HILGARDIA

*A Journal of Agricultural Science Published by the California Agricultural Experiment Station*

VOLUME 20 JUNE, 1950 NUMBER 3

# SUBSIDENCE OF PEAT LANDS OF THE SACRAMENTO-SAN JOAQUIN DELTA, CALIFORNIA

WALTER W. WEIR

UNIVERSITY OF CALIFORNIA · BERKELEY, CALIFORNIA

# CONTENTS

HILGARDIA

*A Journal of Agricultural Science Published by the California Agricultural Experiment Station*

VOL. 20 JUNE, 1950 No. 3

# SUBSIDENCE OF PEAT LANDS OF THE SACRAMENTO–SAN JOAQUIN DELTA, CALIFORNIA[1]

WALTER W. WEIR[2]

## INTRODUCTION

AT THE CONFLUENCE of the Sacramento and San Joaquin rivers in central California an area of about one quarter million acres, known as the Delta, is made up entirely of peat (fig. 1). These highly organic soils are said to comprise the second largest continuous body of peat land in the United States, exceeded only by the Everglades in Florida.

With minor exceptions, the entire Delta has been reclaimed from tule swamp. In its present high state of cultivation, it produces farm products with an annual value of more than 25 million dollars.

The area consists of a number of tracts and islands, each organized into one or more reclamation districts under state law for the construction, maintenance, and operation of levee and drainage systems. There are more than 80 reclamation districts in this area.

Around the borders of the Delta the peat soils merge gradually into the adjacent mineral soils, or feather out in shallow depths of peat overlying mineral soils. The center of the Delta is composed of islands which are entirely surrounded by the interlacing channels of the two major rivers. In portions of this area the peat is 30 feet or more in depth. All of the channels surrounding the islands are navigable to barges and other freight-carrying craft.

Cultivation in the Delta region dates from the passage of the Swamp and Overflow Act of 1850, when title to these lands passed from the federal government to the state. The first levees were low dikes, truly handmade by Chinese labor with wheelbarrows and shovels. The early reclamation, therefore, did not penetrate deeply into the heart of the peat lands.

Prior to reclamation, the entire area was covered with a dense growth of tule (*Scirpus lacustris*), with a fringe of willows and other woody plants along the slightly higher stream banks, where the soil contains the greatest amount of mineral material. The surface of the area was at zero, or sea-level, elevation and was inundated at high tide or at flood stage in the rivers.

[1] Received for publication December 2, 1949.

[2] Drainage Engineer, California Agricultural Experiment Station.

Although the water level in the interlying streams is affected by tidal movement as far inland as Stockton and Sacramento, the water is normally not salty. Slightly brackish water may, however, occur along the western edge of the area during the late summer when the rivers are at their lowest stage.

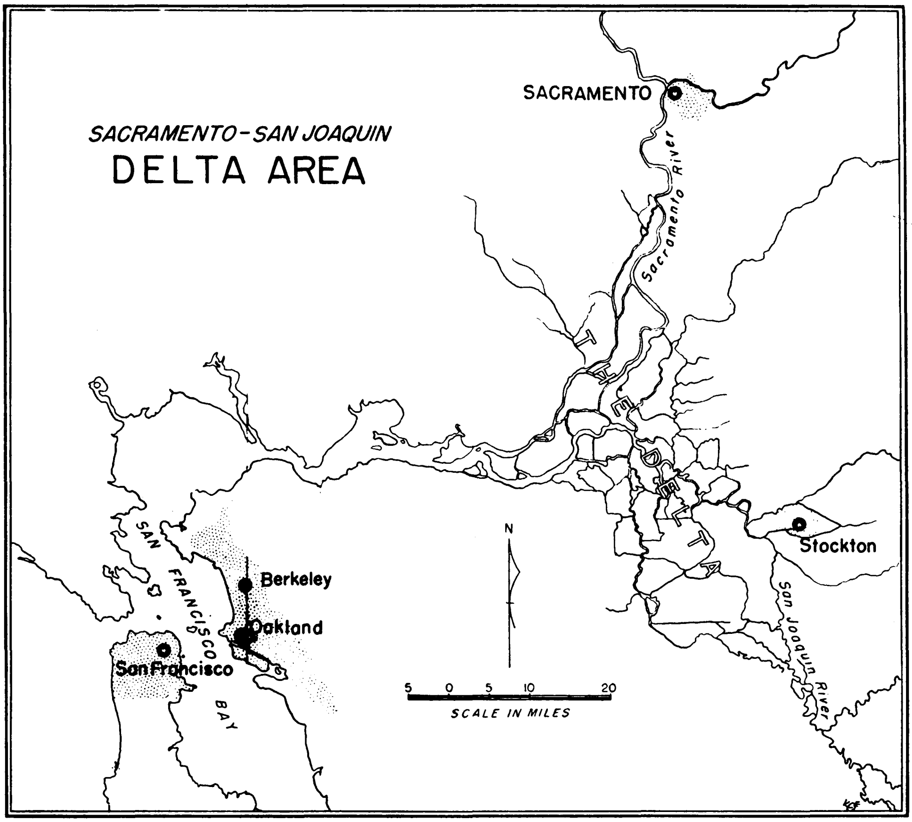


Fig. 1. The Sacramento–San Joaquin Delta area is the site of this study.

## CHARACTER OF THE PEAT

Although there is some variation in the character of the peat soils of the Sacramento–San Joaquin Delta, they are genetically similar. Dachnowski-Stokes[3] describes a typical soil profile from this area as follows:

0 to 23 inches, tule-reed muck. The surface organic material, to a depth of 8 inches, is cultivated organic residue, grayish black in color, granular, friable, and more or less neutral in reaction. Between 8 and 23 inches below the present surface is a rather dense heavy-textured dark grayish-brown tule peaty muck, firm and partly fibrous. This material contains black organic sediments and a variety of seeds from water lilies and pond weeds.

23 to 38 inches, yellowish-brown matted poorly decomposed fibrous reed peat which is commonly referred to as "buckskin peat." It is slightly acid in reaction. This layer represents, probably, a floating mat.

[3] Dachnowski-Stokes, A. P. Peat land in the Pacific Coast states in relation to land and water resources. U.S.D.A. Misc. Pub. No. 248. Oct., 1936.

38 to 72 inches, grayish-brown tule peat, in part sedimentary fibrous. The material consists of varying quantities of rhizomes from reeds and organic sediments and contains seeds from the contemporary herbaceous and aquatic vegetation. At the lower level the material is more distinctly heavy textured and sedimentary fibrous.

72 to 96 inches, brown fibrous or matted fibrous partly decomposed tule-reed peat. The material is mottled with black organic residue and maroon-colored fragments that appear to have been formed by herbaceous plants during high-water stages.

96 to 114 inches, yellowish-brown reed peat characteristic of a floating mat. The material is coherent, essentially well preserved, and porous. It grades rather abruptly in the layer below.

114 to 120 inches, grayish-brown structureless sedimentary peat which developed from plant communities that occupied open water. The material consists in part of transported plant remains, leafy fragments of pond weeds, and bits of fiber from floating mats of vegetation.

The underlying mineral material is gray compact sticky clay.

Cosby[4] mapped the organic soils of this region in five series. Four of these are in cultivated areas and differ mainly in the degree of decomposition of the surface layer, and the proportion of mineral soils incorporated in the profile. He describes Correra peat, an uncultivated type which is probably typical of conditions as they existed prior to reclamation, as follows:

Correra peat consists of practically unaltered virgin deposits of peat characteristically having two layers—a comparatively thin layer of material derived from tule, or bulrush (dominantly *Scirpus lacustris* L.), overlying a deeper accumulation of fibrous remains of reed (chiefly *Phragmites communis* Trin.). In a few localities small quantities of other plant remains are present, but they do not materially alter the general character even of the deeper deposits, although they are distinct enough for identification.

The occurrence and uniformity of this tule-on-reed peat indicate that for a long time—probably during the entire period of accumulation—the relation between ground-water level and land surface was more or less constant. The slow and continuous subsidence [this entire area is presumed to be subject to, and now is undergoing, a geologic subsidence] of the mineral base apparently equaled the slow accumulation of plant remains. The comparative purity of the reed-formed material which in some places exceeds a depth of 30 feet, tends to support such a theory. The surficial layer of tule-formed material, which in few places exceeds 3 feet in thickness, indicates that this plant has been dominant only during comparatively recent times. . . . In general Correra peat has the following profile characteristics: To a depth ranging from 10 to 20 inches the material consists of brown fibrous-matted tule peat containing an abundance of light-brown small fibrous roots and dark-brown or almost black shiny tule rhizomes. This material contains varying small quantities of dark brownish gray finely divided altered plant material; it has a pH value of about 5.0 and an organic content of about 80 per cent. Below this layer and extending to a depth ranging from 30 to 45 inches is brown or light-brown raw fibrous-matted tule-reed peat similar to the surface material but containing many identifiable stems and roots of reeds, which become even more numerous in the lower part. This material grades into the underlying brown softer and more altered reed peat. Thin layers of darker brown highly altered material occur at various depths but aggregate less than 10 per cent of the soil mass. This material is associated with either tule fragments or herbaceous vegetation or both. Such incidental layers probably represent accumulations during a period when the reed cover was thinner or less pure, as following a fire or an abrupt change in water level.

It may be concluded that these descriptions by Dachnowski-Stokes[4] and Cosby are in substantial agreement except for their conceptions of how the deeper layers were deposited. Dachnowski-Stokes repeatedly refers to sedi-

[4] Cosby, Stanley W. Soil survey—the Sacramento–San Joaquin Delta area, California. U.S.D.A. Bur. Pub. Inf. Series 1935, No. 21. 1941.

mentary peats, indicating that they settled out of floating mats in relatively deep water, whereas Cosby believes that the surfaces of the peat beds were always at about sea level and that the whole area has settled.

## RECLAMATION AND IRRIGATION

The first step in a reclamation program in the Delta is the construction of a levee around an island to exclude floods and tidal overflow. Levees are constructed by large floating dredges with clam-shell type of buckets. The dredges

Fig. 2. Navigable stream channels surround the Delta islands. The native vegetation is tule, which now grows only outside the levees.

operate in the stream channels, where they take material for the construction of the levee from the bottom of the channel. Some of the larger dredges with booms 125 feet in length are capable of taking material from the channels and placing it 200 feet distant, where a levee is being constructed.

In some instances, a new channel or dredge cut is made parallel to landward of the open water. This leaves a berm of undisturbed land between the open channel and the levee to protect the levee against wave action. Passing boats sometimes create considerable wave action where the channels are narrow, and wind causes a similar disturbance where the channels are wide. Figure 2 shows one of the open channels with undisturbed tule growth in the middle.

In the fall of the year following levee construction, the tule tops die and can be burned. Following the burning, the main drainage ditches are then constructed and drainage pumps installed. When the land is dry enough it is plowed to a depth of about 2 feet. Plowing turns up large mats and chunks of tule roots and coarse fibrous material known as "buckskin," which are broken up by repeated cultivation to form the future seed bed.

Since the Delta lies in an area of only moderate rainfall (12 to 20 inches), most crops require irrigation. The technique of farming in this area is very different from that in other parts of California. Irrigation water is siphoned over the levees from the surrounding stream channels. Sufficient head to operate a siphon is obtainable as ground level to the landward side of the levee is, even at low tide, several feet below the water surface in the channel.

The land is laid out in fields of 20 to 40 acres, each of which is bordered on at least two sides by an open ditch, frequently called a "4-foot ditch," carry-

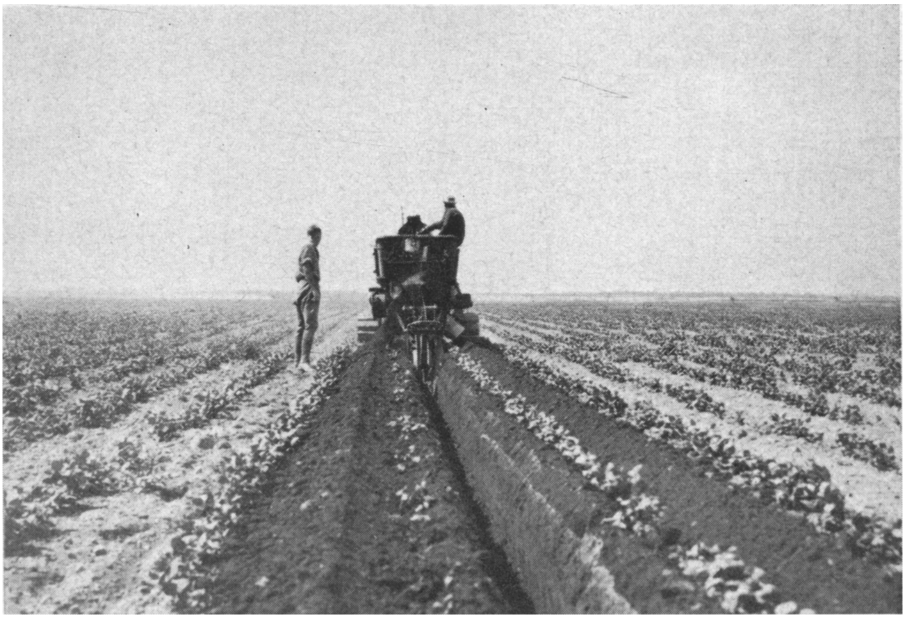

Fig. 3. Irrigation water is distributed through the fields in spud ditches, from which it subs into surrounding soil. Spud ditches are dug annually by small excavators especially adapted to the purpose.

ing irrigation water. The 4-foot ditches are about 4 to 5 feet deep, 3 feet wide on the bottom, and 5 to 6 feet wide on top. They are machine dug. From the 4-foot ditch, smaller "spud" ditches lead water down the crop rows. The 4-foot ditches are permanent installations, but the spud ditches are re-dug each year. Figure 3 shows a spud ditch being constructed with a small trenching machine adapted to this work. These ditches are dug after the crop rows can be seen. The excavated material is spread out on both sides of the ditch in a manner not to disturb the crop. Spud ditches are about 10 inches wide, 18 to 20 inches deep, and spaced according to the crop. For potatoes, the crop shown in figure 3, the spacing is usually about 20 rows apart.

Irrigation water is not applied to the ground surface as in most irrigated areas. Instead, the spud ditches are held nearly full until water has seeped laterally to raise the water table to the surface of the entire field. All row crops, such as potatoes, asparagus, beets, onions, celery, and corn are irrigated in this way. Barley usually is not irrigated.

When a field is completely wetted, the spud ditches are drained back into the larger 4-foot ditches which are connected with permanently installed drainage ditches. Water is pumped from the drainage ditches, over the levee, by large, automatically controlled electric pumps. Seepage through the levees and excess winter water are also discharged through these pumps.

Figure 4 shows a field of barley. The trees in the far distance are willows and cottonwoods growing on the levee surrounding this island. Figure 5 is of an asparagus field showing the raised beds. Both to the right and the left are

Fig. 4. Barley is extensively grown in the Delta as a nonirrigated crop.

newly constructed spud ditches from which water subs laterally to irrigate the field. Onions (fig. 6) and sugar beets (fig. 7) are both important peat-land crops. Neither of these crops nor potatoes are grown on raised beds.

## SUBSIDENCE

It is commonly recognized that the drainage and cultivation of peat and muck soils lower the surface elevations—a condition known as subsidence. In the states bordering the Great Lakes, Louisiana, Florida, Oregon, and elsewhere in the United States, as well as in the British Isles and in Russia, workers not only have measured the amount and rate of subsidence but have offered explanations of the causes. At the end of this report is a partial list of papers dealing specifically with the subsidence of peat and muck soils.

The writer has no knowledge of any other worker in this field covering subsidence of the soils of the Sacramento–San Joaquin Delta. The studies comprising this report were made when subsidence began to cause the farmers in the area concern over the safety of their costly levee systems and other reclamation works.

At the beginning of these studies in 1922 it was anticipated that information could be obtained on: 1) causes of subsidence; 2) rate and amount of subsidence; 3) effect of subsidence on the future drainage and irrigation problems of the area; and 4) possible means of control.

For all practical purposes the entire Delta was in cultivation in 1922, when these investigations were begun. At that time, it was generally believed that a large part of the subsidence was due to compaction by heavy tillage equipment and that, as the islands became older (a longer time under cultivation)

Fig. 5. The major portion of the world's white asparagus for canning comes from the Delta area.

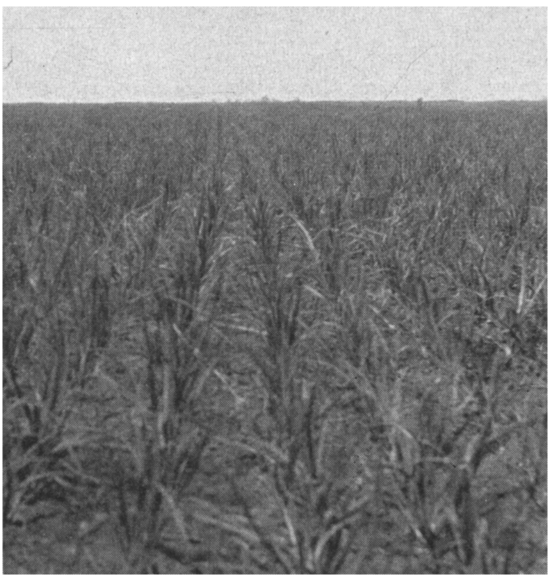

Fig. 6. Onions grow on the peat soils of Mildred Island.

the rate of subsidence would decrease to a negligible point, an assumption not substantiated by these studies.

This assumption, to some degree at least, influenced the choice of location for these studies. Three tracts of land with rather wide differences in age were selected. The oldest, Lower Jones Tract, was first put under cultivation in 1902; the second in age, Bacon Island, was cultivated for the first time in 1915; and the third, Mildred Island, was first farmed in 1921. Thus, the three islands had been reclaimed, respectively, for twenty, six, and one years when this study was started. The time since reclamation is subsequently referred to as the age of the island.

Accessibility was also considered in the selection of these three islands. Middle River on Lower Jones Tract could be reached by train, and the other islands by rowboat from that point. At the present time all of the islands can easily be reached by automobile (fig. 8).

In 1922 there were no permanent bench-marks on the peat lands. It was necessary for a surveyor to go several miles to find a point of known elevation.

Fig. 7. During World War II and since, sugar beets have been a profitable crop in the Delta area.

Prior to 1929, the levels were run from a bench-mark of assumed elevation established on the drainage pump discharge line at Middle River. In 1929 and thereafter, elevations were taken from a permanent bronze tablet, established that year by the East Bay Muncipal Utility District on the east siphon abutment for the district's pipe line at the Middle River crossing. The elevation of this bench-mark is 10.88 feet. All elevations taken previously were converted to sea-level datum.

Geologic raising or lowering of the area, as previously mentioned, would not be reflected in the levels taken on this survey, as the initial bench-mark is within the Delta and would itself be subject to the same changes. Although any geologic subsidence of the area would probably be too slight to be measured, during the period of these studies, by the means at hand, no precise-level check has been made to establish this point. The East Bay Municipal Utility District has not recorded any change in elevation of its bench-mark in the twenty years that it has been established.

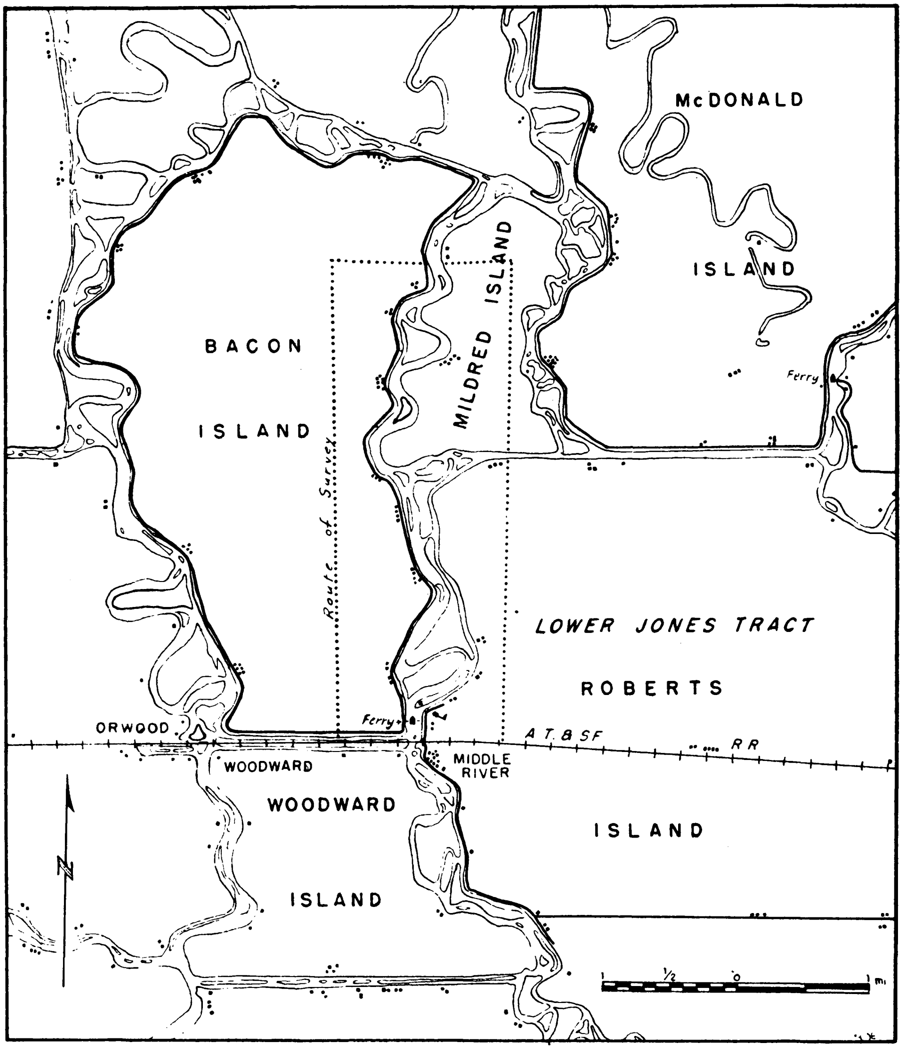


Fig. 8. The route over which levels were taken to obtain data for this study forms a rectangle through the edges of Bacon and Mildred islands, and Lower Jones Tract.

In order that it may be possible to continue these levels at some future time, the line over which they were run and the technique used are briefly described as follows:

Beginning on the levee at the Lower Jones pumping plant at Middle River; thence east along the south side of Lower Jones tract approximately 3,500 feet to a point opposite mile post 1,134 on the Santa Fe Railroad (this point is presumed to be due south of the high steel towers which carry a power line across Empire Cut at the north end of Lower Jones tract); then north across Lower Jones tract, a distance of approximately 11,050 feet, to Empire Cut; thence across Empire Cut to Mildred Island; thence continuing north across Mildred Island, a distance of approximately 7,730 feet; thence west across Mildred Island, a distance of approximately 2,570 feet to the east bank of Middle River at Camp No. 1

Mildred (sometime during the period 1938–1948 Camp No. 1 Mildred was abandoned and all buildings removed); thence across Middle River to Bacon Island; thence westward across Bacon Island, a distance of approximately 3,300 feet; (this point is presumed to be due north of the center of Weyl-Zuckerman warehouse situated on the railroad at the south end of Bacon Island); then south on Bacon Island to the levee at the Weyl-Zuckerman warehouse, a distance of approximately 19,600 feet; thence east along the south side of Bacon Island to the Bacon Island ferry, a distance of approximately 2,700 feet; thence across Middle River to the point of beginning.

TABLE 1

COMPUTED* ELEVATIONS ON THREE DELTA ISLANDS, OF DIFFERENT AGES, FROM 1922 TO 1948, INCLUSIVE

| Year | Below sea-level elevations, in feet | | |
|---|---|---|---|
| | Lower Jones Tract (First cultivated, 1902) | Bacon Island (First cultivated, 1915) | Mildred Island (First cultivated, 1921) |
| 1922 | 5.07 | 3.63 | 2.03 |
| 1923 | 5.66 | 4.06 | 2.08 |
| 1924 | 5.57 | 4.14 | 2.66 |
| 1925 | 5.61 | 4.35 | 2.93 |
| 1926 | 5.61 | 4.42 | 2.80 |
| 1927 | .... | .... | .... |
| 1928 | 6.18 | 4.96 | 3.76 |
| 1929 | 6.38 | 5.18 | 4.31 |
| 1930 | 6.59 | 5.22 | 4.82 |
| 1931 | 7.00 | 5.99 | 5.40 |
| 1932 | 7.18 | 6.51 | 5.86 |
| 1933 | 7.35 | 6.31 | 5.71 |
| 1934 | 7.71 | 7.23 | 5.88 |
| 1936 | 7.83 | 7.59 | 6.32 |
| 1938 | 7.86 | 8.07 | 7.36 |
| 1948 | 10.55 | 10.95 | 10.35 |
| Total subsidence in 26 years | 5.48 ft. | 7.32 ft. | 8.32 ft. |
| Average annual subsidence | 0.21 ft. | 0.27 ft. | 0.32 ft. |
| Average annual subsidence last 10 years | 0.27 ft. | 0.29 ft. | 0.30 ft. |

* Adjusted for closure error.

All distances were measured by stadia and the line maintained by sighting on objects, such as the power poles or the warehouse, ahead or to the rear. No attempt was made to take elevations at exactly the same points in succeeding years. Elevations were taken at intervals of 200 to 400 feet by using an engineer's level and reading to the closest 0.01 foot. Actually, over the succeeding years, elevations were taken at intervals of 200 to 400 feet in a strip 20 to 40 feet wide and nearly 8½ miles long.

With the exception of 1927, levels were taken annually from 1922 to 1934, inclusive, biennially through 1938 and lastly in 1948. This gives 16 measurements over a period of twenty-six years. With only one exception, measurements were taken in the early part of May.

Precise leveling was made difficult by the extreme instability of the peat soils, heat waves, and usually a stiff afternoon breeze. A closure error, therefore, of $\pm$ 0.3 foot on the starting bench-mark was considered satisfactory. In most instances, however, the closure error was considerably less than $\pm$ 0.3 foot.

The data for each island were plotted separately on profile paper from which the computations were made. From these profiles, elevations were taken at 100-foot intervals and averaged separately for each island.

A total of about 90 readings on Lower Jones Tract, 170 on Bacon Island, and 75 on Mildred Island were averaged. Thus, a single figure is obtained for each island each year.

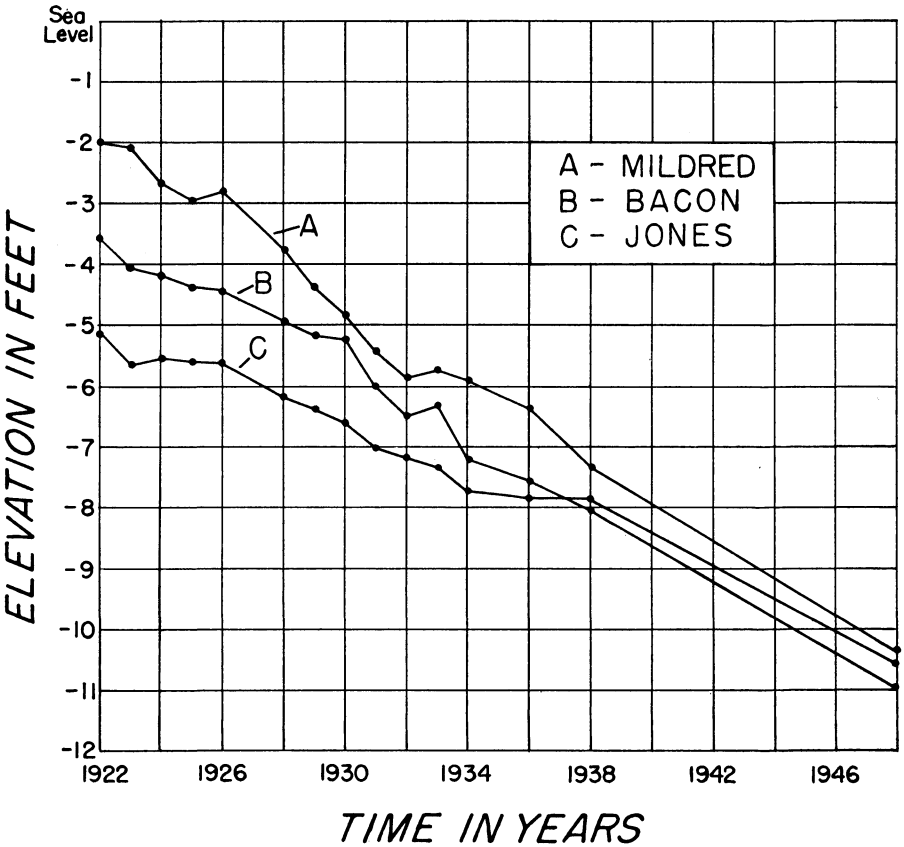


Fig. 9. A progressive subsidence of Mildred, Bacon, and Jones islands took place between 1922 and 1946.

Across the line of survey on each of the islands there is an old slough way, now completely filled and farmed, along which the soils have a very high mineral content. These slough ways now stand several feet above adjacent areas of more truly peat soils. Elevations obtained while crossing these old channels were not included in the computations. These areas of high mineral content, however, make up a relatively small portion of the total.

Table 1 shows the elevation of each island for the years in which observations were made. The same data are shown graphically in figure 9. These data show a measurable and continuous subsidence of the surface of the peat soils of the Delta during the past twenty-six years. During the early period the rate of subsidence was inversely related to the age of the island. Mildred Island, the youngest, subsided at a greater rate than did Lower Jones Tract, the oldest. Bacon Island was intermediate both in age and rate of subsidence.

During the last ten years the rate of subsidence has not decreased for the area as a whole, but has been markedly less influenced by the age of the tract. During the period 1938–1948, Lower Jones Tract subsided at an average rate of 0.27 feet per year, whereas for the entire twenty-six-year period the rate was only 0.21 feet per year. Burning as a stimulus to war-time production, explained later, may be a reason for the increased rate of subsidence on Lower Jones Tract.

It would appear to be a reasonable assumption that each of the islands had approximately the same elevation of sea level (0.0 elevation) before they were reclaimed. At some intermediate point in their age—for example, fifteen years—it would appear that each island would again have approximately the same elevation. This latter assumption is, however, not true. In 1936, when Mildred Island was fifteen years old its elevation was –6.32 feet; in 1930, when Bacon Island was fifteen years old it had an elevation of –5.22 feet; in 1917, Lower Jones Tract had a computed elevation of –4.47 feet. This variation may possibly be explained by differences in the early cropping history and in the management of the older tracts.

In 1948 the three tracts were all very nearly of the same elevation, between 10 and 11 feet below sea level, and continuing to subside at the rate of 0.25 to 0.30 feet per year.

## CAUSES OF SUBSIDENCE

Several factors are involved in the conditions which exist in this area, all of which may have some bearing on the lowering of the soil surface. Among the more important factors are:

**Geologic subsidence of the entire area**
**Compaction by tillage machinery**
**Shrinkage from drying**
**Oxidation**
**Burning**
**Wind erosion**

**Geologic.** The fact that the entire peat profile, to depths of 30 feet or more, is made up of the remains of plants very similar to those growing on the surface at the present time does not seem logical unless the surface elevations have been rather constantly at or about at sea level. Tules and reeds do not normally grow in water 30 feet deep. It would seem more likely that the growth of tules and reeds kept pace with the receding substratum. Unless there is a different rate of movement within the Delta itself—and this has not been investigated—the geologic-movement theory would not account for any of the subsidence reported in this paper. The datum used was itself subject to this same subsidence and, consequently, could not be measured by the means employed in these studies. It will, however, aid in accounting for the occurrence of deep peat soils at this location.

Some geologists hold that the Delta is currently subject to movement, and is undergoing a differential subsidence relative to surrounding areas. Two occurrences of similar nature reported during 1947 may have some bearing on the theory of geological movement. On Brannan Island, east of Rio Vista, and on McDonald Island, near the center of the Delta, farmers reported that steam was rising from the land. Careful examination of the sites disclosed no evidence of fire. In both instances, temperatures some 2 feet below the surface were observed to be as high as 140°F. Temperatures were so high that barley was killed over an area of about one quarter acre. These phenomena may indicate that hot springs had developed in the underlying strata, and that the steam was caused by escaping hot water. Hot springs, the most notable of which is Byron Hot Springs, occur in the hill areas surrounding the Delta.

**Compaction.** The Delta region is owned and farmed in large tracts. From the beginning of cultivation the use of large and heavy farm equipment has been a common practice. Although many of the crops, such as onions, celery, and potatoes, require a great deal of hand labor, the fields are prepared for planting with tractors and heavy tools. A tractor passing over these soils will noticeably shake the surrounding area for a radius of 200 feet or more. The first track-laying type of tractor was made at Stockton for use in the unstable peat soils of this area, to provide a greater bearing surface than was afforded by the wheel-type tractor.

Undoubtedly there is some compaction of the surface soil caused by cultivation. For instance, when "buckskin" is exposed, and the soil is worked down to a condition for planting, the surface is about 2 feet lower than it was in its original wild state. However, the theory that cultivation is responsible for subsidence is less acceptable than formerly. If any considerable portion of the subsidence was due to compaction, there would be a marked increase in volume weight of the surface soils as compared with the subsoil.

Although volume weights of surface soils from cultivated and uncultivated areas were not made in this study, one must conclude that a lowering of 10 feet after twenty to thirty years of cultivation would have developed a compact tilled horizon of sufficient depth to meet all current tillage requirements. On the contrary, each plowing which varies from 12 to 14 inches in depth turns over a layer of peat heretofore untouched by the plows. Furthermore, if the turning over and incorporating of raw peat in the tilled layer was considered a tillage objective, it would, after thirty years of cultivation, now be necessary to plow much deeper than formerly. There is no evidence to indicate that this is true. There is no visible evidence that either the tilled layer of soil or the undisturbed portions immediately below it are more compact than they were when first farmed.

**Shrinkage.** It is common knowledge that highly organic soils shrink on drying. In the Delta this process is most noticeable where large cracks develop in thoroughly dry soil. Newly excavated material placed on levees, for example, where it can become thoroughly dry, will shrink and crack to a marked degree. In cultivated fields, however, the normally high water table and irrigation do not permit the soil to become excessively dry. Some of these soils have a water-holding capacity of 150 per cent (on dry-weight basis) and a very high wilting percentage.

Shrinkage is not a completely reversible process, as thoroughly dry soils do not recover their original volume upon rewetting.

It is believed that shrinkage, although it adds somewhat to the subsidence in this area, is only one of the contributing factors.

**Oxidation.** To a very important degree the almost continuous submergence of the Delta soils in their virgin condition prevented or greatly retarded oxidation. In fact, it was lack of oxidation which enabled these highly organic soils to accumulate to great depths.

Fig. 10. The peat soil around this twenty-year-old house on Lower Jones Tract has subsided more than 4 feet. The pilings on which the house was built kept it from settling.

Reclamation, drainage, and cultivation, on the other hand, have greatly stimulated the disintegration and oxidation. Although most crops are now irrigated, the moisture is dissipated by evaporation and transpiration so that the soils on the immediate surface dry out to at least the wilting percentage during a part of the year. The frequent stirring of the surface soils by tillage must certainly increase the rate of oxidation. However, tillage is not essential to oxidation and some subsidence occurs even where the soils have not been disturbed for several years.

Figure 10 shows a house on Lower Jones Tract (picture taken in 1935) around and under which the soil has subsided about 4 feet. This house is built upon pilings driven into the mineral soils underlying the peat. Obviously neither compaction by tillage equipment nor burning has contributed to the subsidence under this house. The living quarters in this house are confined to the upper story to lessen the danger from floods should the protecting levees fail. The levees are now so well established that the danger of flood is remote, and this precaution is no longer observed in new construction.

Figure 11 shows in some detail the pilings on which this house was built. Steps were added to the stairway to connect with the receding soil.

Oxidation is believed to be the major cause of subsidence in the farmed lands of the Delta area. It is believed to occur at a rate readily measured by the methods employed.

**Burning.** A common cultural practice in the Delta area is the periodic burning off of the upper 3 to 5 inches of soil. This is done to clean up the fields by destroying weeds and weed seeds and to kill plant pests and diseases. It also has the effect of liberating potash and thus stimulating the growth of

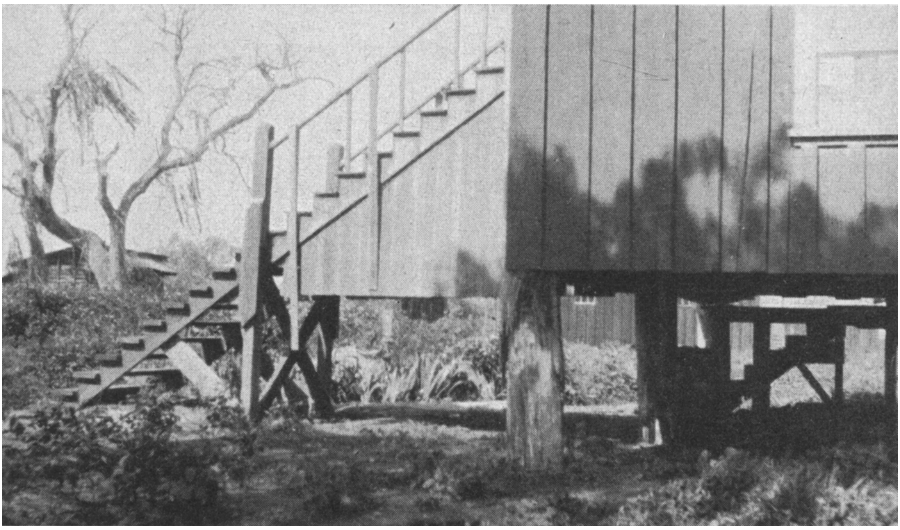

Fig. 11. Extra steps were added to the original steps of the house to connect with the ground.

the next crop. Burning is most frequently done preceding a crop of potatoes, especially if the land has been in barley for a season or two. Potatoes respond to potash fertilization in this area.

The mild climate and almost ideal conditions of moisture, together with a fertile soil, are conducive to a heavy growth of weeds. They sprout, grow, and mature after row crops are too large to be cultivated or after grain is harvested. In potato fields, weeds frequently become so abundant that they interfere with harvesting. Although there are many weeds, kelp and nutgrass are particularly troublesome. Both are very difficult to eradicate.

Plant diseases or pests, especially those which overwinter in the soil or on unharvested crops or weeds, cause considerable trouble with certain crops.

Some farmers believe that newly exposed or raw peat is the best medium for plant growth, and by burning off the top soil plants may use this newly exposed soil more readily. Burning is normally done only about once in five to ten years. However, the support price on potatoes and sugar during World War II made these crops so highly profitable that burning was done more frequently.

Only portions of an island or a tract will be burned in any one year. During the twenty-six years covered by this study, every portion of the areas included was burned at least once to a depth of 3 to 5 inches. In some instances, these studies may include areas that were burned even three or four times.

In this study the effects of burning are merged with other data. They will not appear as markedly influencing the elevation of the tract as a whole for any particular year.

Figure 12 shows a peat fire in progress. There is much evidence to show that burning even to 5 inches does not destroy all weeds nor kill all pests. It is often reported that fire produces killing temperatures in the soil to a depth of 12 to 18 inches below the portion burned. No evidence, however, was

Fig. 12. Burning the peat soils to a depth of 3 to 5 inches to destroy weed seeds, plant diseases, and pests contributes to subsidence.

found during these studies to support this statement. On the contrary, volunteer barley will sprout and come up through the ashes within 2 or 3 weeks after fire is extinguished, and barley seeds are much more easily killed than most weed seeds. The nuts from nutgrass survive uninjured at a depth of only 1 inch below the ashes which remain after the burning.

The peat soils of this area are somewhat lacking in available potash, an element essential to the production of potatoes. Since potatoes are almost invariably the first crop grown after burning, the liberation of available potash may be a more important reason for burning than is generally admitted.

The normal procedure is to grow one or two crops of barley before burning. During the war, however, when potato and sugar-beet production was greatly encouraged, burning was more frequently done and often followed a crop of beets and occasionally a crop of potatoes.

For several years prior to the war, Lower Jones Tract, an older island, was considered less suitable for potatoes and sugar beets than some of the younger islands, such as Mildred and Bacon. The high profits in these crops, however, may have stimulated their production on Lower Jones and increased the frequency of burning and, consequently, the rate of subsidence.

Considerable experimental work is under way on the use of selective sprays for weed control and on the chemical control of nematodes and other pests. It is to be hoped that controls will be found which will make burning unnecessary on the peat soils.

In preparation for burning, the barley stubble and weeds are lightly disked into the dry top soil. The 4-foot ditches and headgates are then repaired and put into workable condition, and spud ditches placed at frequent intervals. Fire is applied quickly over the entire field with oil-burning torches and allowed to burn 24 to 48 hours. When the desired depth of burn is attained, the water table is quickly raised and the field inundated to extinguish the fire.

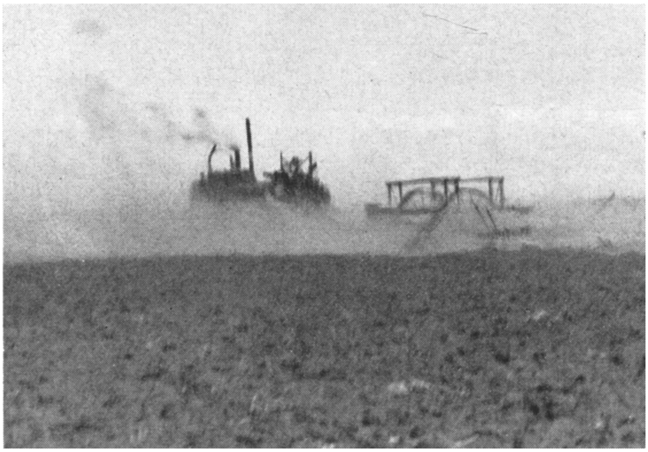

Fig. 13. Cultivation also contributes to subsidence by stirring up dust, some of which is carried out of the area by wind.

This is a hazardous undertaking, and elaborate preparations are made to control the fire within the area to be burned. Weather conditions at the time of burning are important and, notwithstanding the care taken in preparations, fire sometimes escapes into adjacent unprepared fields with great destruction.

Burning the top soil has undoubtedly contributed appreciably to the subsidence of the peat lands, although probably not to the same extent as natural oxidation.

**Wind Erosion.** Wind plays a part in the lowering of the surface soils in the Delta area. Dry peat soils are very light and fluffy, and clouds of dust are easily aroused. It is often impossible to see a tractor moving across a field because of the cloud of dust which surrounds it (fig. 13). Tractor drivers often cover their heads entirely and wear tight-fitting goggles and improvised masks to enable them to breathe. Miniature whirlwinds can be seen any summer afternoon carrying dust high into the air.

If the ashes on a burned field are not plowed under while the surface is still moist, there will be considerable loss by wind erosion. Peat dust and ashes are carried many miles by wind. Although no actual measurements have been made of the amount of soil lost by wind erosion, it may be as much as ¼ to ½ inch a year.

# SUMMARY AND EFFECTS OF SUBSIDENCE

It is evident from the data presented in this study that the peat soils of the Sacramento–San Joaquin Delta are disappearing at a measurable rate, with no indication that the rate is decreasing. This area has lowered from 6 to 8 feet since 1922, and much of it is now between 10 and 11 feet below sea level. The average rate of subsidence in the area under study is slightly over 3 inches a year.

The layer of peat overlying the mineral soils varies from nothing around the edges of the Delta to more than 30 feet in places near the center of the area. The average depth of peat remaining is probably about 10 to 12 feet.

When reclamation of the Delta began in the 1850's, peat soils extended almost to Stockton. At the present time there are no true peat soils left east of Holt, a point about 7 miles west of Stockton. The soils which remain after the peat is gone are, however, of higher organic content than most soils of the state and are still very productive.

Over a period of some sixty years, reclamation proceeded farther and farther into the Delta until about 1920, when Mildred Island was reclaimed. This island, although much smaller than most of the islands (about 1,200 acres) is the last sizable area to be put into cultivation. Reclamation and the destruction of the native cover of tules and reeds prevent any further accumulation of peat in this area, and there are no compensating influences.

The islands are becoming saucer-shaped, lower in the center where peat is deepest, and relatively higher around the edges where the mineral content of the soil is somewhat greater. Drainage is becoming more difficult as the drainage water must be led from the low interior to the base of the levee before it can be pumped into the surrounding sloughs. As the islands subside, drainage ditches must be deepened and the pumping lift increased. On the other hand, irrigation water is more readily obtained through siphoning over the levees and flowing by gravity toward the lower lands.

As the land subsides, the differential between the water level in the sloughs and the land surface on the islands becomes greater. This increases the pressure on the levees which, in turn, tends to increase the seepage through them. Seepage has, however, not yet become a serious problem. Levees are inspected frequently and are kept in good condition. The top of the levee provides the only stable ground for roads. All of the levees, some of which are paved, are therefore used as roads. Levees are also used for warehouse and storage sites; the labor camps and residences are all either on the levees or immediately adjacent. There are no buildings on the interior of the islands.

There has been no major levee failure in the past thirty years. Buildings and labor camps are constructed on pilings driven into the underlying mineral soils. This assures a stable foundation on otherwise unstable soil. In earlier methods of construction, the floors of buildings were approximately at the high-tide level so that if the levees should fail the buildings would not be inundated. Later construction has, however, not followed this plan, and many of the newer buildings have floors well below the water level in surrounding channels.

Although the peat soils have an acid reaction and the waters in the surrounding slough are only slightly affected by salts, there is an ever-increasing tendency for the Delta soils to become saline. As these soils are lost by oxidation or by burning, the salts which they contain will remain. Some salts are removed in the drainage water and small amounts may be removed by wind erosion.

The subbing method of irrigation commonly practiced is conducive to the surface accumulation of alkali salts, as there is always a high water table from which moisture is lost through capillary action and evaporation. Many farmers are becoming aware of the increase in salts, and are improving and enlarging the drainage systems.

Tile drainage is practically nonexistent in the peat lands of the Delta. The constant subsidence and loss of surface soil make tile drains impractical. Within five to eight years they become too shallow to be serviceable.

If the deeper peat soils continue to subside at the rate (3 inches a year) indicated by these studies, it is not difficult to predict the life of the remaining portions. A loss of the major portion of the peat does not, however, indicate that this area will become unproductive. As mentioned above, the outer portions of the area have already lost all or almost all of their peat soils, and yet the remaining soils are productive.

The destruction of the peat on the central portion of the area is, however, more significant than in the peripheral areas. The central islands are already 10 to 11 feet below tide level; a greater lowering will therefore place considerable strain on the levees and materially increase the drainage problems. Should some accident cause a levee to fail and a tract to become submerged, it may not be economically feasible to drain it. Franks Tract, which contains more than 3,000 acres and lies only about 2½ miles northwest of Bacon Island, has been under water for several years.

The burning of peat lands, for whatever purpose, is one of the most destructive practices in this area. This is the only one of the destructive processes which can be prevented, and the total abolition of burning will undoubtedly prolong the life of the peat by several years. A very strong sentiment against burning was being aroused before World War II, but the demand for increased production of potatoes and sugar beets caused many of the Delta operators to increase the frequency of burning.

Burning has been entirely discontinued only in those portions of the Delta where the organic content of the soil is now so low that the soil will not burn.

## PARTIAL LIST OF REFERENCES TO PAPERS ON SUBSIDENCE OF PEAT AND MUCK LANDS


ALWAYS, F. J.

1920. Agricultural value and reclamation of Minnesota peat soils. Minnesota Agr. Exp. Sta. Bul. **188.**

AYRES, C. E., and DANIEL SCOATES.

1928. Land drainage and reclamation. McGraw-Hill Book Co.

CLAYTON, B. S.

1936. Subsidence of peat soils in Florida. U.S.D.A. Bur. Agr. Engin. (Mimeo. report.)

CLAYTON, B. S., and L. A. JONES.

1941. Controlled drainage in the northern Florida Everglades. Agr. Engin. **22** (8).

DACHNOWSKI-STOKES, A. P.

1926. Factors and problems in the selection of peat lands for different uses. U.S.D.A. Bul. **1419.**

1930. Peat profiles of the Florida Everglades. Washington Acad. Sci. Jour.: **20.**

ELLIOTT, G. R. B., E. R. JONES, and O. R. ZEASMAN.

1921. Pump drainage on the University of Wisconsin marsh. Wisconsin Agr. Exp. Sta. Res. Bul. **50.**

FOWLER, GORDON.

1947. Fenland soils and sub-soils. British Sugar Beet Review **16** (1).

GISSING, FRED T.

1920. Peat industry reference book. Moscow, U.S.S.R.

MCCOOL, M. M., and P. M. HARMER.

1925. Muck soils of Minnesota. Michigan Spec. Bul. **136.**

OKEY, CHAS. W., *et al.*

1920. Subsidence of muck and peat soils of southern Louisiana and Florida. U.S.D.A. Bur. Agr. Engin. (Mimeo. report.)

POWERS, W. L.

1919. The improvement of marsh lands in western Oregon. Oregon Agr. Exp. Sta. Bul. **157.**

1932. Subsidence and durability of peaty soils. Agr. Engin. **13** (3).

ROE, H. B.

1939. Some soil changes resulting from drainage. Soil Sci. Soc. of Am. Proc. 4.

1943. The soil moisture and cropping problems of peat and muck lands in the northern United States. Michigan Agr. Exp. Sta. Sci. Paper **2032.**

WEIR, WALTER W.

1937. Subsidence of peat land on the Sacramento–San Joaquin Delta of California. Vol. B, Trans. 6th Commission International Society Soil Science.


4*m*-6,'50 (B9402) MH

141

The journal *Hilgardia* is published at irregular intervals, in volumes of about 600 pages. The number of issues per volume varies.

Subscriptions are not sold. The periodical is sent as published only to libraries, or to institutions in foreign countries having publications to offer in exchange.

You may obtain a single copy of any issue free, as long as the supply lasts; please request by volume and issue number from:

Publications Office
College of Agriculture
Berkeley 4, California

The limit to nonresidents of California is 10 separate issues on a single order. A list of the issues still available will be sent on request.