Rotherham, I.D., 2020. *Peatlands. Ecology, conservation and heritage*. Earthscan Studies in Natural Resource Management. Routledge. Abingdon/New York, United Kingdom/USA.

Schouwenaars, J., 2019. *Rumoer om moerassen*. Elikser, Leeuwarden, the Netherlands (in Dutch).

Schultz, E., 1992. Waterbeheersing van de Nederlandse droogmakerijen. PhD thesis. TU-Delft, Delft, the Netherlands (in Dutch).

Shennan, I., 1992. *Impacts of sea-level rise on the Wash, United Kingdom*. In: M.J. Tooley and S. Jelgersma. Impacts of sea-level rise on European coastal lowlands. Blackwell. Oxford and Cambridge, United Kingdom and USA.

Silvester, R., 1999. *Medieval reclamation of Marsh and Fen*. In: H. Cook and T. Williamson (eds.). Water management in the English landscape: field, marsh and meadow. Edinburgh, United Kingdom.

Taylor, C., 1999. *Post Medieval drainage of Marsh and Fen*. In: H. Cook and T. Williamson (eds.). Water management in the English landscape: field, marsh and meadow. Edinburgh, United Kingdom.

Tielhof, M. van, 2021. *Consensus en conflict. Waterbeheer in de Nederlanden 1200 – 1800*. Verloren, Hilversum, the Netherlands (in Dutch).

United Nations, Department of Economic and Social Affairs, Population Division. 2022. *World population prospects, medium prognosis. The 2022 revision*. New York, USA.

Wells, S., 1830. *The history of the drainage of the Great Level of the Fens called Bedford Level; with the constitution and laws of the Bedford Level Corporation*. Londen, United Kingdom.
Williamson, T., 2006. *Dutch engineers and the draining of the Fens in Eastern England*. In: Danner, H.S., J. Renes, B. Toussaint, G.P. van de Ven and F.D. Zeiler. Polder pioneers. The influence of Dutch engineers on water management in Europe, 1600-2000. Nederlandse Geografische Studies nr. 338. Utrecht, the Netherlands.

Web sites

https://en.wikipedia.org/wiki/Hatfield_Chase
www.axholme.info/drainage-of-the-isle.html
www.rmaidb.co.uk. Web site of the Romney Marsh Internal Drainage Board

Bart Schultz

Lelystad, March 2024

Table II. General characteristics of existing polders in the United Kingdom

Name	Reclamation	Area in ha	Type *)	Latitudes	Longitudes	Elevation in m+MSL	Land use
Romney Marsh	10th and 16th century	26,000	RLL	50° 96' N	0° 92' E	2	Agriculture
Wash Bay	12th, 17th and 18th century	30,000	LGS	52° 54' N	0° 15' E	3	Agriculture
Somerset Levels	16th century	24,257	RLL	51° 17' N	2° 58' W	5	Agriculture
Canvey Island	1622	1845	RLL	51° 31' N	0° 34' E	5	Agriculture, urban and Industry
Isle of Axholme	1626		RLL	53° 35' N	0° 34' W	5	Agriculture
Hatfield Chase	1628	28,400	RLL	53° 33' N	0° 59' W	5	Agriculture
Great Level/Bedford Level	1628-1653	130,000	RLL	52° 35' N	0° 12' E	4	Agriculture
Malvern Chase	About 1630		RLL	51° 13' N	2° 58' W	6	Agriculture
Surrounding of Sedgemoor	1630	1620	RLL	51° 12' N	2° 58' W	5	Agriculture
The Fens	17th century	385,000	RLL				Agriculture
Two Tree Island, Leigh-on-Sea	18th century	259	RLL	51° 32' N	0° 38' E	5	Agriculture
Preston Island	1807	143	RLL	56° 03' N	3° 35' W	12	Agriculture
Traeth Mawr	1814	1214	RLL	53° 11' N	4° 27' W	5	Agriculture
Wapping Marsh	1977-1978	340	RLL	51° 30' N	3° 23' W	2-3	Agriculture
Branston Island			RLL	53° 13' N	0° 23' W	5	Agriculture
Caldicot and Wentloog Levels			RLL	51° 33' N	2° 56' W	4	Agriculture
Cardigan Bay			RLL	52° 18' N	4° 10' W	8	Agriculture
Humberhead			RLL	53° 32' N	0° 59' W	5	Agriculture and nature
Machair Lands		450	RLL				Agriculture
Polders along Bay of Firth			RLL	59° 01' N	3° 4' W	2-3	Agriculture
Polders along Lough Foyle (Northern Ireland)			RLL	55° 6' N	7° 0' W	5	Agriculture
Polder along Morecambe Bay			RLL	54° 6' N	2° 48' W	4	Agriculture
Polders along Solway Firth			RLL	54° 33' N	3° 22' W	5	Agriculture
Sealand			RLL	53° 13' N	2° 89' W	1	Agriculture and industry
Sedimentation polder at Dengie Marsh			LGS	51° 43' N	0° 54' E	2-3	Agriculture
Sunk Island			RLL	53° 29' N	3° 30' W	6	Agriculture
Total		900,000					

*) RLL = reclaimed low-lying land; LGS = land gained on the sea; DL = drained lake

Table III. Characteristics of the water management and flood protection systems in the United Kingdom

Name	Design criteria in chance of occurrence/year							
	Water management						Flood protection Chance per year	
	Drainage					Irrigation	Rural	Urban
	Type	Design criterion	Percentage of open water	Discharge capacity				
				m^3/s	mm/day			
Romney Marsh	RLL							
Wash Bay	LGS							
Somerset Levels	RLL							
Canvey Island	RLL							0.90 m above flood level 1953
Isle of Axholme	RLL							
Hatfield Chase	RLL							
Great Level/Bedford Level	RLL							
Malvern Chase	RLL							
Surrounding of Sedgemoor	RLL							
The Fens	RLL							
Two Tree Island, Leigh-on-Sea	RLL							
Preston Island	RLL							
Traeth Mawr	RLL				6-13			
Wapping Marsh	RLL							
Branston Island	RLL							
Caldicot and Wentloog Levels	RLL							
Cardigan Bay	RLL							
Humberhead	RLL							
Machair Lands	RLL							
Polders along Bay of Firth	RLL							
Polders along Lough Foyle (Northern Ireland)	RLL							
Polder along Morecambe Bay	RLL							
Polders along Solway Firth	RLL							
Sealand	RLL							
Sedimentation polder at Dengie Marsh	LGS							
Sunk Island	RLL							

Table IV. Pictures of polders and lowlands in the United Kingdom by Prof. Adriaan Volker

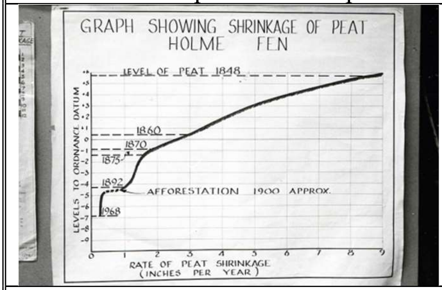
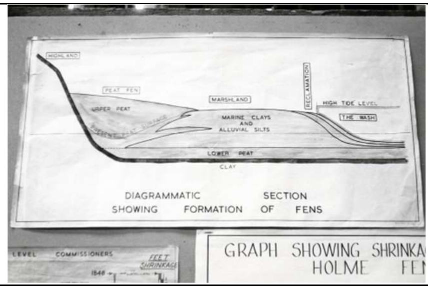
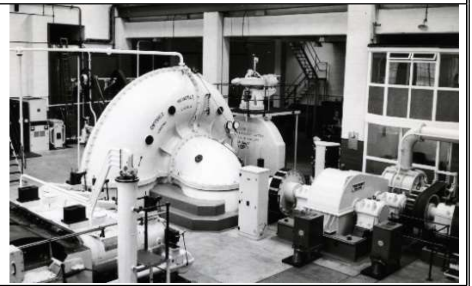
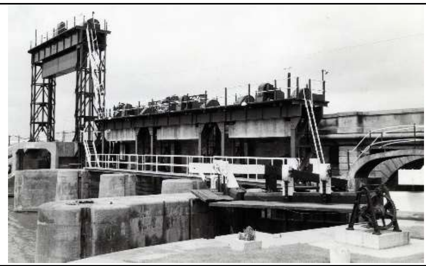
 			
A2 001/VIII.2.1 Prof. Adriaan Volker, Ir. Meulenkamp and another person	A2 002/VIII.2.2 Discharge sluice	A2 003/VIII.2.3 Discharge sluice	A2 004/VIII.2.4 Discharge sluice
 	 		
A2 005/VIII.2.5 Graph showing the subsidence of the Holme Fen	A2 006/VIII.2.6 Vertical cross-section of the Holme Fen	A2 007/VIII.2.7 St. Germans pumping station – Middle level commissioners	A2 008/VIII.2.8 St. Germans pumping station – Middle level commissioners
			
A2 009/VIII.2.9 St. Germans pumping station – Middle level commissioners	A2 010/VIII.2.10 Denver sluice	A2 011/VIII.2.11 Denver sluice	A2 012/VIII.2.12 A.G. Wright sluice

Table IV. Pictures of polders and lowlands in the United Kingdom by Prof. Adriaan Volker (continued)

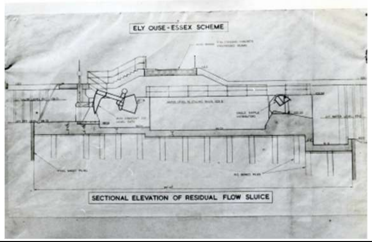
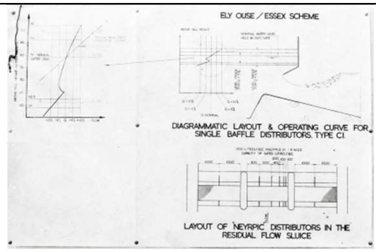
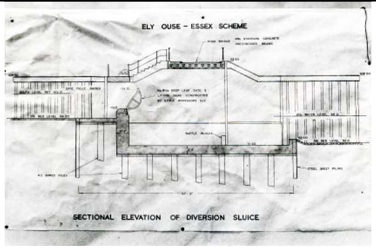
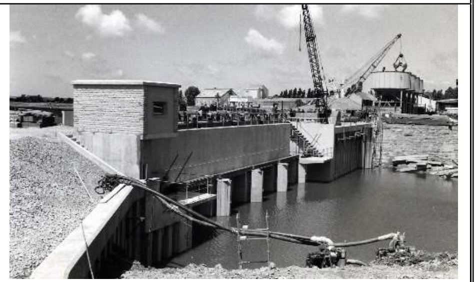
			
A2 013/VIII.2.13 Weir	A2 014/VIII.2.14 Discharge sluice	A2 015/VIII.2.15 Discharge sluice	A2 016/VIII.2.16 Discharge sluice
			
A2 017/VIII.2.17 Discharge sluice	A2 018/VIII.2.18 Inlet sluice	A2 019/VIII.2.19 Inlet sluice	A2 020/VIII.2.20 Taunton French weir
			
A2 021/VIII.2.21 Taunton French weir	A2 022/VIII.2.22 Taunton French weir	A2 023/VIII.2.23 Tidal outlet Parrett and discharge canal Dunball	A2 024/VIII.2.24 Tidal outlet Parrett and discharge canal Dunball

Table IV. Pictures of polders and lowlands in the United Kingdom by Prof. Adriaan Volker (continued)

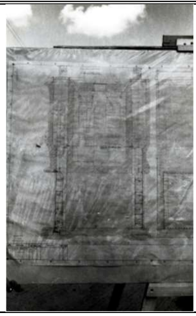
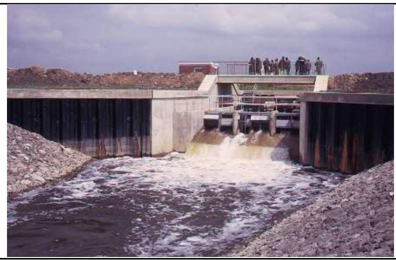
			
A2 025/VIII.2.25 Tidal outlet Parrett and discharge canal Dunball	A2 026/VIII.2.26 Clewer pumping station	B2 5 001/B.2.5.1 Lowland area, hydraulic structures, pumping stations, etc.	B2 5 002/B.2.5.2 Lowland area, hydraulic structures, pumping stations, etc.
			
B2 5 003/B.2.5.3 Lowland area, hydraulic structures, pumping stations, etc.	B2 5 004/B.2.5.4 Lowland area, hydraulic structures, pumping stations, etc.	B2 5 005/B.2.5.5 Lowland area, hydraulic structures, pumping stations, etc.	B2 5 006/B.2.5.6 Lowland area, hydraulic structures, pumping stations, etc.
			
B2 5 007 /B.2.5.7 Lowland area, hydraulic structures, pumping stations, etc.	B2 5 008/B.2.5.8 Lowland area, hydraulic structures, pumping stations, etc.	B2 5 009/B.2.5.9 Lowland area, hydraulic structures, pumping stations, etc.	B2 5 010/B.2.5.10 Lowland area, hydraulic structures, pumping stations, etc.

Table IV. Pictures of polders and lowlands in the United Kingdom by Prof. Adriaan Volker (continued)

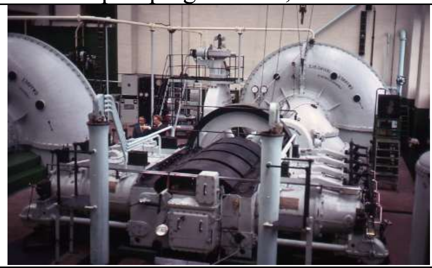
			
B2 5 011/B.2.5.11 Lowland area, hydraulic structures, pumping stations, etc.	B2 5 012/B.2.5.12 Lowland area, hydraulic structures, pumping stations, etc.	B2 5 013/B.2.5.13 Lowland area, hydraulic structures, pumping stations, etc.	B2 5 014/B.2.5.14 Lowland area, hydraulic structures, pumping stations, etc.
			
B2 5 015/B.2.5.15 Lowland area, hydraulic structures, pumping stations, etc.	B2 5 016/B.2.5.16 Lowland area, hydraulic structures, pumping stations, etc.	B2 5 017/B.2.5.17 Lowland area, hydraulic structures, pumping stations, etc.	B2 5 018/B.2.5.18 Lowland area, hydraulic structures, pumping stations, etc.
			
B2 5 019/B.2.5.19 Lowland area, hydraulic structures, pumping stations, etc.	B2 5 020/B.2.5.20 Lowland area, hydraulic structures, pumping stations, etc.	B2 5 021/B.2.5.21 Lowland area, hydraulic structures, pumping stations, etc.	B2 5 022/B.2.5.22 Lowland area, hydraulic structures, pumping stations, etc.

Table IV. Pictures of polders and lowlands in the United Kingdom by Prof. Adriaan Volker (continued)

			
B2 5 023/B.2.5.23 Lowland area, hydraulic structures, pumping stations, etc.	B2 5 024/B.2.5.24 Lowland area, hydraulic structures, pumping stations, etc.	B6 4 76/B.6.4.76 Thames Barrier	B6 4 77/B.6.4.77 Thames Barrier
			
B6 4 78/B.6.4.78 Thames Barrier	B6 4 79/B.6.4.79 Thames Barrier	B6 4 80/B.6.4.80 Thames Barrier	B6 4 81/B.6.4.81 Thames Barrier
			
B6 4 82/B.6.4.82 Thames Barrier	B6 4 83/B.6.4.83 Thames Barrier	B6 4 84/B.6.4.84 Thames Barrier	B6 4 85/B.6.4.85 Thames Barrier

Table IV. Pictures of polders and lowlands in the United Kingdom by Prof. Adriaan Volker (continued)

			
B6 4 86/B.6.4.86 Thames Barrier	B6 4 87/B.6.4.87 Thames Barrier		