Issued October 3, 1911.

U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN 240.

A. C. TRUE, Director.

TIDAL MARSHES AND THEIR RECLAMATION.

BY

GEORGE M. WARREN,
Drainage Engineer.

PREPARED UNDER THE DIRECTION OF
C. G. ELLIOTT,
Chief of Drainage Investigations

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S. M. Woodward, A. E. Morgan, C. F. Brown, L. L. Hidinger.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., February 28, 1911.

Sir: I have the honor to transmit herewith a manuscript upon "Tidal Marshes and Their Reclamation," prepared by George M. Warren, drainage engineer, under the direction of C. G. Elliott, chief of drainage investigations.

Mr. Warren has made a thorough study of the subject and has presented it in a comprehensive manner. His investigations are valuable and throw light on some of the heretofore obscure points connected with the profitable reclamation of tidal marshes. Actual field conditions have been critically examined and the deductions are based upon data secured upon the ground. Except as otherwise noted, all maps, plans, and diagrams were prepared by Mr. Warren and many of the photographs were taken by him.

Among many who have kindly given of their time, furnished teams, or assisted in other ways thanks are hereby especially extended to Harry Hayward, director of the State Experiment Station, Newark, Del.; William J. Beck, Delaware City, Del.; Oliver H. Tomlinson, Dorchester, N. J.; D. Woodruff Boggs, civil engineer, Bricksboro, N. J.; Edward L. Gandy, Mauricetown, N. J.; Dr. Stephen Henry, Marshfield, Mass.; Prof. W. F. Ganong, Smith College, Northampton, Mass.; L. D. Baker, jr., Wellfleet, Mass.; Whitman & Howard, civil engineers, Boston, Mass.; John F. Herbin, Wolfville, Nova Scotia; Gustavus Bishop, Greenwich, Nova Scotia; W. C. Milner, Halifax, Nova Scotia; Mayor J. M. Curry, Amherst, Nova Scotia; Thomas Estabrooks and William B. Fawcett, Sackville, New Brunswick; William B. Mackenzie, chief engineer of Intercolonial Railway of Canada, Moncton, New Brunswick.

The growing scarcity of good upland farms and the rapidly increasing population and consequent demand for good trucking lands near the large cities, particularly on the Atlantic coast, make the reclamation of tidal lands an increasingly important subject.

I therefore recommend that this manuscript be published as Bulletin No. 240 of this office.

Respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

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TIDAL MARSHES AND THEIR RECLAMATION.

INTRODUCTION.

The embanking of tidal marshes and their use for agricultural purposes date back to antiquity. For upward of three centuries the coastal countries of Europe, particularly those bordering on the North Sea, have been engaged in this practice and have developed in the polders of the Netherlands and the fen lands of England the finest agricultural lands in Europe, and drainage works of greater magnitude than elsewhere in the world.

In this country the reclaiming of tidal marshes extends back about 150 years, but the results obtained have not been wholly satisfactory. The comparatively few permanent successes have been accompanied by so many failures that many people have become discouraged and skeptical as to the practicability of such reclamations.

The Department of Agriculture, cognizant of the indifferent successes and appreciating the great importance of the subject, has gathered, published, and disseminated much useful information on tidal marsh lands. The principal departmental publications upon the subject are, "Tidal Marshes of the United States," by D. M. Nesbit, issued in 1885;[1] "Reclamation of Salt Marsh Lands," by Thomas H. Means, revised edition issued in 1903;[2] and "Reclamation of Tide Lands," by J. O. Wright, issued in 1907.[3]

The Nesbit report of 1885 contains 244 pages, and, from data secured by correspondence with landowners and other interested parties, describes the status of marsh reclamation work along the whole length of the Atlantic, Gulf, and Pacific coasts. There are interesting descriptions of drainage works in Nova Scotia, New Brunswick, and the State of Washington, and quotations from the reports of the State geologist of New Jersey for the years 1869 and 1870, giving general accounts of reclamation work in that State, in England, and in Holland. Other sections of the bulletin cover briefly the historical, physical, legislative, and business aspects of the subject.

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[1] U. S. Dept. Agr., Misc. Spec. Rpt. No. 7.

[2] U. S. Dept. Agr., Bur. Soils Circ. 8, rev.

[3] U. S. Dept. Agr., Office Expt. Stas. Rpt. 1906, pp. 373–397.

The Means report of 1903 is a 10-page circular which had its inception in the desire to rid the tidal marshes of the mosquito pest. It contains valuable suggestions relative to the drainage, preparation, cultivation, chemistry, and agricultural value of marsh land.

The Wright report of 1907 contains about 30 pages and treats briefly of the history, objects, results, and causes of failure of tidal-marsh reclamation, and gives pertinent suggestions relative to methods of doing the work; the location, dimensions, and protection of dikes; the construction of sluice gates and pumping plants; and the drainage and treatment of the soil. Drawings are shown for a three-flume concrete and a three-flume wooden sluice with bills of material for each.

The population of the United States is increasing rapidly, and in one State now exceeds 500 to the square mile. Due to this fact, there is a growing scarcity of good upland farms and a widespread inquiry for detailed information on various phases of marsh-reclamation work. Under these circumstances the Department of Agriculture, through drainage investigations of the Office of Experiment Stations, has sought by critical study into certain engineering and agricultural problems involved to further advance the cause of tidal-marsh reclamation and to deduce practical, up-to-date rules for the guidance of those having in charge the design or construction of drainage works in seacoast marshes. An effort has been made to secure accurate information, to treat the subject in a more detailed manner, and to bring out points not covered, or at most only suggested, in the previous publications. The importance of the subject is recognized everywhere. The inherent fertility of much of this land, its exemption from the evil effects of prolonged droughts, and its proximity to the populous seaboard cities, emphasize this importance. Not alone are the agricultural possibilities almost boundless, but the health, comfort, and well-being of thousands of people must inevitably be promoted.

For the purpose of obtaining reliable and first-hand information, numerous marshes in different States have been investigated. Four reclamations have been surveyed, current-meter measurements made of the sluice discharges, notes plotted, and the results studied in detail, as follows:

1. Marsh land belonging to the estate of Arthur Colburn, Delaware City, New Castle County, Del.
2. Marsh land of the St. Georges Marsh Co., New Castle County, Del.
3. Marsh lands belonging to Howard Compton, Alfred H. Lupton, and others, Dorchester, Cumberland County, N. J.
4. Marsh land of the Mauricetown Banking Co., Mauricetown, Cumberland County, N. J.

DEFINITION OF TERMS.

It is thought well at this point to give definitions of some of the terms which will be used in the following discussion.

"Tidal marsh" will be taken to mean any marsh subject to the influences of tidal waters, whether those waters are salt, brackish, or fresh.

"Foreshore" will be considered as the strip of land between the levee and the river or sea.

"Outside" and "without" will be considered as on the river side of the levee.

"Inside" and "within" will be considered as on the land side of the levee.

"M. L. W." is an abbreviation for mean low water; it will be considered as the established mean low water of the river or sea in the locality which may be under consideration, irrespective of whether it is the mean of all the low waters or merely of the lower low waters. It is the datum or plane of reference for levels; its numerical value is zero.

"Elevation" will be considered as distance above mean low water; with a minus sign, as distance below mean low water.

"Second-feet" is an abbreviation for "cubic feet per second."

"Run-off" or "discharge" is the volume of water flowing in a stream or ditch.

"Rainfall" is expressed in depth in inches.

FIELD WORK.

The surveys were made during the summer and fall of 1909. Distances were measured by stadia. Levels were run with a transit and are referred to mean low water in the Delaware or Maurice Rivers. The velocity measurements of sluice leakage and discharge were made with a small Price current meter, the integration method being employed.

Before proceeding to detailed descriptions of the four reclamations already referred to, brief general discussions bearing on the action of tides and the formation of marshes will, it is hoped, prove of interest and value.

TIDES.

In the world of nature few phenomena are more complex than those of the tides. According to the uncorrected equilibrium theory of Newton, elaborated by Laplace, and accepted by most writers for many years after their time, the earth was conceived as a rotating globe covered with a hypothetical sheet of water or by zonal seas, the depth being assumed as uniform, or depending upon latitude but not upon longitude. In such a sea the attraction of the moon would create a wave about 7 inches in height, with a width halfway around the world, and cause a corresponding rise of the waters on the opposite side of the earth. In like manner the sun's attraction would create a wave about 3 inches in height.

In order to fit this theory to the conditions as existing in nature, it was supposed that the tidal wave had its origin in the great ocean area of the globe, the South Pacific and Antarctic Oceans, that it moved from east to west, impinging against the easterly coasts of continents, and that in completing the circuit of the earth a period of time was consumed which varied with the ocean's depth and with the interposition of continents and islands.

The observed conditions of the tide in different parts of the world are so at variance with those formerly supposed to exist that later investigators have discarded or greatly modified the former theories.

The most advanced thought of to-day regards certain of the oceans under the influence of gravity, the earth's rotation, and the horizontal pull of the moon and sun as oscillating areas, that certain areas of the oceans have the right depth and the right length between land barriers, so that the free periods of oscillation of their waters are in approximate unison with the tide-producing influences, and that there exist points of complete or partial rest called nodal points or spots of no tide, somewhat analogous to the conditions in a vibrating violin string. Actual measurements of depth in the North Sea have shown the existence and location of nodal points, and research indicates that in the open seas far removed from land there may be tides of from 2 to 10 feet in height, conditions which formerly were believed impossible.

In illustrating the forces which tend to deflect a particle moving on the earth's surface, Prof. G. H. Darwin says:[1]

> When, in the Northern Hemisphere, water moves from north to south it passes from a place where the surface of the earth is moving slower to where it is moving quicker. Then, as the water goes to the south, it carries with it only the velocity adapted to the northern latitude, and so gets left behind by the earth. Since the earth spins from west to east, a southerly current acquires a westward trend. Conversely, when water is carried northward of its proper latitude it leaves the earth behind and is carried eastward. Hence the water can not oscillate northward and southward without at the same time oscillating eastward and westward.

The oscillating oceans create ocean eddies and currents which transmit the oscillations into all the seas and bays of the earth, causing a constant circulation of oceanic waters, and it is a matter of fact

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[1] Manual of Tides. Part IVb, Cotidal Lines for the World, by R. A. Harris. U. S. Coast and Geodetic Survey Rpt. 1904, Appendix 5, pp. 315–400.

and observance that there is always a tendency for the cold waters of the poles to approach the equator, from which the warm waters tend to drift toward the poles.

Late investigations in Germany have demonstrated tidal movements in the earth's crust itself.

With respect to the sun, the earth revolves on its axis in 24 hours, which is the solar day; with respect to the moon, the earth revolves in about 24 hours and 51 minutes, which is the lunar day. Thus there are two solar and two lunar tides each day, but as the influence of the sun as a tide-producing agency is only about four-tenths that of the moon, the solar tides are noticeable principally through their effect in increasing or diminishing the lunar tides. The period required for the moon to pass from a given phase to the same phase again is 29 days 12 hours.

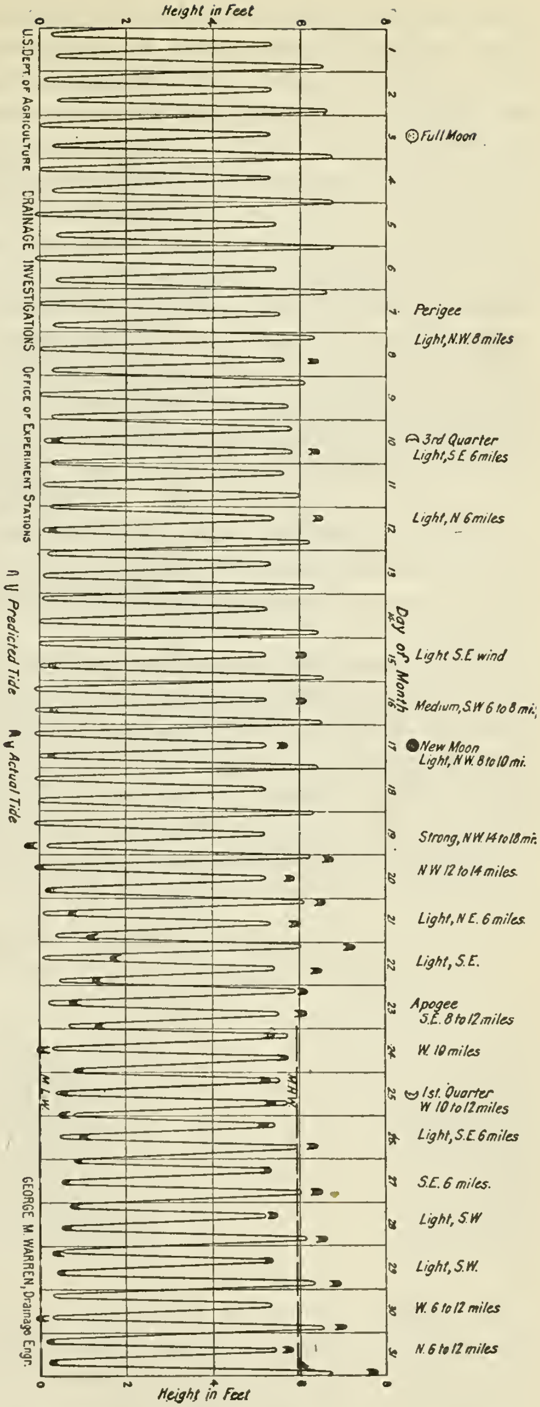

Fig. 1.—Diagram showing predicted and actual time and height of tide in Delaware Bay, July, 1909, and influence of moon and winds.

Soon after passing those points in her journey known as "new moon" and "full moon," that is, when the sun and moon are in the same or opposite parts of the heavens, the two tidal effects are united, and the tides rise higher and fall lower than usual, and are known as "spring tides." At the "quarters" the tides tend to neutralize by the crest of the lunar wave falling in the hollow of the solar wave, and the rise and fall are diminished and are known as "neap tides."

Every 12 hours and 25 minutes, on the average, twice each lunar day, will therefore be a period of high water, and 6 hours and 13 minutes later will be a period of low water.

Notwithstanding the time and height of tides are governed by inexorable laws, both are strongly affected by the force and direction of the wind and the depth and contour of the shore. The diagram (fig. 1), based on the published tide tables of the United States Coast and Geodetic Survey, shows the preponderant influence of the moon and the effect of winds. In Delaware Bay a northwesterly wind favors a low tide, and a southwesterly wind favors a high tide. It will be noted from the diagram that the prevailing winds were southerly and consequently the tides high for the greater part of the month.

Within rivers and streams the tidal undulation or wave becomes a true current, the ebb requiring more time than the flood on account of the fresh water which has been held back. The velocity of the ebb or flood attains a maximum at a time about half way between the high and low "stands" of the tide. The range of the tide, a controlling factor in gravity drainage, varies widely at different places, as is shown by the following table, a number of the selections being in localities where marsh reclamation has been extensive.

Mean range of tide at different places.

Place.	Feet.	Place.	Feet.
Sackville, New Brunswick	39.6	Wilmington, N. C	2.4
Annapolis, Nova Scotia	25.1	Charleston, S. C	5.2
Portland, Me	8.9	Savannah, Ga	6.8
Portsmouth, N. H	9.2	St. Augustine, Fla	4.2
Boston, Mass	9.6	Key West, Fla	1.2
Plymouth, Mass	9.6	Mobile, Ala	.5
Providence, R. I	4.4	Biloxi Light, Miss	.3
New London, Conn	2.5	Port Eads, La	.1
Oyster Bay, N. Y	7.3	Galveston, Tex	.5
Newark, N. J	5.0	San Francisco, Cal	4.0
Salem, N. J	6.4	Astoria, Oreg	6.4
Mauricetown, N. J	5.2	Seattle, Wash	7.7
Delaware City, Del	5.9	Hull, England	16.3
Old Point Comfort, Va	2.5	Harlingen, Netherlands	4.2

The highest tides in the world are found in the spring ranges of 50.5 feet in the Basin of Minas, Bay of Fundy, and 45.6 feet in the Gallegos River on the southeastern coast of Patagonia.

From the above table it is seen that gravity drainage, which is the simplest and least expensive form, is more frequently practicable along the North Atlantic and North Pacific coasts than in the Southern States; the Gulf marshes can not be drained in this way.

Thorough knowledge concerning the tides has numerous practical applications, such as deciding on grade of sluices, height of levees, and opportune time for special construction or repairs. For instance, the most favorable time for making small repairs on a sluice would be when a strong offshore wind came at new or full moon. A severe storm at this time of the month would be an indication of what the height of the dike should be. Construction work which required a cofferdam would encounter the smallest fluctuation of tide when the moon was on the first or third quarter.

It is a matter of general knowledge that the theoretical oscillations of the tide are represented by a simple cosine curve. Such curves for tides having a rise and fall of 1 to 10 feet, which are the practical limits of mean range in the United States, have been plotted and are shown in the diagram (fig. 2).

Example of application.—Required the time of opening and the period of play of a sluice, the ditch water being 2 feet above low water outside and the range of the tide 8 feet.

From the right-hand vertical line follow down the curve which starts at 8 until the horizontal line passing through 2 is intersected. At this instant the tide and ditch water are at the same level and the gates about to open. From the intersection follow vertically downward to the bottom horizontal line, and time is noted as about 2 hours and 4 minutes before low water. This is the approximate time the sluice would play, assuming the interior water to have been discharged by the sluice to approximately the level of mean low water.

Sea water weighs about 64.1 pounds per cubic foot, 1.6 pounds, or 2½ per cent more than ordinary river water. It contains about 3.5 per cent by weight of mineral matter in solution, of which approximately four-fifths, or 1¾ pounds per cubic foot, is common salt.

According to Regnault[1] and Dittmar,[2] the mean composition of sea water is as follows:

Mean composition of sea water.

Constituents.	Regnault.	Dittmar.
	Per cent.	*Per cent.*
Sodium chlorid (common salt)	2.700	2.721
Magnesium chlorid (bittern)	.360	.381
Magnesium sulphate (Epsom salt)	.230	.166
Calcium sulphate (gypsum)	.140	.126
Potassium chlorid	.070	....
Potassium sulphate	....	.086
Calcium carbonate (limestone)	.003	.012
Magnesium bromid	.002	.008
Water (and loss in analysis)	96.495	96.500
Total	100.000	100.000

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[1] Soils, by E. W. Hilgard. New York and London, 1907, p. 26.

[2] Report on the Scientific Results of the Voyage of H. M. S. Challenger during the Years 1873–76. Physics and Chemistry—Vol. I. Part 1.—Report on the Composition of Ocean-Water, by William Dittmar. London, 1884.

While the waters of the ocean contain in solution appreciable quantities of many of the elements, and it is surmised, though not proven, that all the known elements may be represented, yet at considerable distances from land the waters are clear and almost entirely free from suspended matter.

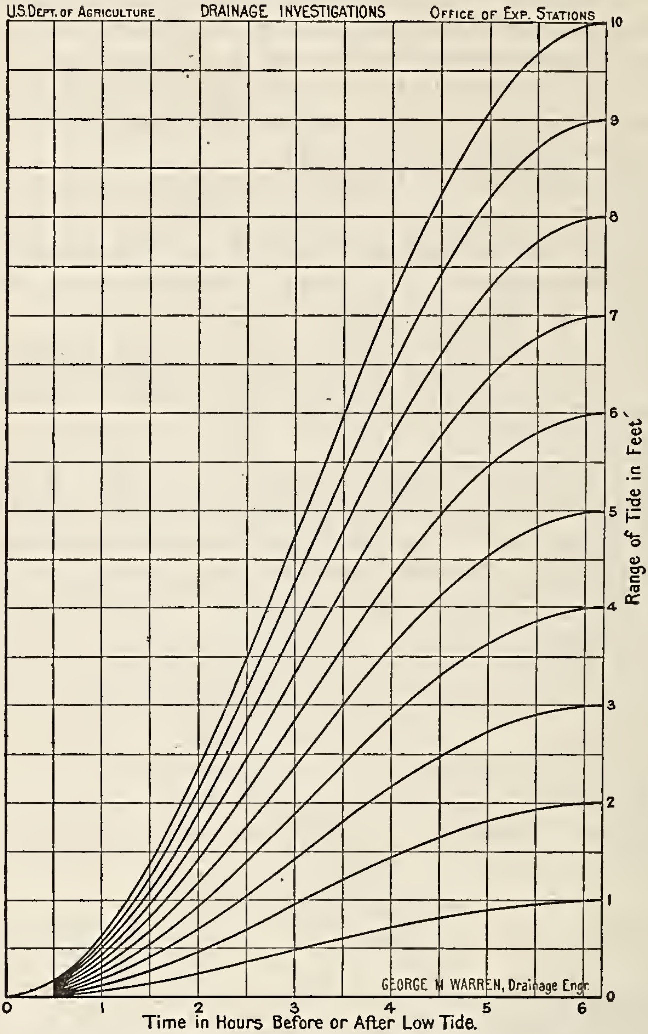

FIG. 2.—Diagram showing vertical rate of ebb and flood for 6 hours 13 minutes, with tidal ranges of 1 to 10 feet.

MARSHES.

Marshes have their youth and old age, existing in all stages of development. Some are old river or lake bottoms filled with the undecomposed vegetable accumulation of ages. These peat marshes, when decomposition is more advanced, become the muck beds so frequently seen along our coasts. The reclamation of such lands should be undertaken with caution. If possessed of sufficient earthy material, they may become extremely fertile, especially adapted to the growing of potatoes, celery, cabbage, and onions, but their shrinkage and consolidation when drained and aerated is very large, and as a foundation for sluices and embankments they are unstable.

Another type of marsh exists as a barren waste of sand, almost devoid of vegetation. Their reclamation is not likely to be financially successful, as the expense of putting the land in a productive condition is very great, and sand as an embanking material is most treacherous.

Still another type of marsh is that found behind barrier beaches along outer coasts and in other locations subject to violent wave action.

Through long-continued mechanical action of the waves on an exposed coast the bowlders, pebbles, and sand are ground into exceedingly fine particles, of which the greater portion is carried by the undertow into the sea, but an appreciable quantity remains to be swept by waves and currents into the indentations and inlets of the shore. Moreover, such inlets or estuaries have a tendency to become closed by ridges or barriers of sand heaped up by the sea and the action of winds. The tidal marshes formed in this way are very extensive, but their reclamation is often difficult, because free outfall channels are not easily constructed and maintained.

Soil is disintegrated rock, and its formation is in progress everywhere through various chemical and mechanical agencies. From the spot of its origin, perhaps hundreds of miles inland, moving water is the vehicle which is ceaselessly conveying it to its resting place to form the fourth and, to the agriculturist, the most important type of marsh. Without the instrumentality of the tides, the fine sand, silt, and clay which is being constantly brought down by rivers would be carried out to sea and lost to man's use forever. The descending fresh water, with its accumulation of detritus, is met and forced back by the comparatively clear water of the flood tide; before the next ebb occurs the silt-laden water has been forced to spread out over the low marshes, and a portion of the suspended matter is deposited. The heavier particles deposit first, thus building up most rapidly the marsh adjacent to the river; the finer, lighter particles are carried farther toward the uplands, and here the marsh-building process is much slower. With the lapse of time enormous areas have in this way been raised, so that they are only submerged by storm tides, and in this condition offer inviting prospects for reclamation and development.

The rate of tidal deposit varies greatly. A heavily wooded watershed, or one in which the agricultural development has been small, will generally be drained by a comparatively clear river, and the marshes will, in consequence, build up very slowly.

Most soils shrink when deprived of their water. Experience, both in this country and abroad, has shown that where marshes have been drained there is a long continued shrinkage or subsidence of the land, the amount of which varies with the depth and character of the soil, being more in those of a peaty or mucky nature, and less in clay, silt, or sand. Approximate subsidences noted in several reclamations are as follows: Green Harbor, Mass., between 1872 and 1908, about 2 feet; Hackensack Meadows, N. J., between 1869 and 1887, from 3 to 3.5 feet; Cohansey Creek, Cumberland County, N. J., from 2½ to 3 feet; Mays Landing, N. J., about 1 foot; Salem, N. J., 3½ to 4½ feet; Whittlesey, England, 7 feet in 18 years, and in the old reclamations, it is said, the subsidence is still going on at the rate of an inch per year. The drainage of the fen lands has, with the lapse of time, been accomplished only through an ever increased use of pumps. In planning drainage works this tendency to subsidence must be fully appreciated as, if long continued, the ditches become more and more ineffective, and thereafter the water can only be removed by pumping. Failure to discern the shrinkage of marsh soils has caused many to believe that the tides rise higher than in former years, but there is no evidence that such is the case.

The following mechanical and chemical analyses of tidal-marsh soils from the vicinity of Oyster Bay, N. Y., are given as probably typical of extensive areas along the Atlantic coast. These analyses are taken from "Reclamation of Salt Marsh Lands" issued in 1903.[1]

Mechanical and chemical analyses of tide-marsh soils from Oyster Bay, N. Y.

Sample No.	Locality of soil.	Sand.	Silt.	Clay.	Lime CaO.	Potash K_2O.	Phosphoric acid P_2O_5.	Organic matter.	Soluble in water.
		Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
5379	Mud from tidal flat, west end Lloyds Harbor, 0–6 inches[2]	13.2	44.8	42.0	0.43	0.57	0.16	7.18	2.16
5374	Sod and grass roots from outer marsh, Center Island, 0–36 inches							29.00	4.07
5375	Eel-grass clay from outer marsh, Center Island, 36–66 inches[3]	28.0	44.9	27.1	.31	.57	.14	5.36	2.55
5376	Sod taken from inner marsh, Center Island, 0–12 inches							34.70	1.87
5377	Decomposing sod from inner marsh, Center Island, 12–24 inches							25.49	3.87
5378	Eel-grass clay from inner marsh, Center Island, 24–72 inches[4]	38.0	37.1	24.9	.41	.68	.12	10.90	3.56

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[1] U. S. Dept. Agr., Bur. Soils Circ. 8, rev.

[2] High tide covered this flat 4 to 5 feet deep.

[3] This marsh was covered at high tide.

[4] The drainage of the inner marsh was in progress, but the marsh had been accidentally covered several times with salt water.

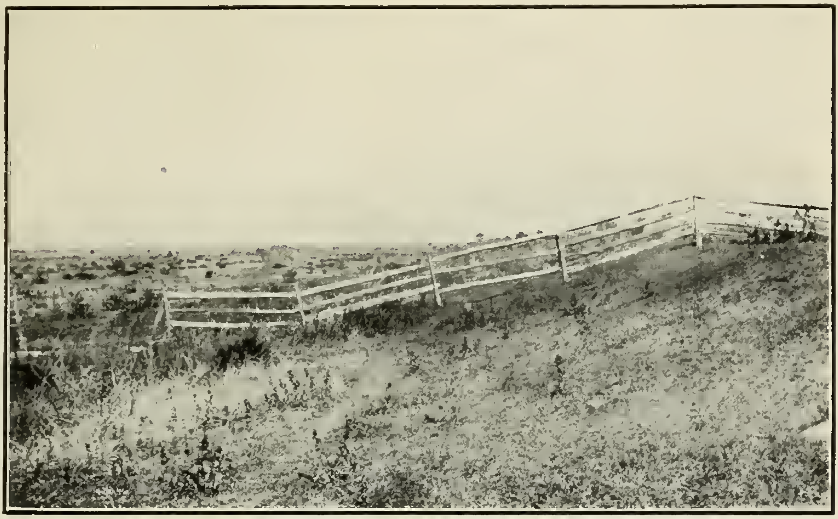

FIG. 1.—LEVEE AND ENCLOSED PASTURE LAND.

FIG. 2.—LEVEE, FIELD, AND FORESHORE.

COLBURN MARSH LANDS, DELAWARE CITY, DEL., NOVEMBER 1 1909.

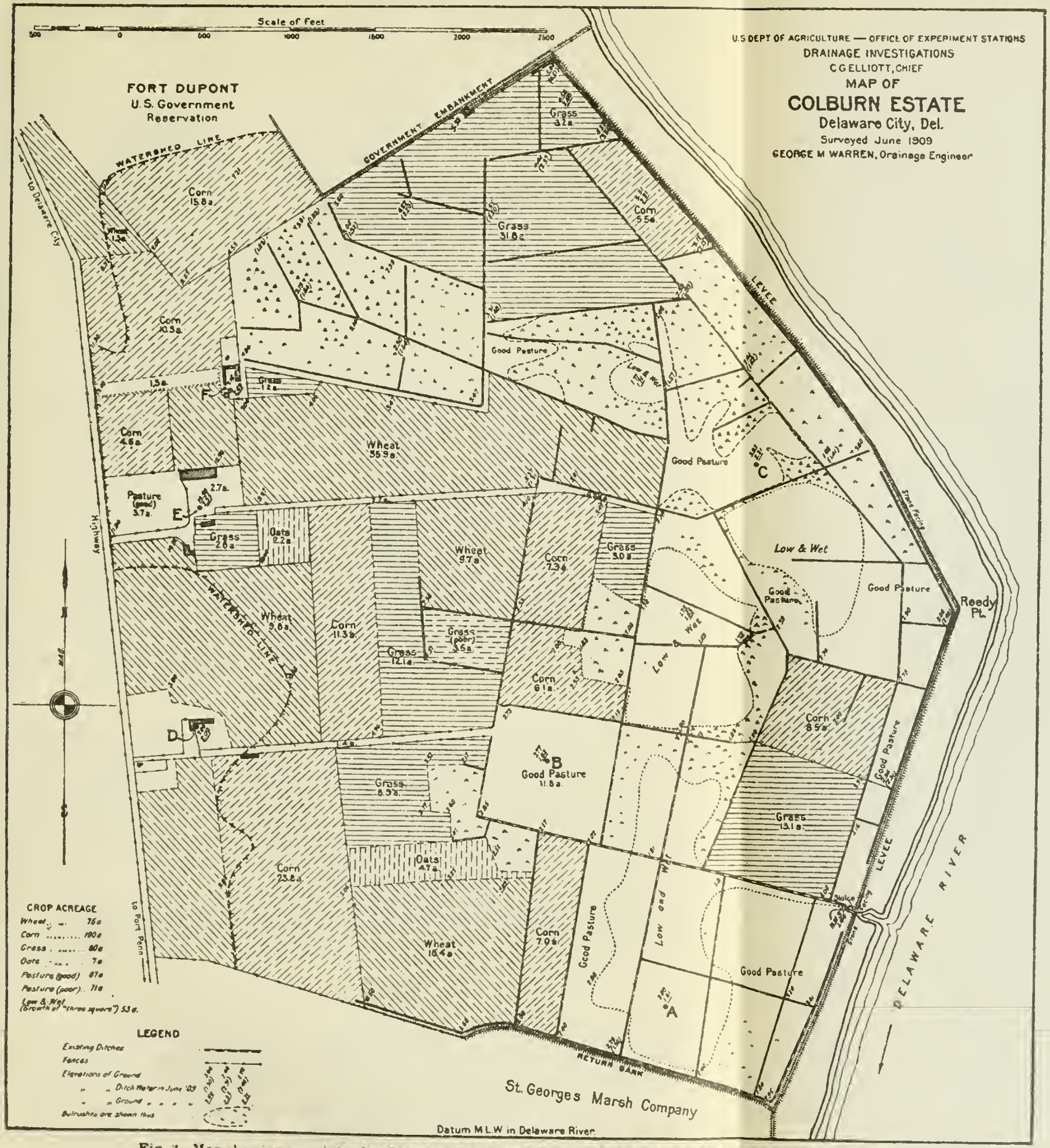

Fig. 3.—Map showing marsh lands of estate of Arthur Colburn, Delaware City, Newcastle County, Delaware.

DESCRIPTIONS OF THE FOUR RECLAMATIONS INVESTIGATED.

MARSH LAND NEAR DELAWARE CITY, NEW CASTLE COUNTY, DEL.

HISTORY AND DESCRIPTION.

The marsh land here considered comprises about three-fifths of the 515 acres making up three farms on the west side of the Delaware River, and situated about 1 mile south of Delaware City, Del.

First reclaimed in the early fifties, the levee was raised and the present sluice built in 1894. Cultivation has been practically continuous for over half a century and to-day the lands are carrying 110 head of cattle and 21 horses. (For plan of lands showing levee, ditch system, topographic features, and crops raised in 1909 see fig. 3.)

The tributary drainage area contains about 488 acres and varies from 1.6 to 16 feet above mean low water. The interior marsh has a dishing or " saucer-shaped " profile. Near the levee the land is from 2.5 to 4.0 feet above datum, the lower portions being in pasture (see Pl. I, fig. 1), and the higher in hay or corn. About 800 feet inland is a well-defined chain of low areas containing collectively 53 acres, and having an almost uniform elevation of 1.7 feet; this land is covered with three-square sedge. Continuing westerly, successive fields being in grass, corn, and wheat, the ground rises to the drainage line, 9 to 11 feet above datum. The foreshore averages about 200 feet wide and is covered with a rank growth of reeds and marsh grass; near the levee it has generally been raised by deposit to ordinary high-water mark. (See Pl. I, fig. 2.)

TIDES.

The mean range of the tide is 5.9 feet; the rise takes place in about 5⅔ hours and the fall in about 6¾ hours. About once a year it may be expected that the tide will reach elevation 9. Within recent years elevation 9.52 was noted, which is several inches above the greater length of the levee. Extreme high water, so far as known, is elevation 11, reached in October, 1878. Extreme low water is believed to be about 2.8 feet below datum. The Delaware River at this point is only slightly brackish, though it is probable that the small rainfall and lessened flow of 1909 allowed the saline water to ascend farther than usual.

SOIL AND SUBSOIL.

The soil, as deposited by the tide, is a plastic, silty clay, and weighs about 86 pounds per cubic foot. When wet it has a bluish color, and when dry is a light gray and is commonly designated as " blue mud " or " gray mud " by farmers and marsh men. Deprived of all moisture except atmospheric, the soil shrinks from 30 to 40 per cent of its volume, and each cubic foot parts with about 35 pounds of water, or 41 per cent by weight. Its interstitial space under field conditions is about 56 per cent of its volume.

Within the levee the soil is stiffer, and its mottled appearance and the wiry nature of the vegetation attest imperfect aeration and drainage. Test pits and sounding show a diminishing depth of "blue mud" approaching the uplands, where a clay loam 12 to 15 inches in thickness was usually followed by a muck or peat formation.

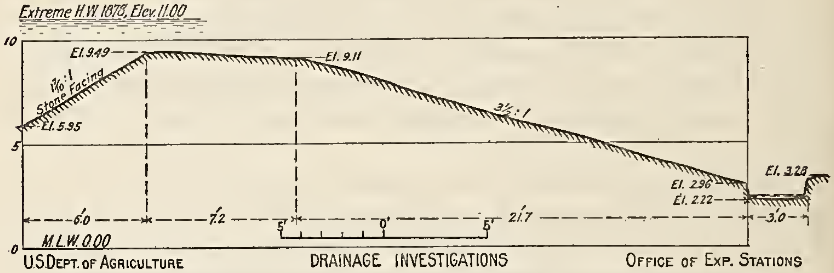

Fig. 4.—Cross section of levee near north end Colburn estate, Delaware City, Del.

There is evidence that near the levee the soil is very deep. Three test borings on the river front, made in 1906 by the Chesapeake and Delaware Canal Commission at Delaware City, St. Augustine pier, and Appoquinimink River, which points are situated respectively 1½ miles northerly, 3 and 5 miles southerly from the Colburn marsh, showed the following stratifications:

At Delaware City.—For 31 feet, soft blue mud containing wood and vegetable matter; next 10 feet, blue mud and sand, mixed in about equal proportions; next 12 feet, very soft blue mud; and next 3 feet, green sand and mud; driving more difficult, and pipe drawn at 56 feet.

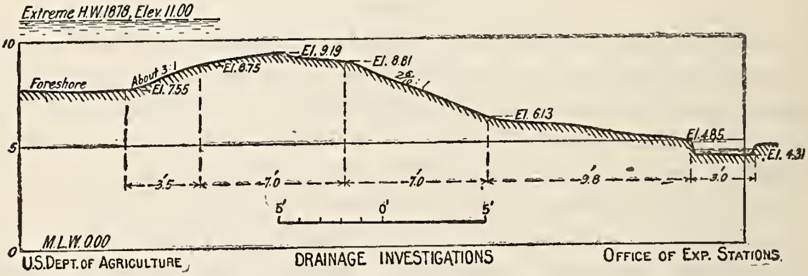

Fig. 5.—Cross section of levee at Reedy Point, Colburn estate, Delaware City, Del.

At St. Augustine pier.—For 22 feet, blue mud; easy driving; next 38 feet, coarse, green, almost black sand, which became finer as depth increased, making driving more difficult; pipe drawn at 60 feet.

At Appoquinimink River.—For 80 feet, stiff blue mud; pipe driven and drawn in one day.

The natural fertility of the Colburn marshes is unquestioned, for they have been tilled many years with little or no artificial fertilization, and without apparent exhaustion of the soil.

LEVEE.

Cross sections of the levee shown in Plate I, giving heights, widths, and slopes, are shown in figures 4, 5, and 6.

The foundation of the levee is believed to be the natural surface of the marsh without other treatment than the cutting and removal of the vegetation upon it. The top and slopes have a good growth of grass but have not been kept sufficiently free from weeds, thus harboring burrowing animals. The condition of the stone facing in places emphasizes the importance of suitable backing. Wave action, by removal of some of the fine material, has left spaces into which the stones have settled. As crushed stone or screened gravel would be too expensive for general use, it is believed that oyster shells would make an excellent substitute. These can be landed in barges at the dock in Delaware City for $3\frac{3}{4}$ cents per bushel.

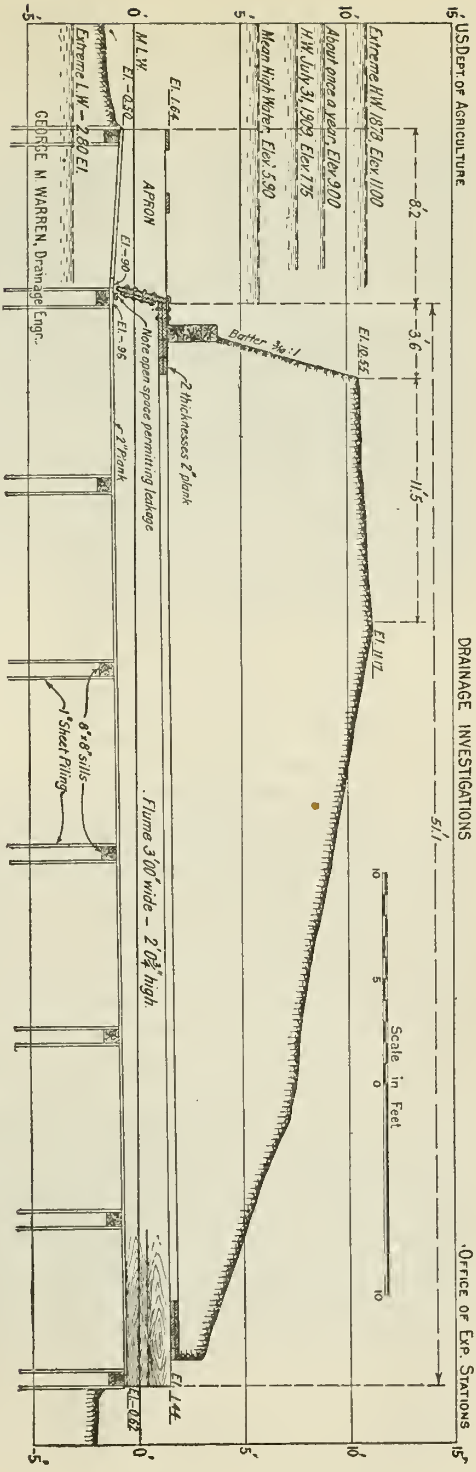

Fig. 6.—Cross section through levee on center line of sluice, Colburn estate, Delaware City, Del.

SLUICE.

The sluice (see Pl. II, fig. 1) is of timber construction 51 by 7 feet, outside dimensions. Figures 6 and 7 show its construction in detail and its present grade. The gates are double thickness, 2-inch unmatched plank, have strap hinges and are unweighted. Near the center of each gate is an opening about 5 by 8 inches, fitted with copper slide working in horizontal copper grooves for admitting river water as needed during times of drought. Both gates seat poorly, permitting large leakage from the river. A strip is missing from the bottom of the southerly gate, with the result that when closed there is an open space beneath its whole length, admitting large quantities of river water.

Figure 8 shows graphically the rise and fall of the tide and the ditch water, the times being plotted as abscissas and the heights as ordinates. Beneath is plotted the sluice leakage or discharge in second-feet at the corresponding moment. The leakage of September 2 and the discharge of August 6 are illustrated for the reason that on those dates the quantities measured approximately represent the normal workings of the sluice during the summer season.

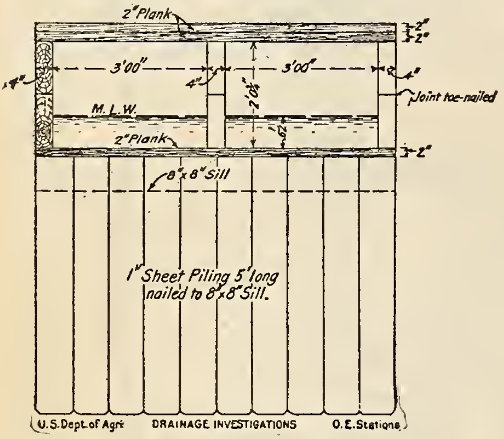

Fig. 7.—Cross section of sluice, Colburn estate, Deleware City, Del.

The following table shows length of time the sluice leaked or played, the rise or fall of the ditch water during that time, the maximum and average rates of flow, and the total leakage or discharge for the period and on the dates given:

Leakage and discharge of sluices.

Date.	Time.		Rise or fall of ditch water.	Rate of flow.		Total leakage from river.	Total discharge to river.
				Maximum.	Average.		
1909:	*Hrs.*	*min.*	*Feet.*	*Sec.-feet.*	*Sec.-feet.*	*Cubic feet.*	*Cubic feet.*
July 28	2	42	1.01	28.35	16.76	....	162,907
Aug. 6	10	00	1.08	13.28	6.68	240,480	....
Do	2	19	.82	31.19	20.98	....	174,973
Aug. 12	1	56	.62	28.09	20.15	....	140,244
Aug. 18	9	30	.32	6.98	5.11	174,762	....
Do	2	30	.73	34.18	24.09	....	216,810
Aug. 30	2	40	1.01	23.11	14.00	....	134,400
Sept. 1	3	12	1.25	29.13	15.69	....	180,748
Sept. 2	9	24	1.23	6.75	4.83	163,447	....
Averages:							
Leakage	9	38	.88	9.00	5.54	....	....
Discharge	2	33	.91	29.01	18.61	....	168,347

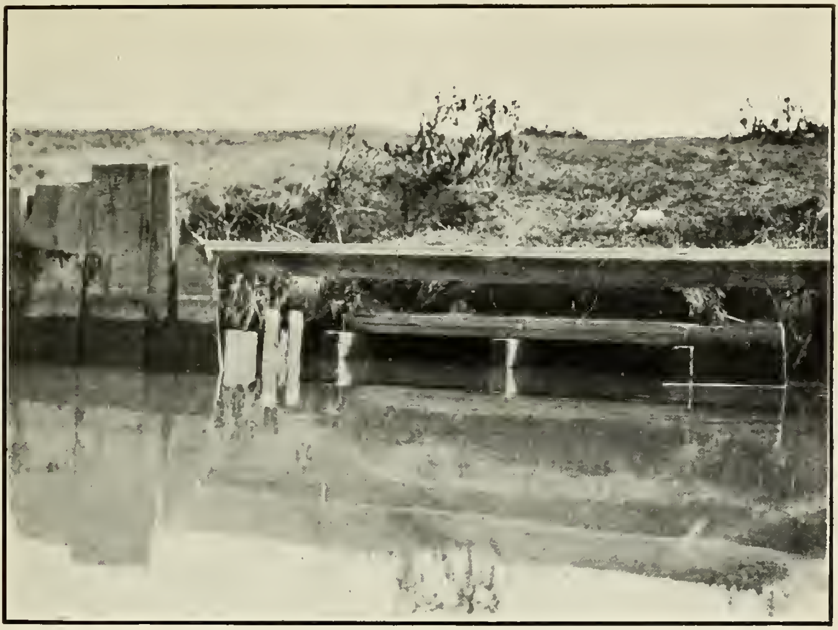

FIG. 1.—LAND END OF SLUICE AT LOW TIDE.

[Horizontal marks about half way up on the sheeting indicate height to which ditch water ordinarily rises.]

FIG. 2.—EXAMPLE OF A LATERAL DRAINAGE DITCH.

COLBURN MARSH LANDS, DELAWARE CITY, DEL., NOVEMBER 1, 1909.

The abnormal leakage of August 6 (249,480 cubic feet) was caused by the northerly gate becoming stuck for about one hour in a partially opened position. From gaugings of the ditch water covering a considerable period, it is very probable that the leakage of September 2 (163,447 cubic feet) is about the usual quantity. Taking the normal leakage between periods of sluice play as 163,447 cubic feet and the normal discharge as 168,347 cubic feet, it is seen that the former amounts to about 97 per cent of the latter. The difference in these quantities, 4,900 cubic feet, represents the amount of water which enters the land by seepage and percolation from the river, and by movement of the upland ground water, during a period averaging about 9 hours and 38 minutes, evaporation being neglected. This is at the rate of about 10 cubic feet per acre of drainage area, twice daily.

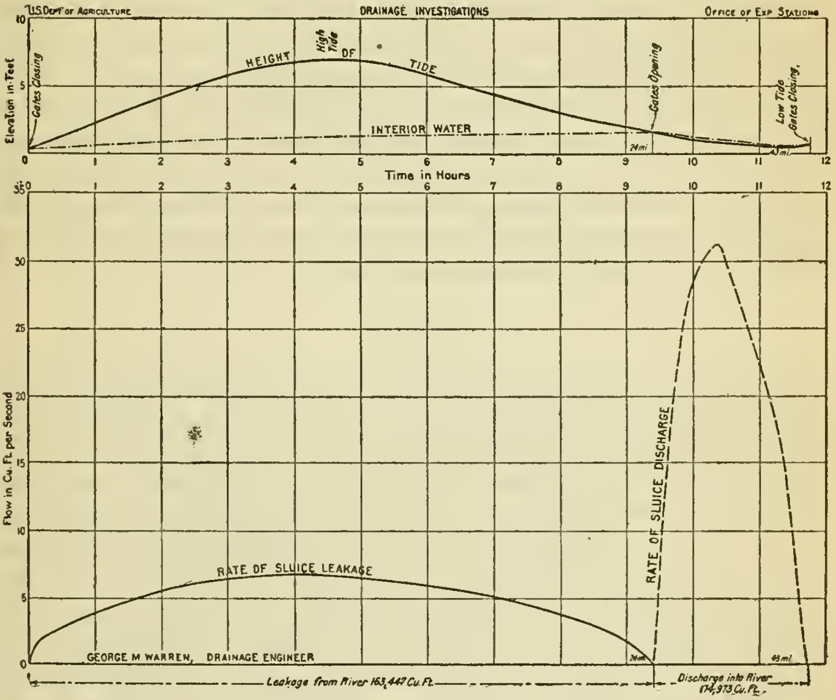

FIG. 8.—Diagram showing rise and fall of tide and ditch water and sluice leakage and discharge, Colburn estate, Delaware City, Del.

Determinations were made of the value of coefficient c in the following formula for sluice discharge:

$$q=ca\sqrt{2gh}, \text{ in which}$$

q=quantity in second-feet
c=coefficient of discharge
a=area of cross section of flow in square feet
h=head in feet
g=acceleration of gravity=32.16

The results show that for unweighted, wooden, flap gates in complete submergence, or where the emergence does not exceed about 15 per cent of the vertical height of the gate, this coefficient has a value of 0.64. As the tide recedes further, the submergence and buoyancy of the gates are diminished; gradually approaching the seating position, successive inclinations and the dead weight of the gates become constantly increasing factors in the retardation of the flow. (See Pl. IX, fig. 2, p. 50.) In consequence, the coefficient of discharge lessens rapidly and near low tide averaged about 0.46.

The coefficients for very small heads are not well determined. The difficulties of making precise gaugings of head in tidal waters and of securing simultaneous velocity measurements are obvious. Any error, however slight, during the first or last minutes of play, affects the coefficient beyond all proportion to the real size or importance of the error. From 30 to 50 seconds are absolutely necessary for a satisfactory current-meter measurement; and this interval of time is sufficient to change the head a full hundredth of a foot or more. The average head under which the sluice discharged, from the beginning to the end of play, was found from observations and deductions to be very close to two-thirds of the maximum head.

DITCHES.

The drainage is secured by about 11.4 miles of open ditches, varying in width from 3 to 24 feet, and in depth from 6 inches to 4 feet. The width averages about 12 feet and the ditch area is about 5.3 per cent of the area of the marsh land. They are badly silted and choked with rank growths of cattails and other weeds, so that effective drainage, with two or three exceptions, is prevented. Indeed, in this condition and with the large sluice leakage which exists, the very object for which the ditches were intended is defeated. For during each tidal cycle the leakage has 9½ to 10 hours in which to work its way back into the choked ditches; the subsequent period of sluice discharge, about 2½ hours, is much too short to remove more than a very small percentage of this water. It is, therefore, and its appearance is confirmation, virtually a stagnant water. To establish the truth of these assertions gaugings were made to the water surface in certain clear ditches, and in others not free. It was found that in a clear ditch (Pl. II, fig. 2), at a point 3,600 feet from the sluice, a movement was observable in 10 minutes after the gates began to open; in 12 minutes the flow was pronounced; in 30 minutes the mean velocity had risen to 15 feet per minute; in 60 minutes the maximum mean velocity of 21.6 feet per minute had been reached; for 3 hours the velocity averaged about 15 feet per minute; and the water surface fell 1.12 feet while the gates were open.

At a point 300 feet from the one just referred to, but in a choked ditch the fall was less than one-quarter of an inch, notwithstanding and at a point 750 feet farther from the sluice up the obstructed ditch the fall was less than one-quarter of an inch, notwithstanding the period of sluice play, 3 hours, was considerably longer than the average. The water which started toward the sluice 10 minutes after the gates opened did not cover the distance of 3,600 feet during the period of play. About 2 hours and 15 minutes were consumed in covering the 2,050 feet of lateral ditch; the remaining 35 minutes of sluice action was much too short, and the flow too feeble to cover the 1,550 feet of main ditch.

The trampling of cattle and the small box-culvert bridges have, in certain instances, forced the drainage through long, circuitous routes, and have even dammed it altogether. Near the northerly end of the lands is an area of pasturage and grassland containing over 40 acres, where the ditch water is permanently held at about elevation 1.7. The large sluice leakage taxes the storage capacity of the ditches to the utmost. With the interior water rising twice a day to elevation 1.6, it is clear that any additional leakage or rainfall, except such small quantity as might fall, be collected, and discharged during the short interval when the sluice is in action, will go largely to flood the areas of three-square sedge, from which its principal escape is by evaporation, or as taken up by vegetation. The total holding capacity of these ditches, between elevations 0 and 1.6, is about 178,000 cubic feet. With the sluice leakage averaging 163,447 cubic feet, and seepage and percolation amounting to 4,900 cubic feet between operations of the sluice, it is obvious that any additional leakage or collected rainfall in excess of 9,643 cubic feet will be forced outside the ditches and over the low areas.

If we should assume that 21 per cent of the precipitation constituted the run-off, which would seem to be fair, in view of the known gravitational space of the soil, the character of the drainage area, and the position of the ground water, it is seen that this reserve storage capacity of 9,643 cubic feet would be obliterated after 37 minutes of a rainfall amounting to 1 inch in 24 hours. These figures illustrate the utterly inadequate storage capacity and the futility under present conditions of preventing a concentration of storm water in the "saucer" shaped low areas.

RAINFALL AND GROUND WATER.

A study of the rainfall records, kept at Delaware City since July 1, 1902, shows that for a period of 86 consecutive months to September 1, 1909, there were 81 days when the precipitation exceeded 1 inch in 24 hours, 9 when it exceeded 2 inches, 4 when it exceeded 3 inches, and 2 when it exceeded 4 inches. Both of the rainfalls exceeding 4 inches came in September, a season of the year when not likely to harm crops and when the water table is usually approaching its lowest stage. The annual rainfall of about 44 inches is well distributed. The monthly average of 3.7 inches will, in the long run, be surpassed during the months of June, July, August, and September. The year 1909, from January to September, was one of the driest for many years. The rainfall during the summer and its effect on the ground water are shown by the following table:

Rainfall and elevations of ground water at six points shown on the plan (fig. 3).

Date.	Rainfall.	A.	B.	C.	D.	E.	F.
1909:		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
June 18	11 showers in June totaled 3.51 inches, the last falling on the 28th.			2.21			
June 28			1.62				
June 29		1.61					
July 10					2.09	2.65	
July 12					2.09	2.65	2.70
July 14			.43		1.93	2.57	2.63
July 15			.44		1.96	2.55	2.65
July 16		.94	.41			2.53	
July 17		.84	.32				
July 18		.75					
July 20		.23					
July 23	0.62 inch						
Aug. 12		—.40					
Aug. 16 and 17	1.05 inches						
Aug. 18		1.73	.47				
Aug. 21		.81		—.15	1.12	1.73	1.65
Sept. 2			—.11				
Sept. 7		—.73	—.22	—.44	.87	1.25	1.02

The conclusions to be drawn from this table and from other measurements made are: (1) The water table is practically unaffected by the fluctuations of the tide during a single day. (2) The wet conditions of spring will raise the ground water to between elevations 1.6 and 2.2 over the greater part of the marsh and about a foot higher in the upland a half mile from the river. (3) The large fluctuation in the water table at A was caused by overflow of the ditches and concentration of water which fell elsewhere in the low areas. (4) The low head on the ground water proves the upland drainage to be slow in motion and small in amount. (5) In summers of very small rainfall capillarity and evaporation may lower the water table considerably below mean low water, against the combined percolation and seepage from land, river, and ditches.

ANTHRAX.

This virulent and fatal disease has cost the farmers along the Delaware River large numbers of cattle. It is generally supposed to have first been communicated in this locality through the wastes from the morocco factories of Wilmington and Philadelphia.[1] The

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[1] U. S. Dept. Agr., Farmers' Bul. 439, "Anthrax," pp. 7, 16.

danger of outbreak among cattle which graze upon embanked lands is much less than among those which frequent unreclaimed marshes. So far as known there has never been a case of anthrax on the Colburn farms.

CROPS.

The staple crops on the Colburn lands are wheat, corn, and hay. Oats, rye, potatoes, and garden truck have been raised to some extent. Ordinary and actual yields upon fields of different elevations are shown in the following table:

Crops and yield in different years upon fields of various elevations.

Crop.	Elevation of land above M. L. W. *Feet.*	Yield per acre.	Remarks.
Wheat	4 or more	21 bushels	Actual yield, year 1909, slightly less than ordinary yield.
Do	3 to 4	15 bushels	Do.
Do	4	37 bushels	Unusually favorable climatic conditions, year 1897, estimated.
Corn	3.5 or more	50 bushels	Ordinary average yield.
Do	2.5 to 3.5	25 bushels	Do.
Do	2.7 to 4.0	21.5 bushels	Actual yield, year 1908.
Hay—timothy and clover	3 to 4	1½ tons	Ordinary average crop.
Hay—red top, white clover, bent grass.	2 to 3	1½ tons	Do.
Oats	10	44 bushels	Actual yield, year 1909.
Do	3.5	31 bushels	Do.

Below the elevations at which the above crops were raised were found pasturage at elevations from 2 to 3 feet, and three-square sedge grows from 1.3 to 2 feet.

Rye, potatoes, and tomatoes of fine quality have been raised on land 2.4 feet above mean low water.

Phosphate is generally applied to the wheat fields at the rate of 200 pounds per acre, but none of the marsh receives any artificial fertilization, as fertilizers are said to produce a rank growth of crops which fail to mature properly.

The live stock is turned on to the pasture about April 15 and gets little or no other feed until November 1. It is said that cattle derive considerable benefit in the spring from the three-square sedge, which at that season is young and tender, and that cows which graze upon marsh lands yield milk of superior quality.

FINANCIAL.

Using the assessed valuations, believed to be fair market values, as a basis, it is estimated that the value of the land comprised within the drainage area of the Colburn lands is as follows.

Value of land in the Colburn area.

Upland, 179 acres, at $45 per acre	$8,055
High marsh, 256 acres, at $30 per acre	7,680
Low marsh, 53 acres, at $20 per acre	1,060
Total	16,795

Foreshore lands are assessed at $1 per acre.

Through the kindness of Mr. William J. Beck, manager of these farms for the Colburn estate, it is possible to present the following table of the actual cash receipts. It does not include a probable income of $300 or $400 per year realized by the tenants from poultry and hogs.

Actual cash receipts, exclusive of those obtained from poultry and hogs, from the Colburn area.

Year.	Milk.	Wheat.	Corn.	Hay.	Tomatoes.	Miscellaneous.	Total cash receipts.
1898	$2,010.80	$1,544.86	$243.56	$76.80	$261.56	$55.50	$4,193.08
1899	2,608.06	1,138.36	370.82	183.74	699.52	113.40	5,113.90
1900	3,373.52	1,682.32	419.02	448.30	321.98	21.00	6,266.14
1901	3,418.30	1,431.54	649.72	387.00	227.04	....	6,113.60
1908	3,143.74	1,000.04	142.36	168.80	160.92	22.78	4,638.64
1909	(1)	1,728.50	(1)	(1)	(1)	(1)	....
Average	2,910.88	1,420.94	365.10	252.93	334.20	42.54	5,265.07

[1] Returns not obtainable at the time survey was made.

The following is submitted as probably a fair estimate of the yearly balance:

RECEIPTS.

Average for 1898, 1899, 1900, 1901, 1908	$5,265.07

EXPENDITURES.

Interest on invested capital, $35,877, at 5 per cent	$1,793.85
Taxes, $20 per thousand, on $23,580	471.60
Insurance	50.00
Wages	1,650.00
Supplies	250.00
Repairs to buildings and fences	225.00
Maintenance of embankment and ditches	250.00
Depreciation	50.00
Total	4,740.45
Surplus	524.62

The invested capital is estimated as follows:

Original cost of land	$2,000.00
Cost of reclamation	16,552.00
Cost of buildings	10,000.00
Cattle, 110 head at $25 per head	2,750.00
Horses, 21 head at $75 per head	1,575.00
Machinery and tools	3,000.00
Total	35,877.00

ESTIMATED COST.

The estimated cost of reclaiming the Colburn marshes is as follows:

River embankment, 7,216 lineal feet, at $1 per foot	$7,216.00
Return bank, 1,940 linear feet, at 50 cents per foot	970.00
Stone facing (in place), 725 cubic yards, at $2.10 per yard	1,522.50
Ditches, earth excavation, 64,440 cubic yards, at 8 cents per yard	5,155.20
Sluice (complete)	900.00
Allow for contingencies, 5 per cent	788.19
Total	16,551.89

This estimate is based on prices prevailing at the time the work was done. Labor then was $1 to $1.10 per day of 10 hours, and stone could be landed in barges near the embankment for $1.25 per perch. At the present time labor is $1.50 for 9 hours, and stone costs $1.75 per perch on the barge.

SUMMARY.

The following is a summary of the information obtained by the investigation and the conclusions arrived at:

(1) The top of the levee, 9 to 11 feet above mean low water, is below the storm tide of October, 1878, and has been reached in more recent years. It is unsafe. Its estimated cost, including sluice, is about $6,900 per mile.

(2) The area of sluice opening is 12.11 square feet, or 1 square foot to each 40 acres of drainage area. This is insufficient to properly drain the land at times of heavy rainfall or adverse winds. The maximum observed discharge was 34.18 second-feet and the corresponding head 0.30 of a foot. The average observed discharge was 18.61 second-feet. Sluice leakage amounts to 97 per cent of all the water discharged. The coefficient of discharge of sluices with unweighted flap gates in complete submergence is 0.64.

(3) The ditches for the most part are so silted and choked that adequate storage capacity and proper drainage of the land are prevented. The ditch water (see Pl. II, fig. 1) rises twice daily to elevation 1.6, and in many ditches is virtually held near that elevation. In the best ditch (see Pl. II, fig. 2) the hydraulic gradient rises to about 7 inches per mile, which is fully double what good engineering practice would recommend for drainage ditches in tidal marshes.

(4) The soil will produce good yields of wheat, oats, rye, potatoes, and tomatoes, but the uncertainty of crops on the lower areas has led to their more extensive use for grass and pasturage.

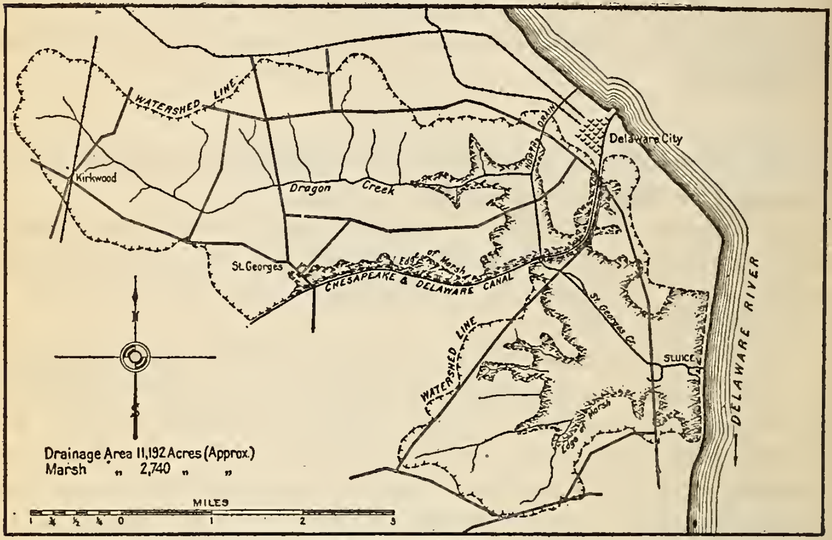
(5) The reclamation of the marsh has cost about $54 per acre; based on the whole drainage area the cost is about $34 per acre. A fair return on the investment is being obtained.

MARSH LANDS ON ST. GEORGES CREEK, NEWCASTLE COUNTY, DEL.

HISTORY AND DESCRIPTION.

These lands comprise an area of about 17.5 square miles, drained by St. Georges Creek, Newcastle County, Del. The charter of the St. Georges Marsh Co. is dated 1762, and it is probable that the first attempts at diking were begun about that date. Except for short intervals, the marshes have been exempt from tidal overflow for upwards of 148 years. During the record-breaking storm of October, 1878, the levee was breached, and for a period of about 6 months the interior marsh was inundated. The deposit of new soil in that short time is said to have had a most beneficial effect upon crops.

The lands (figs. 9 and 10) have a frontage on the Delaware River of about 1½ miles and extend westerly about 8 miles. St. Georges Creek and watershed are crossed by the Delaware and Chesapeake Canal, the waters of which are about 7.66 feet above mean low water in Delaware River; the creek is conveyed by culvert beneath the canal. It is stated that no less than seven different sluices have been built since the organization of the company. When found to be too small or in poor repair it has been deemed the less expensive to abandon them and build anew.



U.S. Dept. of Agriculture. Drainage Investigations. Office of Experiment Stations

Fig. 10.—Map of drainage area tributary to St. Georges sluice, Delaware City, Del.

Some years ago a pumping plant was installed near the present sluice at an expense of about $10,000. This project ended in failure, but whether because of the volume of water to be handled, the expense of operation, or the subsidence of the meadows, or a combination of the three is not now certain. The drainage area tributary to

FIG. 1.—ROCK-FACING FOR PROTECTION OF LEVEE AND FORESHORE AT HALF-TIDE LEVEL, ST. GEORGES MARSH CO., NEW CASTLE COUNTY, DEL., NOVEMBER 1, 1909.

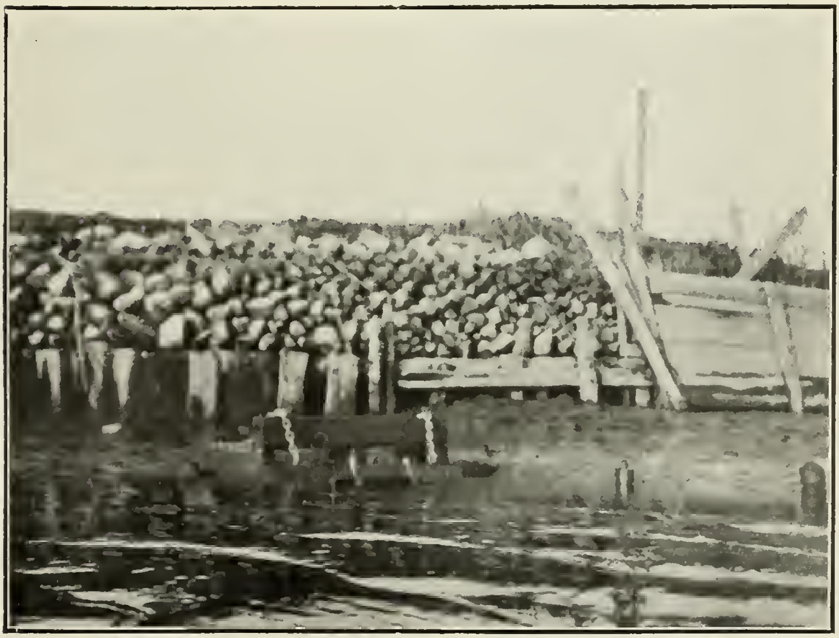


FIG. 2.—METHODS OF LEVEE PROTECTION AND SLUICE 4 AT LOW TIDE IN MAURICE RIVER, DORCHESTER, N. J., NOVEMBER 12, 1909.

[Cord-wood protection is on lands of Alfred H. Lupton; plank bulkhead is on lands of Richard Camp.]

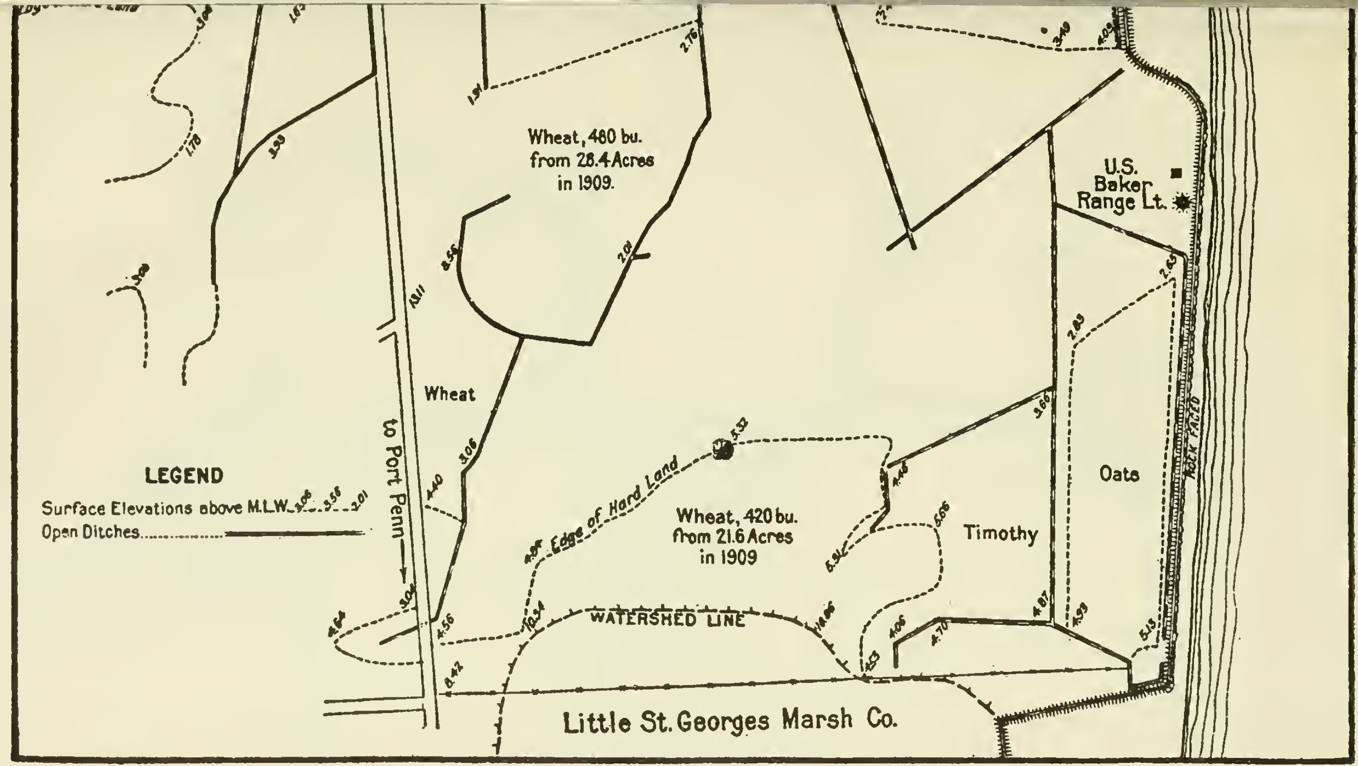


Fig. 9.—Map of portion of St. Georges Marsh Co's. land, Delaware City, Del.

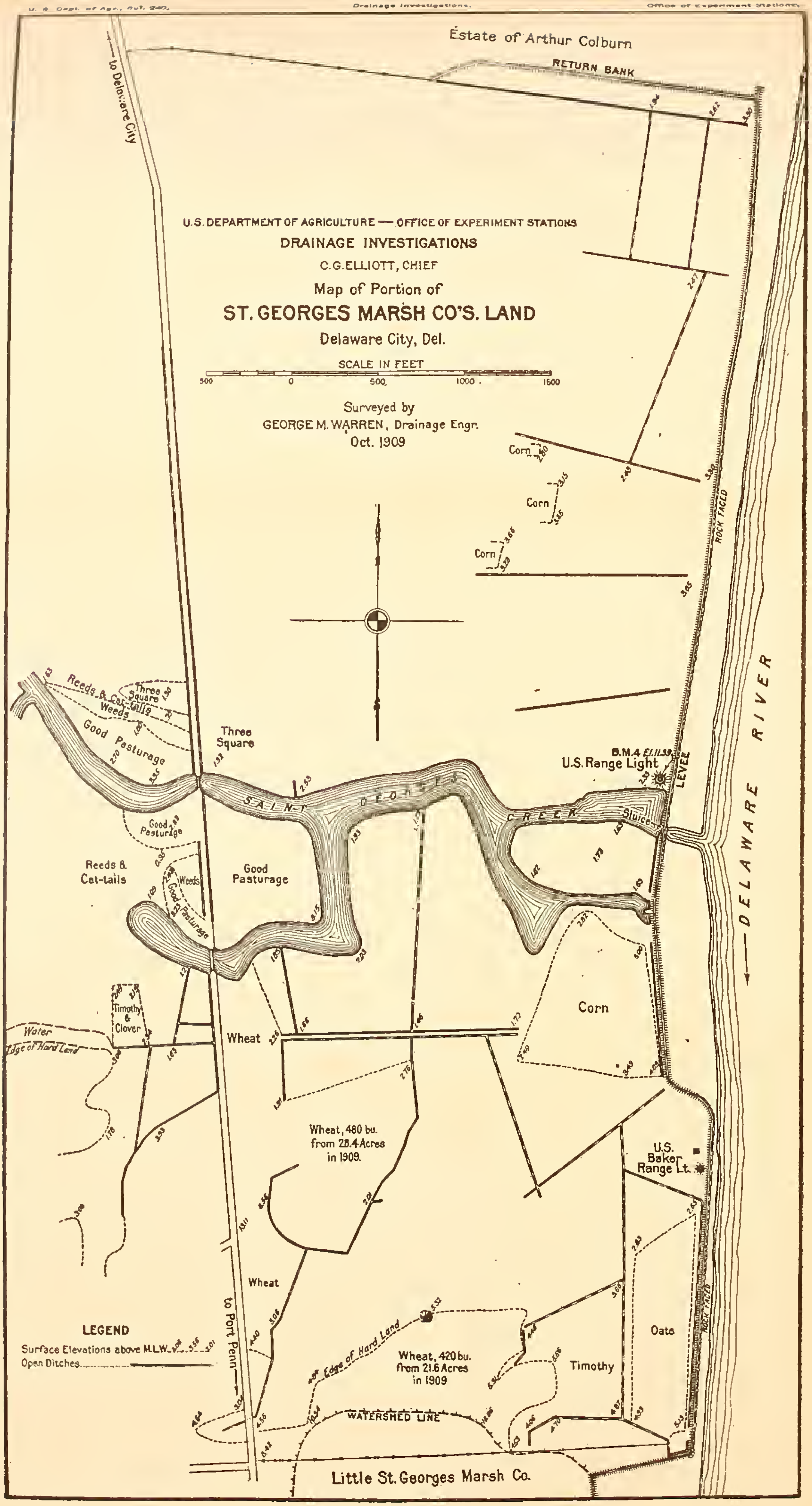


Fig. 9.—Map of portion of St. Georges Marsh Co's. land, Delaware City. Del.

the St. Georges sluice contains 11,192 acres, of which about 2,700 or 2,800 acres constitute the marsh proper.

The foreshore averages about 150 feet in width and has generally been built up by tidal deposit close to ordinary high-water mark. The interior lands show a wide diversity of elevation and vegetation. Immediately within the levee the marsh generally varies from 3 to 4 feet above mean low water, but near the creek drops to 2 feet or less, and near the southerly boundary rises to 5 feet.

Going westerly from the river the land becomes lower, and beyond the Delaware City-Port Penn Road stretch many hundred acres of marsh 0.75 to 1 foot above datum, covered with a rank growth of reeds and cat-tails and incapable, except when frozen over, of sustaining the weight of a man. Soundings have been made in this marsh to a depth of 40 feet without touching firm bottom. To the north of the Chesapeake & Delaware Canal are a number of thousand acres drained by Dragon Creek. A considerable portion of this drainage was formerly conveyed by the north drain, so called, to the Delaware River, but the breaching of the levee at that point and the abandonment of the north sluice have forced this flow to seek an outlet through the St. Georges sluice. The uplands rise to heights of 60 to 80 feet above mean low water.

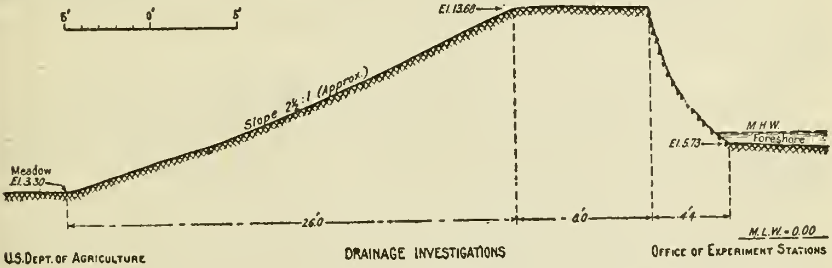


FIG. 11.—Cross section of levee, St. Georges Marsh Co., Delaware City, Del.

LEVEE.

The river levee is about 8,125 feet in length, of which 6,400 feet are rock faced. A cross section is shown in figure 11. The top is about 8 feet wide and from 10 to 14 feet above mean low water or 4 to 8 feet above ordinary high water. The slope on the land side is about 2½ to 1 and has a firm, well-rooted sod. The top is covered with pokeberry and other weeds. The rock facing (see Pl. III, fig. 1) rises by a curved batter to a height of 8 feet in a horizontal distance of 4.4 feet. It is 3½ feet thick at the base and 1 foot at the top, and has no foundation other than the natural surface of the marsh. It is in good repair.

SLUICE.

The sluice is about 42 feet long and 36 feet wide. It is divided into six flumes each about 2½ feet high and 5½ feet wide; the aggregate area of sluice opening is 80.41 square feet. The floor at the land end on the northerly side is 2.30 feet and on the southerly side 2.49 feet below datum, which would place the crown of the sluice practically at mean low water. Men who assisted in its construction state that the floor as built was at mean low water; its settlement, therefore, has been about 2½ feet. The top and bottom are 2-inch unmatched plank; the sides are 6 inches thick. The foundation is stated to be 1-inch sheeting cut in 5-foot lengths driven along both sides and ends and forming, with a 6-inch by 6-inch mudsill, a complete rectangle. The gates are made of 2½-inch unmatched plank.

Two-inch by six-inch cleats about 1 foot from either end of the gate are fastened with three-sixteenth-inch carriage bolts, and three bolts passing through gate and cleat secure the strap hinges, which are three-fourths inch thick, 2½ inches wide, and about 2 feet 10 inches long. This sluice is said to have been built in 1879 at a cost of $3,000.

Only one complete determination of the discharge of the sluice was made. On October 8, 1909, at 12.05 p. m., the interior water stood at elevation 1.37; the sluice began to play and continued for 1 hour 28 minutes, during which time 439,560 cubic feet were discharged. The interior water lowered but 0.03 of a foot, though the tide fell from elevation 1.37 to 1.05 during the period; had the tide fallen to ordinary low-water stage, the sluice would have played fully twice as long a time. The maximum head was 0.23 of a foot; the maximum and average rates of discharge were 123.4 and 83.25 second-feet, respectively. The coefficient of discharge averaged 0.39.

The leakage was measured for a period of 2 hours 12 minutes following the closing of the gates, and in that time amounted to the enormous quantity of 356,400 cubic feet, or at the average rate of 45 second-feet. It is highly improbable that the average rate would have been less than 45 second-feet had measurements been continued over the full period of say 9 hours. Upon that assumption the leakage between successive operations of the sluice is seen to be the enormous quantity of 1,458,000 cubic feet or more. The northerly gate was in very bad repair and admitted about 36 per cent of the total sluice leakage; the next gate southerly admitted 14 per cent; the next, 14 per cent; the next, 11 per cent; the next, 8 per cent; and the southerly gate about 17 per cent.

With these conditions of sluice leakage, therefore, is it to be wondered that the farmers are discouraged at the agricultural and financial showing of the St. Georges marshes? One can but admire the persistency of the men who in the face of adverse circumstances and meager returns have kept these works intact for nearly a century and a half.

DITCHES.

The main creek as far as examined has ample width and depth, the bottom generally being from 5 to 6 feet below mean low water.

The ditches are filled with cat-tails and other growths and are practically abandoned.

CROPS.

Very little of value is grown upon land which is below an elevation of 3 feet. Near the southeasterly corner of the marsh a 9-acre field, averaging about 4 feet above mean low water and planted to oats, failed entirely. Just westerly was a field having an average elevation of about 4.5 feet which yielded, it was stated, 2 tons of timothy to the acre.

A wheat field containing 21.6 acres yielded 420 bushels, an average of nearly 19½ bushels per acre; this field was the beginning of the uplands and ranged from 4.5 to 11 feet above datum.

Another containing 28.4 acres near the Port Penn Road, ranging from 2 to 13 feet above datum, but the average elevation of which was lower than the first wheat field, yielded 480 bushels, or at the rate of 16.9 bushels per acre. Corn planted on land 2.5 to 3.5 feet above mean low water did not make a satisfactory showing; in places it was fair and at other locations in the same field was almost entirely lacking.

Certain lands situated 2 to 3 feet above datum showed excellent pasturage. Between elevations 1.5 and 2 there was a varied growth of weeds and tall, wiry marsh grass. At elevation 1.3 were many acres of three-square sedge, while below elevation 1 there was a rank growth of worthless reeds and cat-tails.

FINANCIAL.

The amount of money which has been expended upon the St. Georges reclamation since its inception can never be determined. It is a large sum. An examination of the treasurer's books shows that the company expended the sum of $83,409.13 for construction and maintenance of levee and sluices between January 1, 1870, and January 21, 1909. For many years the county of New Castle, in consideration of the protection afforded to several miles of highway, has contributed, on an average, about $400 per year toward the maintenance of the levee and sluice, while the company's assessment on the marsh owners has yielded, on the average for the last 10 years, about

$1,000 per year. A disinterested board of commissioners, elected by the stockholders at the annual meeting, fix all valuations and assessments. Assessments become a lien on the marsh land and on the hay, stock, or other personal property upon it.

The cat-tail marshes have a nominal value of $1 per acre. It is probable that the levee, facing, and sluice would to-day cost about $22,000. Including sluice, this is about $14,300 per mile.

SUMMARY.

(1) That there has been a considerable but unknown amount of subsidence in the surface of the marsh is highly probable. Many hundred acres now covered with reeds and cat-tails can not be drained by gravity. The only hope lies in drainage by pumping or in raising the land by hydraulic dredging or by the slower process of natural deposit by the tide.

(2) Large areas adjacent to the uplands can be greatly improved, either for pasturage or dry-land crops, by checking the extraordinary sluice leakage and cleaning and deepening the ditches.

(3) The clear opening of sluice is 80.41 square feet, or 1 square foot to each 139 acres of drainage area. This size is insufficient.

MARSH LANDS NEAR DORCHESTER, CUMBERLAND COUNTY, N. J.

HISTORY AND DESCRIPTION.

These lands are situated on the east side of the Maurice River about 1 mile north of Dorchester, Maurice River Township, Cumberland County, N. J. (See fig. 12.)

The reclaimed marsh comprises 176.5 acres owned by seven different parties. It was first embanked in 1808, but has been out to tide at intervals for many years. Its condition as late as the summer of 1903 is shown in Plate IV, figure 1.

The present levee was built in part by dredge in 1903, and the highway forming the northern boundary of the tract was built the same year. (See Pl. IV, fig. 2.) The transformation which has been wrought by this reclamation is well depicted by the series of views shown in Plates IV, V, VI, and VII, figure 1. The contributing drainage area contains about 2,180 acres, has a frontage on the river of 1.2 miles, and extends easterly therefrom about 2½ miles. Only about 176.5 acres near the river have been put to agricultural purposes; the remaining area consists largely of woodland, varying from wet and swampy at elevation 3 to hills having summits upwards of 50 feet above mean low water.

The drainage from 2,014 acres is collected by Beaver Brook, which, running by tortuous course, is discharged by sluice 2 into the river.

FIG. 1.—AT ORDINARY HIGH TIDE (TWICE DAILY) JULY, 1903.

[Note the lean of the telegraph poles along the old marsh road.]

FIG. 2.—DURING NEW CONSTRUCTION WORK, DECEMBER, 1903.

[Note the wave or roll of marsh soil along the right toe of embankment and the lean of telegraph poles on the left.]

VIEWS FROM MAURICETOWN BRIDGE, EASTERLY ALONG HIGHWAY, DORCHESTER, N. J. MARSH LAND OF ALFRED H. LUPTON IS IN THE FOREGROUND ON THE RIGHT; HOWARD COMPTON'S IN THE BACKGROUND.

FIG. 1.—PLOWING ON LAND 1.2 FEET ABOVE MEAN LOW TIDE IN MAURICE RIVER, NOVEMBER 12, 1909.

FIG. 2.—STRAWBERRY FIELD 2.2 FEET ABOVE MEAN LOW TIDE IN MAURICE RIVER, NOVEMBER 2, 1909.

MARSH LANDS OF ALFRED H. LUPTON, DORCHESTER, N. J.

FIG. 1.—DITCH SYSTEM AND PROTECTED FIELDS AND WOODLAND, NOVEMBER 2, 1909.

FIG. 2.—STACKING CORN SHOCKS FOR WINTER FEEDING, NOVEMBER 12, 1909.

MARSH LANDS OF HOWARD COMPTON, DORCHESTER, N. J.

FIG. 1.—CORN FIELDS AND 58-BUSHEL LOAD OF CORN GROWN ON LAND 2 FEET ABOVE MEAN LOW TIDE IN MAURICE RIVER, NOVEMBER 13, 1909.

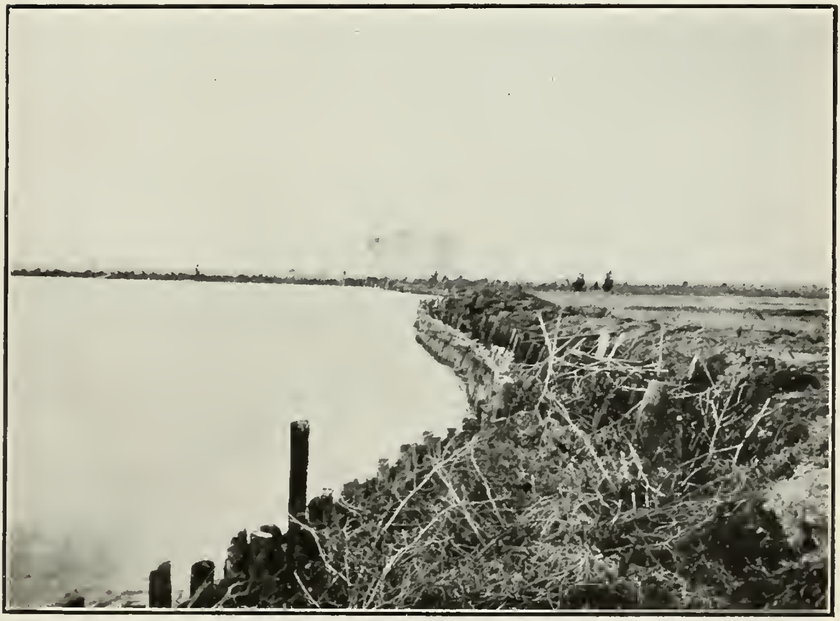
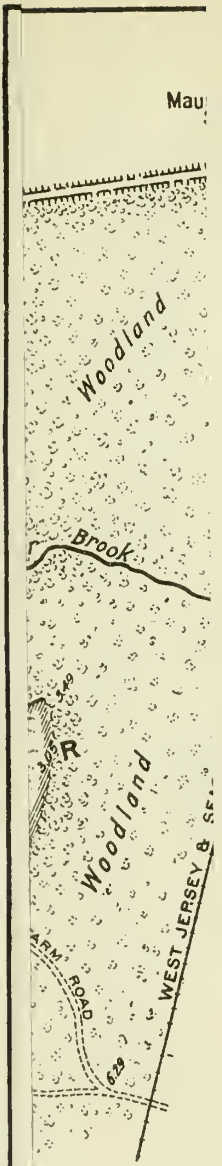


FIG. 2.—LEVEE AND PILE AND BRUSH PROTECTION, MAURICE RIVER, NOVEMBER 2, 1909.

MARSH LANDS OF HOWARD COMPTON, DORCHESTER, N. J.



, Lupton, and others.

Fig. 12.—Map of marsh lands near Dorchester, Cumberland County, N. J., owned by Howard Compton, Alfred H. Lupton, and others.

Forty-nine acres belonging to Howard Compton in the southeasterly part of the tract are generally 2 to 3 feet above datum.

Near the center of the marsh is a low return bank, extending from the river levee to the highway. To the westerly of this return bank is the 91-acre farm of Alfred H. Lupton, which varies from 1 to 3.5 feet above datum, and to the easterly are parcels of 12.4 acres, 12.1 acres, and 5.4 acres, owned by Richard Camp, Charles T. Grassman, and George Blisard, respectively.

The Camp tract is from 1.75 to 3 feet above datum, the Grassman from 1.5 to 1.9, and the Blisard from 1.5 to 2.

In the northeasterly corner of the marsh is a parcel of 4 acres belonging to D. W. Boggs and varying from 1.5 to 2 feet above datum. A triangular-shaped parcel of 2.4 acres near the southeasterly corner, belonging to Eliza West, is from 3 to 3.5 feet above datum.

The interior lands at the river levee are generally from 2.5 to 3.5 feet above datum. Going from the river the land falls about 1 foot in a distance of 600 feet, at which approximate distance the lowest area is usually found. This low marsh varies from elevation 1 foot or less on land of Lupton to 2.5 feet on the better parts of the Compton land, but probably averages about 1.7 feet above datum. From this low area the marsh rises gradually as we go northerly to the highway or easterly to the woodland.

TIDES.

There being no established bench marks in the vicinity of Dorchester which were known to be referred to mean low water, the height of the tide at 8.57 a. m., October 2, was arbitrarily chosen as such datum.

At that time it was the belief of those familiar with the Maurice River that an average low tide prevailed, and it was assumed as mean low water.

The mean range observed was 5.62 feet.

From the testimony of citizens it is probable that extreme high water is about elevation 7.62; the lowest tide observed was —1, on November 11.

The flood continued for about 6 hours 11 minutes and the ebb for 6 hours 19 minutes.

The vertical movement of the tides averaged about 0.9 of a foot per hour; at half tide it was about 1.1 feet per hour, and about 1½ hours before low and at the time when the sluices generally would begin to play it was about 0.7 of a foot per hour. The Maurice River at this point, about 11 miles by water from Delaware Bay, is only slightly brackish.

SOIL AND SUBSOIL.

The soil is a stiff, grayish, silty clay often mottled in appearance, and all tests with blue litmus paper showed more or less pronounced acid reaction. Tilled and with the humus incorporated in it, it has a very dark-brown color and possesses great fertility. This stratum of silty clay varies in thickness from a few inches near the woodland to probably as much as 10 or 12 feet at the levee.

Tests made in 1902 along the line of the highway leading to Mauricetown by Mr. D. W. Boggs, civil engineer, and at points indicated on the plan (see fig. 12, p. 34) show a firm, gritty bottom at depths of from 9 to 57 feet below the surface of the marsh. These soundings were made with small-sized wrought-iron pipes, and one or two men had no difficulty in pushing the pipe by hand to the depths shown on the plan. Mr. Boggs found that in general the stratification was as follows: For the first 10 or 12 feet, a grayish, silty clay through which the pipe went without any great difficulty; for the next 8 feet a very soft mud and slime through which the pipe would almost drop by reason of its own weight; for the next 6 feet a partially decomposed vegetable deposit offering a somewhat greater resistance to the pipe than the last-mentioned stratum. Continuing downward the 8-foot and 6-foot layers as just described were encountered in rotation to the firm bottom.

The inability of this marsh soil to sustain any considerable load is well illustrated by the happenings during and subsequent to the time of construction of the new highway.

In a total distance of about 5,100 feet the estimated quantity of sand filling required for this highway was about 42,000 cubic yards. The quantity actually taken from the borrow pits and placed in this embankment to bring it to the established grade was 139,125 cubic yards. Ninety-seven thousand one hundred and twenty-five cubic yards, therefore, represented the compression and displacement of the marsh soil beneath the base of the roadway up to the time of the completion of the construction work in 1903. Since that time a further settlement equivalent to 10,000 cubic yards has taken place, so that at present, of the 139,125 cubic yards of sand deposited, 107,125 cubic yards are below the surface of the marsh and only 32,000 cubic yards are above.

This large settlement and displacement has taken place over a strip of marsh approximately 5,100 feet long and 51 feet wide, and where the anticipated load was not over 1,100 pounds per square foot.

Plate IV, figure 2, shows how, under the weight of the embankment and construction trains, a wave or roll of marsh soil 7 to 8 feet in height was created along each toe, and how the bottoms of the tele-

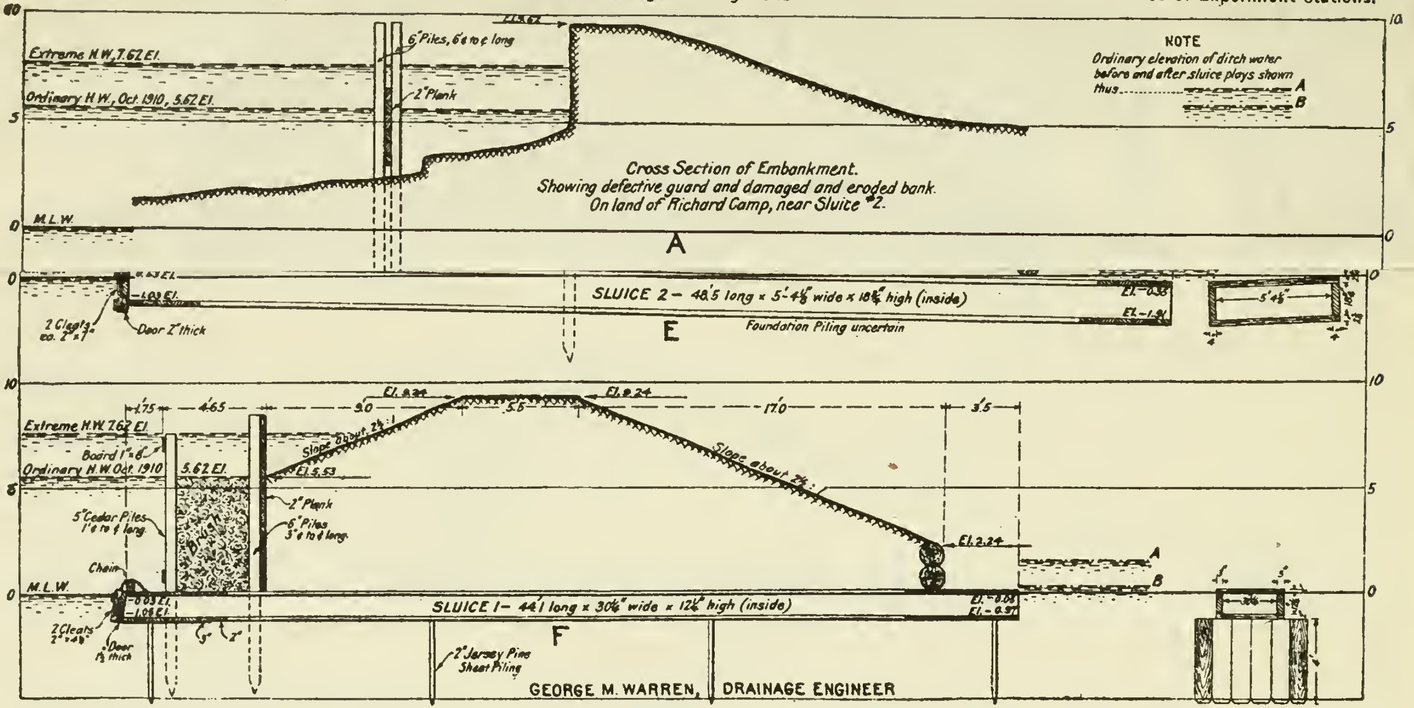


Fig. 13.—Sections of levee and sluices between Dorchester and Mauricetown, Maurice River township, Cumberland County, N. J.

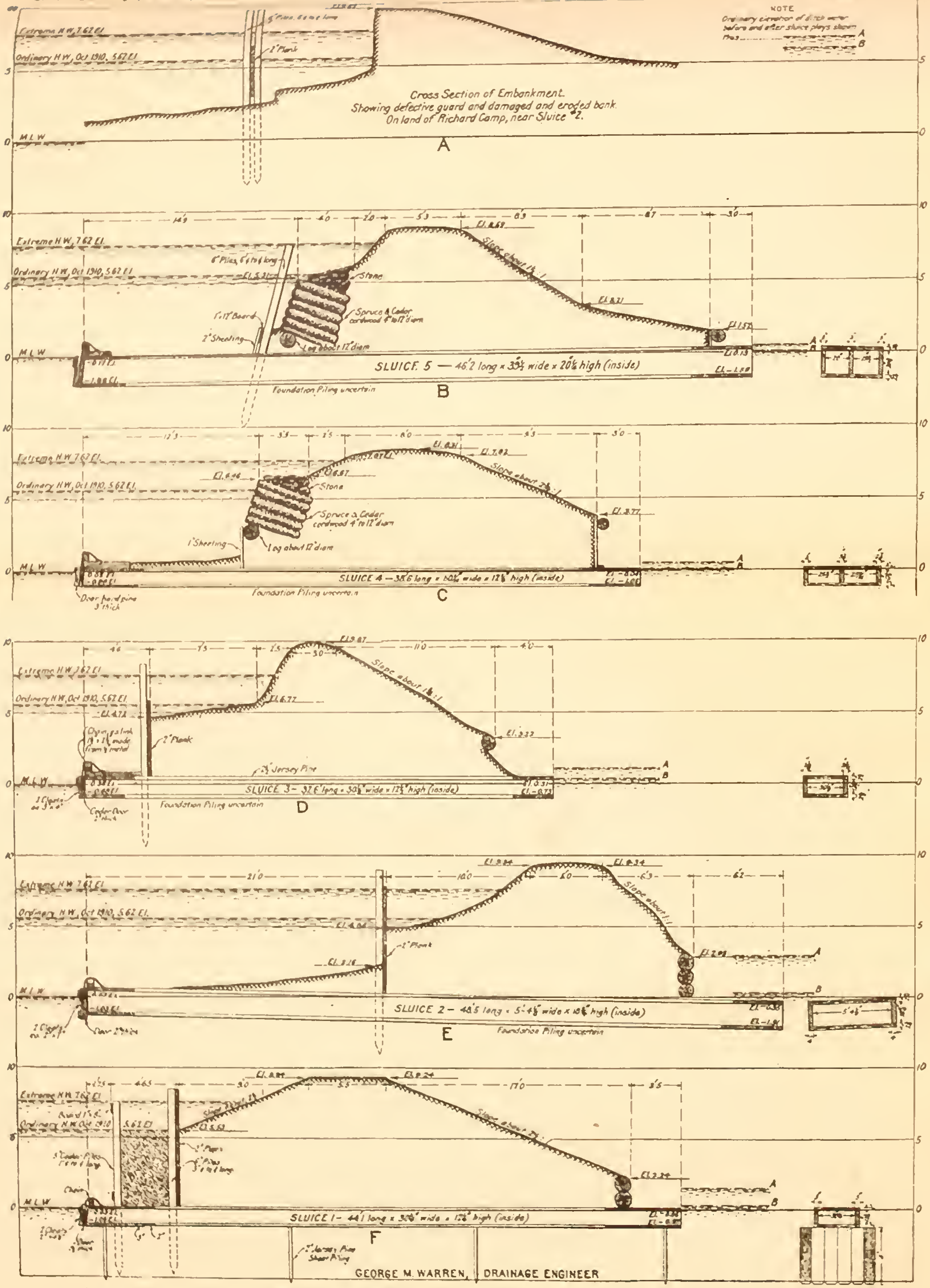


Fig. 15.—Sections of levee and sluices between Dorchester and Mauricetown, Maurice River township, Cumberland County, N. J.

graph poles were pushed away from the fill. It is said that on one occasion the embankment and construction cars settled 7 feet in a single night, and that piles 72 feet in length were driven to support the West Jersey & Seashore Railroad track over Beaver Brook. A water-bearing sand shows in the bottom of the ditch along the edge of the woodland near the southeasterly corner of the Compton marsh.

LEVEE.

Six cross sections of the river levee are shown in figure 13, A, B, C, D, E, and F. There is no foreshore, as may be seen from Plate VII, figure 2.

The top width of the levee averages about 5.5 feet and its elevation from 8 to 9.5 feet above datum.

The slopes and the methods of shore protection vary greatly. On the Compton land both slopes are about 2½ to 1, and protection (see Pl. VII, fig. 2) on the river side is afforded by a double line of 5-inch to 6-inch piles, the intervening space, about 18 inches, being filled with brush; to the inside face of the inner row of piles is spiked a 2-inch plank bulkhead up to above extreme high water. Levee and protection are in a fair state of repair.

On the Camp land both levee and protection (see Pl. III, fig. 2 and fig. 13A) are in bad condition. The guard has been riddled by the waves, which work under, through, and over it, and are rapidly washing away the levee. The slopes are steep and irregular and covered with pokeberry and other weeds.

At times considerable seepage was noticed through the levee between sluices 2 and 3 and contiguous to the only area of three-square sedge on the marsh.

On the Lupton land both levee and protection (see Pl. III, fig. 2) are in fair condition. Erosion by the river is prevented by a 3½ to 4 foot pile of cordwood, laid butt ends to the river and weighted with stone; the outer face, battering about 4½ inches to the foot, is supported by a 12-inch longitudinal log or mudsill. On portions of the levee there is a fair stand of grass.

It is stated by old bankmen that the brush facing makes a good protection; that because of its yielding nature it breaks up waves and swells and escapes injury better than a more solid bulkhead, and has the added advantage of being easily and cheaply repaired.

SLUICES.

Five sluices vent the interior waters. The size, length, grade, and tributary drainage area of these sluices are shown in the following table:

Size, length, grade, and tributary drainage area of sluices at Dorchester, N. J.

Sluice.	Clear opening.	Length.	Elevation river end.		Elevation land end.		Tributary drainage area.
			Crown.	Floor.	Crown.	Floor.	
	Sq.ft.	*Feet.*	*Foot.*	*Feet.*	*Foot.*	*Feet.*	*Acres.*
1	2.57	41.4	−0.03	−1.05	0.05	−0.97	46.8
2	8.33	48.5	.53	−1.03	−.35	−1.91	2,014.0
3	2.61	32.6	.36	− .68	.31	− .73	28.0
4	4.29	38.6	.05	− .96	−.04	−1.05	91.2
5	5.56	46.2	− .17	−1.86	.13	−1.56	....

The foundation of sluice 1 consists of 4 lines of Jersey-pine sheet piling 4 feet long and 2 inches thick approximately trisecting the length of the sluice. (See fig. 13F.) The foundations of the other sluices are believed to be similar.

Generally the sides are 3-inch hard pine and top and bottom 2-inch unmatched Jersey pine spiked to the side pieces.

The gates vary from 1½ to 3 inches in thickness of single unmatched plank and are held in place by two ½-inch chains, playing over wooden blocking 6 inches to 14 inches in height, set up on the roof of the sluice at its extreme outer end. (See Pl. III, fig. 2.) The chains are fastened to the top edge of the gate and to the roof of the sluice by one-half-inch iron staples 6 inches in length. It is stated that gates hung in this manner are not so liable to become obstructed as are some other styles on account of the wide opening along the upper edge when the sluice is in operation.

Sluice 2 is the only one which is badly out of level, the land end being about 10½ inches lower than the river end, and laterally the easterly side is about 3 inches lower than the westerly. None of the sluices are doing the work they should. The gates, to insure closing, are heavily weighted, which gives low coefficients of discharge, and their poor mechanical construction is responsible for large leakage from the river. The average head under which they operated was found to be about two-thirds of the maximum head.

The table following shows the average length of time sluices play, average discharge to river and coefficient of discharge, leakage from river, and leakage divided by discharge, expressed in percentages.

FIG. 1.—MAIN DITCH LEADING TO SLUICE 1, MARSH LANDS OF HOWARD COMPTON, DORCHESTER, N. J., NOVEMBER 2, 1909.

FIG. 2.—CLEARING AND BURNING BRUSH AND STUMPS IN CEDAR SWAMP, MARSH LANDS OF THE MAURICETOWN BANKING CO., MAURICETOWN, N. J., DECEMBER 18, 1909.

Leakage and discharge from sluices.

Number of sluice.	Average length of time sluice plays.	Average discharge to river.	Average coefficient of discharge.	Approximate leakage from river between closing and opening.	Leakage divided by discharge.
	Hrs. min.	*Cu.ft.*		*Cu.ft.*	*Per cent.*
1	2 04	18,431	0.36	15,650	85
2	3 32	74,048	.39	33,580	45
3	1 24	8,400	.43	6,740	80
4	49	(1)	(1)	(1)	....
5	34	(1)	(1)	8,960	....

[1] Not taken.

DITCHES.

Interior drainage is effected by about 2,423 rods of open ditches, varying in width from 2 to 24 feet and in depth from 1 foot to 3.5 feet. On the Compton land the ditches are generally of trapezoidal cross section; the sides are neatly trimmed, and the bottoms and sides are free from obstructing vegetable growths.

The main ditch (see Pl. VIII, fig. 1) leading to sluice 1, which takes the drainage from some 47 acres of land on the south side of Beaver Brook, is 19 feet wide at the top, 10 feet at the bottom, and about 3.5 feet deep. The bottom is little above the floor of the sluice and would probably average about 0.75 of a foot below datum.

The lateral ditches divide the lands into irregular quadrilaterals, averaging about 1⅓ acres each. These ditches average about 5 feet wide, and their bottoms are from 0.5 of a foot below datum in the ditches near the river to 1.2 feet above mean low water in the ditch next the woodland. There are about 2,000 lineal feet of underdrains of wooden construction. Beaver Brook, draining 2,014 acres, flows by winding course and between slightly raised banks through the land of Compton and Camp and is discharged by sluice 2 into the river. From the railroad to the river this brook averages about 18 feet wide and 4 feet deep at the center. The bed is rough and unclean and from 1 to 3 feet above the floor of sluice 2. The brook water at the sluice is ordinarily lowered about 2.85 feet during the period of sluice action. At the railroad culvert, half a mile away, the fall is usually not more than 1 inch.

North of Beaver Brook the Compton land is somewhat lower and the ditches are shallower and subdivide the lands into lots of about 2 acres each. The drainage from this land is received into Beaver Brook through a small sluice 12 inches by 14 inches, situated about 300 feet northeasterly from sluice 2.

The ditches on the Camp, Grassman, Blisard, and Boggs lands are in poor condition. Not only are they badly choked with wild oats and other grasses, but are much too shallow to properly drain the land. Their bottoms would probably average at least a foot above the floor of sluice 3, to which they drain. Their average width is about 4 feet.

The main ditch on the westerly side of Camp's land is about 6 feet in width and 2 feet in depth; its storage capacity in the vicinity of the sluice is entirely inadequate, and two artificial barriers greatly diminish its usefulness even as a conducting channel.

The lateral ditches subdivide the Camp lands into 3 fields of about 4 acres each, Grassman's land into 6 fields of about 2 acres each, and Blisard's into 4 fields of about 1⅓ acres each. Bogg's area of 4 acres is undivided.

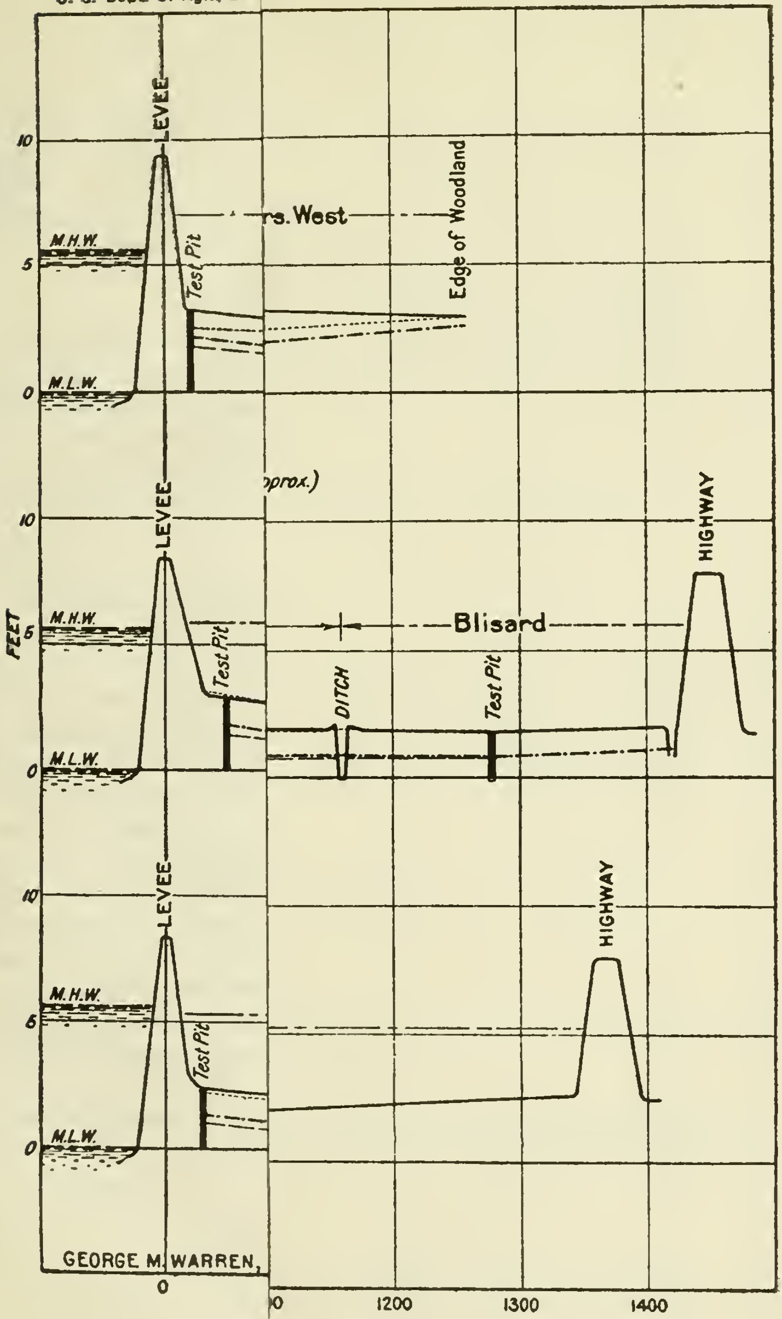
The Lupton farm is the lowest of the entire tract. It is a self-contained area of about 91 acres, free from all upland drainage and subdivided by ditches into fields, averaging about 5 acres in area each.

The main ditch leading to sluice 5 is from 11 to 24 feet in width and from 2 to 3 feet in depth; its bottom is from 1 to 1.5 feet below datum. In general the bottoms of all the ditches on this farm are from 0.5 of a foot to 1 foot below mean low water and are free from vegetable growths and serious obstructions. The laterals average 8 feet in width. The ditch water seldom rises more than 5 to 6 inches above mean low water, though sluices 4 and 5 play but for short periods and very frequently not at all. The difference in elevation of the water in the various ditches is shown by the table below:

Ordinary elevation of ditch water at opening and closing of sluices, and entire fall.

Number of sluice.	Owner of land.	Ordinary elevation ditch water.		Fall.
		When gates open.	When gates close.	
		Feet.	*Foot.*	*Feet.*
1	Compton	1.55	0.15	1.40
2	Camp	3.00	.15	2.85
3	do	1.10	.10	1.00
4,5	Lupton	.13	.06	.07

The areas of the different marshes, length and storage capacity (between M. L. W. and elevation of lowest part of tract being considered) of ditches, and ratio of superficial area of ditches to marsh, are noted in the table following.



GEORGE M. WARREN,

r. N. J.

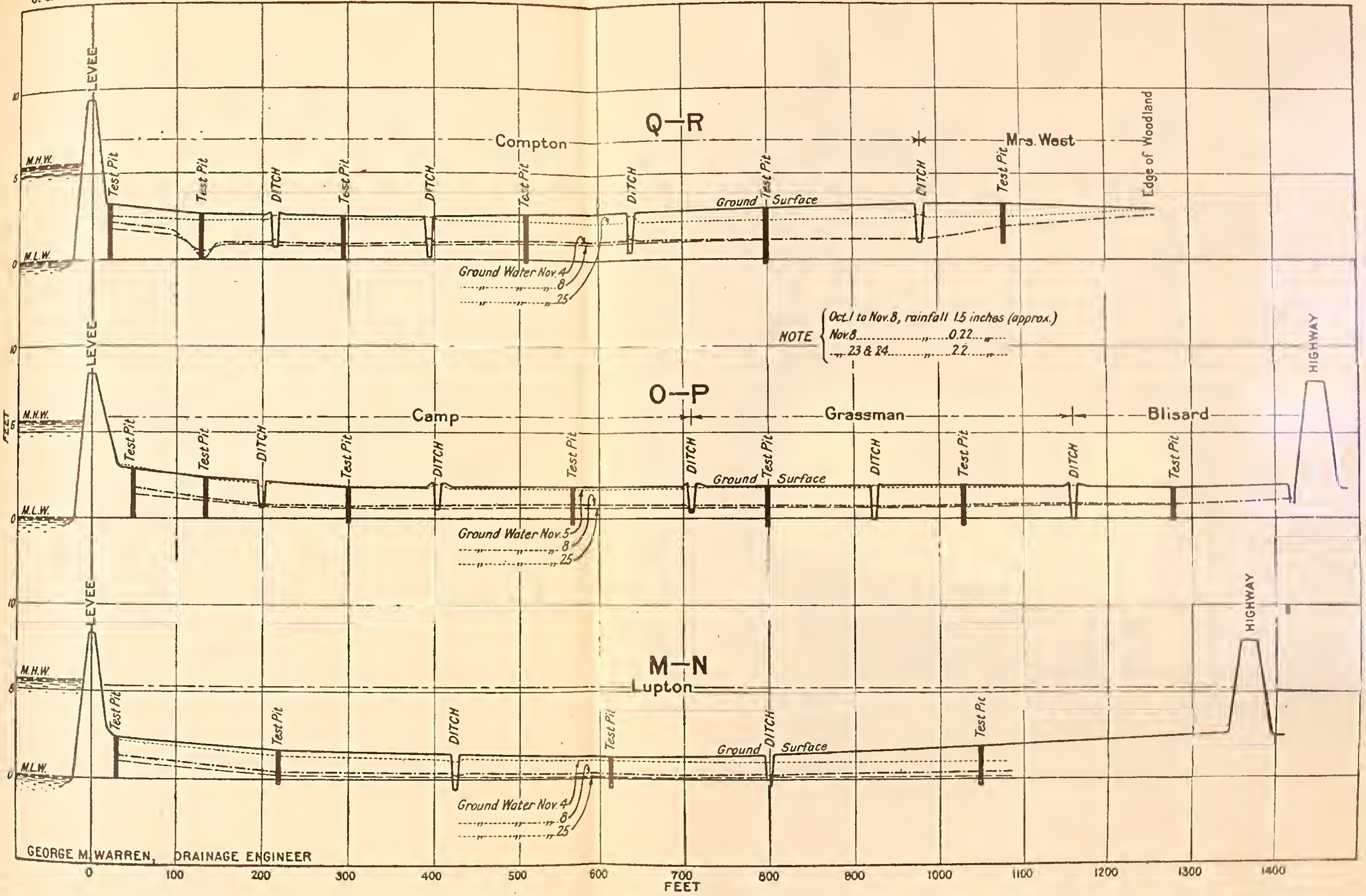


Fig. 14.—Profiles showing position of ground water in November, 1909, on lines M-N, O-P, and Q-R of Fig. 12, Dorchester, N. J.

Ditch data, etc., for marsh lands near Dorchester, N. J.

Owner.	Area of marsh.	Length of ditches.		Storage capacity.		Ratio of ditch and marsh areas.
		Total.	Per acre.	Total.	Per acre.	
	Acres.	*Feet.*	*Feet.*	*Cu.ft.*	*Cu.ft.*	
Compton south of brook	22.6	8,754	387	88,970	3,937	4.5 : 100
Compton north of brook	26.4	6,385	242	26,426	1,001	1.8 : 100
Blisard	5.4	2,095	388	10,662	1,975	3.1 : 100
Grassman	12.1	4,614	381	21,561	1,782	3.0 : 100
Camp	12.4	2,900	234	16,995	1,371	2.4 : 100
Lupton	91.2	15,230	167	108,747	1,192	3.0 : 100

RAINFALL AND GROUND WATER.

The month of October, 1909, was exceptionally cool and dry throughout New Jersey, the rainfall being generally less than for any October in the past 25 years except in 1892. Judging by the recorded rainfall at three places in the vicinity, it is probable that the precipitation at Dorchester was about 1.5 inches for the month, nearly all of which came in three rains, approximating one-half inch each on the 12th, 15th, and 24th. Little rain fell in November until the 8th.

Seventeen test pits for purposes of observation on the ground water were dug. Their position is shown on the plan (see fig. 12). Four were in a north and south line (M–N) near the eastern side of the Lupton farm. Seven were in a nearly parallel line (O–P) on Camp, Grassman, and Blisard lands; and six were southerly of Beaver Brook on lands of Compton and Mrs. West (Q–R).

The positions of the ground water on November 4, 8, and 25 are shown in figure 14. On November 8 it was the lowest observed for a period of nearly one and one-half months. During the night of November 8, about 0.22 of an inch of rain fell, raising the water table about 0.18 of a foot in land of Camp, Grassman, and Blisard, but only 0.06 of a foot in Compton's land.

On the 23d and 24th of November about 2.2 inches of rain fell, raising the ground water about a foot at most of the test pits. While this storm caused the ground water to rise to the surface and completely saturate the marsh of Camp, Grassman, and Blisard, the lands of Compton and Lupton were firm under the foot and about 5 inches above the water table.

Positions of ground water on November 8 and 25, the lowest and highest observed.

Profile.	Date.	Ground water.	
		Approximate elevation above M. L. W.	Approximate distance below surface of ground.
	1909.	*Feet.*	*Inches.*
M-N	Nov. 8	0.12	17
O-P	Nov. 8	.68	13
Q-R	Nov. 8	.82	22½
M-N	Nov. 25	1.11	5
O-P	Nov. 25	1.75	0
Q-R	Nov. 25	2.27	5

The distance from the surface of the marsh to the ground water, taking the average of all gaugings made at the several test pits from November 4 to December 6, was as follows:

	Feet.
Upon land of Compton	1.39
Upon land of West	1.22
Upon land of Lupton	1.14
Upon land of Grassman	.88
Upon land of Camp	.82
Upon land of Blisard	.75

From that which has preceded, it is clear:

(1) That the deeper, cleaner character and greater proportional storage capacity of the ditches on Compton's marsh, notwithstanding their interception of considerable ground water near the southeasterly corner of the tract, made possible, at the end of one and one-third months during which about 1.5 inches of rain fell, an average depth of soil above the water table of 22½ inches.

(2) That the deeper, cleaner character of the ditches on Lupton's marsh, notwithstanding the low elevation of the land and comparatively small storage capacity of the ditches themselves, made possible an average depth of soil above the water table of 17 inches.

(3) That the shallow, choked ditches on the marsh of Camp, Grassman, and Blisard, notwithstanding fair elevation of the tracts and slight drainage from the uplands, could not make possible a greater average depth of soil above the water table than 13 inches.

The marsh of Mr. Boggs is unimproved and the water stood practically at the surface of the ground at all times. The single test pit near the center of Mrs. West's lot showed the ground water with very slight variations at elevation 1.95. Just east of this test pit at the edge of the woods the water table varied little from 5 inches below the surface of the ground.

It is obvious that a run of low tides produces a corresponding lowering of the water table and that a series of high tides, by increasing the leakage and seepage, produces a corresponding rise. In passing from the former conditions of the tide to the latter, the interior ground water very frequently was found to be rising near the levee while still falling in the remote parts.

At test pits considerably removed from the ditches it was found that a rise or fall of the ground water might follow the tides which produced the movement by from one to three days. Under the influence of a low run of tides and favorable weather the ground water may fall from 1 to 3 inches per day adjacent to the levee, ¼ to 1 inch near the center of the marsh, and from 0 to 1 inch at the more remote parts.

It is very probable from the studies made that in the long run the water table is very close to a mean between the surface of the ditch water at the opening and at the closing of a sluice.

CROPS AND THEIR VALUE.

The principal crops are corn, hay, strawberries, and potatoes. In 1909 16.4 acres of Compton land produced 2,235 bushels of corn in the ear, an average of 136 bushels per acre. These fields varied from 2 to 3 feet above datum. The best yield was 265 bushels from an area of 1.1 acres, averaging 3 feet above datum, which is at the rate of 241 bushels per acre. The poorest yield was 300 bushels from 3.9 acres near the southeast corner of the tract, where, from the inflow of upland ground water, the marsh had until recently been too soft to permit of working with horses. (See Pl. VI, fig. 2, and Pl. VII, fig. 1.)

Twenty-four acres of grass land yielded about 48 tons of timothy, red clover, and herd's grass, or an average of 2 tons per acre. This land varied from 1.6 to 4 feet above mean low water. The best yield is stated to have been in excess of 4 tons of timothy and red clover from a field which was found to contain 1.2 acres and its elevation to be about 3 feet above datum.

Three and five-tenths acres in potatoes yielded 300 bushels, which was stated by the foreman to have been about one-half an ordinary crop.

In 1907 an area of 0.55 of an acre 3 feet above datum yielded 150 crates of 32 quarts each Shropshire strawberries, which sold for $2 per crate; $1.40 must be deducted for crate, picking, freight, and commissions, leaving a profit of over $163 per acre, less the cost of raising. In the same year 9 acres, set out in 1905 with Gandy Prize strawberry plants, cleared over $1,600, or about $180 per acre. In 1906 4 acres yielded 527 crates of Gandy Prize strawberries, which cleared over $600, or about $150 per acre. The last two parcels of land were from 2.5 to 4 feet above datum.

The Camp land, 12.4 acres, is largely covered with weeds and three-square sedge. The middle lot produced a small quantity of inferior hay, probably not exceeding $25 in value.

The Grassman land, 12.1 acres, probably did not yield on the average more than a ton of inferior hay to the acre, worth from $5 to $8 per ton; the easterly lots are covered with weeds and tussocks.

The Blisard land, 5.4 acres, is estimated to yield about 3 tons of herd's grass, worth $8 per ton, and to furnish about $30 worth of pasturage per year. The two easterly lots are covered with weeds and tussocks.

The Boggs land, 4 acres, is covered with cat-tails, weeds and brush; it is producing nothing of value.

The land of Mrs. West is producing about 3 tons of rough hay and tussocks, worth perhaps $6.50 per ton.

Mr. Lupton estimated the 1909 yield of his cornfield at 1,000 bushels; it contained 9 acres and its elevation varied from 1.3 to 3.8 feet above datum. Four and four-tenths acres of strawberries (see Pl. V, fig. 2), about 2.2 feet above datum, yielded 170 crates which brought $467.50, but this is probably much below the ordinary crop. It is conservatively estimated that the remainder of the Lupton farm, 77.6 acres, produced an average of 2 tons of hay to the acre. Inside the levee, fields ranging from 1.5 to 2.4 feet above datum are said to have yielded 3 to 4 tons of timothy and red clover to the acre. When visited late in October there was still a fine growth of red clover. Four lots near the center of the farm contain 12.7 acres ranging from 0.9 to 1.2 feet above datum. The rough grass upon this area was sold standing for $30.

Summarized, the value of the 1909 crops at market quotations would be as follows:

Value of 1909 crops at market quotations from 172.5 acres of marsh lands at Dorchester, N. J.

Compton, 49 acres:		
Corn, 2,235 bushels, at $0.35 per bushel	$782.25	
Hay, 48 tons, at $16 per ton	768.00	
Potatoes, 300 bushels, at $0.70 per bushel	210.00	
Pasturage	50.00	
Miscellaneous	50.00	
		$1,860.25
Revenue per acre, $37.96.		
Camp, 12.4 acres:		
Hay	25.00	
		25.00
Revenue per acre, $2.02.		
Grassman, 12.1 acres:		
Hay, 12 tons, at $6.50 per ton	78.00	
		78.00
Revenue per acre $6.45.		

Blisard, 5.4 acres:		
Hay, 3 tons, at $8 per ton	$24.00	
Pasturage	30.00	
		$54.00
Revenue per acre, $10.		
West, 2.4 acres:		
Hay, 3 tons, at $6.50 per ton	19.50	
		19.50
Revenue per acre, $8.13.		
Lupton, 91.2 acres:		
Corn, 1,000 bushels, at $0.35 per bushel	350.00	
Hay, 155 tons, at $14 per ton	2,170.00	
Strawberries, 170 crates, at $2.75 per crate	467.50	
Miscellaneous	100.00	
		3,087.50
Revenue per acre, $33.85.		
Total		5,124.25

VALUE OF LANDS.

Unembanked these marshes had merely a nominal value. The gunning and trapping privileges might have created a value of $5 per acre; agriculturally, they were worthless. After embanking in 1808, transfers were made at $34 per acre. At the present time the assessed valuations range from $10 to $50 per acre, according to elevation and the amount of improvement. Upon this basis the value of these lands is as follows:

Value of marsh lands near Dorchester, N. J.

High marsh, 50 acres, at $50 per acre	$2,500
Low marsh, 90 acres, at $20 per acre	1,800
Low marsh, 36.5 acres, at $10 per acre	365
Total	4,665

Property transfers and the testimony of competent appraisers would indicate that market values are about $10 per acre more than those above stated. This would make the fair market value of these marshes, exclusive of protected woodlands, $6,430.

The woodland is assessed for $3 to $5 per acre, but some of the best groves of cedar are worth $400 or $500 per acre.

The cost of effecting this reclamation is given below in some detail, so that the cost of the different classes of work can be compared.

Estimated cost.

Embankment:		
River embankment, 6,250 lineal feet, at $0.80 per foot	$5,000.00	
Return bank (Compton's), 565 lineal feet, at $0.50 per foot	282.50	
Return bank (Lupton's), 1,450 lineal feet, at $0.25 per foot	362.50	
		$5,645.00

Shore protection:		
Brush, 2,100 linear feet, at $0.32 per foot	$672.00	
Cordwood, 1,300 linear feet, at $0.90 per foot	1,170.00	
Plank, 850 linear feet, at $0.40 per foot	340.00	
		$2,182.00
Ditches, 2,423 linear rods, at $0.60 per rod	1,453.80	
		1,453.80
Sluices:		
No. 1 (actual cost)	63.32	
No. 2	140.00	
No. 3	60.00	
No. 4	90.00	
No. 5	110.00	
		463.32
Underdrains, 2,500 linear feet, at $0.05 per foot		125.00
Allowance for contingencies, 5 per cent		493.45
Total		10,362.57

SUMMARY.

As a result of the study of this reclamation, deductions may be made as follows:

(1) The soil will produce good yields of corn, hay, strawberries, and vegetables. Still better results would be obtained by the use of lime to correct the acidity of the soil and by improving the drainage conditions. Corn averages about 130 bushels and hay about 2 tons per acre.

(2) The marsh will not sustain any considerable weight without large settlement and displacement.

(3) Those tracts which have the deepest, cleanest, and most capacious ditches are the best drained and are making the best agricultural and financial showing.

(4) The sluices have coefficients of discharge varying from 0.36 to 0.43. From 45 to 85 per cent of the water discharged is leakage through the sluices from the river.

(5) Those tracts having less than 1 foot of soil above the water table generally are producing little of value.

(6) The height of the water table is about a mean between the heights of the ditch water before and after the sluices play.

(7) On the basis of the marsh thus far utilized, this reclamation has cost about $59 per acre. The estimated cost is $10,362.57, and the yearly income from the lands about $5.124.25. The fair market value of the 176.5 acres of marsh land to-day is $6,430. The levee, including sluices, cost about $6,370 per mile.

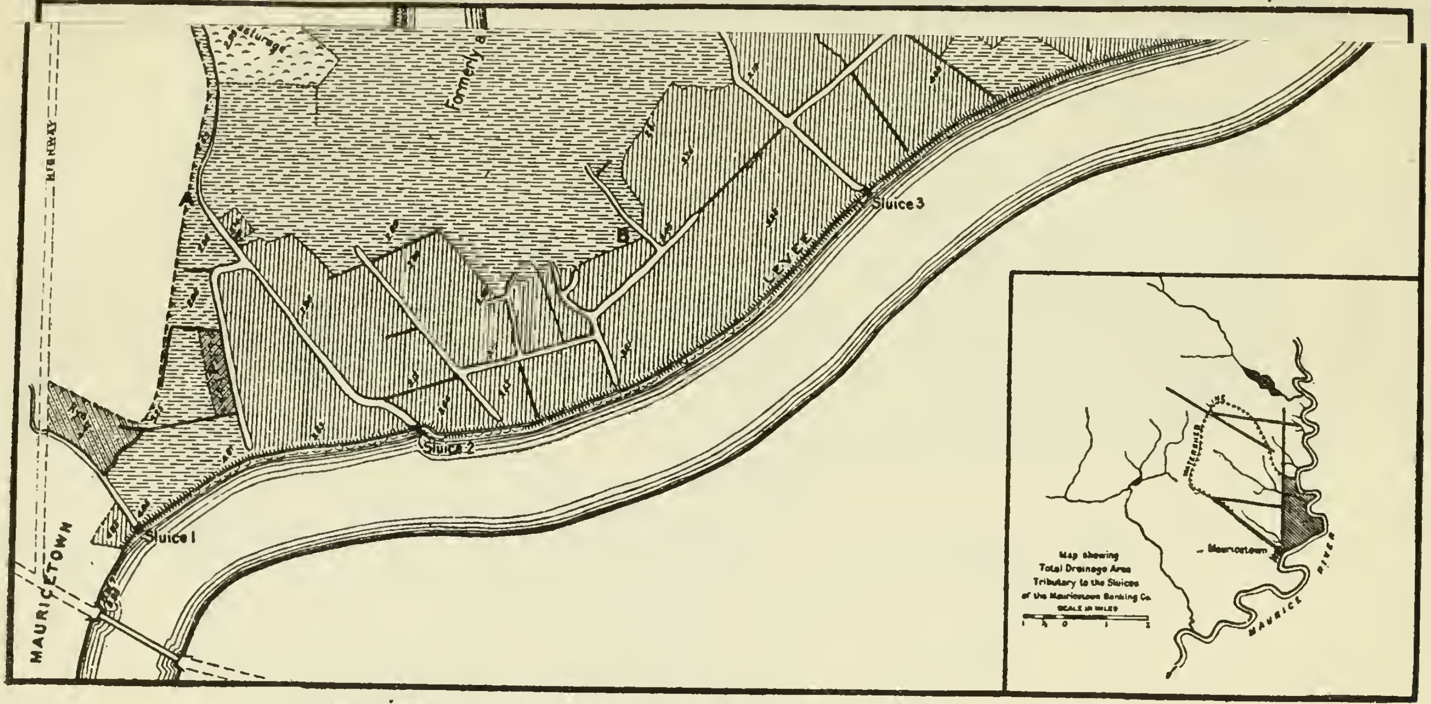


Fig. 15.—Map of Mauricetown Banking Co.'s land, Mauricetown, Cumberland County, N. J.

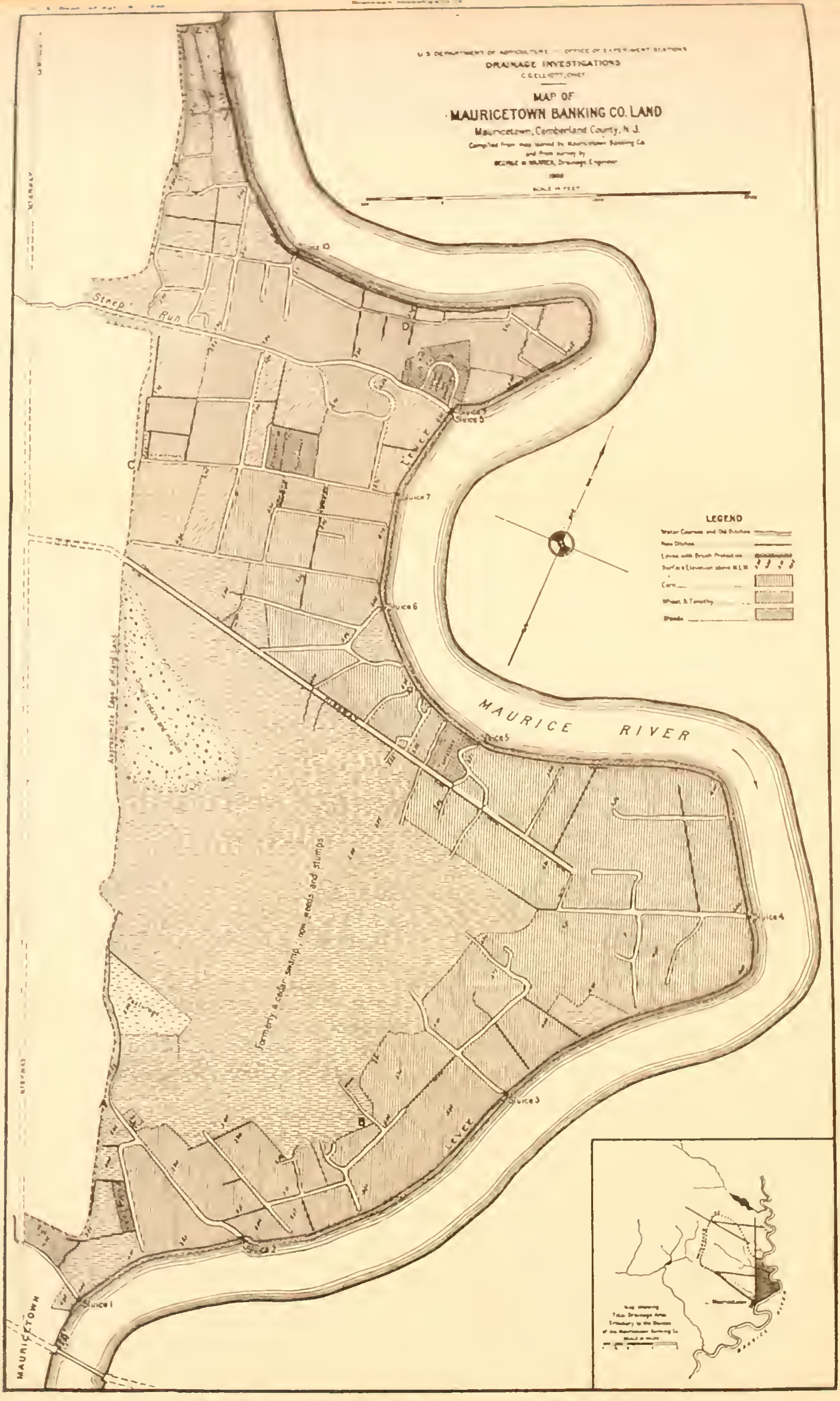


Fig. 15.—Map of Mauricetown Banking Co.'s land, Mauricetown, Cumberland County, N. J.

MARSH LAND NEAR MAURICETOWN, CUMBERLAND COUNTY, N. J.

HISTORY AND DESCRIPTION.

The lands of this company are situated on the westerly side of the Maurice River, northerly from Mauricetown, Commercial Township, Cumberland County, N. J. (See fig. 15.)

They were first embanked about 100 years ago, but some 32 years ago, after the levee had become breached in a number of places, were practically abandoned until April, 1906. At the latter date embanking was again undertaken. A 1-cubic-yard orange-peel dredge placed about two-thirds of the material over the whole length of the levee, about 3 miles. The work was finished with a three-fourths-yard dredge of the same type.

The contributing drainage area contains about 3,635 acres, of which 459 acres constitute the marsh proper. The drainage from about 2,000 acres, collected in Steep Run, so called, is discharged through sluices 8 and 9 into the river. The drainage from 822 acres, collected by a brook just northerly of the village of Mauricetown, is discharged by sluice 1.

The remainder of the drainage area, 813 acres, furnishes the discharge for seven sluices; of these, sluice 7 is the only one which receives directly any considerable amount of upland drainage. Collectively, 5 sluices receive, through crooked and obstructed natural watercourses, the drainage from an old cedar swamp of about 170 acres. (See Pl. VIII, fig. 2.)

Immediately within the levee the marsh is generally from 3.5 to 4 feet above datum. The lowest area is adjacent to the bluff, where the ground ranges from 2 to 3 feet above datum.

The bluff marking the western limit of the marsh is 10 to 15 feet in height, and beyond the drainage area rises to heights of 50 feet or more above mean low water. The rise and fall of the tide is about 5.2 feet, and all levels are referred to the same datum as used on the Dorchester work.

SOIL AND SUBSOIL.

Beneath a thin layer of vegetable mold the soil is a plastic silty clay, generally grayish in color, and often mottled. Both the soil and soil water have a decided acid reaction. The deposit of new soil between 1877 and 1906, a period of 29 years, during which the tide was free to flood the marsh, is plainly observable along the sides of newly dug ditches. Its thickness ranges from 6 inches to 30 inches, and would probably average about 2 feet. Along the sides of ditches which had been opened a considerable length of time there was a fringe of tussocks and grasses growing from the cleavage line between the top of the marsh of 1877 and the bottom of the superimposed layer.

The downstream side of points of land projecting toward the river are higher and the deposit of new mud is thicker than on the upstream side. Beneath the decomposing vegetable matter marking the top of the marsh of 1877, the deposit of silty clay continues to a greater or less depth. A number of soundings, near the levee, were made into it a distance of 8 or 10 feet, but adjacent to the bluff it is much thinner.

Of the inherent fertility, the apparently inexhaustible supply of plant food in this soil, there can be little question. The oxidation and conversion into humus of its organic matter, the improvement of its structural condition, is the most that is necessary to render these lands extremely productive, and this result can be obtained by thorough drainage and tillage. A sample of this soil, No. 23016, which was recently examined by the Bureau of Soils had a total salt content of 350 parts in 100,000, mainly sulphates and chlorids. Tests by the Veitch method showed that 19,600 pounds of lime would be required to fully neutralize the acidity in 1 acre of soil to a depth of 1 foot. Proper drainage and aeration of the land would, of course, greatly reduce the lime requirement.

LEVEE.

The levee was built by dredge operating from the river side. A typical section is shown in figure 16 A, and cross sections at sluices 1 and 7 are shown in figure 16 B and C.

The channel cut by the dredge is about 31 feet wide and 4.5 to 5 feet in depth, and was made in the foreshore at that point, which is about half-tide level. There is a 9-foot berm between the channel and the levee. The levee is about 28 feet wide at the base, 5 feet at the top, and 5 feet high. The top is generally about 9 feet above mean low water; this is about 3½ feet above mean high water and 1½ feet above extreme high water.

The top and slopes of the levee are rough and irregular and covered with a thick growth of weeds. No attempt has been made to dress the slopes and secure a stand of grass, but the material is as it was deposited from the buckets.

The bank protection which covers about two-thirds of the 3⅓ miles of levee, consists of a double row of 4-inch oak piles, spaced about 2½ feet longitudinally and 1½ feet transversely, the intervening space being filled with brush.

The piles are from 8 to 13 feet in length and were driven by a gang of three men. Two men with linemen's climbing irons would put their weight to a pile while the third, by a rotary motion, quickly

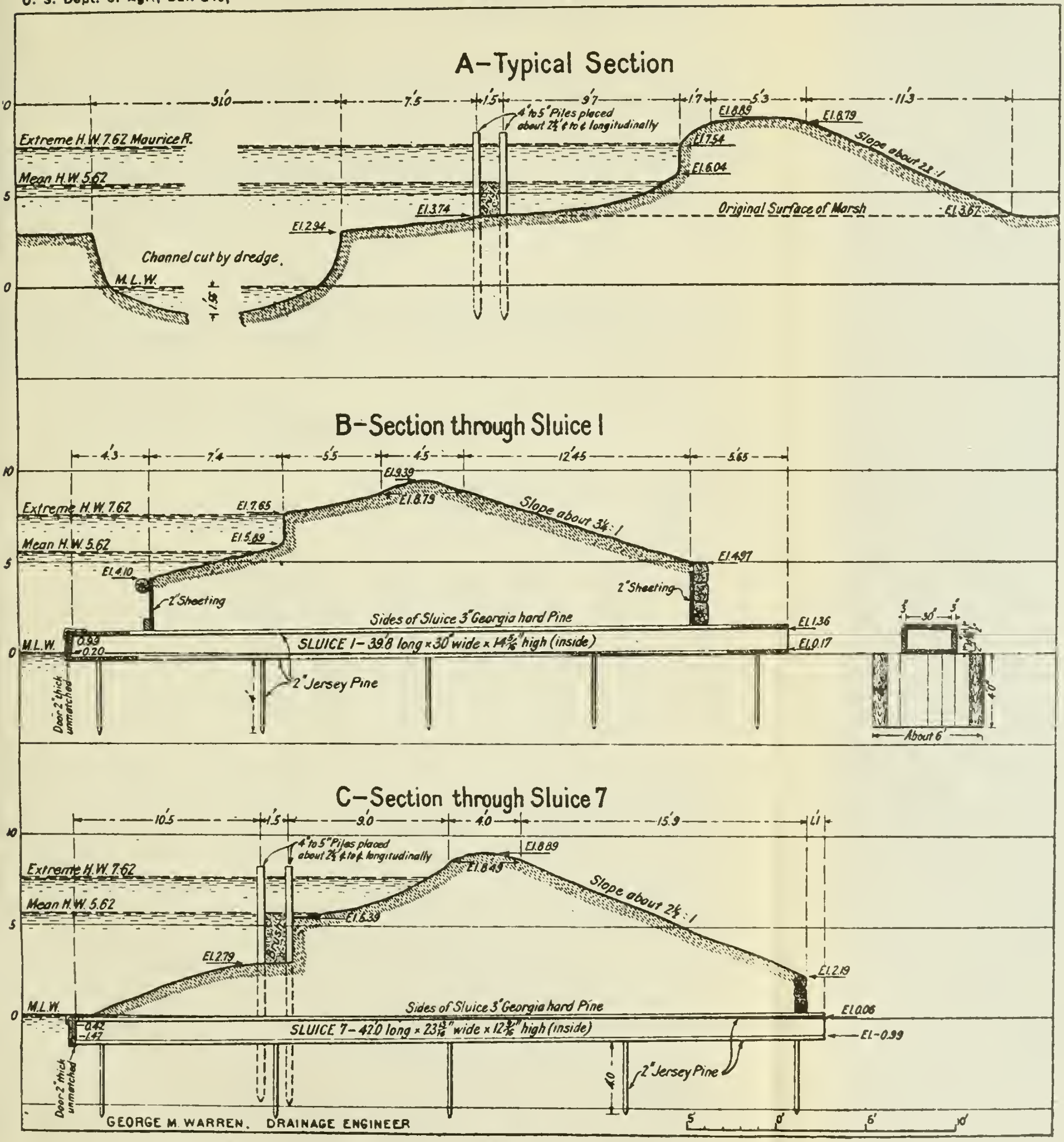


Fig. 16.—Sections of levee and sluices, Mauricetown Banking Co., Mauricetown, N. J.

worked it downward. It is stated that these piles cost about 5 cents each delivered on the work, and that three men have put down as many as 700 in a day.

The protection is insufficient in extent and lacking in strength. In places the waves are working under the brush, and at other points over it. The destructive effects to the levee at and above mean high-water level are clearly seen in figure 15, A, B, and C. At still other points the entire protection is practically destroyed. It is stated that there were twenty-five breaches in the old levee which required piling in order to close them.

SLUICES.

Ten sluices vent the interior waters. The size, length, grade, and approximate tributary drainage area of these sluices are shown in the following table:

Size, length, grade, and approximate tributary drainage area of 10 sluices at Mauricetown, N. J.

Sluice.	Clear opening.	Length.	Elevation river end.		Elevation land end.		Approximate drainage area.
			Crown.	Floor.	Crown.	Floor.	
	Sq. ft.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Acres.*
1	2.97	39.8	0.99	−0.20	1.36	−0.17	822
2	2.05	37.4	.78	− .25	.82	− .21	130
3	2.06	45.0	.42	− .60	.27	− .75	110
4	2.02	39.1	.49	− .51	.53	− .47	45
5	3.06	41.0	.53	− .49	.16	− .86	65
6	1.21	39.0	.57	− .48	.58	− .47	80
7	2.07	42.0	−.42	−1.47	.06	− .99	250
8	4.45	31.8	1.23	− .07	.97	− .33	2,000
9	6.32	39.8	1.70	....	1.44	− .26	
10	2.11	41.2	.91	− .11	.60	− .42	133

The foundation of each sluice consists of five rows of sheet piling 2 inches thick and 4 feet long. About 18 inches from both ends of the sluice and parallel with the levee, 6-foot rows of piling are driven; the distance between these two lines is approximately quadrisected by the other three rows. The tops, bottoms, and doors are 2-inch Jersey pine, costing $20 per thousand. The sides are Georgia hard pine about 3 inches in thickness, costing $30 per thousand.

The sluices were built complete at the edge of the hard land, floated to the several locations, and at low tide set upon the foundations previously prepared. It is to be regretted that they were not placed at a lower grade; this circumstance will become more apparent with the inevitable shrinkage and settlement of the marsh. For various reasons few of these sluices are doing the work they should. The ditches at the sluice entrances are too often narrow, shallow, or obstructed, and the small submergence of the gates, combined with their weight, gives low coefficients of discharge. (See Pl. IX.)

The time of play, discharge to river, average coefficient of discharge, elevation of ditch water at opening and closing of gates, and fall in feet, on the dates and for the sluices given, appear in the following table:

Sluice data for the marsh lands near Mauricetown, N. J.

Date.	Number of sluice.	Time of play.		Discharge to river.	Average coefficient of discharge.	Elevation of ditch water.		Fall.
						When gate opened.	When gate closed.	
1909.		*Hrs.*	*Min.*	*Cu. ft.*		*Feet.*	*Fect.*	*Feet.*
Dec. 7	1	2	07	4,648	0.20	2.07	1.01	1.06
Dec 8	2	2	14	11,175	.32	.80	.40	.40
Dec. 9	3	2	17	6,905	.20	.29	— .34	.53
Dec. 11	5	3	39	11,563	.17	1.15	— .47	1.62
Dec. 15	7	2	50	66,504	.46	.96	.05	.91
Do	8	4	46	62,977	.45	2.66	.45	2.21
Do	9	4	46	67,782	.45	2.66	.45	2.21

The leakage of the majority of these sluices is believed not to be excessive. Sluice 7, at half tide on December 14, was leaking at the rate of 1.27 second-feet, and it is known that there is a large leakage through sluice 9. On December 15, two days after a rainfall of between 2 and 3 inches, a weir was set in Steep Run just westerly of the highway. The drainage area tributary at that point was 1,943 acres. During a period of eight hours the flow over this weir was about 100,000 cubic feet. The subsequent discharge from sluices 8 and 9 was 130,759 cubic feet. The difference in these volumes is 30,759 cubic feet, and largely represents the leakage through the two sluices from the river. It amounts to over 23 per cent of the discharge

DITCHES.

The interior drainage is largely through natural sloughs or watercourses, which are of all widths up to 40 or 50 feet. They are rough and crooked and the flat sloping sides have favored a rank growth of vegetation. (See Pl. X, fig. 1.)

Such well-aligned ditches (see Pl. X, fig. 2) as have been dug are inadequate for the proper drainage of the land. There are about 3¼ miles of these ditches, 4 to 5 feet wide at top, 2 to 3 feet wide at bottom, and about 2½ feet deep. Many are badly choked with wild oats and other grasses. Observations on the ditch water at five different points on the marsh, designated on the plan (see fig. 15) by the letters A, B, C, D, E, showed the ordinary drop during the period of sluice play to be about as follows:

FIG. 1.—SLUICES 8 AND 9, SHOWING FORMATION OF ICE BELOW ORDINARY HIGH WATER MARK.

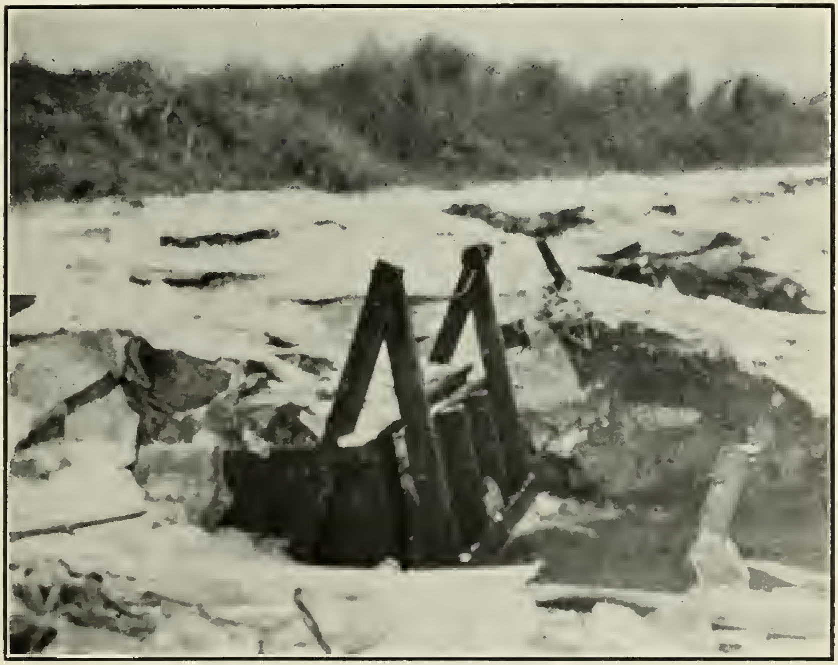


FIG. 2.—SLUICE 8, SHOWING GATE SLIGHTLY OPEN, HOW THE WEIGHT OF THE GATE RETARDS THE DISCHARGE AND THE LIABILITY TO INTERFERENCE FROM ICE.

OUTER END OF SLUICES AT LOW TIDE IN MAURICE RIVER, MARSH LANDS OF THE MAURICETOWN BANKING CO., MAURICETOWN, N. J., DECEMBER 20, 1909.

FIG. 1.—MAIN DITCH LEADING TO SLUICE 4.
[Example of a choked ditch.]

FIG. 2.—LATERAL DITCH NEAR SLUICE 3.
[Example of a clear ditch.]

DITCHES IN MARSH LANDS OF THE MAURICETOWN BANKING CO., MAURICETOWN, N. J., DECEMBER 18, 1909.

Ditch-water elevations.

Point.	Controlling sluice.	Ditch-water elevation lowered—	
		From—	To—
		Feet.	*Feet.*
A	2	0.85	0.56
B	3	1.37	1.37
C	7	1.72	1.72
D	10	1.43	1.40
E	10	3.08	3.06

It should be stated that point C was in a small ditch, slightly up the slope of the bluff, and that, while the surface of the water was practically the same at all times, there was a distinct and constant flow toward the main ditch leading to sluice 7.

From these figures it will be seen that the movement of the ditch water is very sluggish, and it is probable that the effect of the sluice discharge is not felt at some of these, and other points in obstructed ditches, until several hours after the gates have closed.

On December 13 a rainfall of between 2 and 3 inches raised the water a foot or more in most of the ditches. The elevations next morning, December 14, and four days later, December 18, were as follows:

Ditch-water elevation due to a 2 to 3 inch rainfall.

Date.	A.	B.	C.	D.	E.
1909.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Dec. 14	1.77	2.00	2.04	2.75	3.21
Dec. 18	.97	1.64	1.78	1.50	3.03
Drop in 4 days	.80	.36	.26	1.25	.18

CROPS.

The principal efforts at tillage and crop production have thus far been confined to a strip of land, 600 to 800 feet in width, contiguous to the levee. In 1908 numerous attempts to raise corn proved failures. There was some growth along the edges of the ditches, but a few feet therefrom toward the centers of the fields corn would not grow, and the crop was worthless. The attempts at growing hay were almost as discouraging. The manager of the company reports that about 7 tons of timothy was the total product from upward of 15 acres.

During the year 1909 the yield of corn has been much better, and some spots have shown a very gratifying production. One man obtained 1,700 bushels in the ear from 30 acres; another, 160 bushels from 5 acres; another, 30 bushels from 3 acres. The best average yield was obtained from the field to the south of point D and lying in part on the southerly side of Steep Run, where 6.8 acres yielded 700 bushels of corn in the ear, or at the rate of about 103 bushels per acre. A near-by field in strawberries yielded well. Wheat, buckwheat, rye, tomatoes, potatoes, cabbages, melons, and celery were other crops grown with varying degrees of success.

With continued development of the ditches and thorough tillage, the next few years will, beyond question, bring these lands to a high state of productiveness.

VALUE OF LANDS.

Unembanked these lands had a nominal value of $2.50 per acre. The assessments for construction purposes were $30 per acre on land near the levee, $10 per acre on land near the bluff, and $20 per acre on the intermediate areas. Present values may best be judged by recent transfers. Five and thirty-five hundredths acres near sluice 5 sold for $55 per acre; two lots containing 2.8 and 4.25 acres, near sluice 4, sold for $70 per acre in March, 1909; 6¼ acres on the northerly side of the cedar swamp (see Pl. VIII, fig. 2) sold for $32 per acre. Taking the whole tract of 459 acres, the present market value is about $50 per acre.

ACTUAL COST.

The actual cost of this reclamation as furnished by Mr. E. L. Gandy, manager of the company, is as follows:

COST OF RECLAMATION.

Levee, 16,434 linear feet		$9,701.08
Sluice 1	$36.30	
Sluice 2	31.52	
Sluice 3	34.92	
Sluice 4	33.18	
Sluice 5	38.46	
Sluice 6	55.72	
Sluice 7	33.66	
Sluice 8	33.00	
Sluice 9	56.40	
Sluice 10	34.48	
		387.64
Levee protection, about 10,000 linear feet		1,400.00
Dredging Steep Run (25 feet wide), about 2,200 linear feet		475.00
Interior ditches		200.00
Salaries of commissioners, surveying, and staking lots		380.40
Fee of attorney		70.00
Incidental expenses		200.00
Total		12,814.12

To this should be added about $600 for ditches which have been dug by individual owners.

SUMMARY.

(1) The inherent fertility of the soil is beyond question. The crops have been all that could reasonably be expected in view of the newness of the enterprise and the crude and unweathered condition of the soil. Satisfactory yields can not be expected upon newly reclaimed lands in less than three years.

(2) The levee should be trimmed and seeded and the protection raised and strengthened.

(3) The sluices are high and have low coefficients of discharge. The combined area of sluice openings is 28.32 square feet.

(4) The ditch system must be further developed. Many existing channels must be deepened and freed of the impeding vegetation.

(5) The deposit of new mud in 29 years averages about 2 feet in depth. The thickest deposit is on the downstream side of projecting points.

(6) This reclamation has cost $29.29 per acre and raised the land values from $2.50 to an average of $50 per acre. The actual cost, including $600 expended on ditches by individuals, has been $13,414.12. The levee, including sluices and protection, has cost about $3,700 per mile.

BENCH MARKS.

The bench marks listed below have been used in making the surveys outlined, and may prove useful to engineers who may make other surveys in these localities:

List of bench marks.

No.	Elevation.	Description.
	Feet.	
1	12.114	Delaware City, Del., intersection of Battery Lane and Maple Boulevard, Fort Dupont, top of granite monument.
2	10.448	Delaware City, Del., Battery Gibson, Fort Dupont, rear of emplacement No. 1, concrete manhole in roadway, top of northeasterly corner.
3	1.44	Delaware City, Del., marsh of the Arthur Colburn estate, land end of sluice, southerly flume, top of 4-inch timber side, southwesterly corner.
4	11.39	Delaware City, Del., St. Georges Marsh, range light at St. Georges Creek, steel column marked "A IIII," top of northerly anchor bolt.
5	4.99	Dorchester, N. J., Howard Compton's marsh, large maple tree 25 feet westerly of tool house, westerly root, 20 inches from trunk of tree, 12 inches above ground, top of spike.
6	8.11	Mauricetown Station, N. J., West Jersey & Seashore R. R. track, center of highway crossing, top of westerly rail.
7	9.95	Mauricetown, N. J., highway bridge over Maurice River, westerly abutment, top of bridge seat, northeasterly corner.

GENERAL SUMMARY AND DISCUSSION.

The principal points established or elucidated by these investigations may be summarized as follows:

SLUICES.

(1) A sluice will play longer for a given height of interior water the less the range of tide.

(2) The length of time a sluice will play is governed almost exclusively by the behavior of the tide and by the relative elevations of the outer and inner waters. On the ebb tide the gate will open when the water without passes the level of that within, and will remain open until the succeeding flood tide rises to the level of the interior water.

(3) The coefficient of discharge of sluices having unweighted wooden flap gates in complete submergence is 0.64. Heavily weighted and poorly constructed gates may cause the coefficient to drop to as low as 0.10 or even less. Light gates with long radius of swing, good mechanical construction, and complete submergence are all favorable to a high coefficient of discharge.

(4) Sluice leakage was found to exist to an unexpected extent. The smallest leakage measured was 23 per cent and the largest 97 per cent of all the water discharged.

(5) The practice is general of making sluices too small and setting them too high.

(6) The relative merits of the so-called " high sluice " and " low sluice " have been discussed far and wide. The advantage is distinctly with the latter. Only in case of an exceptionally high marsh and large tidal range should the top of a sluice be placed above ordinary low-water mark. The advantages of the low sluice are:

(*a*) It will discharge more water.

(*b*) Its life, if of wooden construction, is immeasurably increased by reason of being always submerged and not exposed alternately to the action of air and water.

(*c*) Its effectiveness will not be diminished by any ordinary settlement or subsidence of the marsh.

(*d*) There is less liability of obstruction and clogging of the gates from floating sticks, reeds, or other débris which, on the flood tide, has a set toward shore.

(*e*) It is less liable to interference from sportsmen or persons mischievously or maliciously inclined.

(*f*) It is less liable to injury or interference in its workings from the action of ice.

(*g*) The outfall channel is not more liable to become silted than in the case of a " high sluice." In either case silting does not usually occur in the immediate vicinity of the sluice, but at a point some distance therefrom where the velocity of flow has been reduced by a commingling with the quieter waters outside.

The advantages of the high sluice are:

(*a*) It is less costly to construct.

(*b*) Inspection and repairs are more easily and cheaply made.

LEVEES.

The best protection which a levee can have, all things considered, is one that nature itself may supply, i. e., a high, wide foreshore. Few levees are built to a safe height, nor do they receive the inspection and care which their importance demands. Including sluices and protection, the Colburn levee has cost about $6,900 per mile; the St. Georges, $14,300; the Dorchester, $6,370; and the Mauricetown, $3,700.

DITCHES.

While the ditch system and its maintenance is one of the most important factors in marsh reclamation, it is also one of the most neglected. Sluices and levees may be in perfect order, but if the ditches are inadequate through faulty design, or by reason of accumulated deposit and impeding vegetation, the land will remain undrained.

There should be no "seepage ditch" along the inside toe of the levee as it weakens the embankment to that extent and serves as a playground for muskrats, snakes, and fiddler crabs. If interception of seepage through the levee is necessary, it should be done by underdraining. In actual practice few ditches in our reclaimed marshes have a water gradient of less than 7 inches per mile, and in very many it runs as high as 16 to 24 inches. In the reclamation of low, flat marsh lands, there are several practical advantages in making the bottoms of ditches deep and level, viz:

(1) Storage capacity is increased.

(2) The friction head is reduced.

(3) Vegetation does not so readily take root and grows less rank by reason of the bottom being always well submerged.

(4) Since velocity is dependent upon inclination of the water surface and not of ditch bottom, no advantage is gained by giving slopes to the bottoms of the ditches.

SOIL.

Marshes composed of a deep soil which contains sufficient clay to render it when moist somewhat slippery under the foot are most likely to prove agriculturally profitable, to be subject to only moderate settlement and subsidence, and to be best adapted to the building and sustaining of levees and sluices, or to the digging of ditches.

The marsh soils generally show an acid reaction, due to the decomposition of vegetable matter, and require lime as a corrective. The beneficial effects of lime do not continue as long as on upland soils, for it unites with the chlorin forming chlorid of lime which is soluble in water. Hence applications of lime may on some soils be needed every three or four years. The presence of marl, shells, or other calcareous matter is a favorable sign.

GROUND WATER.

The height of the ground water in the long run will be about a mean between the elevations of the ditch water just before and just after the sluice has played. The height of the ground water is practically unaffected by the oscillations of the tide for a single day. From one to three days must elapse before a low run of tides will have noticeably lowered the water table. In seasons of very small rainfall the water table may be lowered by evaporation considerably below mean low water outside.

VEGETATION AND RELATION TO WATER TABLE.

Upon salt marshes proper, depending upon the height to which they have been built up, are found various sedges, joint grass, salt grass, and black grass. On brackish marshes are found three-square sedge, snip-snap, cat-tails, cord grass, wild oats, and red fescue. On reclaimed marshes where the ditch water rises to such a height as to frequently submerge and keep the lands constantly saturated, reeds, flags, and cat-tails will abound. Land which is occasionally submerged and but a few inches above the water table is in a favorable condition for a profuse growth of three-square sedge.

Little of value is obtained from land less than 1 foot above the water table. At slightly higher elevation, 1 to 1½ feet above the water table, June grass and other natural grasses come in, and with white clover or fescue afford excellent pasturage. There should be not less than 1½ to 2 feet of soil above the ground water for good timothy and corn and 3½ to 4 feet for wheat. If sluices and ditches can maintain the water table within 6 inches above mean low water outside, and this usually should be possible, we may conclude that land situated 1½ to 2 feet above mean low tide would make good pasturage; 2 to 2½ feet above, good hay and corn fields; and 4 to 4½ feet above, good wheat fields. Conservative forecasts on the crop production of such lands would be 2 tons of hay, 65 bushels of shelled corn, and 20 to 25 bushels of wheat to the acre. The botany of tidal marshes has been studied by the Connecticut State Experiment Station, which has also reported complete chemical analyses showing the forage value of the principal marsh grasses.[1]

TREATMENT OF LAND AND CROPS GROWN.

Draining marsh land should be done gradually, as otherwise the mechanical condition of the soil may be injuriously affected, its capillary power destroyed, and decomposition of the organic matter retarded. Where fresh water is available and can be promptly re-

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[1] Connecticut State Station Rpt. 1889, p. 233.

moved, much of the saline matter can be washed from the soil. The usual method of subduing a rank sod is by burning, and is to be recommended, despite criticisms which have been made. If the burning does not extend deeper than 1 foot, comparatively little available plant food is destroyed and the ashes and charred matter improve the texture of the soil, correct acidity, and hasten nitrification. Every facility should be offered for air, rain, sunlight, and frost to enter and act upon the soil. Many marsh soils, in common with clay soils generally, bake when exposed to sun and drought. Plowing should be done in the fall or winter, and when the land is neither very wet nor very dry, as at such times a baked or lumpy surface will result, and proper preparation of the land will be rendered difficult, if not impossible. The land should be plowed when gentle rains have brought it to its most friable condition. The furrow-slice should be shallow the first year and increase in depth in subsequent years.

Corn is a favorite crop on newly reclaimed marshes, as it withstands considerable acidity. Red top, bent grass, meadow grass, and alsike clover grow well on damp, sour land; and timothy, rye, oats, buckwheat, potatoes, tomatoes, strawberries, celery, melons, and rice have all shown adaptability to marsh soils. Asparagus, onions, beets, and sorghum are crops that resist considerable salt.

FINANCIAL.

Unreclaimed, the marsh lands have a value of from $1 to $20 per acre, depending upon their location, elevation, and capability of growing salt hay. In general, the values are greater in the more thickly populated North Atlantic States than in the sparsely settled South Atlantic States. Reclaimed, the marsh lands are worth from $20 to $100 or more per acre, varying with the elevation of the land, the character of the soil, and the thoroughness of the development. Probably $50 to $60 per acre would be a fair average value at the present time.

The acre cost of a projected reclamation will of course vary widely with the extent of the land to be protected, the amount of upland drainage, and the length and height of the levee. Under average conditions it may run from $50 to $60 per acre.

SANITARY.

Marshes which are daily submerged by the tide or are so little above high tide as to be frequently covered through moon, wind, or storm influences are not considered prejudicial to health nor dangerous as mosquito-breeding territory. When the marsh becomes so high or its contour is such that flooding is infrequent the deleterious effects become manifest in malaria, chills, fevers, the mosquito pest, and in certain localities, anthrax. Reclamation of land of this character and its utilization for agricultural purposes has seldom failed to abate the harmful influences and to destroy the mosquito nuisance.

REASONS FOR POOR PROGRESS AND CAUSES OF FAILURE.

Why has not greater progress in marsh reclamation been made and what are the causes of numerous failures where it has been tried?

A Massachusetts commission which investigated the matter reported as follows:

> We are fully convinced that the chief obstacles hereto in the way of extensive reclamation on our New England coast have been—
>
> (1) The real value and profit of such improvement is not fully realized or understood.
>
> (2) The lack of practical experience in the art and proper method of reclaiming and subsequent treatment.
>
> (3) The necessity of united and harmonious action on the part of all the owners.
>
> (4) The absence of a plain and practical diking law, easily understood and simply applied, by which the best interests of all the owners are duly protected and promoted.
>
> (5) Want of sufficient capital that can be spared for the purpose by some of the owners of the marshes.

To the above may be added as the principal causes of failure:

(*a*) Lack of cooperation among landowners.

(*b*) Ignorance or disregard of the fact that many marshes, unless renewed by annual deposition of the tide or by allowing them to remain "out" for a term of years, will settle and subside to such an extent that drainage by pumping is the only possible method of relief.

(*c*) Levees of insufficient height, and poorly constructed, protected, and maintained.

(*d*) Sluices of insufficient size and of so poor mechanical construction that leakage to the land becomes a preponderate proportion of the discharge.

(*e*) Ditches so silted and choked with vegetation that adequate drainage of the land is impossible.

IMPORTANT QUESTIONS TO BE DECIDED BEFORE RECLAIMING.

In considering a proposed reclamation, the all-important questions to be decided are:

(1) What is the character of the soil, especially its fertility and depth?

(2) What is the elevation of the land with respect to low tide, and the range of the tide?

(3) What is the area and slope of the land?

(4) How is the land situated with reference to shelter from storm tides?

(5) Is the shore line advancing or receding?
(6) What is the amount and character of the upland drainage?
(7) Can intersecting streams be diverted?
(8) What is the market for the products of the land?

Especial emphasis should be placed on the importance of carefully considered plans and thorough construction in the matter of levees, sluices, ditches, and pumping plants, as much money has been squandered in the past through hasty, ill-advised, and poorly constructed works.

THE DESIGN AND CONSTRUCTION OF DRAINAGE WORKS.

LEVEES.

With due allowance for existing physical conditions, levees should be located well back from the shore line. There is usually along tidal shores a fairly well-defined zone where the marsh has been built highest and where the deposit of new material is thickest and firmest. This should generally be the site of the levee, having in mind also the great value of a wide foreshore for the protection it affords to the levee.

The foreshore should not be less than 100 feet wide and preferably much more, and its rapid building up by tidal deposit should be assisted, when necessary, by the building of groynes or by the spread of vegetation. Instances are numerous where the foreshore is so high that ordinary high tide does not reach the levee at all. Such levees, provided no holes or depressions containing stagnant water are left on either side, are practically exempt from the operation of burrowing animals and the expense of artificial protection is avoided.

Where the sweep of currents and waves comes against a levee, artificial protection is indispensable. All the systems in common use have serious defects. Brush and wood are light, fragile, and short lived; riprap is often expensive, nor does it wholly prevent the burrowing of animals and the washing away of the fine material beneath it; paving is also expensive and unless the blocks are of large size and suitably backed is unequal to the requirements.

In this extremity it is believed that concrete blocks about 3 feet square and 5 inches thick covering the slope from the toe to above ordinary high water would make an ideal protection. Such blocks would weigh between 500 and 600 pounds, could be made at the most favorable location, and after the newly made levee had settled and solidified could be placed on the slope from a scow. This protection would circumvent all the evils which have been mentioned, would intercept considerable seepage, and its cost would be moderate. The top of the levee should be from 1½ to 4 feet, depending upon exposure to severe storm tides or the height of freshets, above the highest known high water. Only in exceptional cases should the top width be made less than 5 feet.

The slopes will vary somewhat with the material, the exposure, and the method of protection. In no case should the inner slope be steeper than will take a good stand of grass and one that can be mowed over with a machine; such slope is probably about 2 horizontal to 1 vertical. The outer slope, unless protected, should be made very flat, for the certain effect of high waves and heavy swells is to batter down a steep bank and cause it to assume the slope and conditions of a natural beach. Waves can be "tired out," but the power of their sweep against a near-vertical face is tremendous. It has invariably been found that a slope is ultimately established up which the waves climb, come to rest through loss of inertia by friction and gravity, and recede with diminished velocity and lessened destructive capacity. This natural slope in a silt-clay mud exposed to moderate wave action is about 3 to 1. With an increased percentage of sand and stronger waves this slope may become 4 or 5 to 1, and pure sand may be laid by severe storms as flat as 6 to 1, or even 10 to 1.

With the improvements which have been made in dredging machinery, dredges afford the only practicable method of levee construction in tidal marshes, excepting the work be of very limited extent and the conditions unusual. Some form of floating dredge is best suited to the work, and the boom should be of such length that a berm of not less than 10 feet can be left along the outer toe.

No specific directions can be given as to the proper allowances to be made for the combined effects of waste, shrinkage of the material in a levee, and settlement beneath the base. The allowance should vary with the character of the material, the method of construction, and the nature of the marsh, but will seldom amount to less than 40 per cent of the material as measured in excavation, and may amount to 80 per cent or more. It is probable that 15 to 20 per cent should be added to the height for shrinkage in the levee if made of clay-silt, and 25 to 30 per cent if composed of muck.

The site should be cleared of all vegetation, stumps, logs, or anything of a perishable nature, and longitudinally furrowed or ditched to secure an intimate bond with the subsoil. If the base can be deepened (which is usually not possible) to a firm, impervious stratum, the stability and worth of the levee are greatly increased. A line of sheet piling or a thin concrete core wall is of great service in cutting off seepage and preventing the operations of burrowing animals.

After the levee has been built and sufficiently dried out and weathered, the slopes should be trimmed and seeded. A grass suited to the latitude and which forms a thick, tough sod should be used. There are numerous soil-binding grasses but Bermuda grass and couch grass are two of the best, the former being used in the South and the latter in the North. Redtop, white clover, and blue grass are also extensively used. Beach or marram grass is the most used of the sand-binding grasses.

DITCHES AND SLUICES.

There is probably very little tidal marsh in the United States so high or so favorably situated that successful gravity drainage ultimately will not call into requisition every artifice of the engineer in reducing the ditch water to the lowest possible level. It is necessary that storm water and seepage should be intercepted by the ditches and delivered promptly to the sluices, and that there should be adequate storage capacity to hold the undischarged drainage at times of excessive precipitation or intermittent sluice action by reason of continued high tides.

To accomplish these ends there must be large storage facilities as near the sluice as possible, and the lateral ditches, especially those far from the sluice, should be designed as carriers rather than storage ditches. This arrangement places the accumulated drainage where it is discharged quickly; the head necessary to move water to the sluice is reduced to a minimum and the discharge head of the sluice correspondingly increased. The small lateral ditches then become real drains and continue their flow toward the reservoir or storage basin for a long time after the gates have closed.

All ditches should be designed to reduce the friction head to a minimum. They should be on direct lines, free from obstructions and vegetation. The quotient arising from dividing the cross sectional area of flow by the wetted perimeter or rubbed surface should be as near a maximum as possible. This condition is geometrically complied with when the form is semicircular and the flow line on the diameter. However, in practice such form would be impracticable and rectangular or trapezoidal sections are necessary. The most efficient width is twice the depth, but since velocities vary not directly but approximately as the square root of the depths, the efficiency is not materially lessened if the width is made three or four times the depth.

From a consideration of numerous marshes and a study of rainfall statistics covering both the Atlantic and Pacific coasts, it would seem that ditches and sluices capable of caring for the run-off of a 3-inch rainfall in 24 hours over the entire drainage area would be fulfilling the conditions of an adequate yet not too costly design. With such a rainfall, actual measurements of run-off, which are confirmed by the known gravitational space of marsh soils, show that provision must be made for the removal of three-fourths of an inch per day over the entire area. This run-off amounts to 2,722 cubic feet per acre per day, but in view of the occasional failure of sluices to play, it is a reasonable and necessary assumption that storage should be provided in the ditches for at least all of this amount. It will also be assumed that the ditch water should not rise higher than 1 foot above mean low water and that at the end of sluice play it will be lowered to within 1 inch of the outside water.

On these premises the ditch area for each acre of land will be 3,000 square feet, or, in other words, about 7 per cent of the land must be given up to ditches. Under an average head of 1 inch, each square foot of sluice opening will discharge 1.5 second-feet, and in one and one-half hours, the period of time a sluice would play with the assumed height of ditch water and a tidal range of 7 feet, would discharge 8,100 cubic feet per operation, or 16,200 cubic feet per day. Since each acre yields 2,722 cubic feet per day, it is seen that each square foot of sluice opening would care for but 6 acres. This would lead to sluices of extraordinary size, and it is highly probable that if built little advantage would be gained for the reason that the high tides which usually accompany a storm make sluice action very uncertain, if indeed it be not entirely eliminated. Since the drainage water is stored in the ditches no harm can be done the land if two or three days, say five operations of the sluice, are required to discharge it, and therefore 1 square foot of sluice opening would protect 15 acres of land.

The table (see fig. 17) has been prepared along the lines above indicated.

In view of the fact that slopes of ½ to 1, or as usually dug by dredge, will, in a silt-clay soil, soon flatten below the flow line to about 2 to 1, reducing the capacity and efficiency of the ditch, it is recommended that the bottom as excavated be made about 9 feet wider than the tabular widths. It will generally be found preferable in large reclamations to use several small sluices rather than one large sluice.

Sluices should be built in the most substantial and workmanlike manner. In important works and where suitable foundations can be secured, mass concrete has many advantages. Reinforced concrete, because of its lightness and ability to withstand tensional and torsional strains, is especially to be recommended. If timber is used it should be antiseptically treated, preferably with creosote (dead oil of coal tar). Wood impregnated with zinc chlorid, corrosive sublimate, or copper sulphate will prove less satisfactory on account of the solubility of these compounds in water.

All hardware should be noncorrosive, preferably of bronze, brass, copper, or galvanized iron.

U.S. DEPARTMENT OF AGRICULTURE —— OFFICE OF EXPERIMENT STATIONS

DRAINAGE INVESTIGATIONS

C.G. ELLIOTT, CHIEF

The Periods that Sluices Play, the Necessary Clear Openings of Sluices and the Minimum Bottom Widths of Main Ditches for Draining Marsh Lands.

Prepared by GEORGE M. WARREN, Drainage Engr.

1910

Land Drained in Acres	Mean Range of Tide in Feet																	
	2		3		4		5		6		7		8		9		10	
	Period Sluice Plays in Hours and Minutes																	
	3-05		2-25		2-05		1-50		1-40		1-30		1-25		1-20		1-15	
	Clear Opening of Sluice in Sq. Ft.	Bottom Width of Main Ditch in Feet	Clear Opening of Sluice in Sq. Ft.	Bottom Width of Main Ditch in Feet	Clear Opening of Sluice in Sq. Ft.	Bottom Width of Main Ditch in Feet	Clear Opening of Sluice in Sq. Ft.	Bottom Width of Main Ditch in Feet	Clear Opening of Sluice in Sq. Ft.	Bottom Width of Main Ditch in Feet	Clear Opening of Sluice in Sq. Ft.	Bottom Width of Main Ditch in Feet	Clear Opening of Sluice in Sq. Ft.	Bottom Width of Main Ditch in Feet	Clear Opening of Sluice in Sq. Ft.	Bottom Width of Main Ditch in Feet	Clear Opening of Sluice in Sq. Ft.	Bottom Width of Main Ditch in Feet
25	.9	1	1.1	1	1.3	1	1.4	1	1.6	1	1.7	1	1.8	1	1.9	1	2.1	1
50	1.7	1	2.1	1	2.5	1	2.8	1	3.1	1	3.4	1	3.6	1	3.8	1	4.1	1
75	2.5	1	3.3	1	3.7	1	4.2	1	4.6	1	5.1	1	5.4	1	5.7	1	6.1	1
100	3.3	1	4.2	1	4.9	1	5.5	1	6.1	1	6.8	2	7.2	2	7.6	2	8.1	2
200	6.6	2	8.4	2	9.7	3	11.0	3	12.2	3	13.5	4	14.3	4	15.2	4	16.2	5
300	9.9	3	12.6	3	14.6	4	16.5	5	18.2	5	20.2	6	21.4	6	22.7	6	24.3	7
400	13.1	4	16.7	5	19.4	5	22.0	6	24.2	7	26.9	7	28.5	8	30.3	8	32.3	9
500	16.4	5	20.9	6	24.2	7	27.5	7	30.3	8	33.6	9	35.6	9	37.8	10	40.4	10
600	19.7	5	25.1	7	29.1	8	33.0	9	36.3	10	40.4	10	42.8	11	45.4	12	48.5	12
700	22.9	6	29.2	8	33.9	9	38.5	10	42.4	11	47.1	12	49.9	13	53.0	13	56.5	14
800	26.2	7	33.4	9	38.8	10	44.0	11	48.4	12	53.8	14	57.0	14	60.5	15	64.6	16
900	29.5	8	37.6	10	43.6	11	49.5	13	54.5	14	60.5	15	64.1	16	68.1	17	72.7	18
1000	32.7	9	41.7	11	48.4	12	55.0	14	60.5	15	67.2	17	71.2	18	75.6	19	80.7	20
1200	39.3	10	50.1	13	58.1	14	66.0	16	72.6	18	80.7	20	85.5	21	90.8	22	96.9	23
1400	45.8	12	58.4	15	67.8	17	77.0	19	84.7	21	94.1	23	99.7	24	105.9	25	113.0	27
1600	52.4	13	66.8	17	77.5	19	88.0	21	96.8	23	107.6	26	114.0	27	121.0	29	129.2	30
1800	58.9	15	75.1	19	87.2	21	99.0	24	108.9	26	121.0	29	128.2	30	136.1	32	145.3	34
2000	65.4	16	83.4	20	96.8	23	110.0	26	121.0	29	134.4	32	142.4	33	151.2	35	161.4	37
2500	81.8	20	104.3	25	121.0	29	137.5	32	151.3	35	168.0	39	178.0	41	189.0	43	201.8	46
3000	98.1	24	125.1	30	145.2	34	165.0	38	181.5	42	201.6	46	213.6	48	226.8	51	242.1	55
3500	114.5	27	146.0	34	169.4	39	192.5	44	211.8	48	235.2	53	249.2	56	264.6	60	282.5	64
4000	130.8	31	166.8	39	193.6	44	220.0	50	242.0	55	268.8	60	284.8	65	302.4	68	322.8	72

Fig. 17—Showing the periods that sluices play, the necessary clear openings of sluices, and the minimum bottom widths of main ditches for draining marsh lands.

The gate and its seat demand special attention. The link-hinge allows the gate to adjust itself to the seat, which should have a rubber or other resilient lining or cushion. To protect the gate and seat from the gnawing of animals or the depredations of passers-by, it is recommended that it be set within a chamber or large manhole near the center line of the levee and both the outer and inner ends of the sluice covered with suitable metallic bar screens. This position and protection of the gate would also insure its exemption from obstruction and interference by floating débris and ice.

To obviate cofferdam work with the attendant expense when renewals or repairs on the gate are made, it is suggested that each end of the sluice be fitted with two or more permanent vertical grooves or guides, so that stop planks may be tightly placed over the ends, and the imprisoned water inside the sluice pumped out through the chamber or manhole, which should be surmounted with a suitable wooden or iron cover equipped with padlock.

Not less than two "cut-off" lines of strong tongued and grooved sheet piling should be driven under the sluice and carried well into the levee on both sides to prevent seepage or "blow outs" under or along the sides. The weakest point in a levee is apt to be at the sluice, but if the sheet piling is driven deeply into the mud or to an impervious stratum, little apprehension need be felt.

For the purpose of counterbalancing heavy gates that they may swing under slight pressure, several devices have been employed, but there is probably none in use which is not open to more or less objection. Complete submergence of the gates greatly lessens the need of any counterbalancing mechanism. Gates of the "barn door" or "canal lock" pattern have been extensively used abroad and to some extent in this country. They are best adapted to tidal streams draining large areas and where it might be desirable to pass small boats. The closing of these gates by the rising tide is liable to be accompanied by so much shock as to damage the gate or fastenings. They are believed to be growing in disfavor in this country and unsuited to the conditions of our present comparatively small reclamations.

DRAINAGE BY PUMPING.

GENERAL OBSERVATIONS.

In many localities the small tidal range and naturally low elevation of the marsh and at other places the large subsidence of the land render gravity drainage impossible and the water must be removed by pumping. It is not the purpose here to give explicit information regarding the design of pumping plants, for each reclamation requires special study and treatment.

The questions of rainfall, evaporation, seepage, use to which the land is to be put, fuel supply, and capacity and type of machinery which shall properly balance operating expenses and interest and sinking fund requirements are matters which should receive the consideration of engineers experienced in the design and installation of pumping machinery. There are, however, certain general observations more or less applicable to all projects of this character.

The plant should be located near the natural drainage outlet, upon a substantial foundation, and where fuel may be landed cheaply. The machinery should be suitably housed, preferably in a fireproof building, and should be devoid of any unnecessarily complicated parts.

The head pumped against should be as small as practicable, and this can be accomplished by the use of a check valve in the discharge pipe, by laying the discharge pipe so that siphon action will take place therein, or by pumping through a sluice and not over the top of the levee. If 7 per cent of the marsh area is in ditches, as previously recommended, it will seldom be found that pumps capable of removing 900 cubic feet per acre per working day of eight hours (this is one-fourth of an inch in depth) are inadequate for the complete drainage of cultivated lands.

Many contend for continuous pumping. We believe this is inadvisable under ordinary circumstances. A plant intended for continuous running at times of large precipitation is without reserve capacity for emergencies, and the strain on machinery and men can not be ignored. In large works where the machinery is in duplicate and reserve crews available, the advantage of diminishing the size of plant and lengthening the hours of pumping is increased.

PUMPS.

Various styles of pump have been used at different times both here and abroad. Some form of centrifugal pump is probably best adapted to drainage work. Essentially, this pump consists of a shell containing a revolving runner or propeller, water entering the runner in the center and delivering by centrifugal force at its periphery into the receiving-pump shell. It is very simple, the revolving runner and shaft being the only working parts, and the discharge is continuous. The centrifugal pump is compactly built, does not require heavy foundations, may be belt driven or direct connected, and its cost is moderate.

The submerged type of centrifugal pump has a vertical shaft, the impeller being below the surface of the water to be raised. There is no suction pipe to cause friction and it is always primed. Against it are the difficulties of inspection and repair, and it must be driven with a twisted belt or by bevel gears and jack shaft. Belt drive is unsatisfactory and uneconomical.

The more common type, the horizontal centrifugal, consisting of a rotating vertical impeller on a horizontal shaft, is placed above the water to be raised. For low or moderate lifts of large quantities of water, and where the head is changing, both of these types are very satisfactory. The efficiency will range from 30 per cent in the smaller sizes to 50 or 60 per cent in the medium, and may reach 75 per cent or more in the larger sizes, which are specially designed. The pump should be set near the water to be raised and the suction pipe should be absolutely air tight, with few elbows, and laid so as to avoid air pockets. Before starting, the pump must be completely filled with water or primed. The small sizes can be primed with a hose or by pouring water into the opening at the top of the shell or with a hand primer. In larger sizes than 8-inch it is desirable to prime with a steam ejector, and for this purpose either the discharge pipe must have a check valve or the suction pipe a foot valve. To prevent damage to the pump in freezing weather, it should be drained after using unless properly housed. In the table below are given the size, capacity, and horsepower for ordinary centrifugal pumps with medium length of suction and discharge pipe and based on a velocity of 10 feet per second in the discharge pipe and efficiencies ranging from 30 to 60 per cent:

Data of small centrifugal pumps.

Diameter in inches.		Capacity in gallons per minute.	Horse-power required for each foot of lift.
Discharge opening.	Suction opening.		
1½	2	55	0.05
2	3	98	.08
2½	3½	153	.13
3	4	220	.18
4	5	391	.25
5	6	612	.38
6	8	882	.50
8	10	1,567	.78
10	12	2,448	1.22
12	15	3,525	1.62
15	18	5,508	2.75
18	20	7,931	3.60
20	22	9,792	4.45
24	24	14,100	5.88

A type of pump used in the Southern States consists of a vertical centrifugal pump within a wooden casing. There is no suction or discharge pipe, but the movement of the impeller causes the water to enter the casing through openings near the bottom and, rising with slight friction, to escape through large openings at the desired height into the outfall canal. Pulley, shaft, bearings, and impeller are the only metal parts, and it is therefore a low-cost pump. It is well adapted to large quantities of water and low lifts, but lacks the durability of all-metal pumps.

The rotary pump has been used to some extent and is more efficient than the centrifugal, but it is heavy and being geared directly to the engine shaft requires foundations that permit of no settlement.

POWER.

The power to be used must depend upon local conditions; steam, oil, gasoline, gas producer, alcohol, electricity, and wind have been used.

The cost of pumping by windmills is very low, but the uncertain character of this power and the small size and duty of the mills found in the United States eliminate this source in all large or important plants. As an auxiliary it may be made very useful.

Pumping by electricity has in numerous cases proven advantageous. The efficiency, cleanliness, noiselessness, and simplicity of electric pumping, together with the small foundations and compact plant, make this method very attractive. Where electricity must be purchased the cost of pumping is likely to be high.

Alcohol engines have not been developed as yet to the point where they are successfully competing with those of other types, but with the lapse of time there is good reason to believe the competition will be stronger and more successful. The source of the fuel is inexhaustible, and its storage, handling, and use in internal combustion engines is not dangerous or unclean. There is no tendency for the interior of the engine to become sooty, and the odor of the exhaust is not offensive. Alcohol engines develop more power than gasoline or oil, but this increase is at the expense of greater consumption of fuel.

Gas-producer plants are unsuccessful for intermittent work and for sizes under 25 horsepower.

Gasoline and oil engines have long since passed the experimental stage. The advantages over steam are a saving in the first cost through absence of chimney, boiler house, coal shed, and large engine room, less attendance required, quick starting and stopping, and general adaptability to intermittent service.

Gasoline must be stored in metal tanks beneath ground to prevent loss by evaporation, and it is highly inflammable and explosive. Gasoline plants are generally less efficient than either steam or electric plants and the depreciation is higher. The fuel cost at 15 cents per gallon is about 1.7 cents per horsepower per hour. This is higher than in steam or gas-producer plants, but less than in alcohol.

Oil engines using crude or fuel oil, though costly, are splendidly adapted to small or medium-sized drainage operations. The fuel is

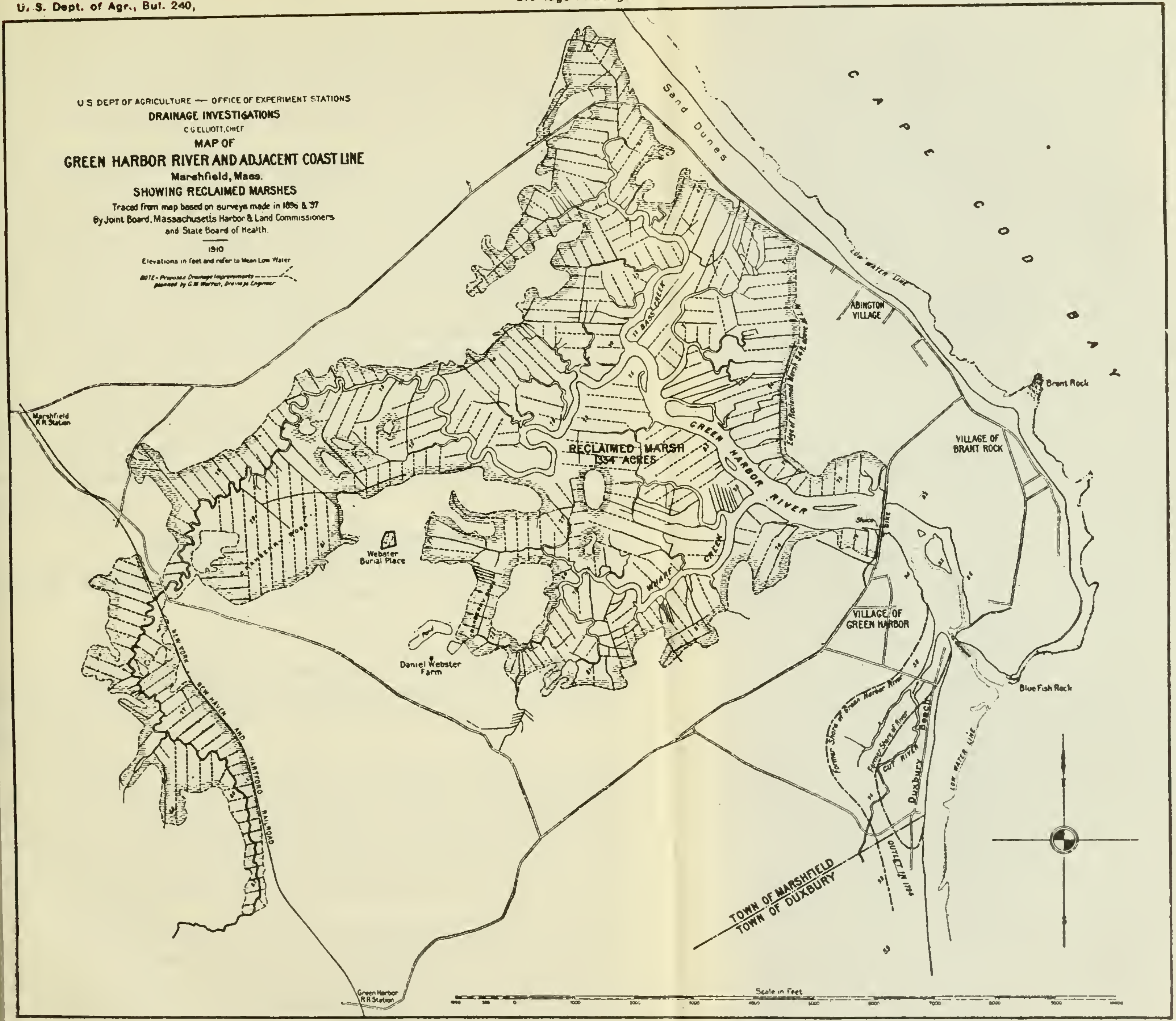

Fig. 18.—Map of Green Harbor River and adjacent coast line, Marshfield, Mass., showing reclaimed marshes.

safe and economical, and no licensed attendant is required in operating the plant. If the engines are properly installed and handled, the exhaust is not objectionable, nor does the cylinder become sooty. The beginning and end of the run should be made on kerosene. At 4 cents per gallon the fuel cost is about 0.7 cent per horsepower per hour.

Steam is an old and dependable power. In very large reclamations it continues to have the preference. Perhaps the most economical plan, where it is necessary to maintain a number of isolated pumping units, is to generate electricity at a central power house and install electric pumps at the several substations. Small steam plants, however, are very wasteful of fuel and ill adapted to the intermittent character of drainage pumping. The large initial cost in foundations, settings, and appurtenances, the high grade of mechanical ability demanded of the pumping engineer, and the constant and close attention necessary in steam plants render their operation unsatisfactory and uneconomical for ordinary drainage work. Where well-designed plants have been installed artificial drainage has proven less expensive than might be supposed, the annual operating expenses on large areas in England being surprisingly low.

SUPPLEMENTAL INVESTIGATIONS.

MARSH LANDS AT GREEN HARBOR, MARSHFIELD, PLYMOUTH COUNTY, MASS.

HISTORY AND DESCRIPTION.

The largest and best-known reclaimed salt marshes on the New England coast are situated at Marshfield, Plymouth County, Mass., about 30 miles southeast of Boston and 10 miles north from Plymouth.

The history of this reclamation is unique, and no description should omit the salient facts covering a period of more than 100 years. The reclaimed marsh comprises an area of 1,334 acres situated in the southeast part of the town of Marshfield, and formerly drained by a small tidal stream known as Green Harbor River. This river, the reclaimed marsh, adjacent uplands, and coast lines are shown in figure 18.

In 1794 the mouth of the river was about five-eighths of a mile south of the present outlet, but not long previous to May, 1806, a violent storm closed the former mouth with sand and converted the marshes into a lake. For a period of four or five years following the latter date, the old outlet remained sealed and the agricultural value of the marsh was temporarily destroyed. In the latter part of 1810 or early in 1811 another violent storm opened a new channel through the beach at substantially the location of the present mouth, though there is evidence to show that the breach had artificial assistance. In 1812 it was said that this channel at high tide would float a 100-ton vessel.

In June, 1826, the inhabitants of the town petitioned the legislature for an act or law to preserve and secure from damage the whole of Marshfield Beach, alleging that the mouth of the river had of late years been in a shifting and uncertain state, being at one time choked by a sand bar, and at another time so open that not only was it difficult to cut the salt hay on the marshes but that storm tides took the greater portion of the stacks of hay off the staddles and carried them on to the uplands and into the adjacent swamps.

In February, 1827, legislative authority was granted the people to build and keep in repair a sea wall, palisades or hedge fences, but whatever work was done under the act is not now certain.

About 1870, when the reclamation of the marshes was being considered, certain investigations relative to the harbor were made under the direction of the United States Coast Survey, and in the report, which was prepared, is found the following statement:

> As a small local harbor it also has some character. Once within the mouth of the river, a small vessel would find good anchorage, sufficient depth of water and complete shelter. The entrance, however, is shoaler than the river within, and really can not be called navigable at low water. As a harbor of refuge it will probably never be of use except by the local fishing boats and small pleasure yachts of the immediate neighborhood.

Up to this time there had never been a way of crossing Green Harbor River except by boat. From the village of Green Harbor on the south side to the village of Brant Rock on the north side was about 7 miles by road, while in a direct line across the river it was about three-fourths of a mile. Better facilities were needed. Two methods were projected and earnestly advocated. One was to build a bridge a short distance above the mouth of the river; the other to build a dike and road in connection therewith at a point farther up the river.

On February 19, 1870, the legislature passed a law authorizing the county commissioners of Plymouth County to construct a bridge with a draw across Green Harbor River at a point not less than 2,000 feet above the mouth.

On May 17, 1871, the legislature passed a law authorizing the proprietors of Green Harbor marsh to erect a dam and dikes at or near Turkey Point, so-called, with one or more sluiceways and gates for the purpose of draining the marsh, improving the same, and preventing flowage from the sea. The act also provided for the organization of the marsh owners as "proprietors of general fields," and for the appointment of a commission to execute the work, which commission was authorized to contract with the county commissioners of Plymouth County for the erection of a highway bridge and dam without a draw. The act further provided—

> should shoaling take place above the level of mean low water in the channel of Green Harbor River, and its approaches below the dam and dike in consequence of the construction of said dam and dike, said shoaling shall be removed by the proprietors of Green Harbor marsh under the direction and to the acceptance of the board of harbor commissioners. And if the proprietors of said marsh shall fail to remove said obstructions in six months after due notice from said commission, then said commission shall cause the obstruction to be removed at the expense of said proprietors.

The bill, without any conditions or stipulations as to shoaling, was unanimously reported by the joint committee on agriculture and also by the joint committee on harbors and met little opposition in either branch of the legislature, but the petitioners for the bill were induced and agreed that the fourth section—that relating to shoaling—might be added.

Pursuant to the provisions of the act, commissioners were appointed by the superior court at its June term, 1871. This commission was headed by Clemens Herschel, civil and hydraulic engineer, now of New York, who during the year 1870 had made surveys and investigations for the interested marsh owners. Mr. Herschel's report to the marsh owners was dated January 28, 1871. It recommended a dike having a top width of 4 feet, inside slope 1½ to 1, outside slopes varying from 1½ to 1 to 3 to 1 at the bottom, and a height of 8¼ feet above the level of the marsh, or 2½ feet above the storm tide which destroyed Minots Ledge lighthouse in 1851. The material was to be deposited in horizontal layers, each rolled and rammed. The sluice was to be of timber construction and have two flumes, each 4 feet square. The total estimated cost was $14,536.50. The report states that "the marshes are all high marshes and are on a plane of about 8¾ feet above mean low water."

During the summer of 1871 the commissioners endeavored to negotiate with the county commissioners of Plymouth County to secure their cooperation in the building of a dike which should have a roadway on its top or along its shelter, but were unsuccessful, and finally decided to proceed independently.

In June, 1872, the commissioners, having received bids which were unsatisfactory, resolved to do the work by day labor, though subsequently several contracts were made for parts of the work.

On November 1, 1872, in making the final closure in the current of the river, there was a "blow-out" beneath the 70-foot timber apron, which had been laid and weighted with stone and gravel. On a low ebb tide the imprisoned water in the marshes cut away 14 feet in depth of mud beneath the apron and canted the pile foundation downstream. This unfortunate, but not rare, occurrence added greatly to the cost and delayed the completion of the dike until July 1, 1873. The total actual cost was $32,261.68.

Following the building of the dike came certain changes in the harbor. While it is of course impossible to determine to just what extent the dike is responsible for these changes, since the history of the river shows that changes were taking place many years before the marshes were reclaimed, yet the evidence is conclusive that with the upper reaches of the river cut off there was a diminished tidal scour which facilitated the deposition in the harbor below the dike of the shifting sands brought in by the sea. These changes have undoubtedly been an injury to the fishing interests of Green Harbor, and the dike itself has been a disappointment to the interests which in 1870 had petitioned for a bridge. With the lapse of time much feeling and bitterness has arisen between the two factions, composed respectively of those in favor of the dike and of those who opposed it and desired its removal. Five attempts have been made to blow up the sluice or dike.

In 1875 petitions were presented to the Massachusetts harbor commissioners alleging that shoaling had taken place and asking for relief. The board, with its engineers, visited the harbor, and in its tenth annual report said:

> Shoaling has undoubtedly taken place both in the channel and its approaches above mean low water. Natural causes have contributed to this shoaling to some extent, and it would not be practicable to separate with precision the results of natural causes from the results of the dike, but it is clear that what has occurred must be mainly attributed to the dike.

After further surveys, which confirmed the board's opinion as to the responsibility of the dike, an order was issued directing the removal of the accumulation, but nothing was done.

On May 11, 1877, the legislature passed an act authorizing the supreme judicial court sitting as a court of equity to hear and determine the rights of all parties under the original act of 1871 and authorizing the attorney general, under certain conditions, to compel any and all parties liable to remove shoaling or other obstruction, and on May 9, 1878, appropriated $2,000 to enforce the provisions of the original act.

In 1879 the dike was widened by the town at an expense of about $3,000 to carry the road from Green Harbor to Brant Rock. This road is now a county road.

On May 7, 1881, the act of 1870, authorizing a bridge over Green Harbor River, was repealed. On May 22, 1888, an act was passed authorizing the county commissioners of Plymouth County, whenever a majority of the legal voters of Marshfield present and voting should request them by a vote so to do, to construct a bridge with a draw not less than 2,000 feet above the mouth of the river.

June 5, 1896, an act was passed requiring an examination by competent engineers representing a joint board, consisting of the harbor and land commissioners and the State board of health, into the condition of Green Harbor, the marshes, and dike, and the feasibility of the removal of the dike, and $12,000 was appropriated for the investigation. Very careful surveys and investigations were made under the direction of Messrs. F. W. Hodgdon and X. H. Goodnough, chief engineers, respectively, of the Massachusetts Board of Harbor and Land Commissioners and the State board of health. The expense of the work was $9,645.62. The findings of the joint board were that the dike should not be removed; that the increased volume of the ebb tide due to the subsidence of the marsh would create a tidal scour greater than any formerly known and cause the washing away and destruction of considerable property, including 25 cottages and a hotel; that submergence of the marsh by salt water would destroy the existing vegetation and convert the land into foul mud flats to the detriment of the health and attractiveness of the neighborhood; that the damage to vested property rights would be far greater than the benefit to the harbor; and that in dollars and cents the dredging of an anchorage basin with channel thereto with two jetties and a training wall, all at an estimated cost of $67,000, would be less costly than the removal of the dike, estimated to cost $27,200, plus $40,000 for necessary jetties and training wall, plus $12,000 for land, cottages, and hotel likely to be washed away, a total of $79,200, exclusive of damage to the reclaimed marsh, which at the assessed valuation would probably amount to about $29,000.

On May 26, 1898, the legislature passed an act authorizing the harbor and land commissioners to expend a sum not exceeding $67,000 for anchorage basin, channel, jetties, and training wall in accordance with the report of the joint board, and on May 29, 1899, $37,000 additional was appropriated. The stone jetties, extending from the shore into the sea on each side of the entrance channel to a point where there was a depth of 6 feet at mean low water, were commenced late in 1898 and completed in September, 1899, and a timber training wall was built across the mouth of Cut River to deflect the ebb current from this branch and keep its flow in line with the current from the main harbor. During 1900 a channel 60 feet wide on the bottom and 5 feet deep at mean low water, with an anchorage basin 300 feet square at its inner end just inside the Narrows, was dredged, 92,000 cubic yards of material being excavated and deposited at sea. Observations in 1901, 1902, and 1904 showed that shoaling within the channel and anchorage basin was still in progress; in 1901 there was a depth of 2 feet in the channel at mean low water, and in 1902 it had been reduced to about 1 foot.

On June 2, 1904, $10,000 was appropriated for further dredging at the discretion of the harbor and land commissioners, but it was decided inadvisable to do any more dredging until the southwesterly jetty had been built up to a sufficient height (this jetty was built upon soft sand and had settled considerably) to prevent the sand from being driven by wind and wave over the jetty and into the channel.

On June 4, 1908, the legislature passed an act authorizing the board of harbor and land commissioners and the State board of health, acting jointly, to examine the harbor, dike, and marshes to determine the feasibility of restoring the harbor to its conditions prior to the construction of the dike by the removal of the dike in whole or in part or by placing therein sufficient tide gates or otherwise. As before, the investigation was conducted by Mr. Hodgdon and Mr. Goodnough; the expense was $1,227.34. The joint board in its findings, as did the previous joint board, believed it inexpedient to remove the dike and further said:

> The experiment of reclaiming the marshes above the present dike has been costly to the Commonwealth, of slight benefit to the marsh owners who built the dike, and a source of undoubted injury to this small harbor. The relief, however, from this injury can not, in our opinion, be obtained by removing the dike, because the level of the meadows as they now exist above the dike is so low that, if the dike were removed, a tidal scour would be established in Green Harbor capable of destroying much valuable property and creating a serious nuisance to the whole neighborhood.

The engineers developed two plans to secure the ends sought. Plan 1 was for the control of the dike by the State, the building therein of six masonry sluices with operating gates, utilizing the storage capacity of the river and main tributaries above the dike up to grade 5 or possibly to grade 6 in winter, and permitting the escape of this impounded water on the ebb tide in such quantities and at such times that its scouring action would remove existing deposits and prevent further accumulations. With a capitalization of $25,000 for superintendence and maintenance of sluices this plan was estimated to cost $82,200.

Plan 2 did not disturb the dike but provided for the dredging of a channel 100 feet wide on the bottom, 7 feet deep at mean low water from the sea to the Narrows, the excavation of the whole area of the harbor from the Narrows to the dike to a depth of 5 feet at mean low water, and reconstruction of the southwesterly jetty together with pile and timber fence. This plan was estimated to cost $158,900. The joint board made no recommendation as to the expediency of the necessary expenditure in connection with either plan. The total expenditures to date, November 30, 1910, by the State amount to $76,333.26, which includes construction and investigational work.

Green Harbor River has a total drainage area of about 7.5 square miles, while the tributary drainage area at the dike is 6.9 square miles. The upland watershed is covered with scattered farms and woodland. The reclaimed marsh comprises 1,334 acres below the level of ordinary high tide and a total of 1,696 acres below the level of the very high tides reached several times in the course of a year. In a direction perpendicular to the coast line the marshes are about 2½ miles in length and parallel the sea for about 1¾ miles. They are separated from the sea by a narrow strip of land from 600 to 3,000 feet in width, consisting partly of two upland areas, the sites of the villages of Brant Rock and Abington Village, and partly of shingly, sandy beaches and sand dunes. Both of these villages are summer resorts and have few permanent residents. South of the river are the villages of Duxbury Beach and Green Harbor, the former a summer resort and the latter a small all-the-year village inhabited principally by fishermen. The permanent population of the region about Green Harbor is small, probably not far from 200, while in summer the temporary residents number several thousand. Near the center of the reclaimed marsh is the farm formerly owned by Daniel Webster and near by the burial place of the Great Expounder.

TIDES.

The mean range of the tide is about 9.4 feet, and the high tides which may be expected several times a year reach 3.6 feet higher, or to about elevation 13. The great storm tides, April, 1851, when Minots Ledge lighthouse was destroyed, and November, 1898, when the steamer *Portland* with all on board were lost, probably reached to about elevation 14.5. It is known that the latter storm overtopped a portion of the dike and scoured a 50-foot breach down to the level of the marsh, and also broke through the sand dunes separating the marsh from the sea at several points, carrying sand, gravel, and débris on to the meadow. The hardest storms come from the northeast, but without any considerable shoaling at the harbor entrance, because of the protection afforded by Bluefish Rock and the adjacent headland, a natural riprap of bowlders. South of the entrance stretches a sandy beach 6 miles in length to Gurnet Point. The harbor opening widely to the south and southeast is the natural receptacle for the sand caught up by the wind and wave of southeasterly storms along this 6-mile stretch of beach. Glimpses of the contest between these two forces, the wind, wave, and flood tide on the one side, and the varying ebb tide on the other, together with man's efforts to establish equilibrium between them, have already been given.

DRAINAGE CONDITIONS.

Drainage has been secured mainly by the natural river with its tributary creeks. Considerable ditching has been done, but it has not been systematic nor general, nor have the ditches been well maintained. At the dike the river is about 500 feet in width; at Wharf Creek, 2,200 feet above the dike, the river is 350 feet in width; near Bass Creek, about 1 mile from the dike, it is 125 feet in width; above this it narrows gradually until at the highway and railway bridges it is a very narrow stream, and the flow ordinarily feeble. Through the greater body of the marsh the bed of the river and of Wharf and Bass Creeks are below the level of mean low water. At the highway bridge the bottom is about 4 feet above mean low water. The surface of the water in the river is practically level for a distance of over 3 miles from the dike, but above that point the gradient rises quite rapidly. From the investigations made during the summer and fall of 1908 it appears that the interior water was generally between elevations 3.75 and 4, substantially the same as in 1897. Below the dike the conditions were very different, for where in 1897 the surface of the water was held by sand bars or shoals at elevation 3.5 at low tide, in 1908 it averaged about elevation 1.6, or nearly 2 feet lower. These figures demonstrate one or both of two conditions. Either the leakage of the sluice to the land has increased tremendously since 1897 or else the sluice opening is too small for the tributary drainage area. There is evidence that both conditions obtain. Below the dike the discharge from the sluice is apparently maintaining a basin or channel which, starting with a depth of about 4 feet below mean low water near the gates, gradually shoals in a distance of 650 feet downstream to about 1 foot below mean low water.

SOIL.

The reclaimed marsh is not now receiving, nor has it received for many years in the past, any considerable amount of deposit either from the uplands or the sea. The top 6 to 12 inches is generally turf, beneath which is a layer of muck or peat from 1 to 3 feet in thickness, the peat predominating in the upper part of the marsh where poor drainage has retarded decomposition. Near the larger creeks and adjacent to the sand dunes on the narrow barrier toward the sea there is a considerable percentage of sand. Beneath the 2 to 4 feet of soil, which is largely of vegetable origin, is a stratum of blue silt clay from 3 to 6 feet in thickness overlaying a firm sand bottom. The average depth to the sand bottom is about 8 feet, but at several places is from 20 to 25 feet. As would be expected in a soft, spongy, muck or peat soil, there has been a considerable and rapid shrinkage or subsidence of the marsh following reclamation, and the large amount of investigational work which has been done on the Green Harbor marshes affords reliable figures as to the amount of this settlement.

Mr. Herschel states in his report of 1871 that the marshes are " on a plane of about 8¾ feet above mean low water." This is well confirmed by the testimony of old residents who say that the marsh was formerly about at the level of ordinary high water but was submerged a foot or more by spring tides, and also by levels taken in 1897 by the engineers of the joint board. They found the unreclaimed marsh just below the dike to have an average elevation of about 9.1 feet in 1897. The interior lands at the latter date were generally between elevations 7 and 7.5. It is apparent, therefore, that in a period of 24 years the subsidence has amounted on the average to about 20 inches, or at the rate of about 0.8 inch per year. In 1908 further leveling showed that the subsidence in 11 years had amounted to from 0.2 to 0.4 foot, or at the rate of about one-third of an inch per year. In 35 years following the completion of the dike the average settlement over the marsh has, therefore, been just about 2 feet. It is well known that certain areas have settled much more than this and others considerably less. The shrinkage of the soil is of course mainly due to the decomposition of the vegetable matter therein. The small roots and fibers contained in samples of the soil from the reclaimed marsh were generally much discolored and decomposed, while in samples from below the dike they were bright and in a state of vigorous growth. Tests made in 1897 by the State's engineer indicated that flooding the shrunken soil would not cause the surface of the meadows to rise appreciably. Chemical examinations also showed that the water entering the marsh at the upper end contained only about 3 parts of chlorin per 100,000; that the water of the sea contained about 1,740 parts per 100,000, and that from samples collected near the bottom of the river and main creeks the latter was generally about 70 per cent sea water. Much of the turf and muck soil had a specific gravity less than that of water.

DIKE AND SLUICE.

The dike is situated about 3,600 feet from the present mouth of the river at a place where the uplands approaching on both sides narrow the stream to about 500 feet in width. The top of the dike is about 22 feet wide and 1,600 feet long, and its average elevation 14.6 feet above mean low water. It is stated that a line of sheet piling was driven across the river and surrounded by a filling of stones, gravel, and marsh soil, built out from the upland on each side. The outer slope averages about 2½ to 1 with a facing of large and small bowlders roughly placed. The sluice is 65 feet long by 9.3 feet wide, outside dimensions. It has two flumes, each 4 feet high and 3.5 feet wide inside, although the clear opening is reduced by the thickness of the 4-inch upright timbers spaced about 4 feet apart along the inner sides and which sustain the side walls and partition. The top is 6-inch plank. The floor of the sluice is about 1.6 feet above mean low water and is practically level. Each flume has two automatic tide gates, one on the outer end of the sluice and one within but near the inner end. It is said that at the inner end of the sluice there were formerly two gates to be operated by hand and intended to control the level of the interior water, but these have disappeared, leaving only the decaying framing timbers. (See Pl. XI, fig. 1.) The sluice is in poor repair, and is leaking very badly. Observations made by the engineers of the joint board of 1896 showed that the leakage amounted to about 150,000 cubic feet at each tide, and it is stated to have increased since that time. The actual cost of dike and sluice in 1872 was as follows:

Cost of dike and sluice.

Land, gravel, and stone	$2, 435. 20
Lumber and piles	2, 842. 46
Bolts, rods, spikes, etc	570. 41
Labor	3, 941. 79
Pile driving	3, 647. 70
Gravel filling (two contracts)	12, 049. 01
Sluices and tide gates	1, 520. 64
Sundry expenses	960. 84
Interest account	1, 131. 71
Legal expenses	582. 00
Salary of commissioners and collector's fees	2, 579. 92
Total	32, 261. 68

There was received for interest on deposits and petty sales, $170.89. In 1879, $3,000 was expended in widening the dike and making a road along the top.

CROPS.

The uses to which the reclaimed marsh was being put in 1897 and 1908 were, approximately, as follows:

Crop acreage for marsh lands at Green Harbor, Mass.

	1897	1908
	Acres.	*Acres.*
Hay and pasturage land	630	750
Cranberry bogs	25	100
Reservoir for flooding bog	16	....
Truck and seeded areas	2	47
Unimproved and partially wooded	660	430

In October, 1910, the cranberry bogs were estimated at 125 acres, and the average yield was about 60 barrels per acre. The berries were

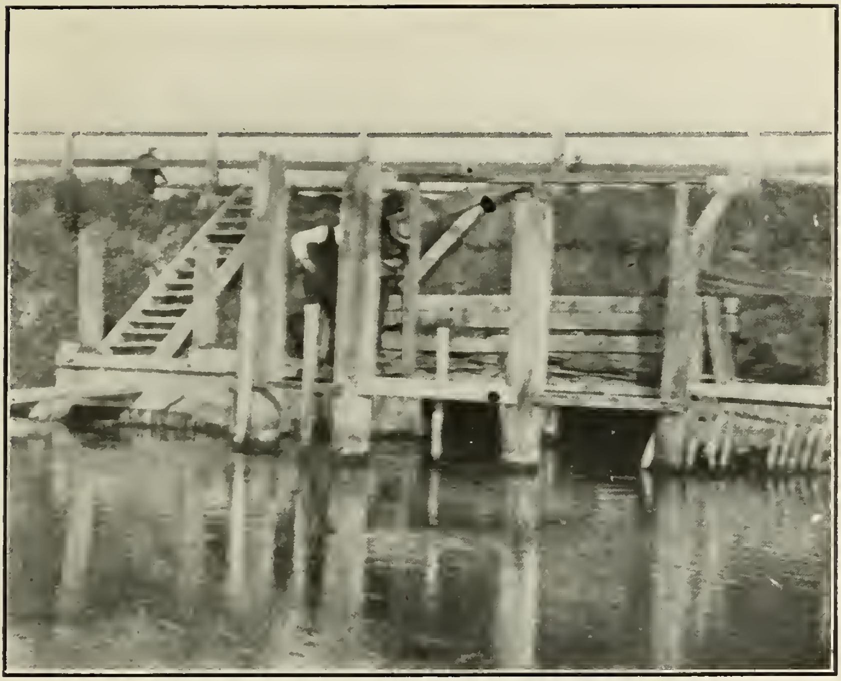

FIG. 1.—DIKE AND LAND END OF SLUICE AT LOW TIDE.

FIG. 2.—JAPANESE MILLET GROWN ON LAND ABOUT 7 FEET ABOVE MEAN LOW WATER.

MARSH LANDS AT GREEN HARBOR, MASS., SEPTEMBER 9, 1910.

large and of excellent quality and for a series of years should net a yearly profit of not less than $135 per acre. Timothy, redtop, Japanese millet (see Pl. XI, fig. 2), corn, onions, squashes, and rhubarb have all yielded splendidly the present season without fertilizer of any kind. Oats, rye, asparagus, and strawberries have been raised with pronounced success.

In 1909 Dr. Stephen Henry tried the following experiment upon a 2-acre piece of marsh. The land was divided into 4 plats of one-half acre each. The first plat was given 200 pounds of ground bone; the second plat, 100 pounds of sulphate of potash; the third plat, 200 pounds of ground bone and 100 pounds of sulphate of potash; the fourth plat had nothing. On June 10 the four plats were planted to corn and harvested in the middle of October. There was no apparent difference in the yield of the four plats. In reseeding a field Dr. Henry breaks the land and puts on 6 or 8 casks of stone lime, placed in heaps at convenient distances, per acre. The lime is then slaked and spread with a shovel. This application is good for three years. The first and second years the yield of timothy and redtop is a strong 2 tons per acre, but the timothy gradually runs out and the third year the yield is not quite as good. A measured acre has produced 6,800 pounds of hay in a season, and another acre 34 bushels of rye and 5,454 pounds of straw. Dr. Wm. P. Brooks, director of the experiment station at Amherst, Mass., states in a recent publication:[1] "The best redtop that the author has ever seen in any part of Massachusetts was produced on the reclaimed salt marshes in the town of Marshfield."

FINANCIAL.

From such information as is available it appears that prior to reclamation the salt marsh was assessed for about $12 or $13 per acre. In 1888 1,054 acres were assessed for $24,635, the valuations ranging from $13 to $32 per acre, but averaging $23.37. In 1895 1,031 acres were assessed for $22,335, an average of $22.63 per acre, and in 1908 1,000 acres were assessed for about $30,000, an average of $30 per acre. The market value of the improved areas at the present time is from $80 to $100 per acre, and the cranberry bogs would probably run up to several hundred dollars per acre. Reliable statistics as to the revenues from the fishing interests of the harbor are not at hand, but it is estimated that during the 1909 season at least $15,000 worth of lobsters were caught, besides a considerable quantity of fish.

CONCLUSION.

The reclamation at Green Harbor is one of great natural opportunity. There are few localities where 1,600 feet of dike will pro-

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[1] Report of the Massachusetts State Board of Agriculture for 1905, p. 363.

tect 1,334 acres of rich marsh or, taking in all the area to the level of the higher tides, nearly 1,700 acres, and where the upland drainage is so small. Beyond all question the dike is a legal structure, and the controversy and bitterness which have continued through the years since its construction are much to be regretted. Reclaiming should add and doubtless has added to the healthfulness and attractiveness of the locality and there can be no question but that the agricultural and financial success of the undertaking would have been very much greater than it has, had the marsh owners been allowed to remain in peaceable possession of their property. There should be a new sluice of larger capacity and set lower, and the land should be ditched in a systematic way. With these improvements well maintained, good management, and a better feeling in the community there is every reason to believe that thorough gravity drainage may be secured and a new era be opened up in the history of the Green Harbor reclamation.

DIKED LANDS AT WELLFLEET, BARNSTABLE COUNTY, MASS.

GEOGRAPHY.

The town of Wellfleet is situated on Cape Cod, 106 miles by rail from Boston and 14 miles from Provincetown, at the extreme end of the cape. The town has an area of 20.8 square miles. On the west it has Cape Cod Bay, while the Atlantic Ocean beats against its eastern boundary, the approximate distance between the two shores being at this point about 5 miles. The outer coast is stern and unbroken, but on the bay side is a beautiful land-locked harbor. Along the ocean shore is a chain of a half dozen or more fresh-water ponds and from one of these, Herring Pond, in the northeasterly part of the town, flows Herring River, the largest in the town, which, flowing in a southwesterly direction, empties into Wellfleet Harbor.

The town has a population of about 1,000, largely engaged in fishing or allied industries, especially the culture and catching of oysters. The agriculture of the community has declined, due in part to the drift of the people to the cities and in part to the sandy, unproductive, almost barren character of much of the upland. The locality has great scenic attractions, however, which, combined with the invigorating breezes that blow across this narrow neck of land and the fine boating and bathing in the harbor, bring here a considerable and increasing number of summer residents. Its growth as a summer resort has been slower than might be expected, however, because myriads of mosquitoes, propagated in the stagnant waters of the Herring River and other marshes, have infested the whole locality and constituted a serious drawback to any development.

HISTORY.

Through the efforts of public-spirited citizens a campaign was inaugurated, which had three principal objects in view: (1) The extermination of the mosquito pest; (2) the drainage of the marshes that the agricultural resources of the community might be increased; and (3) the transformation of the foul, unsightly marshes and swamps into healthy and attractive areas.

On February 1, 1904, the town appropriated $1,000 to drain the marsh and oil the stagnant pools, and one year later voted $1,000 more to continue the work. In September, 1905, the late Henry Clay Weeks, of New York, then secretary of the American Mosquito Extermination Society, visited Wellfleet, addressed the citizens and, in a report dated September 15, 1905, advised the diking of Herring River near its mouth and the ditching and draining of the inclosed marsh, thereby removing the conditions favorable to the propagation of the mosquito.

At a special town meeting held November 3, 1905, the services of Whitman and Howard, civil engineers of Boston, were authorized in investigating the feasibility and cost of diking Herring River. In their report dated February 5, 1906, the project is commended and plans and estimates are given for a dike 935 feet long at a point a little less than 1 mile above Wellfleet Harbor. The estimated cost of the dike was $15,944.75. On January 23, 1906, a petition and bill were presented to the legislature asking authority to build the dike, to borrow therefor, and for a State appropriation. The appropriation was denied, but the remainder of the bill was passed.

Some of the citizens were apprehensive that the dike would cut off the food supply delivered by the river to the shellfish in the bay, and others that the harbor would be injured by shoaling. In these connections the statements of Dr. G. W. Field, chairman of the Massachusetts Fish and Game Commission, and of Messrs. Whitman and Howard, are of more than passing interest.

Dr. Field's statement is as follows:

> The department of fisheries and game of Massachusetts strongly advocate the diking of the lands surrounding Herring River in the town of Wellfleet, for the reason that it has been the invariable experience in other places that the shellfish in bays into which runs the water from properly cultivated lands grow more rapidly than is the case where the water comes from barren lands, on the one extreme, or carries sewage pollution, on the other. The reason has been found to be that water from cultivated land carries with it a larger proportion of substances which serve as food for the microscopic plants and animals upon which such valuable shellfish as the oyster, quahaug, and clam depend for food. Therefore, the increase of such soluble substances in the waters of Herring River must increase the amount of shellfish food in Wellfleet Harbor and thus cause a more rapid growth and a large yield per acre of all the valuable shellfish. To a considerable degree, also, it will attract larger numbers of young

herring, porgies, smelts, and other surface-feeding fish, which at some period of their lives depend directly or indirectly upon these microscopic plants for food. These small, surface-feeding fish when abundant attract the rapacious species, e. g., mackerel, bluefish, squiteague, pollock, and others. Thus, by increasing the productiveness of both land and water, the good effects will be extended to practically every inhabitant of the town.

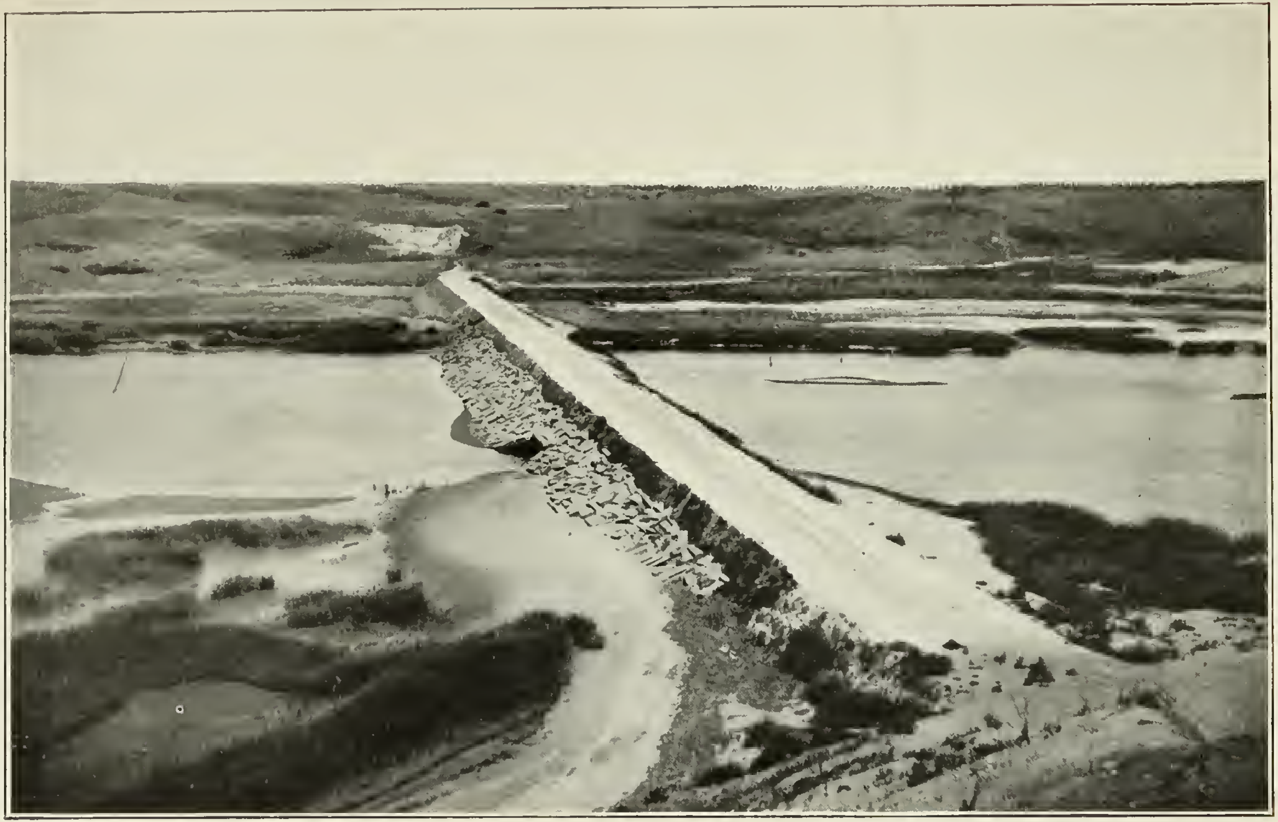
Concerning the after effect of the dike on the harbor, Messrs. Whitman and Howard in a report dated December 1, 1906, state:

> We do not think the building of the dike and cutting off the relatively small portion of salt water which now ebbs and flows above the dike location will reduce the velocity of the current so that there will be any visible detrimental effect in keeping clear the channels below.
>
> The area of creek and flats above the proposed dike is about 80 acres, and this area will hold at mean high tide about 12,000,000 cubic feet of water. A rough computation shows that this amount is about 15 per cent of the amount of water contained in the flats and creek above a line drawn northeasterly from the point of Great Island, i. e., the whole of Herring River to its mouth. Another calculation shows that this 12,000,000 cubic feet of water is but about 2 per cent of the water contained in the basin and estuaries above or northerly from a line drawn from the point of Great Island to Indian Neck. This line from Great Island to Indian Neck is about the northerly end of the Wellfleet Harbor channel proper, and all the waters above this line are conducive to the keeping open of the channel or to moving the sands which tend to fill up the channel, as the case may be.
>
> At spring tides this proportion would be slightly augmented, but we do not think it would be material in any case.

In February, 1907, Dr. Elwood Mead, of the United States Department of Agriculture, visited Wellfleet, looked over the ground, examined the plans, and in a subsequent report gave the project his hearty support. The legislature was again petitioned for an appropriation, this time for $10,000. A bill granting $10,000, an equal amount to be raised by the town, was passed. In order, however, to meet objections which had been raised as to the constitutionality of the act and the legality of certain acts at town meeting, a new bill amending the bill of the previous year was presented in the legislature of 1908. This became a law without opposition. A special town meeting on March 28, 1908, accepted the amendatory act, and the town's appropriation of $10,000 was finally deposited with the State treasurer. On January 10, 1908, a hearing was given by the War Department, but no opposition to the project developed. By the act the construction of the dike was placed in charge of the State board of harbor and land commissioners. The lowest bid for the work was $16,250. Construction was begun in August, 1908, and completed late in 1909. The land, sand, and gravel necessary were given by the town free of cost.

DESCRIPTION.

Herring River has a drainage area above the dike of about 5,800 acres, or 9 square miles, of which 1,100 acres, including water sur-



GENERAL VIEW OF DIKE AT LOW TIDE, SHOWING METHOD OF PROTECTION, DIKED LANDS AT WELLFLEET, MASS., SEPTEMBER 22, 1910.

[High tide comes about 1 foot below top of facing.]

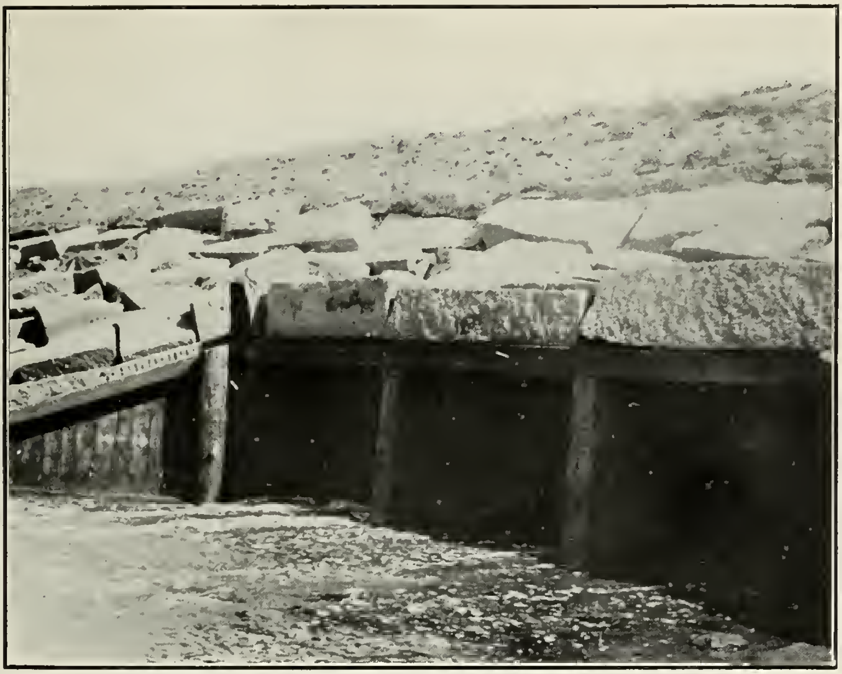
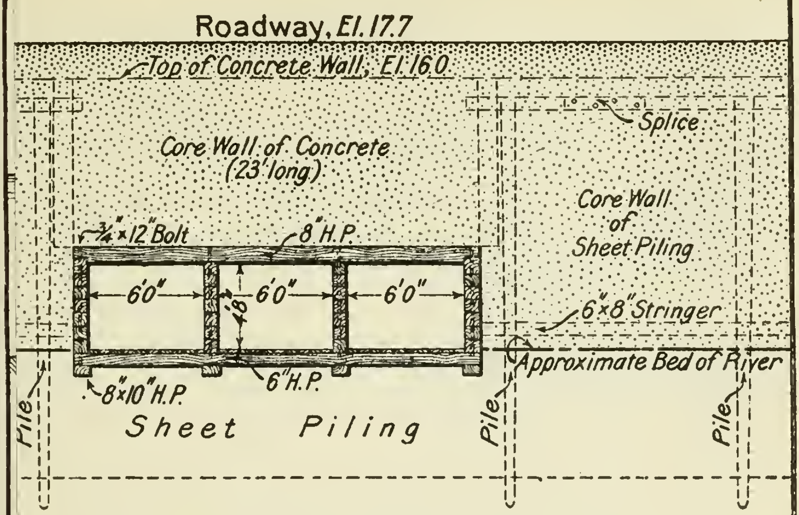


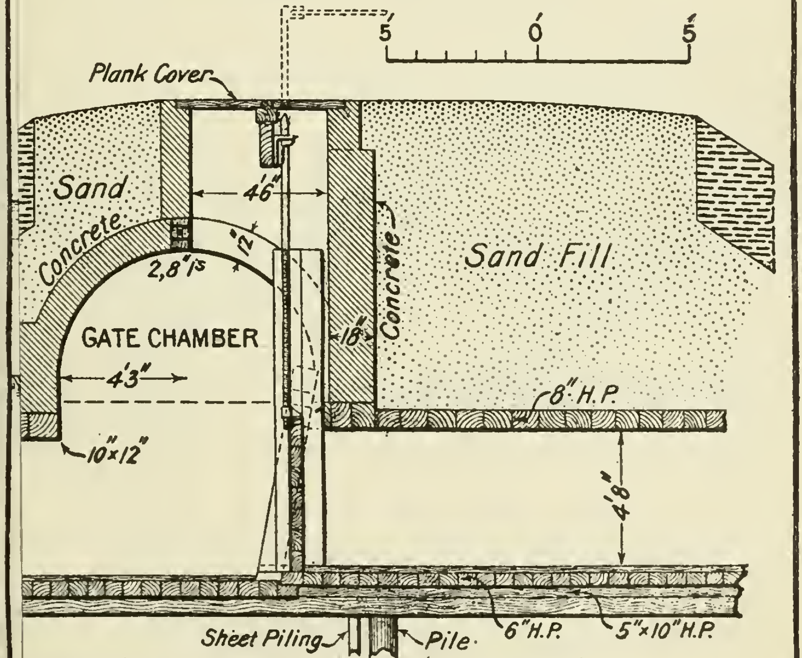
FIG. 1.—OUTER END OF SLUICE AT LOW TIDE, SHOWING GRANITE QUARRY GROUT FACING.

FIG. 2.—DIKING OPERATIONS, SHOWING METHOD OF PLACING MATERIAL.

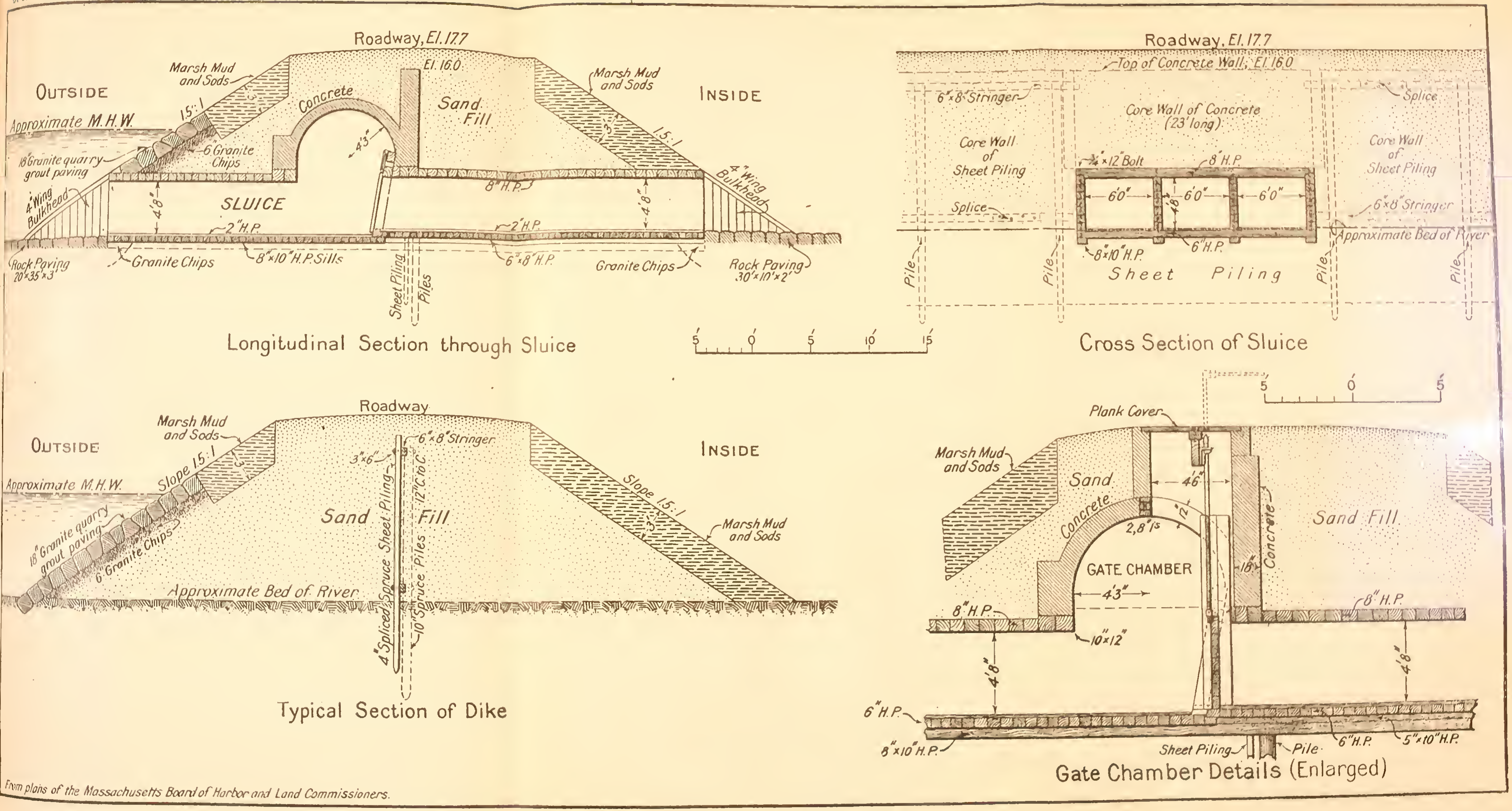
DIKED LANDS AT WELLFLEET, MASS., SEPTEMBER 22, 1910.



Cross Section of Sluice



Gate Chamber Details (Enlarged)



Longitudinal Section through Sluice

Cross Section of Sluice

Typical Section of Dike

Gate Chamber Details (Enlarged)

From plans of the Massachusetts Board of Harbor and Land Commissioners.

Fig. 19.—Sections of dike and details of sluice and gate chamber, Wellfleet, Mass.

faces, are marsh. The marsh land lies in narrow strips of perhaps 1,000 feet in width along the river and the three principal tidal creeks which meander through them. The adjacent uplands consist of steep, sandy, almost bare hills, sometimes rolling, which, long since deforested, have been deprived of their fertility through long-continued erosion by wind and water. The marsh generally is close to mean high water level, though some of the distant parts appear to be as much as 1 foot or more below.

Inside the dike is a natural basin which, with creeks running into it, has an area of about 80 acres, and through which the tide formerly ebbed and flowed for upward of a mile above the present dike. Above this the marshes were considered as brackish or fresh and not salt.

The river at the dike is about 500 feet wide, and its sandy bottom is from 1 to 2 feet above mean low water in the harbor. At low tide on September 22, 1910, when it was said that about an average low tide prevailed, there were 10 inches of water on the floor of the sluice. (See Pl. XIII, fig. 1.) The mean tidal range at Wellfleet is 10.7 feet, the spring range 12.3 feet, and the neap range 9 feet.

DIKE AND SLUICE.

The dike (see Pls. XII and XIII, figs. 1 and 2 and fig. 19) is a sand embankment about 900 feet long and 22 feet wide on top, and has side slopes of 1½ to 1. The crown of the roadway along the top is at grade 17.7 feet above mean low water, or about 7 feet above ordinary high tide. The maximum bottom width is about 68 feet. The filling was obtained from pits in the hills at each end of the dike, and was hauled in automatic side dumping cars of about 3 cubic yards capacity. The 20-inch gauge track was laid so that the cars ran out from the pit by gravity; the empty cars were pushed back on the level track along the dike by two men and drawn up the grade to the pit by a rope and hoisting engine. On September 22, 1910, the writer visited diking operations at South Wellfleet, where the same track, cars, and methods of placing the material were being employed, except that the cars were returned to the pit entirely by hand. The sand was being placed at a labor cost of about 8 cents per cubic yard, the haul being about 450 feet. (See Pl. XIII, fig. 2.)

Along the center line of the dike from end to end 4-inch splined spruce sheeting was driven about 6 feet into the river bed, the top of the sheeting extending nearly to the top of the dike. The upstream slope of the dike is protected by a layer of marsh mud and sods 3 feet in thickness, while the downstream slope, up to 1 foot above mean high water, has a heavy 18-inch granite quarry grout facing backed by a 6-inch layer of granite chips. (See Pl. XIII, fig. 1.) Some of the blocks in this facing weigh upward of 3 tons, and the whole construction appears to be very safe and durable. Above the heavy facing the protection is the same as on the upstream slope. The top of the dike is surfaced with a mixture of fine sand and clay silt, and is sufficiently compact to make a fair roadway for light teaming.

The sluice is about 52 feet long, 20.7 feet wide, and the floor 2 feet above mean low water outside. It has three flumes, each 6 feet wide and 4 feet 8 inches high inside. The top and sides are longleaf Georgia pine, 8 inches in thickness. The floor consists of four 8-inch by 10-inch hard pine longitudinal mud sills, covered with 6-inch by 6-inch hard pine crosspieces, close laid, which in turn are covered with a 2-inch hard-pine flooring laid lengthwise of the sluice. Above and just in front of the gates, and resting on 10-inch by 12-inch hard-pine timbers in the roof, is a concrete arched gate chamber, with a manhole 4½ feet square extending to the top of the dike, where there is plank cover set flush with the roadway. The arch is 12 inches thick, semicircular, and has a span of 8 feet 6 inches. The gates are 5 feet 1 inch wide, 6 feet 5 inches long, and 3¾ inches thick, of longleaf pine and bolted with Tobin bronze bolts. Two of the gates are of the swing type, each hung with three heavy patented cast-iron link hinges with bronze pins, and counterweighted by a system of weights and pulleys. The third gate, intended for use in emergencies, or for allowing the passage of fish, is an ordinary wooden sluice gate, raised and lowered vertically by a Tobin bronze screw operated by a crank at the top of the dike. The leakage past the gates is very small. The three gates, including hardware and frames (except the frame of the fixed gate), were furnished by an East Boston foundry for the sum of $682.80.

The wing bulkheads (see Pl. XIII, fig. 1) are of spruce, 4 inches thick, with hard-pine splines.

The method of making the closure in the river, several of the attempts being not wholly successful, is thus described by Mr. F. W. Hodgdon, chief engineer of the Massachusetts harbor and land commissioners, under whose direction the work was done:

> The closure was made at low tide during a course of neap tides. After building out from both ends until a gap of about 100 feet remained, the sheeting across the gap was driven and cut off as soon as driven at about 18 inches above the river bottom at the level of one of the stringers used as a frame for guiding it. The pieces sawed off were saved to be replaced and spiked in place when the closure was made. Then the river bottom on both sides was protected with sand bags. The frame for guiding the sheeting was then strengthened by additional piles and stringers and was braced by wire guy ropes from the heads of the piles to other piles and heaps of quarry grout placed about 100 feet above and below the center of the dike.

At low tide on the day selected the pieces of the sheeting which had been cut off and saved were replaced and spiked in position, closing the gap before the tide rose against it. Two gangs of four men each were employed and finished just as the tide rose against the sheeting.

The placing of the sand was at once begun, but it was nearly two weeks before the embankment was filled across the gap. The sand filling below high-tide level was either dumped into the water or was covered by the tide soon after it was deposited, and very little attempt was made to ram or otherwise compact it. It was mostly dumped from a trestle at about the level of the top of the dike from automatic side dumping cars which carried about 3 cubic yards each.

The cost of the dike and sluice to date, November 30, 1910, is as follows:

Cost of dike and sluice at Wellfleet, Mass.

Embankment (contract price)	$16, 250. 00
Gates and frames	682. 80
Riprap (additional outside contract)	505. 14
Plans, engineering, and maintenance	2, 530. 05
Repairs on leak	580. 87
Total	20, 548. 86

In addition the town has expended $547.70 in building two small dikes at other points where very high tides entered the marsh. These dikes are about 300 feet long, 8 feet wide on top, have steep slopes and no artificial protection, since the foreshore is so high that only spring tides reach them at all.

DITCHES.

Very little ditching has yet been done more than to open up small ditches for the removal of surface water and the abatement of conditions favorable to mosquito propagation. During 1910 the town spent $3,000 for this work. In a small way, the soil has demonstrated its capability of producing quite a variety of agricultural products.

THE MARSH LANDS OF NOVA SCOTIA AND NEW BRUNSWICK.

GEOGRAPHY AND EXTENT.

Nova Scotia, New Brunswick, and Prince Edward Island constitute what are known as the maritime provinces of Canada.

Nova Scotia, the most easterly, is a jagged oblong peninsula about 360 miles in length from Glace Bay, on the island of Cape Breton in the northeast, to Cape Sable, at the southwest extremity. It has an average width of 60 miles, an area of 21,428 square miles, and a population of 459,574—about 22 to the square mile. The surface is traversed by several well-defined ranges of moderate elevation. The North and South Mountains parallel the Bay of Fundy shore and inclose the beautiful Annapolis Basin, River, and Valley, where De Monts in 1604 founded the first settlement by Europeans north of the Gulf of Mexico. This section is famous for its apple orchards. The Cobequid Mountains, traversing Colchester and Cumberland Counties at the head of the bay, have extensive mineral deposits.

The rivers are not of any great navigable length and are conspicuous mainly because of the extensive marshes through which they flow. The principal streams entering the Bay of Fundy are the Annapolis, with Annapolis, Granville, Bridgetown, and Laurencetown on or near it; the Canard, Cornwallis, and Gaspereau, with Wolfville and Grand Pre near their mouths; the Avon, with Windsor at its mouth; the Shubenacadie, with Maitland as a port; the Salmon, with Truro at its mouth; and the Herbert, Maccan, Nappan, La Planche, and Misseguash, with the thriving city of Amherst not far from their outlets, the latter river constituting the boundary line between Nova Scotia and New Brunswick. Along the lower reaches of these and other smaller streams are extensive areas of marsh land, the aggregate of which is only very approximately known, but is probably more than 120 square miles. Away from the shores the land is rocky and was formerly heavily wooded, but lumbering operations have been extensive and reforestation has been neglected.

While agriculture, lumbering, mining, and fishing are the principal industries, the steel plants at Sydney, Londonderry, and New Glasgow and the manufacturing establishments at Yarmouth, Windsor, Truro, Amherst, and Dartmouth have contributed much to the prosperity of the people, who are characterized by piety, patriotism, honesty, and respect for the law.

Nova Scotia is joined to the Province of New Brunswick by the Isthmus of Chignecto, which at its narrowest place between Cumberland Basin and the waters of Northumberland Strait is only 15 miles wide.

New Brunswick is in form an irregular square and contains 27,985 square miles and a population of 331,120—about 12 to the square mile. For the most part it has navigable waters on three sides.

The principal rivers emptying into the Bay of Fundy are the Aulac, the Tantramar, with Sackville near its mouth; the Memramcook, with Dorchester near it; the Peticodiac, with Moncton about 20 miles above its mouth; and the St. John, with the thriving maritime city of St. John at its outlet. The Province is more heavily timbered than Nova Scotia, spruce, hemlock, and tamarack forests stretching for many miles.

The diked marsh lands are the most fertile in the Province.

The two Provinces are divided by the Bay of Fundy, the "Backwater of the Atlantic," a long trumpet-shaped body of water, possessing probably the most remarkable tides in the world.

The bay has a length, including Chignecto Bay and Cumberland Basin up to Amherst or through Minas Channel and Basin, of about 150 miles, while its width diminishes from about 50 miles opposite the international boundary to about 30 miles where the Cobequid Mountains cleave the waters and form the two converging arms, that of Chignecto Bay and Cumberland Basin on the north and that of Minas Basin and Cobequid Bay on the east.

The bay lies in a northeasterly and southwesterly direction, between walls increasing in height toward its head, and the two tapering arms serve to lengthen and intensify its trumpetlike character.

CLIMATE.

Rainfall data are not readily obtainable in the different sections of Nova Scotia and New Brunswick. It appears, however, that the mean annual rainfall at Truro is about 43 inches; at Moncton, 45 inches; at St. John, 47 inches; and at Charlottetown, Prince Edward Island, 41.5 inches. The distribution through the several months of the year, as shown by records kept for a long series of years at St. John, is as follows: January, 5.55; February, 3.93; March, 3.80; April, 2.50; May, 3.66; June, 2.72; July, 3.29; August, 4.64; September, 3.08; October, 4.13; November, 4.71; and December, 5.16 inches.

Midwinter, therefore, would seem to have the greatest precipitation, closely followed by the late fall. From the temperature records kept at St. John it appears that the mean annual temperature is about 41° F., ranging from a maximum of 89° to a minimum of 21° below zero.

Prof. W. F. Ganong, of Smith College, Northampton, Mass., from the records of the meteorological office at Ottawa, is authority for the following table on temperatures at St. John:

Average monthly and annual mean temperatures at St. John, New Brunswick.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
	°F.	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*
Mean highest	28.2	27.6	34.3	46.4	57.2	64.4	68.8	68.8	63.3	51.8	43.3	32.4	48.9
Mean lowest	9.0	9.7	18.3	30.8	40.4	48.3	53.2	53.7	47.8	37.6	28.9	15.1	32.7
Mean temperature	18.6	18.7	26.3	38.6	48.8	56.3	61.0	61.3	55.6	44.7	36.1	23.7	40.8
Mean daily range	19.2	17.9	16.0	15.6	16.8	16.1	15.6	15.1	15.5	14.2	14.4	17.3	16.2
Absolute highest	50.0	49.0	52.0	71.7	75.0	86.7	88.9	85.0	85.0	72.4	61.0	54.5	88.9
Absolute lowest	−21.0	−15.0	−10.0	12.0	27.0	35.0	41.0	43.0	32.5	21.4	−1.5	−19.5	−21.0

The prevailing winds are southwesterly. Like the tides, every southerly wind takes the course of the bay, is condensed and concentrated and exercises a marked effect on the vegetation, on and adjacent to the marshes, where trees or bushes are bent to the northeast and show a marked development of branches on that side.

Although the apparent width of the Bay of Fundy at its mouth is about 50 miles, its actual deep-water passage is reduced by Grand Manan Island and contiguous shoals to about 24 miles, of which 20 miles has an average depth of about 600 feet.

The tidal wave progressing across from the South Atlantic and pressing against the submerged border of the continent, undergoes a lateral compression in the mouth of the bay and creates through the passage a 3-mile-per-hour current, which continues up the rough, uneven grade of about 4 feet per mile of the floor of the bay with varying velocities into all the indentations and rivers. Through Parrsboro Passage the tides rush with a velocity of 10 miles per hour. Wherever projecting headlands or concealed submarine ledges hinder the progress of this tremendous current, powerful erosion is going on, and the swirling waters catching up the detritus deposit the same as their velocity is checked in the ascent of the rivers or by overspreading the marshes. All are agreed that the Bay of Fundy marshes have been built up in this way from the red Permocarboniferous sandstone forming the sides and bottom of the channels, and not from material brought down by the rivers, which are generally small and have wooded or swampy watersheds and carry little in suspension above the reach of the tides.

The following table gives the mean, spring, and neap ranges of the tide at several places, but it should be stated that in some cases they are theoretical rather than actual, for the reason that sand bars "pond" in the low water and prevent its falling to true low-tide level in the bay.

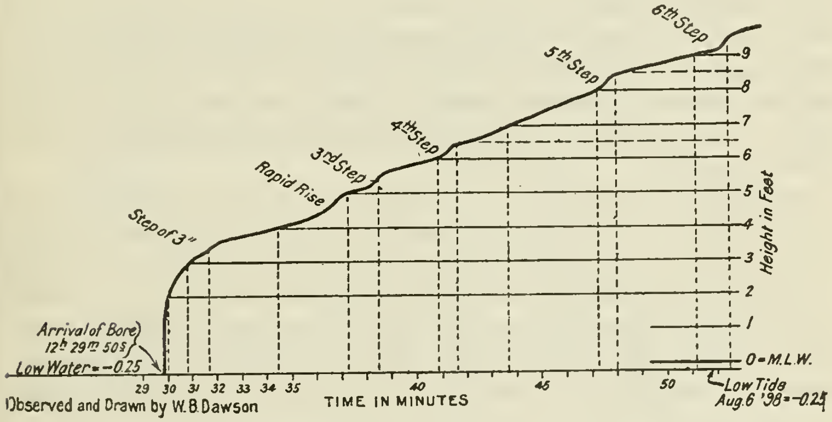
Range of tides at different points on the Bay of Fundy.

Place.	Range of tide in feet.		
	Mean.	Spring.	Neap.
Annapolis, Annapolis Basin, Nova Scotia	25.1	28.7	21.2
Horton Bluff, Minas Basin, Nova Scotia	42.0	48.0	35.5
Noel Bay, Minas Basin, Nova Scotia	44.2	50.5	37.4
Sackville, Cumberland Basin, New Brunswick	39.6	45.2	33.5
Moncton, Petitcodiac River, New Brunswick	41.2	47.0	34.9
St. John, New Brunswick	20.9	23.8	17.6

On October 5, 1869, occurred the famous Saxby tide, the highest ever recorded in the Bay of Fundy, the tide rising in different parts of the bay from 4 to 8 feet above high-water springs and submerging the marsh lands generally. High-water spring tides run about 6 feet above high-water neaps; low-water springs fall about 5 feet below low-water neaps.

Levels taken by the engineers of the projected Chignecto Ship Railway, probably in 1893, show: (1) That mean sea level at the head of the Bay of Fundy and in the Gulf of St. Lawrence is practically the same; (2) that at ordinary high water the waters of the former are 18 feet above and at ordinary low water are 18 feet below mean sea level; (3) that the Saxby tide rose more than 29 feet above mean sea level, and (4) that extreme low tides may fall nearly 24 feet below mean sea level.

In the Petitcodiac River at Moncton, New Brunswick, the rise of the tide is so rapid that it comes in as a nearly perpendicular wall of water from 1 to 6 feet in height, and is known as the "bore." The bore is the broken water at the front edge of a long water slope, which advances up the river and travels about 8½ miles per hour. The arrival is the first indication of the rising tide, which breaks into a bore about 8 miles below Moncton and continues up the river for 21 miles, or about 33 miles from the bay. The form of the bore is shown by figure 20.



Observed and Drawn by W. B. Dawson

FIG. 20.—Diagram showing form of bore, Petitcodiac River, Moncton, N. B.

Levels show that high tide, and, consequently, the marsh, is higher near the tide heads of these rivers than at their mouths, due to the tendency of the waters to pile up from the inertia of their rush. The phenomenon of two distinct columns of water flowing in opposite directions in the same channel at the same time can be observed. The greater weight of sea water by 1.6 pounds per cubic foot, or 2½ per cent, causes the flood tide to be forced in a wedge-shaped column under the descending fresh water, stirring up and placing in suspension a large amount of sediment which the ebb tide removes. The amount of mud carried by the tides is astonishing, especially on the first of the flood and the last of the ebb. The greatest quantity is found in the rivers emptying out at low tide, when it may amount to as much as 4 per cent by volume; at flood tide it seldom reaches 2 per cent.

The deposit from a single tide may range from a mere film on the higher parts of a marsh to several inches in the depressions, and old lake bottoms have been filled 1 foot in the course of five or six days, though ordinarily the rate is much less.

SOIL.

The soil of the marshes is a very fine, reddish sand and silt with from 5 to 10 per cent of clay and a somewhat less percentage of organic matter. When saturated it weighs about 101 pounds per cubic foot and contains 41 pounds of water, or about 66 per cent of its volume is interstitial space. Very little grit can be detected by the fingers or teeth.

The depth of marsh mud is believed to be very great. A boring at Aulac showed a depth of 80 feet overlying a 29-foot stratum of peat. This, together with other evidences, such as buried forests, stumps, and the presence of certain species of shells, indicate that the whole region is much depressed from the position it occupied in later post-glacial periods.

Borings at the wharves in Amherst, Nova Scotia, show depths of 10 to 25 feet of marsh mud, followed by sand, gravel, sometimes blue clay and peat, and an unknown depth of bowlder clay.

At Moncton, New Brunswick, a boring showed 12 feet of marsh mud, followed by 228 feet, mainly of red clay, before striking ledge.

The following mechanical and chemical analyses have been furnished by courtesy of Prof. W. F. Ganong, of Smith College, Northampton, Mass.:

Mechanical and chemical analyses of tide marsh soils from the Bay of Fundy.

Analyst.	Constituents.	Samples.					
		I. Timothy marsh unplowed for 40 years.	II. Low marsh with poor vegetation.	III. Brought in fresh by tide.	IV. Blue mud from 18 inches under surface.	V. From 30 inches below surface under canal above Point de Bute, Nova Scotia.	VI. From river Habitant, Nova Scotia.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Mechanical analysis by Prof. G. E. Stone.[1]	Water	2.000	2.600	1.800	3.160	....	3.400
	Organic matter	6.505	10.920	6.200	7.360	....	3.200
	Gravel, 2–1 millimeters diameter.	.025	.000	1.125	.125	....	.125
	Coarse sand, 1–0.5 millimeters.	.275	.400	3.100	.325	....	.260
	Medium sand, 0.5–0.25 millimeter.	4.125	.285	2.025	2.400	....	1.485
	Fine sand, 0.25–0.1 millimeter.	9.360	1.900	4.225	6.210	....	4.060
	Very fine sand, 0.1–0.05 millimeter.	22.185	1.300	45.275	33.885	....	46.010
	Silt, 0.05–0.01 millimeter	36.165	50.110	14.125	20.375	....	26.800
	Fine silt, 0.01–0.005 millimeter.	10.390	17.735	12.400	10.865	....	8.710
	Clay, 0.005–0.001 millimeter	8.585	10.530	9.660	15.200	....	5.825
	Total	99.815	[2] 95.780	99.935	99.905	....	99.875
Chemical analysis by Prof. F. T. Shutt.[3]	Organic and volatile matter.	6.54	10.60	6.02	6.77	3.10	4.14
	Clay and sand	75.29	73.18	75.83	76.01	84.48	75.59
	Oxid of iron and alumina	14.72	12.64	13.79	14.01	9.87	11.71
	Lime	.239	.234	.652	.409	.288	1.40
	Magnesia	.513	.397	.283	.183	.154	.48
	Potash	.817	.852	.902	.996	.646	.25
	Phosphoric acid	.136	.124	.146	.094	.110	.15
	Soluble silica	.091	.059	.063	.056	.063	....
	Carbonic acid, etc., undetermined.	1.654	1.914	2.314	1.472	1.289	....
	Total	100.0	100.0	100.0	100.0	100.0	....
	Nitrogen	.182	.338	.122	.106	.062	.128
	Available potash	.0088	.034	.0748	.0073	.030	.06
	Available phosphoric acid	.026	.016	.0466	.0436	.0354	.05
	Available lime	.0626	.0449	.397	.0792	.108	....
	Reaction	Acid.	Acid.	([4])	Acid.	Acid.	....
	Common salt	.037	1.048	4.16	.939	.217	.86

[1] Professor of botany, Massachusetts Agricultural College, Amherst, Mass.
[2] Obviously a considerable error; cause unknown.
[3] Chief chemist, Experimental Farms, Ottawa.
[4] Neutral or slightly alkaline.

As will be seen from the table and the records of test borings, the Bay of Fundy soils are remarkable for their fineness, homogeneity, and depth, and it is undoubtedly due to these qualities that the lands remain unimpaired after the croppings of two centuries. The soluble minerals tend to diffuse evenly throughout the marsh, and as the ground water is practically motionless little or none of the valuable soluble mineral matter is lost, as is the case in well-drained upland soils, but by evaporation from the surface, the transpiration of plants, and the natural processes of diffusion, an upward movement is created from below which ever supplies to the marsh vegetation the elements required for its growth. Experiment and experience both show that a 1-foot layer of mud will not maintain fertility for so long a time as a 6-foot layer.

Because of the fine texture of the soil, it readily holds and delivers moisture to the plant, but aeration is difficult, and hence it follows that the soil is much better adapted to grasses and grains which have superficial or slender roots, than to truck crops or any woody growths which are thick rooted and require more air.

Although the deposits as laid down by the tide are of a red color, there are areas of greater or less extent where the mud is blue and unproductive. These areas are low and poorly drained, and the soil, subjected to long-continued fresh-water saturation, has undergone chemical changes, which are described by Dawson in his Acadian Geology as follows:

> The red marsh derives its color from the peroxid of iron. In the gray or blue marsh the iron exists in the form of a sulphuret, as may easily be proved by exposing a piece of it to a red heat, when a strong sulphurous odor is exhaled, and the red color is restored. The change is produced by the action of the animal and vegetable matters present in the mud. These in their decay have a strong affinity for oxygen, by virtue of which they decompose the sulphuric acid present in the sea water in the forms of sulphate of magnesia and sulphate of lime. The sulphur thus liberated enters into combination with hydrogen obtained from the organic matter or from water, and the product is sulphureted hydrogen, the gas which gives to the mud its unpleasant smell. This gas dissolves in the water which permeates the mud, enters into combination with the oxid of iron, producing a sulphuret of iron, which, with the remains of the organic matter, serves to color the marsh blue or gray. The sulphuret of iron remains unchanged while submerged or water soaked, but when exposed to the atmosphere the oxygen of the air acts upon it and it passes into sulphate of iron or green vitriol—a substance poisonous to most cultivated crops, and which when dried or exposed to the action of alkaline substances deposits the hydrated brown oxid of iron. Hence the bad effects of disturbing blue marsh, and hence also the rusty color of the water coming from it. The remedies for this condition of the soil are draining and liming. Draining admits air and removes the saline water; lime decomposes the sulphate of iron and produces sulphate of lime and oxid of iron, both of which are useful substances to the farmer.

Marsh mud has been extensively used on poor upland soils, and its use is said to serve a better purpose than the common commercial fertilizers, because it does not act as a quick stimulant, leaving the soil poorer, but seems permanently to enrich the land.

Mr. Gustavus Bishop, of Greenwich, Nova Scotia, relates that old apple trees which had been bearing only every other year and a poor quality of fruit were made to bear annually more and better apples by simply spreading several loads of marsh mud around them.

DIKES.

The dikes go back to the Acadian French in the middle of the seventeenth century, who not long after the first occupation of the

FIG. 1.—WATER SIDE, SHOWING METHOD OF PICKET AND HEADING BRUSH PROTECTION, AND ON THE LEFT, PLANK PROTECTION FOR "RUNNING DIKE."

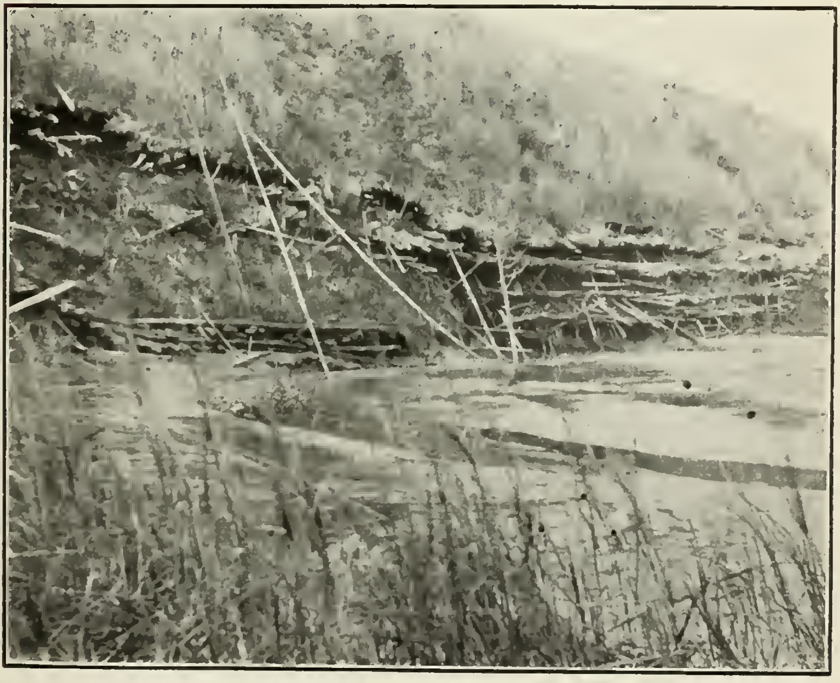
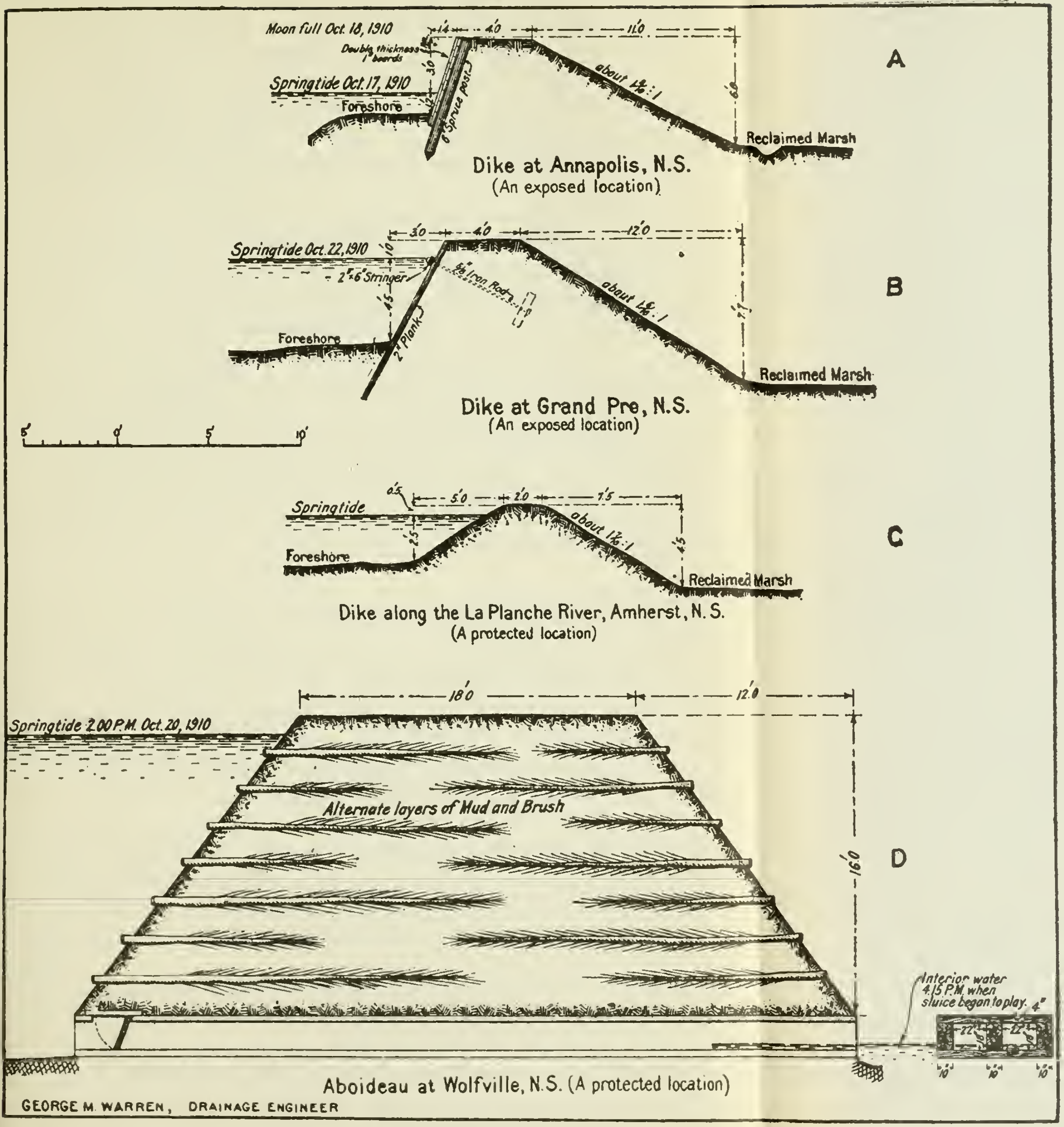


FIG. 2.—LAND SIDE, SHOWING LAYERS OF BRUSH AND ORDINARY HEIGHT OF INTERIOR WATER.

ABOIDEAU, DISCHARGE CREEK, GRAND PRE, NOVA SCOTIA, TOP 16½ FEET, BASE 55 FEET, HEIGHT 45 FEET. SLUICE BEGINNING TO PLAY, OCTOBER 22, 1910.



Dike at Annapolis, N.S. (An exposed location)

Dike at Grand Pre, N.S. (An exposed location)

Dike along the La Planche River, Amherst, N. S. (A protected location)

Aboideau at Wolfville, N.S. (A protected location)

Fig. 21.—Cross sections of dikes, Nova Scotia.

country began to throw out embankments and wrest the marshes from the sea. Their English successors have steadily extended the work and to-day the serpentine embankments following up both sides of the tidal streams or the "aboideaux"[1] boldly projected across the rivers can be seen throughout the Bay of Fundy marshes.

Since the marshes generally have been built up to about ordinary high-water mark, the dikes, or the "running dike," as termed in Nova Scotia, are usually no higher than those in the North Atlantic States—from 4 to 10 feet.

Three cross sections of dikes are shown in figure 21–A, B, and C, and the approximate cross section of a medium height aboideau in figure 21–D. The purpose of the brush is partially to afford a footing for teams, and it is used in alternate layers, great care being taken that none shall extend completely through the aboideau, as this allows water to seep through and create leaks.

The highest aboideau in the maritime provinces is across Discharge Creek, near Grand Pre, Nova Scotia. The water side and the land side of this aboideau are shown in Plate XIV, figures 1 and 2. Figure 1 clearly shows the method of picket and heading-brush protection, and beyond is seen the plank protection for the "running dike." This aboideau was built in 1871, costing $5,000. It is 16½ feet wide on top, about 55 feet in thickness at the bottom, and 45 feet high, a mass wholly of mud and brush.

The art of combining and placing these two materials in a manner to exclude water and to close the deep, swift tidal streams is not easily acquired, and there are few men in the Provinces who can do the work successfully. However, when well done, the work lasts for generations with only moderate expenditure for repairs. In places the "running dike" is sometimes protected by a low palisade and in exceptionally exposed locations, though not often, by riprap.

The methods of construction are essentially primitive. Material is taken from both sides of the dike, and, while formerly deposited by hand or wheelbarrow, it is said that scoops and teams have grown in favor, especially where the work is of considerable magnitude. The dikes are built to no established heights, grades, or widths, and are so little above the level of spring tides as to be occasionally overtopped.

The average dike contains from 35 to 45 cubic yards of material per rod, and a quarter of a century ago with labor commanding about one-half the price paid to-day could be built for about 15 cents per cubic yard. Labor now is $1.50 for 10 hours, and it is probable that

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[1] A word introduced by the Acadians from Saintonge, France, where it is still used in the form "aboteau." While originally it may have referred to the sluice or water box, the term as now used in the Provinces refers to the entire structure, dike and sluice, which extends across and closes a tidal stream or channel.

dikes cost 25 to 30 cents per cubic yard in place. The plank protection costs about $7.50 per rod. So far as known no dikes have been built in the Provinces by dredge.

SLUICES.

There is no observable rule as to the grade or size of sluices. They are set at such elevation as the topographical conditions of the marsh demand and are made of such size as meets the ideas of the builder unaided, usually, by engineering advice.

They are very small, but the conditions under which they operate do not require large sluices, and furnish no criterion for practice in the United States. Both marshes and sluices are so high that even spring tides in the average case will fall below the level of the interior water in 1 or 2 hours, permitting the sluice to play 8 to 10 hours, and it is probable that in many instances neap tides do not reach sufficiently high to close the gates at all.

The Wickwire dike at Wolfville, Nova Scotia, has roughly 133 acres of drainage area for each square foot of sluice opening; the Wellington aboideau at Lower Canard, Nova Scotia, has 350 acres for each square foot, and the Aulac aboideau at Aulac Station, New Brunswick, has 282 acres for each square foot.

The sluices are generally made of native spruce, birch frequently being used in the gates. In many of the later constructions, gates, seats, and frames of bronze are being used, and are said to give excellent satisfaction, as they can not be gnawed, are very durable, and the carefully ground seats permit little leakage.

Arthur A. Hicks, of Upper Sackville, New Brunswick, has built a number of sluices equipped with a very simple and effective device for preventing sluice leakage. (See Pl. XV, fig. 1.) Mr. Hicks takes a strip of horseshoe iron about one-fourth inch thick and $1\frac{1}{4}$ inches wide and draws down one edge so that the iron has a wedge-shaped cross section with a base of one-fourth of an inch and an altitude of $1\frac{3}{4}$ inches. The strip is then fashioned into a square or rectangular shape of such size that when the one-fourth-inch base is placed on the inside face of the gate the sharp edge of the wedge will coincide with the center line of the top, bottom, and side timbers of the sluice at the face against which the gate closes. At frequent intervals five-eighth-inch bolts are welded and riveted to the base, the free end of the bolt having a thread, washer, and nut. The bolts extend completely through the gate, and the nuts on the outer face draw the quarter-inch base tightly against or into the inner face. A V-shaped groove is then burned or chiseled in the end of the sluice along the lines which the wedge edge has scarred—that is, along the center line of top, bottom, and sides. The heavy strap hinges have an

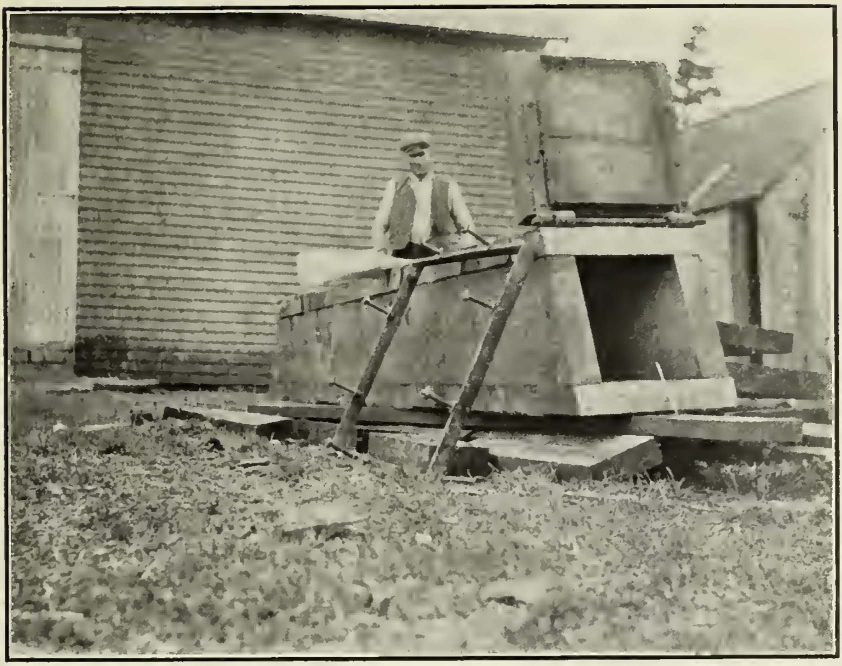

FIG. 1.—SLUICE UNDER CONSTRUCTION AND DEVICE BY ARTHUR A. HICKS, UPPER SACKVILLE, NEW BRUNSWICK, FOR SEALING THE SEAT AND PREVENTING LEAKAGE.

[Iron for a larger gate leans against sluice, and a diking spade rests on top.]

FIG. 2.—TANTRAMAR RIVER, NEW BRUNSWICK, AT HALF TIDE, SHOWING FORESHORE, "RUNNING DIKE," AND HAY BARNS IN THE DISTANCE.

[Seventy years ago forded at low tide and now crossed by bridge of 3 spans of 125 feet each, October 31, 1910.]

elongated eye, permitting the gate to adjust itself to its seat. These gates are said to form a most effectual seal, and cut off practically all leakage.

Gates are generally placed from 2 to 5 feet from the outer end to prevent injury or interference from ice, and the top and sides of the flume at this point recessed or enlarged, affording a clear, unobstructed waterway when the gate is opened to the horizontal position. In some cases two separate and independent gates, one in front of the other, are placed in the same flume.

Notwithstanding the high pressure to which many of the sluice gates are subjected, it is generally to be observed that, as regards leakage, the sluices of the maritime Provinces are much more effective than are ours on the reclaimed salt marshes of the United States. Moreover, any considerable leakage there, where the waters are so heavily charged with sediment, would quickly silt up and destroy the interior drainage channels, and for this reason sluices must be made tight.

DITCHES.

One looks almost in vain for examples of deep systematic ditching for the removal of fresh water from the reclaimed marshes. The tides are below the level of the lands so much of the time and sluices play for such long periods that a fair degree of drainage becomes a simple problem and is readily secured through the natural depressions, sloughs, and water courses.

The lands are often gridironed by small ditches 12 to 15 inches deep and from 40 to 60 feet apart, and at other places the land has been plowed so as to raise slightly the centers of contiguous fields, leaving a dead furrow between. The object sought in both instances is to prevent surface water from standing on the land, rather than secure deep effective land drainage. Much greater success would be attained, beyond doubt, by more careful attention to the ditching.

Prof. W. W. Andrews of Mount Allison College, Sackville, New Brunswick, who is an owner and experimenter in the diked lands, says in a letter dated November 30, 1910:

> I have found that the great evil in these lands is the lack of adequate drainage. All the poor land I have found is sour and contains considerable quantities of ferrous salts, especially the sulphate and silicate. Underdraining seems to be more effective than the ordinary open drain for well-understood reasons. I have used lime at the rate of 3 to 6 casks per acre to correct acidity, and have used basic slag phosphate and potassium chlorid, but no nitrate, as fertilizers. These have been thoroughly adequate.

BOGS AND WARPING.

Emptying into Cumberland Basin at the head of the bay and near the boundary line between Nova Scotia and New Brunswick are several tidal rivers, already mentioned, extending back into the country from 10 to 20 miles. Above the reach of the tide, the marsh merges into extensive areas of fresh-water bog, from 1 to 7 feet in depth, and literally afloat.

The formation of these bogs will readily be understood if the previous discussions of tidal hydraulics and deposits are recalled. The marsh builds fastest and highest along the banks of a river. At tide head, where the ascending salt water may be said to meet the descending fresh water, there is always a tendency for a river to dam itself, and such would be the case except for the scouring action of fresh water as the tide ebbs. Moreover, the gradual subsidence of the whole marsh country, together with the building of successive tide heads through eons of time, has assisted in the creation of large depressed areas adjacent to the uplands, at the heads of rivers, and even between rivers in the same watershed.

These depressed areas, through accumulation of rain water and drainage from the uplands, become the sites of shallow lakes, which develop a fresh-water vegetation, consisting mainly of sedges, which overspread the surface and give rise to the formation of true bog. As the age of the bog increases, various mosses, such as Sphagnum and other forms of vegetation, come in until there is formed a floating mat from 1 to 4 feet thick, often sufficiently firm to sustain the weight of a man. In still older bog the decomposition of this vegetable mass has produced sufficient soil so that coarse grasses and heath bushes take root, and even larches upward of 20 to 30 feet in height are found.

Beneath the bog formation everywhere is found the true tidal mud, blue near the top and red below, and sloping gradually downward from tide head to the remote upper parts of the marsh. Bogs are, of course, due to poor drainage, and moreover they have a constant tendency to extend seaward, and thus encroach upon and injure reclaimed areas near the rivers and toward the bay.

The French in all their reclamation work had merely diked where the land had already been made up by tidal deposit, and it remained for one, Toler Thompson, a farmer of Upper Sackville, who, after long study of the tides and bog levels, about 1815, began to build a canal from the Tantramar River to Rush Lake, a distance of 2½ miles, for the purpose of draining off the fresh water and allowing the tide to enter and, by deposit, to build up the bog. His experiment was entirely successful, a large area of fine English marsh being made up, but the canal was aboideaued, and in the course of years the lands deteriorated.

The effects of Thompson's experiment were far-reaching, however, and the system he inaugurated, which in the Provinces is called

" tiding " or " flooding," and is substantially the English " warping," has been steadily employed since and has resulted in the creation of thousands of acres of extraordinarily fine land.

When the fresh water is removed from a bog the vegetation shrinks to a small fraction of its original bulk, and most of it is instantly killed by the salt water, probably due to the plasmolysis of the root hairs and possibly to some poisonous action of the salt itself. The tides are allowed to flood the bog until the deposit of new mud becomes firm and of sufficient depth so that deep plowing will not turn up the bog vegetation. It is said that some of the most productive lands around Sackville are old lake or river bottoms which have been filled to a depth of 20 and even 30 feet. The tides are then diked out, the land is ditched, and small sluices are placed in the lateral ditches, for it is the opinion and belief of experienced marsh men about the great Amherst-Sackville marshes and bogs that the main streams or canals should not be aboideaued, but every facility afforded the tides to flood the rivers so that an adequate tidal scour may be created to prevent silting or damming up of the outfalls, with consequent interference with drainage and deterioration of the lands.

In this contention the Bay of Fundy marshmen point to the well-established principle in river and harbor work throughout the world, that of concentrating the flow and securing free rush of the tide up and of the freshet down.

The effects of aboideauing these swift tidal streams are shown in the cases of the Aulac and the Tantramar Rivers. In 1827 the Aulac was aboideaued 4 miles from its mouth, and again in 1840 about 2 miles below. In 1863 an aboideau having four openings, each 4 feet square, was built at a cost of $27,500, and since then a new sluice having four openings, each 3½ feet square, has been put in, over which cross a highway and the tracks of the Intercolonial Railway. This river has grown steadily smaller; the upper reaches, practically abandoned, have reverted to lake, bog, or poorly drained marsh, and even the adjacent uplands have depreciated.

On the other hand, the Tantramar was never aboideaued, and has not only kept its own channel scoured out, but has greatly increased its size (see Pl. XV, fig. 2) and thousands of acres of worthless bog and lake have been made into productive land with corresponding benefit to contiguous upland farms. The largest and most systematic attempt at bog reclamation has been on the Misseguash River, the boundary between Nova Scotia and New Brunswick, and having a lake, bog, and marsh area aggregating 8,300 acres. The Misseguash Marsh Co., composed of Boston and Dominion capitalists, acquired control of about 7,000 acres of this land, and on July 1, 1897, commenced the dredging of a canal from Mount Whatley, about 3 miles above the mouth of the river, to Hacmatack Lake, a distance of 6 miles. This canal was 30 feet wide, 15 feet deep, and had a uniform grade of 2 feet to the mile. From the levels of this company, taking the surface of the marsh at the mouth of the river as a datum, it appears that the surface of the bog, 10 miles above, is 3 feet above datum, and the bottom of the lakes and bog from 3 to 6 feet below datum, over which, when the fresh water was drawn off, spring tides would place from 7 to 10 feet of salt water.

The effect of this canal was to cause a rapid enlargement of the river below and enlargement of the canal itself, commencing at its outlet and working back. Where at its mouth the canal was originally 30 to 36 feet wide, in a few years it had become 100 feet wide. The drainage area above, estimated at 40 square miles, is bringing down a large amount of fresh water, so that the deposit of tidal mud over the land has not been up to the present all that might be desired. The company has recently (February, 1911) fitted up a power-driven machine for opening up the channels and assisting the processes of nature. This machine consists of a skeleton drum, 9 feet long and 2 feet in diameter, carrying about 40 knives. Power is furnished by a 20-horsepower gasoline engine and is transmitted by sprocket wheels and a chain drive. The whole is mounted on a scow, the drum being attached by pivoted arms so that it can be raised or lowered as required. The machine is said to have cost $1,000 and to be very effective in freeing the channels of sedges and salt grasses. The machine is shown in Plate XVI, figure 1, and a view of the extensive hay fields of the Misseguash marsh appears on the same plate.as figure 2.

The entire cost of the reclamation to the stockholders to the present time is but $14 per acre.

During and after the deposit of tidal mud a new and varied vegetation springs up on the reclaimed bogs. At first the sedges come in, followed by samphire, but as drainage becomes more perfect and the soil becomes freshened these inferior forms are replaced by others, such as fox grass, broad leaf, and brown top, which in turn go down as an optimum is approached favorable to couch and timothy, which come in naturally and spontaneously in from three to five years. Timothy stands as the last of the succession, and under favorable drainage conditions holds its own indefinitely against all competition, weeds or any woody growths being unable to gain a foothold. When drainage becomes defective brown top comes in, and that in turn gives way to broad leaf.

CROPS AND THEIR VALUE.

The principal crop is hay. The soil, the climate, the incompleteness of the drainage attained, and the economic conditions all favor

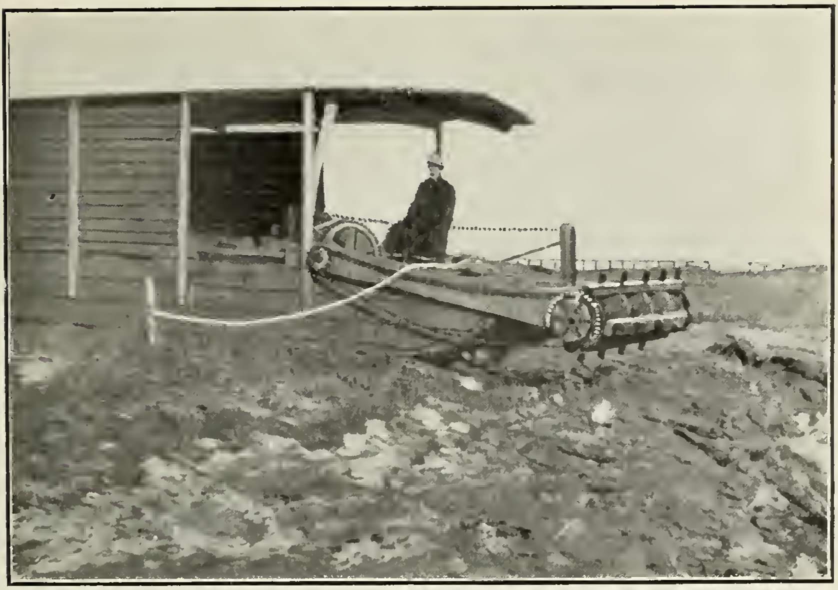

FIG. 1.—POWER-DRIVEN MACHINE FOR FREEING CHANNELS OF SEDGES AND SALT GRASSES, MISSEGUASH MARSH, NEW BRUNSWICK.

FIG. 2.—HAYING ON WARPED FRESH-WATER BOGS, UPPER REACHES OF MISSEGUASH RIVER, NEW BRUNSWICK.

the grasses as the most advantageous crop that can be raised, and although good root crops can be grown, as is evidenced by the experimental plats of turnips and celery on the Misseguash, conditions do not seem to warrant efforts in that direction.

Timothy, red, white, mammoth, and alsike clover, blue grass, and couch grow luxuriantly, and for a long series of years will probably average 1½ to 2 tons per acre. Three tons per acre are common, and 4 tons per acre are occasionally produced. On the other hand, if the drainage becomes impaired, coarser grasses come in, and the quality and value of the yield, if not the quantity, are diminished. The year 1910 was one of enormous yield of hay. On November 1 good timothy was selling in the Nova Scotia markets for $8 to $11 per ton, but the price generally is $10 to $12, with extremes depending upon yield and demand of $8 and $14. On the above date the market price at Charlottetown, Prince Edward Island, was $8 to $8.50; at Bangor, Me., $15; and at Boston, Mass., $23 per ton.

Broad leaf, which grows on newly diked lands before the salt has been washed out and on the poorly drained blue marshes, has considerable feeding value for horned cattle, but is not considered suitable for horses.

No attempt is made to secure more than one crop per season. The best farmers break the marsh once in six or seven years, put in oats, from which they get an average yield of 30 to 40 bushels, worth about 45 cents per bushel, and immediately reseed with timothy and clover. Other farmers do not plow oftener than every 10 or 15 years, and many tracts are known to have been cropped for generations without renovation of any kind, and without once failing to yield good crops of the best English grasses.

The hay is cut between the middle and the latter part of July, and about September 10 thousands of cattle are turned onto the marshes to feed and fatten until early November or until killed off to replenish the beef supply. Grazing is especially prominent on the marshes of the Annapolis Valley, and in the southerly portion of the Nova Scotia Peninsula where the beef supply is quite largely native, and where the market is less accessible for shipments from the western Provinces. Statistics of the Canadian Provinces show that according to acreage under cultivation the number of cattle killed in Nova Scotia is very high, while the export of hay, which is the principal product of the marshes, is very low; herein is one of the factors accounting for the high value of marsh lands and for the prominent place which they hold in the agricultural life of the community.

For the "open" or grazing season of about six weeks the rental charge varies from 75 cents to $2 per acre, with a usual allotment of 3 acres for every cow, ox, or steer, and 1 to 2 acres for yearlings.

LAND VALUES.

The value of the marsh lands, like the uplands, varies greatly with their condition and situation. Good English marsh in the Annapolis Valley is assessed for $60 to $80 per acre, but its market value is from $80 to $150 per acre. On the Grand Pre values run from $100 to $200 per acre, and it is vouched for that transfers of particularly favorable parcels on the Canard River diked lands have been made at $400 per acre. On the Amherst-Sackville marshes the values will run from $80 to $150, but nearness to villages and good drainage may here, as elsewhere, send its value up to $180 or $200 per acre.

Prof. Andrews, of Sackville, New Brunswick, referring to crop yields in his letter of November 30, 1910, says:

> Land which three years ago I bought at the rate of $15 per acre yielded me a crop of hay which was sold standing at a rate which paid me 5 per cent on a valuation of $180 per acre, and the man who bought the hay estimates that he paid considerably less than $4 a ton, so great was the yield.

Upland farms, including buildings, if not far removed from villages and in fair condition, are worth $75 per acre for general farming purposes. Away from the towns values may drop to $30 or $40, and on the other hand, deep, loamy tracts well situated for orcharding are worth upward of $300 per acre.

The value of the broad-leaf marshes drops to one-half or one-third of the English marshes, and the unreclaimed bog lands have merely a nominal value of 50 cents to $1 an acre.

"MARSH ACT."

In 1900 the Nova Scotia Legislature enacted very complete and comprehensive drainage laws, known as the "Marsh act."

These laws effectively provide for the organization of "a majority in interest of the proprietors," for the appointment and remuneration of commissioners, clerk, collector, overseers, and auditor, methods of procedure, execution of the work, adjustment of claims and damages, apportionment of cost, issuance of debentures and the complete administration of the affairs of the "body."

The chartered banks of Canada can not by law take mortgages on real estate, but it is said that through loan and trust companies and from individuals there is no difficulty in borrowing money on the marsh lands to the extent of 50 per cent on a fair valuation.

CONCLUSION.

The reclaimed marsh lands around the Bay of Fundy are very extensive, very valuable, an important agricultural asset, and are closely interwoven with the industrial and economic life of the people. Not only farmers, but merchants and professional men who are looking for good, sound 8 and 10 per cent investments believe and invest in these reclaimed marsh lands.

The leading social club of the thriving city of Amherst is named the Marshlands Club.

We may well ask why Nova Scotia and New Brunswick, with a less inviting climate, sparse population, inferior transportation facilities, and poorer markets, have made such pronounced success in marsh-reclamation work, while the great bulk of our marshes, even within an hour's ride of such populous and wealthy cities as Boston, New York, and Philadelphia, are still in their natural state, or where reclaimed the successes have been few or indifferent. Unquestionably the fundamental reason lies in the great nature-bestowed gift of a large range of tide, which has built the marshes high and permits the sluices to play long periods of time, thus securing adequate drainage easily, cheaply, and certainly. There are, of course, other reasons of historical, physical, and economic nature which have contributed, but they are relatively insignificant and are more than offset by our own economic needs and by American energy, enterprise, and resourcefulness.

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