CANADA

Source: esri

General

Canada extends from the Atlantic to the Pacific and northward into the Arctic Ocean. It is the world's second-largest country by total area, it's southern border with the United States is the world's longest bi-national land border. The country has an area of 998 Mha (million hectares), with in 2022 a population of 38.5 million, or 0.04 persons per ha. The country is highly urbanized with 82% of the people concentrated in large and medium-sized cities, many near the southern border (Wikipedia and United Nations, 2022).

Climate and geography

Average winter and summer high temperatures across Canada vary from region to region. Winters can be harsh in many parts of the country, particularly in the interior and Prairie provinces, which experience a continental climate, where daily average temperatures are near −15 °C, but can drop below −40 °C with severe wind chills. In non-coastal regions, snow can cover the ground for almost six months of the year, while in parts of the north snow can persist year-round. Coastal British Columbia has a temperate climate, with a mild and rainy winter. On the east and west coasts, average high temperatures are generally in the low 20s °C, while between the coasts, the average summer high temperature ranges from 25 to 30 °C, with temperatures in some areas occasionally exceeding 40 °C (source: Wikipedia).

Much of Northern Canada is covered by ice and permafrost. The future of the permafrost is uncertain because the Arctic has been warming at three times the global average as a result of climate change in Canada. Canada has over 2 million lakes - 563 of which are larger than 100 km^2 - containing much of the world's fresh water. There are also fresh water glaciers in the Canadian Rocky Mountains. The rate of warming has been higher across the North and in the Prairies. In the southern regions of Canada, air pollution from both Canada and the United States - caused by metal smelting, burning coal to power utilities, and vehicle emissions - has resulted in acid rain, which has severely impacted waterways, forest growth, and agricultural productivity in Canada. The majority of the land territory is dominated by forest, tundra, the Rocky Mountains, and the relatively flat Canadian Prairies in the southwest with mostly agriculture. The Great Lakes feed the St. Lawrence River (in the Southeast) where the lowlands host much of Canada's economic output (source: Wikipedia).

Existing polders

Bay of Fundy

The earliest records of reclamation in the Bay of Fundy dates back to about 1633 at Port Royal by settlers from France (Desplanque, 1983). They started to apply the endiking and drainage techniques known to them. They transformed 36,000 ha of the salt marshes into polders (Figure 1). These polders are spread along the coast from the mouth of the Bay of Fundy, where the tidal range is 3.0 m and the spring tide range can be 4.2 m, to the head of the bay, where the tidal range can reach 15.4 m (Warren, 1911). The polder area consists of many small polders. Most of the endiked marshes are found in the head of the Cumberland Basin. Along this bay there are polders with a total area of 14,700 ha. The largest block of 7,200 ha is found along the Tantramar and Aulac rivers. At Prince Edward Island there is a polder of 20 ha (Figure 1) (Schott, 1955; Desplanque, 1983). The protection works include (Group Polder Development, 1982):

- some 400 km of dikes;
- 433 structures, e.g. sluices;
- 30 km of riverbank control installations;
- 3 major tidal dams, e.g. Annapolis River Dam. This dam provides protection against salt-water flooding to some 1,700 ha of marshland and eliminates the need for reconstruction of alternative protective works.

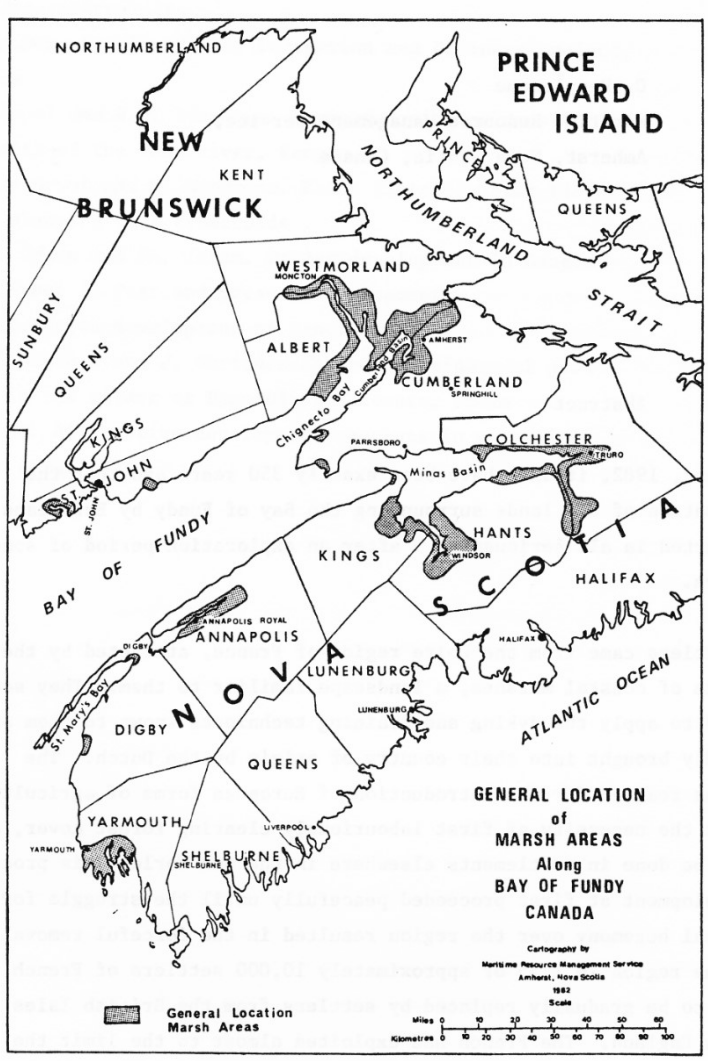


Figure 1. General location of the polder areas along the Bay of Fundy, not their exact outline (Desplanque, 1983)

Part of the reclaimed area – the Grand Pré marshland in the Province of Nova Scotia - is a UNESCO Heritage Site (Figure 2) (UNESCO World Heritage Centre, 2012). In the justification it is described that the Grand Pré marshland and archaeological sites constitute a cultural landscape bearing testimony to the development of agricultural farmland using dikes and the *aboiteau* wooden sluice system, started by the Acadians – primarily immigrants from France - in the 17th century and further developed and maintained by the Planters and present-day inhabitants. Over 1,300 ha, the cultural landscape encompasses a large expanse of polder farmland and archaeological elements of the towns of Grand Pré and Hortonville, which were built by the Acadians and their successors. The landscape is an exceptional example of the adaptation of the first European settlers to the conditions of the North American Atlantic coast. The site – marked by one of the most extreme tidal ranges in the world – is also inscribed as a memorial to Acadian way of life and deportation, which started in 1755, known as the *Grand Dérangement*.

The Lower Fraser Valley is subject to periodic flooding from spring freshets as well as high tides in the lower reaches. The valley has been partly endiked (Figure 3), this includes the Pitt Polder and Allouette Polder on the Pitt River (Figure 4) (Group Polder Development, 1982). The area was first developed in 1911, but the dikes were too low. Waite (2008) describes that Dutch dike builders, under the supervision of Biezefeld, a civil engineer, repaired the older dikes in 1951 and built them up just over 5 m+MSL (mean sea level). He also describes that in the period from 1949 to 1961 the dikes were gradually further strengthened and that new dikes and flood protection provisions were added.

Figure 2. Sherman Bleakney's map of the Grand Pré polders showing the sequence of dyking (UNESCO World Heritage Centre, 2012)

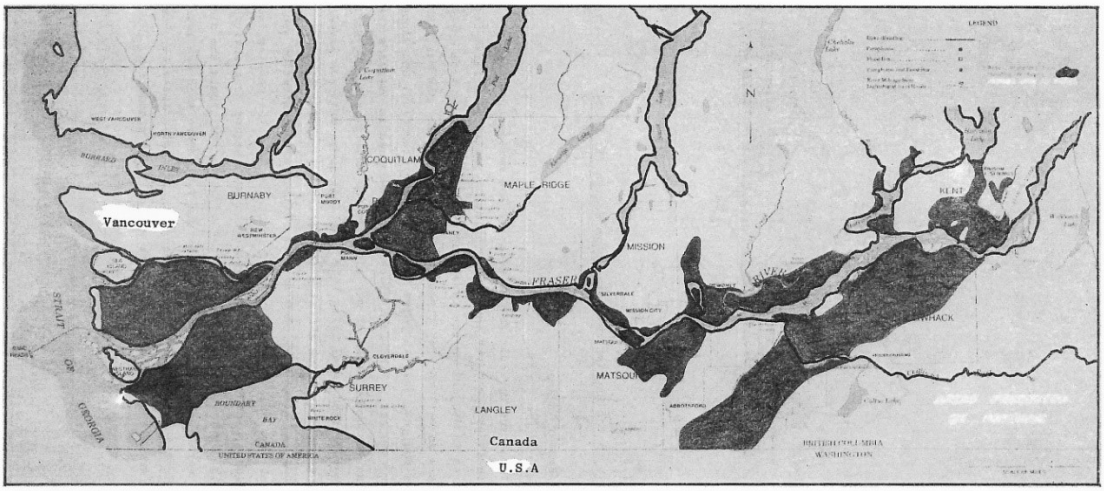


Figure 3. Polder areas in the Lower Fraser Valley (Group Polder Development, 1982)

The Holland Marsh (8,500 ha) is a mixed land use lowland (Classens, 2018; Madramootoo and Abbasi, 2022). The originally cultivated land (2,833 ha) supports 125 farms. Brownell and Scott (1949) refer in the Holland Marsh to the Old Marsh, which is the area that is a polder of 2,833 ha and the New Marsh, which was an area of 5,250 ha proposed to be reclaimed (Figure 5). However, on Google Earth it looks like that only a small part of the area has been impoldered. Smart and Associates (2009) give a detailed parcellation of the Holland Marsh (Figure 6).

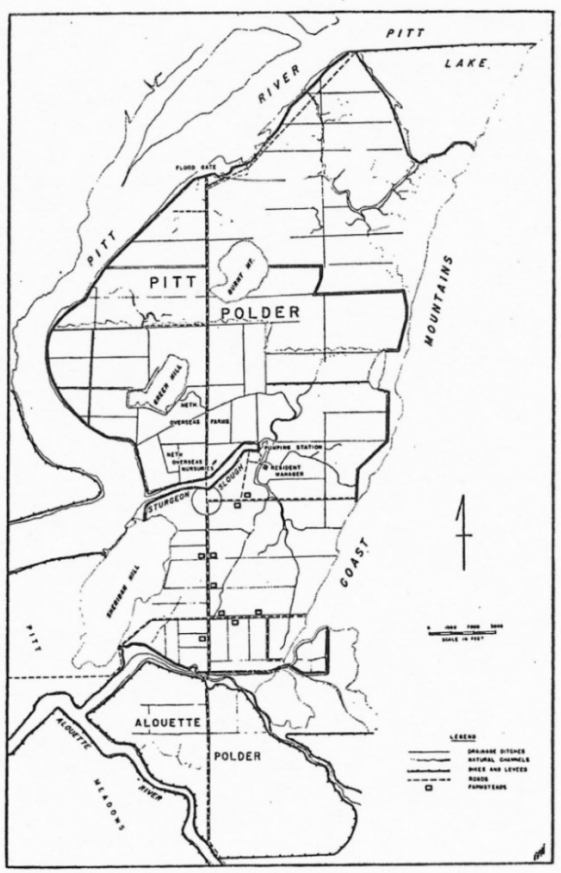
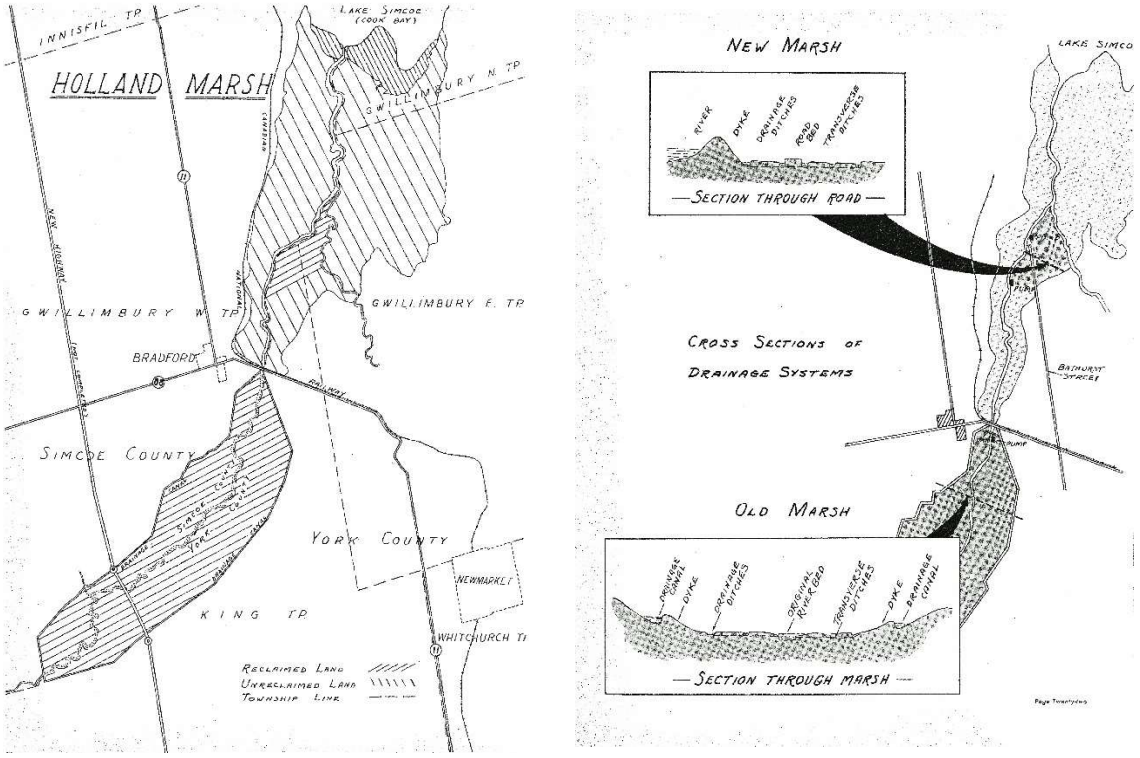


Figure 4. Pitt Polder and Alouette Polder in the Lower Fraser Valley (Group Polder Development, 1982)



(a) (b)

Figure 5. (a) Holland Marsh and (b) cross-sections of drainage systems in the (Old) Holland Marsh and New Holland Marsh (Brownell and Scott, 1949)

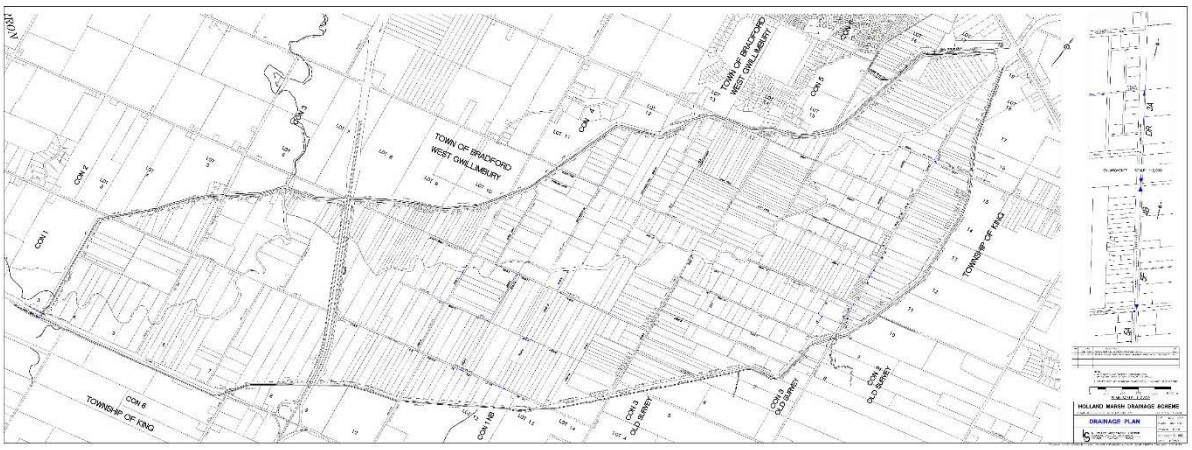


Figure 6. Detailed parcellation of the Holland Marsh (Smart and Associates, 2009)

The Squamish River Delta is an estuary, at the head of a fjord like inlet, endiked to protect the seaport town of Squamisch and surrounding industrial, residential area from periodic flooding due to spring freshet and winter rainstorms (Group Polder Development, 1982).

The Kootenay River - Creston Valley is a hinterland river valley, located at the head of Kootenay Lake near Creston. The area is subject to a reduced threat of periodic flooding due to partial regulation from hydropower development and endikements (Group Polder Development, 1982).

Jackson (1998) describes the reclamation of the Bradford Scheme (Figure 7).

Since the beginning of the 20th Century reclamation has added at least 800 ha to the city of Toronto (Group Polder Development, 1982).

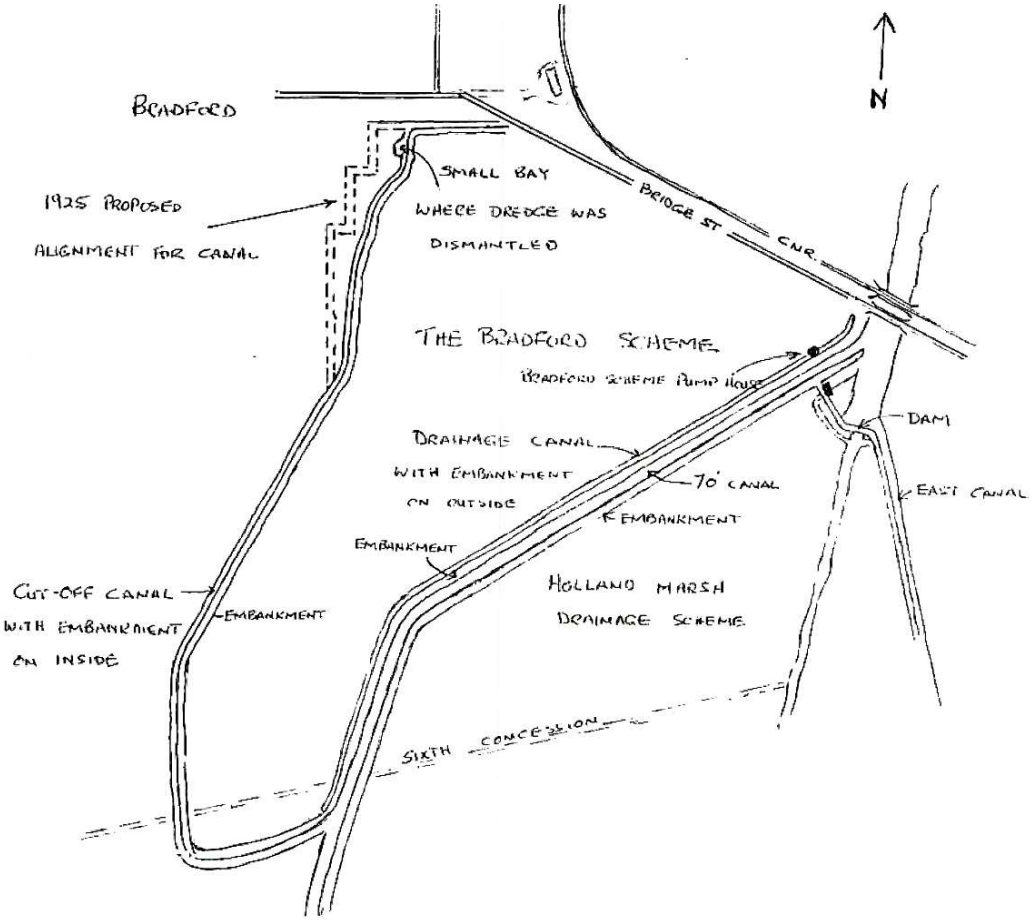


Figure 7. The Bradford Scheme (Jackson, 1998)

General characteristics of the polders in Canada are shown in Table I. Table II shows the characteristics of the water management and flood protection systems of the existing polders.

Proposed polders

No proposed polders have been identified.

Design, construction, operation and maintenance

Schott (1955) describes that in the area of the Bay of Fundy the dikes along the coasts were higher than the dikes along the rivers. The height of the old dikes (since about 1620) was about 1.50 – 1.80 m. He shows profiles of dikes with different bank protection (Figure 8).

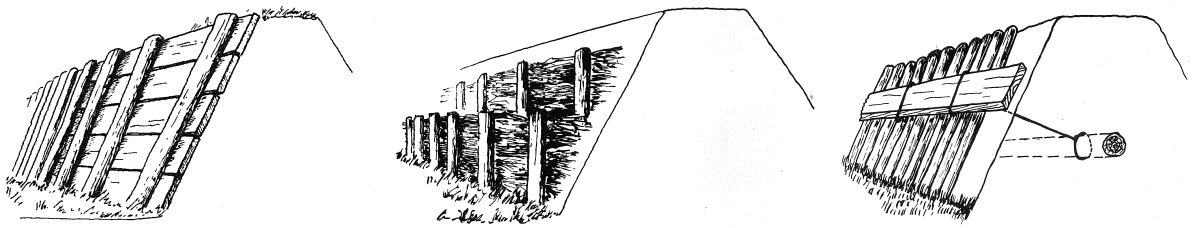


Figure 8. Old dike profiles with different bank protection of the polders along the coasts of the Bay of Fundy (Schott, 1955)

UNESCO World Heritage Centre (2012) shows a typical cross-section of the polders in the Grand Pré (Figure 9). They also show the principle lay out of the aboiteau, that refers to the section of the dike surrounding the sluice (Figure 10).

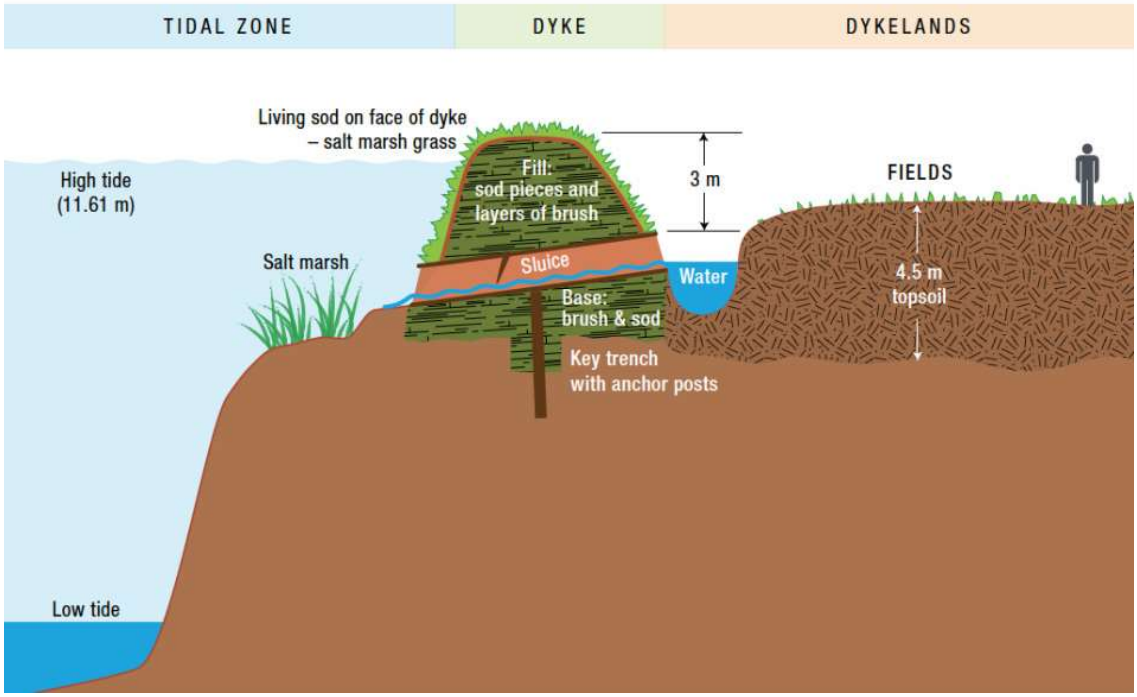
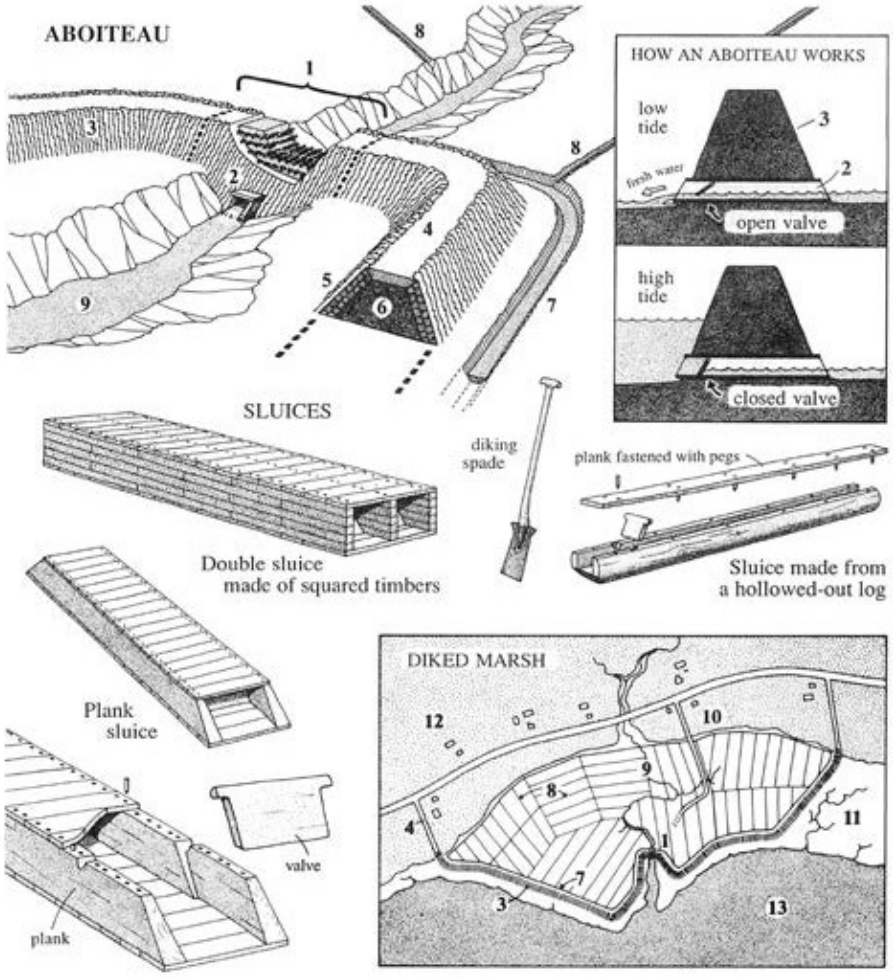


Figure 9. Typical cross-section of the polders at Grand Pré, including the tidal range, salt marsh, aboiteau system and fields (UNESCO World Heritage Centre, 2012)

Desplanque (1983) describes that for the polders in the Bay of Fundy pumped drainage was uneconomical and that the discharge of the polders was provided by tidal sluices. The sluices ranged

from 3 * 3 m boxes to multiples of 1.2 * 1.5 m boxes, set side by side, and made from chemically treated lumber and of with asphalt-coated steel pipes. The flap gates were made of bronze, or steel and were hung by hinges or steel chains. Provisions were made to protect them from ice pressure. He also mentions that for operation and maintenance there were *marsh bodies*, elected by the landowners, and assisted by provincial officers of the Departments of Agriculture of Nova Scotia – 86 *marsh bodies* - and New Brunswick - 39 *marsh bodies*.



Legend: 1 – Aboiteau. This term designates not only the sluice but also the part of the dike which crosses the stream. Here, the dike is reinforced by fir trees laid transversally with alternate layers of clay soil. 2 – Sluice. 3 – Levee or dike. 4 – Road or path along the top of the dike. 5 – Dike facing made of sod. 6 – Earthen core (made of soil dug from the marshlands). 7 – *Contre-ceinture*. 8 – Drainage ditch. 9 – Stream. 10 – Road leading into the marshlands. 11 – Salt marsh. 12 – Dwellings on higher terrain. 13 – River or bay.

Figure 10. Lay out and principles of an aboiteau (UNESCO World Heritage Centre, 2012)

The Bradford Scheme was constructed in 1925-1926 and provided with an electric pumping station of 18,9 m^3/min (5,000 gpm) (Jackson, 1998).

The historic development of the Holland Marsh has among others been described by Jackson (1998), Bartram *et al*. (2007) Smart and Associates (2009, report and power point) and Madramootoo and Abbasi (2022). Some points from these references related to drainage and flood protection are:

- area of the Holland Marsh 2833 ha (7000 acre);
- the Marsh is provided with a drainage and an irrigation system;
- the pumping stations are located at both ends of the former Schomberg River in the Holland Marsh;

- originally one electrical pumping station - the Art Janse Pumping Station – with two pumps was built, capacity 151 m^3/min (40,000 gpm), which is 7.7 mm/day counted over the polder area. In 1945 the pumping station was reconstructed;
- 1949 the Springdale Pumping Station – later called the V. Bardawill Pumping Station with a capacity of 68 m^3/min (18,000 gpm), 3.5 mm/day was built in addition. This capacity has later been downgraded to 42 m^3/min (11,000 gpm), 2.1 mm/day;
- at 15 October 1954 the polder was flooded due to the impact of Hurricane Hazel;
- in 1955 the Charles Davis Pumping Station – original capacity 91 m^3/min (24,000 gpm), 4.6 mm/day later downgraded to 51 m^3/min (13,500 gpm), 2.6 mm/day - was built in addition at the site of the V. Bardawill Pumping Station;
- 1993 reconstruction of the Art Janse Pumping Station, capacity 254 m^3/min (67,000 gpm) , which is 13 mm/day counted over the polder area (Figure 11);
- flood protection based on a risk of failure of 1% per year;
- irrigation water is provided from outside by pipes through the dike.

Figure 11. Art Janse Pumping Station of the Holland Marsh (Bartram et al., 2007)

Madramootoo and Abbasi (2022) describe that originally the agricultural lands were drained by open drains and that in 1957 subsurface drains were installed.

Rupke and Associates Ltd. (1985) did a calibration study of the two drainage pumping stations of the Holland Marsh. At the time of the study excess water of the Holland Marsh was pumped out by the two electrical pumps of the Art Janse Pumping Station, the three diesel powered pumps of the V. Bardawill and by the Charles Davis Pumping Station.

The original design of A. Baird showed the dimensions of canals and dikes. After the flooding due to Hurricane Hazel reconstruction of the canal resulted in the revisions (Table III) (Smart and Associates, 2009).

Location of the polders in Canada as shown on the World polder map

The location of the polders in Canada is shown in Figure 12.

In Table IV the pictures by Prof. Adriaan Volker are shown.

Acknowledgement

The author likes to thank Prof. Chandra Madramootoo for check of the document and for submission of additional information.

Figure 12. Location of the polders in Canada (source: esri – Batavialand)

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Table I. General characteristics of existing polders in Canada

Name	Reclamation	Area in ha	Type *)	Latitudes	Longitudes	Elevation in m+MSL	Land use
Polders along the Bay of Fundy:							
• polder at Prince Edward Island	1633	20	LGS	46º 39' N	63º 57' W	9	Agriculture
• polders in Nova Scotia		18,000	LGS	45º 07' N	64º 18' W	6	Agriculture
• polders in New Brunswick		18,000	LGS	45º 54' N	64º 19' W	4	Agriculture
Pitt Polder	1911/1951	2,833	RLL	49º 18' N	122º 37' W	9	Agriculture
Alouette Polder	1911/1953	440	RLL	49º 15' N	122º 38' W	9	Agriculture
Bradford Scheme	1925-1926	81	RLL	44º 07' N	97º 33' W	218	Agriculture
Holland Marsh	1925-1930	2,833	RLL	44º 03' N	79º 35' W	215	Horticulture
New Holland Marsh		5,250	RLL	44º 10' N	79º 31' W	215	Horticulture
Kootenay River-Creston Valley			RLL	49º 06' N	116º 34' W	535	Agriculture
Polder in Toronto		800	RLL	43º 52' N	78º 46' W	70	Urban
Squamish River Delta			RLL	49º 42' N	123º 10' W	6	Multiple land use
Tantramar Marshes			RLL	45º 56' N	64º 19' W	4	Agriculture
Total		42,931					

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

Table II. Characteristics of the water management and flood protection system in Canada

Name	Design criteria in chance of occurrence/year							
	Water management						Flood protection	
	Drainage					Irrigation	Rural	Urban
	Type	Design criterion	Percentage of open water	Discharge capacity				
				m^3/s	mm/day			
Polders along the Bay of Fundy: • polder at Prince Edward Island • polders in Nova Scotia • polders in New Brunswick	 LGS LGS LGS						 Dike crest 6 m+MSL Dike crest 6 m+MSL Dike crest 6 m+MSL	
Pitt Polder	RLL						Dike crest 16 m+MSL	
Alouette Polder	RLL						Dike crest 16 m+MSL	
Bradford Scheme	RLL			0.32	33.6			
Holland Marsh	RLL	See Table III		4.1	12.4			
New Holland Marsh	RLL							
Kootenay River-Creston Valley	RLL							
Polder in Toronto	RLL							
Squamish River Delta	RLL							
Tantramar Marshes								

Table III. Specifications of the drainage and flood protection systems of the Holland Marsh (after Smart and Associates, 2009)

	North Canal from Highway 9 to North Branch River	North Branch River to 2000 feet east of Simcoe Road	East of Simcoe Road to converging point west of CN Railroad	South Canal Throughout
Original design by A. Baird				
Canal: • top width • bottom wodth • depth	 11.6 6.1 2.1	 18.3 12.2 2.1	 21.3 12.2 2.1	 11.6 6.1 2.1
Dike: • top width • bottom wodth • height	≥ 5.5 ≥ 11,6 2.1			
Separation width between toe of dike and top of canal	1.8			
Reconstructed canal after the flooding due to Hurricane Hazel				
Canal: • top width • bottom wodth • depth	 17.7 12.2 – 18.3 3.0	 19.8 12.2 – 18.3 3.0	 23.2 12.2 – 18.3 3.0	 16.5 12.2 – 18.3 3.0
Separation width between toe of dike and top of canal	0	0	0	0

Table IV. Pictures on polders in Canada by Prof. Adriaan Volker

		
A2 001/II.2.1 Drainage machine in Canada	A2 002/II.2.2 Drainage machine in Canada	A2 003/II.2.3 Drainage machine in Canada
		
A2 004/II.2.4 Series of Shiplocks, presumably in Ottawa	A2 005/II.2.5 Prof. Volker on a ferry at John Diefenbaker Lake	A2 006/II.2.6 Prof. Volker on a ferry at John Diefenbaker Lake