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Spoil Banks: Effects on a Coastal Marsh Water-Level Regime

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Above- and below-ground water-level fluctuations were measured in the marshes south of New Orleans, Louisiana, between November 1982 and December 1983. The purpose of the program was to define the basic marsh water-level regime and to investigate how canal spoil banks may influence the water-level regime. Two study areas were used: (1) a control area, defined as a section of marsh with unrestricted hydrologic connection to an adjacent bayou; and, (2) a partially-impounded area, defined as an area with limited hydrologic connection to an adjacent bayou due to the presence of dredged canal spoil banks. Data sources included marsh water levels from gages deployed at three sites within the study areas and water levels from the adjacent bayous obtained from the tide gages of U.S. Army Corps of Engineers.

Data from all marsh gage sites showed a similar pattern with a distinct surface and subsurface diurnal tidal signal superimposed upon other, larger scale events. These larger scale events correspond to the passage of weather fronts. The data also indicated that a significant amount of water-level fluctuation in the marshes occurs below ground.

A comparison of the control area and the partially-impounded site indicated that the spoil banks changed the response of the marsh water levels to the forcing from the bayou, with the result that the partially-impounded area: (1) was flooded 141 hours more per month than the control area; (2) had fewer, but longer flooding events; (3) had fewer but longer drying events; and (4) reduced water exchange, both above and below ground.

Introduction

Wetland management and use often involve the direct or indirect manipulation of the hydrologic regime. Such manipulation may, or may not, be intentional and can result from many different activities. Canals and their resulting spoil banks, weirs, and tidal gates have been used in wetlands to assist navigation, regulate water levels and salinity, and implement management plans. Many of the canals and spoil banks in south Louisiana were constructed solely to assist oil and gas recovery operations. Spoil banks, in conjunction with weirs, plugs or water-control structures, have also been built to control water levels for over-wintering ducks. However, spoil banks have also been implicated as one of the contributing factors to the high wetland loss rate in southern Louisiana.

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The annual loss rate is currently estimated to be about 0·8% of the existing marsh (Scaife *et al.*, 1983). Several studies (e.g., Adams *et al.*, 1978; Craig *et al.*, 1979; Turner *et al.*, 1982; Scaife *et al.*, 1983) have noted the empirical relationship between erosion and canal- and spoil-bank density. The connection between spoil banks and wetland loss is presumably through their influence on marsh hydrologic conditions, which in turn influence biotic and physical factors important in sustaining land-building processes in an otherwise sinking (through sediment compaction and sea-level rise) deltaic coast. Despite the clear ecological, economic, and social value of this enormous wetland area (about 41% of the U.S. coastal wetlands; Turner & Gosselink, 1975) there has been little detailed field research on the hydrology of these marshes or on the effects of spoil banks on wetland hydrology. Many authors (Craig *et al.*, 1979; Gael & Hopkinson, 1979; Turner *et al.*, 1982, 1984) have implicated hydrologic changes as the major mechanism for canal and spoil-bank influence on wetland (marsh) ecology. However, none of these studies have any detailed field measurements of the hydrologic regime. It was the purpose of this study to determine the effects of spoil banks on a marsh hydrologic regime and how this might influence future management of the southern Louisiana marsh ecosystem.

Materials and methods

Study sites

The study areas are located in a brackish marsh south of New Orleans, Louisiana (Figure 1), in the still active Golden Meadow oil and gas field. We used two areas: (1) a control area, which had a natural berm along a major bayou; and (2) a partially-impounded area where about 75% of the natural berm had been replaced by a dredged canal spoil bank, which limited the hydrologic connection to the adjacent bayou. Water level gages were deployed at two sites within the partially-impounded area and one site within the control areas.

The control area (Figure 1), was approximately 33·4 ha and was vegetated with a mixture of *Spartina alterniflora* and *Spartina patens,* the most commonly occurring emergent marsh vegetation in this general area (Chabreck, 1972). The bayou had a natural levee 1–2 m wide, with an average berm height about 0·1 m higher than the adjacent marsh. In an earlier study, De-Laune *et al.* (1983), noted berm heights of about 0·1 m for a natural *Spartina alterniflora* marsh in Barataria Bay, Louisiana. It was because of the natural edge along the bayou that this area was chosen for a control where there was a noticeable ‘ edge effect ’ with much more robust marsh vegetation along the bayou bank. The water-level gage was installed on the marsh surface at a site about 50 m inland from the edge of the Grand Bayou.

The partially-impounded area (Figure 1) was vegetated by a mixture of *Spartina alterniflora* and *Spartina patens* and covered about 7·5 ha. At this site, the natural edge along Grand Bayou had been replaced by a spoil bank, and the northern and southern edges of the area were also formed by canal spoil banks. It was estimated that the spoil banks cover about 75% of the perimeter; hence, the site is referred to as partially-impounded. Water-level gages were placed at two sites within the area: (1) Impound-1 was on a firm section of marsh about 50 m inland from Grand Bayou; (2) Impound-2 was installed on the edge of a large pond located about 50 m inland from the edge of the canal which forms the southern boundary. A linear correlation of Impound-1 to Impound-2 indicated no significant difference between the water-level fluctuations at the two sites.

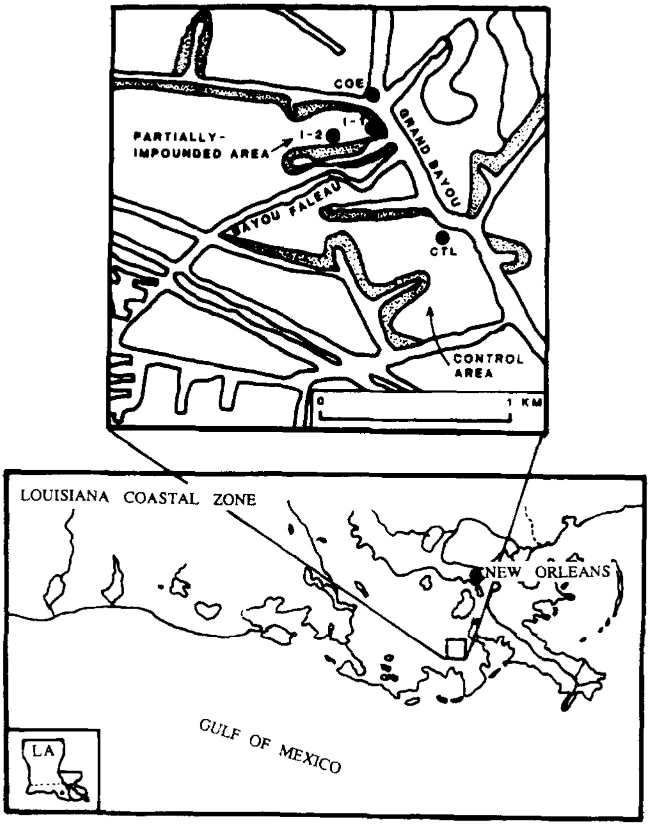

Figure 1. Generalized map of Louisiana coastal zone showing the study location south of New Orleans. The insert presents a detailed map of the study location, showing the water-level gage sites (I–1, Impound–1; I–2, Impound-2; COE, Corps. of Engineers; CTL, control) and the canal geometry. The stippled areas are spoil banks.

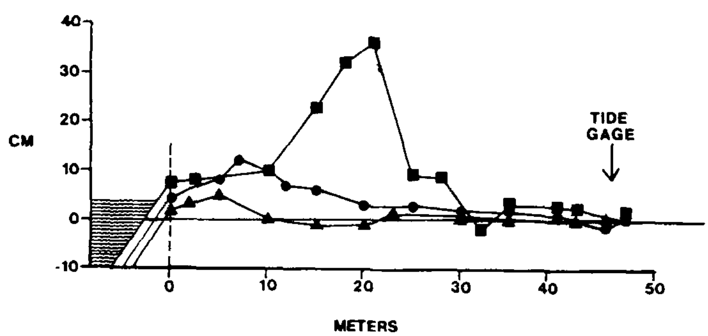

Figure 2. Marsh elevation transects from each of the gage sites. The height of the marsh (above the water surface at the time of the survey) is indicated as a function of distance into the marsh from the waters' edge. ▲, CTL; ●, I–1; ■, I–2.

Thus, the data presented in this paper are from the Impound-1 gage site, which had the longest record.

The relative heights of the marsh and the water-level gages were surveyed using a self-leveling Leitz level and stadia rod. Figure 2 presents the results of the survey. Along

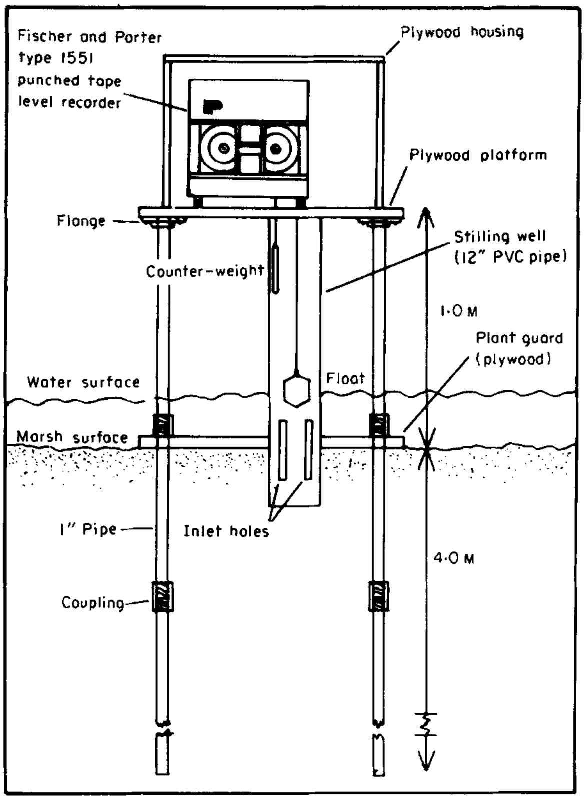

Figure 3. Schematic diagram illustrating the water level gage installation.

the Grand Bayou edge, the spoil bank at the Impound-1 gage site was about 0·10–0·15 m higher than the natural levee along Grand Bayou at the control area (CTL gage site). The spoil bank along the canal at the Impound-2 gage site was about 20 m wide and 0·40 high.

Data collection

Water levels were measured with level gages and recorded at hourly intervals on paper tape (Fisher and Porter type 1551). Installation (Figure 3) consisted of a plywood platform located about 1·0 m above the marsh surface. A 30-cm diameter stilling well suspended from the platform housed the measuring float. The stilling well was dug into the marsh, resulting in an operating range from approximately 0·6 m below marsh surface to 1·0 m above marsh surface. The gages were serviced every other month, at which time data tapes were collected, the batteries changed and the clock checked. The worst drift for the clock was 1·0 h month^{-1}. The marsh surface was quite 'bumpy', with elevation differences between the vegetation clumps and mud surface of about 0·04 m. Therefore, for this study, the marsh surface was defined to be the top of the plywood plant guard which formed the base of the water-level measuring station. The gages were adjusted to record water levels relative to the marsh surface, as defined above. During servicing, this base level setting of the gages was also checked.

Water levels in Grand Bayou, near the study areas, were measured at a nearby gage (Figure 1) maintained by the U.S. Army Corps of Engineers (COE). Copies of the data records from this gage were supplied to us by the Corps.

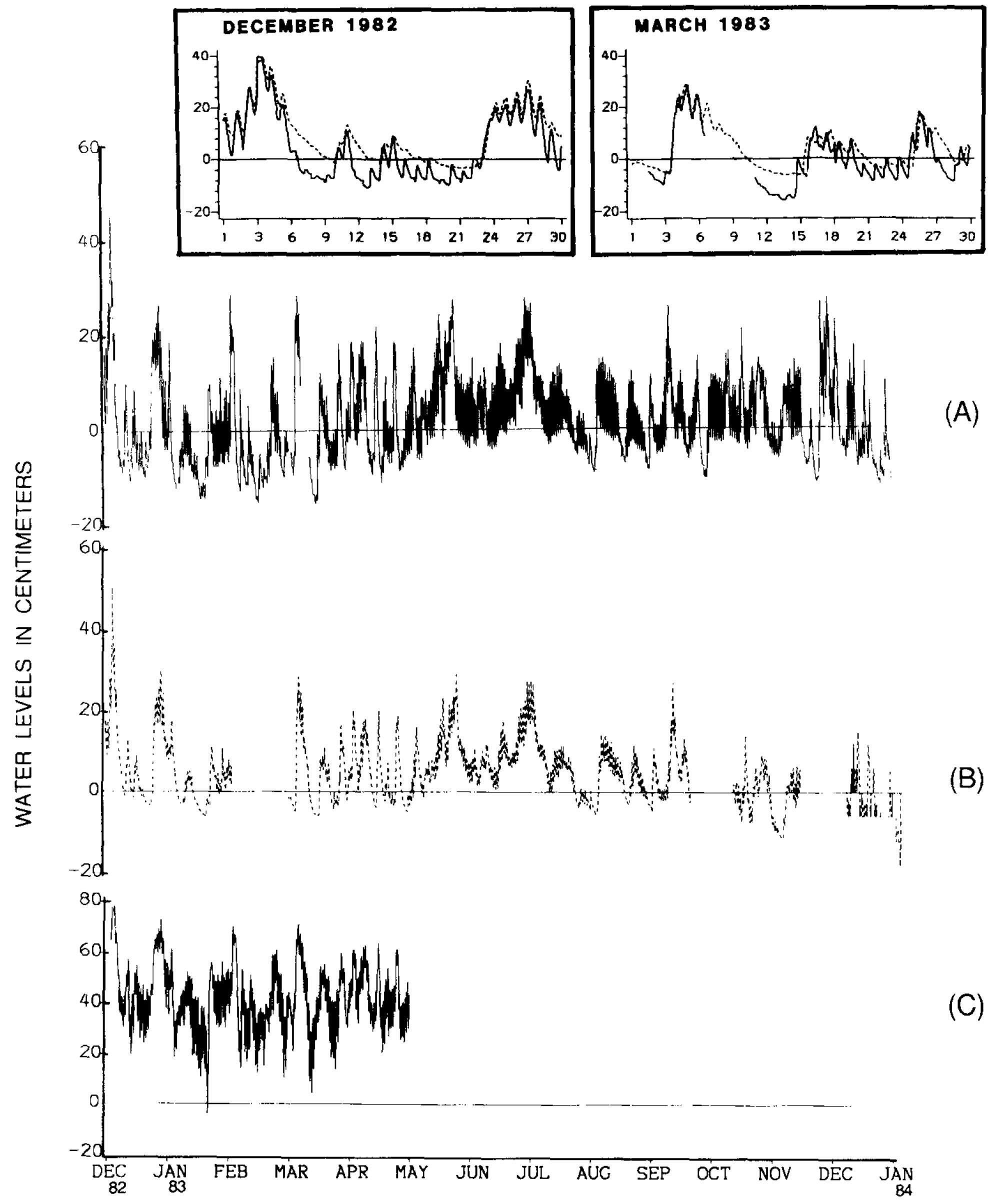

Figure 4. Raw (unfiltered) water level time series data from: (A) the control area, (B) the partially-impounded area, and (C) Grand Bayou for December 1982 thru April 1983. The bayou water levels are in centimeters relative to National Geodetic Vertical Datum (NGVD). The marsh water levels are in centimeters above or below the marsh surface. Boxes at top present detailed time series of plots of water levels from the control area (solid line) and the partially-impounded area (dashed line), for December 1982 and March 1983.

Data analyses

The data were analysed using Louisiana State University's IBM 3083 computer with the Statistical Analysis Systems software (SAS Institute Inc. 1981, 1982*a,b*). Because all of the data were collected in a time series format, the same analysis procedures were used for each data set. The Bayou data (chart-recorder records) were digitized by hand at three-hour intervals. The marsh water levels (punched paper type) were read by machine at one-hour intervals. The digitized data were then transferred to the LSU mainframe computer, checked for errors, and converted to metric units. Any correction factors needed to adjust for gage base-level drift were applied at this time. The data were averaged by month to obtain summary statistics of: (1) mean below-ground water levels; (2) mean above-ground water levels; (3) percentage of the total fluctuations occurring below-ground; and (4) the percentage of time the marsh is flooded.

Water exchange into and out of the marsh was estimated from the water-level data using the procedures described below. The first derivative of the water level versus time curves was calculated; the first derivative is the change in water level over a one-hour interval (the sampling interval). This change with time was expressed as a water volume exchange per unit area (m^2) of marsh. For example, a water-level drop of 10 cm corresponds to a volume exchange of $0{\cdot}10\,m^3\,h^{-1}$ per m^2 of marsh. The time history of volume flux was then numerically integrated to obtain total flux values for above- and below-ground water levels for both flood and ebb tides. The integration followed the general form of:

$$R_p = \sum_{i=0}^{n} f(W_i)\,\Delta X$$

where: R_p = estimated area under the curve; $f(W_i)$ = height of curve relative to marsh surface at time i, ΔX = sampling interval (1 h); n = total time intervals. For this analysis, three types of sums were calculated: (1) $f(W_i)_{min}$ = minimum curve height during sample period; (2) $f(W_i)_{max}$ = maximum curve height during sample period; (3) $f(W_i)_{avg}$ = (minimum + maximum)/2.

The analysis, therefore, yielded estimates for the average area under the curve (3), along with an estimate of the minimum (1) and maximum (2) range. In making these calculations, it was assumed that any change in water level (either above- or below-ground) represented a layer or ‘ slab ’ of water being exchanged, implying that the water surface on the marsh was level.

Results

Figure 4 presents time series water-level data for Grand Bayou, the control area, and the partially-impounded area between December 1982 and January 1984.

The most notable feature in Figure 4 is the dominant diurnal tidal signal, which is superimposed upon other larger scale water-level fluctuations. This diurnal signal is present in both the above-ground and below-ground portions of the water level signal. The amplitude of the below-ground tidal portion is around 5–10 cm while the above-ground tidal portion has amplitudes of 20–30 cm. The larger scale fluctuations, with amplitudes of 40 cm or greater, result from wind-induced set-up caused by passing weather fronts (Swenson, 1983).

The difference in the way in which the control area and the partially-impounded area are coupled to the bayou is also evident. Although the water-level signals at both marsh sites mimic the signal in the bayou, the water-level signal in the partially-impounded area shows less short-term (tidal) fluctuation than the control area. The detailed inserts, which show data from December 1982 to March 1983, show that, although both reach the same levels during a flooding event, the partially-impounded area drains at a much slower rate. The control area also shows a great deal more water-level oscillation than the partially-impounded area.

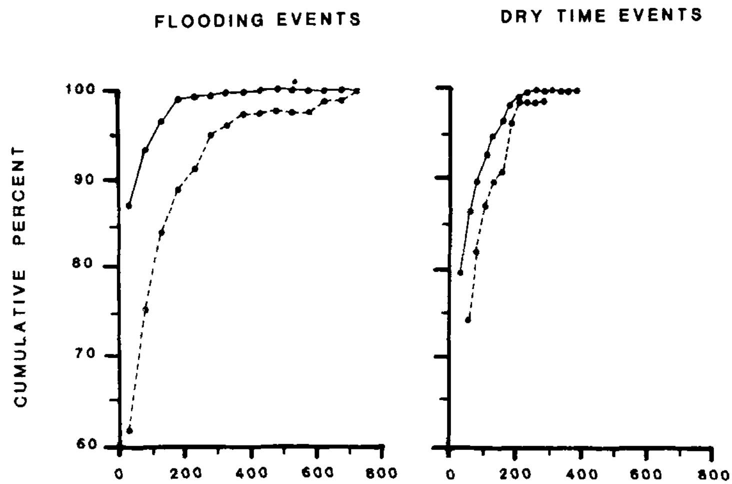

Figure 5. Distribution of flooding event lengths (left) and dry time intervals (right) for the control area (solid line) and the partially-impounded marsh area (broken line). The horizontal axis is the length of the flooding event (in hours) and the vertical axis is the percentage of time that event occurred during the sampling period. The sample period covers the time from November 1982 to November 1984.

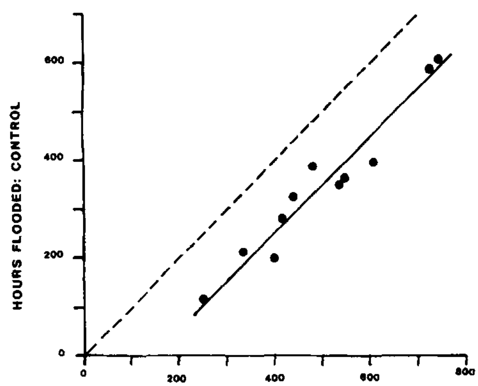

Figure 6. Plot of total hours flooded, for the month, at the control area (vertical axis) against total hours flooded, for the month, at the partially-impounded area. The broken line represents a one-to-one relationship; the solid line is the fitted line to the data points, given by $y = 0{\cdot}96X\text{-}141$; $R^2 = 0{\cdot}84$.

The length of each flooding event (number of hours the marsh was flooded) and the interval between each event was determined, on a monthly basis, from November 1982 to October 1984 (Figure 5). A comparison of flooding event lengths for each area indicates that flooding events shorter than 20 h occur 80% of the time in the control area, but only 28% of the time in the partially-impounded area. Similarly, flooding events which are longer than 100 h occur about 10% of the time in the control area, and about 37% of the time in the partially-impounded area. The mean flooding event lengths were 29·7 h and 149·9 h for the control and partially-impounded areas, respectively. Figure 6 is a plot of

TABLE 1. Comparative summary statistics for the control and partially impounded marsh areas. August 1982–December 1983*

	Control	Partially-impounded site
Flooding		
Number of events	12·92±02·65	4·50±01·20
Event length (h)	29·71±07·51	149·92±98·62
Drying		
Number of events	11·57±02·49	4·00±01·26
Event length (h)	31·21±09·60	53·93±22·82
Other		
Mean water level (cm)	1·71±02·15	3·99±02·24
Volume exchange (m^3/m^2 marsh surface)		
Above-ground	0·15± 0·04	0·06± 0·02
Below-ground	0·09± 0·02	0·04± 0·01

*All values, except for the volume flux estimates, represent the average monthly means ± 2 times the standard error of the mean. The volume flux estimates are the tidal cycle means plus or minus the range of the estimate.

the total hours flooded each month for the control area against the total hours flooded each month at the partially-impounded area. The relationship is highly significant, with an r^2 value of 0·84 and a slope which is not significantly different from one. On the average, the partially-impounded area is flooded 141 h month^{-1} more (about 33%) than the control area.

The water-volume estimates indicated that the average above-ground water exchange per tidal cycle was 0·15 m^3 and 0·06 m^3 per m^2 of marsh surface for the control and partially-impounded areas, respectively. Similarly, the average below-ground water volume exchange was 0·09 m^3 and 0·04 m^3 per m^2 of marsh surface for the control and partially-impounded areas, respectively. The below-ground estimates are for ebb tide conditions only. The water-level gage deployment scheme allowed water to enter the wells from the top during flood tide conditions, thus making below-ground water exchange estimates during flood-tide conditions invalid. The above-ground estimates at each area were not significantly different for flood and ebb.

Table 1 summarizes the average hydrologic regime at the two areas. Flooding events of 100 h or greater occurred 10% of the time in the control marsh and 40% of the time in the partially-impounded marsh, indicating independence of water flow into and out of the marsh due to the spoil banks. Compared to the control site, the partially-impounded marsh had 65% fewer drying events but these events were 73% longer. Similarly, the partially-impounded marsh had 65% fewer flooding events, but these events were about 405% longer. The above ground water exchange was reduced by 60% and the below-ground exchange was reduced by 55%. The end result is an increase in flooding duration on average of 141 h month^{-1}.

Discussion

We studied one of the many partially-impounded marshes on the Louisiana coast. A cursory survey of other impounded sites indicates that there are two general types of impoundment: (1) those that are planned and actively managed; and (2) those that result from independent dredging and filling activities (i.e., the intersection of several canals) and hence are not planned or managed. This study was concerned with the latter case, and the general results may be broadly applicable to a significant number of these types of sites because spoil banks are built using common techniques and machinery.

Chabreck *et al.* (1979) monitored soil and water variables in Louisiana coastal marshes influenced by weirs. In their study, the weirs were installed in tidal channels, with the weir crest 0·15 m below the adjacent marsh surface, thus allowing free water exchange over the structures. The results indicated that the presence of weirs increases the percentage of time that the bottoms of marsh ponds are flooded. Our data indicate that the presence of spoil banks, which are on the marsh surface, leads to an increase in flooding over the entire marsh surface, as well as a decrease in the below-ground exchange.

Sasser (1979) described the broad empirical limits of plant distribution and flooding in these marshes, noting the wide range of flooding tolerance of plants. However, the optimum flooding conditions for plant growth are not clearly defined nor is it clear how large a disruption in the natural water-level regime can be tolerated. King *et al.* (1982) showed that an increase in subsurface drainage can lead to an increase in plant production, and Mendelssohn *et al.* (1981) showed that decreased drainage may result in less plant production. As these studies indicate, the water-level regime does influence marsh vegetation production. However, the ecological significance of the monthly hydrologic averages may be overshadowed by the few, but relatively stressful, long periods of flooding. Turner *et al.* (1984) showed that when marsh sediment is flooded for one week, the eH can drop by as much as 380 mV. Coupling the data of Turner *et al.* (1984) with the mean flooding event lengths measured in this study, one would expect the partially-impounded soil eH to fluctuate about a lower mean than the control-site soil eH. Longer periods of flooding, as are common in the impounded marsh but not in the control marsh, could result in extremely low soil eh/pH values. Such soil chemistry changes would be ecologically significant, particularly if sulphates were reduced to toxic sulfides (Mendelssohn *et al.*, 1981; King *et al.*, 1982; DeLaune *et al.*, 1983).

This study has shown that canal spoil banks significantly influence the marsh water-level regime in this system. As the above studies indicate, these changes can have profound effects on the marsh ecosystem. In order to alleviate the adverse impacts of these hydrologic changes, management options that minimize the disruption of the hydrologic regime need to be exercised. These options include backfilling the canals, placing gaps in the spoil banks, the use of weirs or flap gates, and alternative dredging techniques not requiring spoil bank construction.

However, at the present time the degree to which the options need to be exercised, and under what conditions are not well known. What is needed now are longer-term experimental studies to investigate the marsh water-level regime together with the entire ecosystem in natural and managed wetlands. Such data would be invaluable in answering more detailed questions about the marsh ecosystem functions and would provide an improved data base to managers that would allow them to develop guidelines for these various marsh mitigation measures.

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