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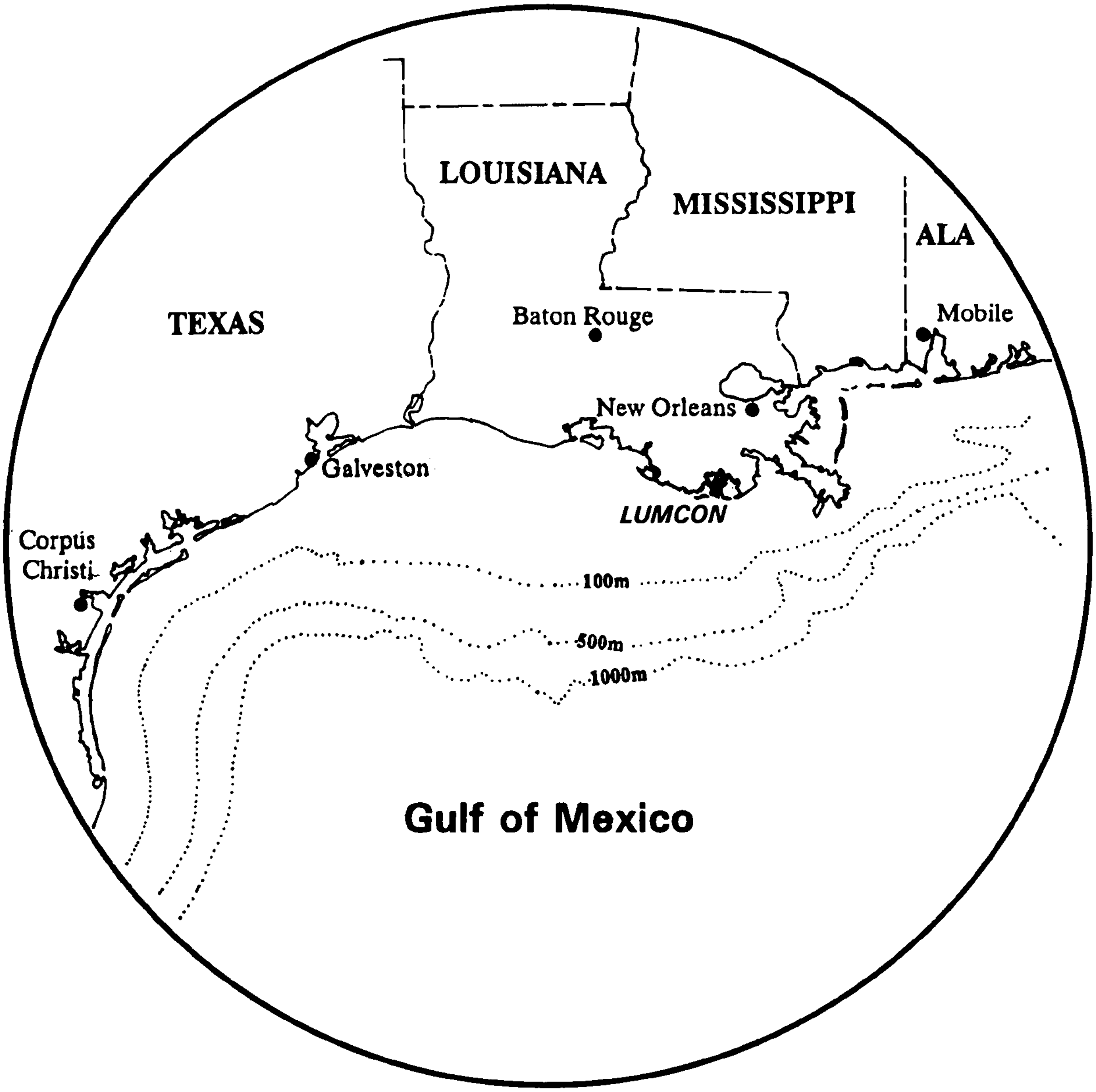
Backfilling Canals as a Wetland Restoration Technique in Coastal Louisiana



MMS U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

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University Research Initiative
Louisiana Universities Marine Consortium

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Backfilling Canals as a Wetland Restoration Technique in Coastal Louisiana

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ABSTRACT

Thousands of canals have been dredged in coastal Louisiana wetlands for oil and gas exploration and extraction since 1938. These canals are typically dredged to 2.5 m depth and are 20 to 40 m wide. Canal lengths vary from 100 m to several 1000s m in the case of OCS pipeline canals. Canals have a number of harmful effects on the wetland environment including alterations in salinity, flooding and draining patterns, direct loss of marsh by conversion to open water, and increases in marsh erosion rates. One method to compensate for these impacts is to return spoil material from the spoil banks to the canal with the hope that marsh vegetation will be reestablished on the old spoil banks and in the canal. The movement of former spoil bank material back into the canal is referred to as "backfilling." At least thirty-three canals have been backfilled in coastal Louisiana with varying degrees of success.

We examined the sites of a previous study to document and interpret changes occurring since 1983/4 and to statistically model the combined data derived from these new and previous analyses. We wanted to determine recent changes in (1) soils, (2) vegetative cover, and (3) fish use. A statistical model of the data was constructed using the resulting data. Hypotheses tested about restoration through backfilling were that success is a function of: (1) canal length, (2) canal age, (3) marsh soil organic matter content, (4) presence of a plug at the mouth of the canal, and (5) the percentage of the available spoil material returned to the canal. Field observations were made to determine the success of restoration and to collect information on environmental conditions suspected of influencing restoration success. Aerial imagery taken from 916 m was used to determine the percentage of the old spoil bank area that is now marsh vegetation, upland vegetation, and open water.

The major factors determining backfilling restoration success are the depth of the canal, soil type, canal dimensions, locale, dredge operator skill, and permitting conditions. Plugging the canal has no apparent effect on water depth or vegetation cover, with one exception. Submerged aquatic vegetation was more frequently observed behind backfilled canals with plugs than in backfilled canals without plugs. Canal age, soil organic matter content, and whether the restoration was within or away from the permitted dredging site were the most important predictors of canal depth. Canal length and percentage of spoil returned (+) had the greatest effect on vegetation cover. Backfilled canals were shallower if they were older, in soils lower in organic matter, and backfilled as mitigation for dredging done at another location. Vegetation cover increased with increased canal length and percentage of spoil material returned.

Backfilling canals restores wetlands at a cost of $1,200 to $3,400/ha, depending on whether only the direct, or also the indirect impacts, respectively, were included. The restoration costs compare favorably with funded restoration projects in south Louisiana, including structural marsh management and river diversions. Backfilling is a technique to manage canals and spoil banks in coastal Louisiana that demonstrates stability over decades. It is a reasonably short management action, requiring existing well-proven equipment and no on-site maintenance. Fish and waterfowl habitats are produced. There are tens of thousands of hectares of canal and spoil banks available for backfilling today. Many more will become available as the oil and gas fields are abandoned.

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CHAPTER 1. EXECUTIVE SUMMARY

Canals have been dredged in coastal Louisiana wetlands since 1930s for oil and gas exploration and extraction. Most waterways are abandoned after mineral extraction is completed. Today, thousands of miles of canals crisscross these wetlands. These canals are typically dredged to 2.5 m depth and are 20 to 40 m wide. Canal lengths vary from 100 m to several 1000s m in the case of OCS pipeline canals.

Studies have linked dredged canals to a number of undesirable effects on the wetland environment including alterations in salinity, flooding and drainage patterns, direct loss of marsh by conversion to open water, and increases in marsh erosion rates. These effects have led state and federal agencies charged with managing the wetland resource to look for methods of mitigating canal impacts. One possible method of dealing with spoil banks after the abandonment of a drilling site is to return spoil material from the spoil banks to the canal with the hope that marsh vegetation will be reestablished on the old spoil banks and in the canal. The movement of former spoil bank material back into the canal is referred to as "backfilling".

Backfilling began to be required in a small number of cases, starting in 1979 (Neill and Turner 1987a, b), as a condition for the issuance of permits to dredge a canal (after the drilling site is abandoned the canal must be backfilled 'on-site'), or, as mitigation at another location (an 'off-site' mitigation site) different from the location of the newly permitted canal. At least thirty-three canals have been backfilled to date, with varying degrees of success (Neill and Turner 1987a).

The purpose of this study was to investigate the factors that affect backfilling success and to develop a model that could be used by managers to predict the success of backfilling. We examined the sites of a previous study to document and interpret changes occurring since 1983/4 and to statistically model the combined data derived from these new and previous analyses. Specifically, we wanted to determine the recovery rates of vegetation, water depth, and soils in backfilled canals, 'restored' spoil banks, and in nearby marshes, and quantify the influence of plugging canals on these rates. We wanted to know if the initial growth of submerged aquatic vegetation was maintained, if additional growth appeared, and if the growth of submerged aquatics was sustained after the plug washed out.

The backfilled canals examined in 1983/4 were re-examined to determine recent changes in: (1) soils, (2) vegetative cover, and (3) fish use. A statistical model of the data was constructed using the resulting data. These backfilled canals are occasionally plugged (or at least were plugged several years ago) and are most of the backfilled canals in Louisiana. Hypotheses tested about restoration through backfilling were that success is a function of: (1) canal length, (2) canal age, (3) marsh soil organic matter content, (4) presence of a plug at the mouth of the canal, (5) the percentage of the available spoil material returned to the canal. Field observations were made to determine the success of restoration and to collect information on environmental conditions suspected of influencing restoration success. All canals were photographed in color infra-red imagery in November 1990 using an aircraft-mounted large-format (5 inch x 5 inch) camera. The imagery was taken from an altitude of approximately 916 m. An 8 inch x 8 inch photograph was developed from the resulting transparencies to determine the percentage of the old spoil bank area that is now marsh vegetation, upland vegetation, and open water. The 1990 photography was also visually compared to black and white photographs taken during the earlier study.

The major factors determining backfilling restoration success are the depth of the canal, soil type, canal dimensions, locale, dredge operator skill, and permitting conditions. Plugging the canal has no apparent effect on water depth or vegetation cover, with one exception. Neill and Turner (1987a) noted that submerged aquatic vegetation was more frequently observed behind backfilled canals with plugs than in backfilled canals without plugs. Canal age, soil organic matter content, and whether restoration was done as mitigation on-site or off-site were the most important predictors of canal depth. Canal length and percentage of spoil returned (+) had the greatest effect on vegetation cover. Backfilled canals were shallower if they were older, in soils lower in organic matter, and backfilled off-site. Vegetation cover increased with increased canal length and percentage of spoil material returned.

The decisions managers can constructively make when requiring backfilling are to choose among those candidate canals that are in low organic soils, longer, and near sources of suspended sediment supply. Canals in the Chenier Plain of southwestern coastal Louisiana may have a higher restoration success than in the Deltaic Plain region. However, all canals with a healthy wetland around them should be included as potential backfilled sites. Even canals that are 20 years old may benefit from backfilling.

Backfilling the canal would restore wetlands at a cost of $1,200 to $3,400/ha, depending on whether only the direct, or also the indirect impacts, respectively, were included. The restoration costs compare favorably with existing restoration projects in south Louisiana, including structural marsh management and river diversions.

In summary, backfilling is a means of managing canals and spoil banks in coastal Louisiana. It is a management technique that demonstrates stability over decades. It is a reasonably short management action, requiring existing well-proven equipment and no on-site maintenance. There are tens of thousands of hectares of canal and spoil banks available for backfilling. Many more will become available as the oil and gas recovery efforts continue to decline.

CHAPTER 2. INTRODUCTION

2.1 Background

Canals have been dredged in coastal Louisiana wetlands for oil and gas exploration and extraction since 1938. Most waterways are abandoned after mineral extraction is completed. Today, thousands of miles of canals crisscross these wetlands. Today, thousands of miles of canals crisscross these wetlands. These canals are typically dredged to 2.5 m depth and are 20 to 40 m wide. Canal lengths vary from 100 m to several 1000s m in the case of OCS pipeline canals.

Studies have linked dredged canals to a number of undesirable effects on the wetland environment. These include alterations in salinity, flooding and draining patterns, direct loss of marsh by conversion to open water, and increases in marsh erosion rates (Craig et. al. 1979; Gagliano et. al. 1981, Swenson and Turner 1987; Cahoon and Turner 1989). Direct and indirect impacts of canals and spoil banks are the likely cause for 30 to 59 percent of the coastal wetland losses from 1955 to 1978 that averaged 0.86% annually (Turner and Cahoon 1987).

These impacts have led state and federal agencies charged with managing wetland resources to look for methods of mitigating canal impacts. One possible method of dealing with spoil banks after the abandonment of a drilling site is return dredged spoil material from the spoil banks back to the canal. The intention of this method is to reestablish marsh on the old spoil banks and in the canal, with a return to a more natural hydrological regime. The re-dredging of former spoil bank material back into the canal is referred to as "backfilling".

Backfilling has been documented as a useful restoration technique by several investigators (Adkins and Bowman 1976; Lindall et. al. 1979; Turner et. al. 1983; Neill and Turner 1987a) and natural resource managers. Backfilling has been required in a small number of cases, starting in 1979 (Neill and Turner 1987a, b), as a condition for the issuance of permits to dredge a canal (after the drilling site is abandoned the canal must be backfilled) or as off-site mitigation for the issuance of a permit for a new canal. At least thirty-three canals have been backfilled to date, with varying degrees of success (Neill and Turner 1987a).

The goals of backfilling are (adapted from Neill and Turner 1987a):

1) re-establishment of wetland vegetation in the canal and on the re-graded spoil bank;
2) restoration of marsh soils on the re-graded spoil bank;
3) restoration of natural hydrological conditions including reestablishing the original drainage patterns; and,
4) restoration of habitat for fish and wildlife.

The purpose of this study was to investigate the factors that affect backfilling success and to develop a model that can be used by marsh managers to predict the success of backfilling in both oil and gas canals and in dredged pipeline canals.

2.2 Previous Studies

Thirty-three backfilled canals, representing virtually the entire population of permitted backfilling of oil and gas canals, were assessed by Neill and Turner (1985, 1987a) to document the initial success of habitat restoration. Restoration success appeared to depend on marsh type, canal location and age, marsh soil characteristics, the presence or absence of a plug at the canal mouth, whether mitigation was conducted at the dredging site upon canal abandonment (on-site mitigation) or away from the permit location (off-site mitigation), and dredge operator performance. Backfilling initially reduced the median canal depth from 2.4 to 1.1 m and restored marsh vegetation on the backfilled spoil bank, but did not then result in restoration of the emergent marsh vegetation in the canal because of the lack of sufficient spoil material to fill the canal and/or time. The organic matter and water content of spoil bank soils were intermediate between spoil bank levels and pre-dredging marsh conditions. Restoration success then was higher in the Chenier plain marshes than in the Deltaic plain marshes.

Backfilling has great potential for improving unfilled canals as aquatic habitat for fish and wildlife (Turner et al. 1988). Backfilling *initially* creates shallow open water areas in the former canal that support large numbers of small fishes, including juveniles of species that use shallow marsh water bodies as nurseries (Neill and Turner 1987b). Backfilled canals often bear a visual resemblance to natural marsh ponds, have similar dimensions, support aquatic vegetation, and have a high amount of marsh-water edge. Such shallow marsh ponds have been widely shown to be excellent habitat for estuarine fishes and macroinvertebrates (Perry 1976; Weinstein 1979; Bozeman and Dean 1980). One study found that the mean annual abundance of macrofauna in a backfilled canal was similar to a natural creek and double the abundance in an unfilled canal (Sikora and Sikora 1984). Mean annual abundance of meiofauna was six times greater in the backfilled canal than in the unfilled canal. The unfilled canal was classified as a highly disturbed benthic habitat, where the abundance of macro- and meiofauna appeared to be controlled by low levels of dissolved oxygen and high sulfide levels (Sikora and Sikora 1984). Benthic populations in the backfilled canal appeared to be controlled by biotic factors such as predation, rather than physical factors.

Backfilled canals also have the potential to be high quality habitat for waterfowl because they often contain at least some species of aquatic vegetation important to waterfowl including: widgeongrass (Ruppia maritma), dwarf spikerush (Eleocharis parvula), floating waterprimrose (Ludwigia peploides), coontail (Ceratophyllum demersum), southern naiad (Najas quadalupensis), fanwort (Cabomba caroliniana), and duckweed (Lemna minor). Shallow open water areas in backfilled canals or on backfilled spoil banks are often less than 50 cm deep, a depth that can potentially be used by dabbling ducks for feeding (Chabreck 1979; Fredrickson and Drobney 1979).

Oil and gas canals are often plugged with earthen or shell dams (also known as plugs) upon abandonment at approximately 30-60 cm above the elevation of surrounding marshes. Plugs are designed to maintain elevated marsh water levels, prevent salt water intrusion into low-salinity marshes, and reduce tidal exchange thereby reducing bank erosion. However, by limiting the tidal exchange between canal and adjacent waterbody, plugs also interfere with the movement of aquatic organisms and may significantly reduce the area of potentially suitable habitat. Plugs may induce erosion by forcing water to drain elsewhere, particularly around the plug. Plugging canals encourages the growth of submerged aquatic vegetation (Table 1), but also restricts the access of migratory estuarine fishes (Neill and Turner 1987a, b). An improved strategy for managing backfilled canals for fish and wildlife may be to plug canals to promote the growth of aquatic vegetation in fresh marshes or in preferred waterfowl areas, but leave canals in brackish and saline marshes open or semi-plugged to allow access of juvenile migratory fishes.

Table 1. The influence of plugs on the presence of aquatic vegetation (from Neill and Turner 1987a).

	Number of Canals with Submerged Aquatic Vegetation	
Plug Status	Present	Absent
Plugged	12	1
Unplugged	6	8

2.3 Objectives

We examined the sites of Neill and Turner (1987a) to document and interpret changes occurring since 1983/4 (the date of their field surveys) and to statistically model the combined data derived from these new and previous analyses. Specifically, we wanted to determine the recovery rates of vegetation, water depth, and soils in backfilled canals, 'restored' spoil banks, and in nearby marshes, and quantify the influence of plugging canals on these rates. We wanted to know if the initial growth of submerged aquatic vegetation was maintained, if additional growth appeared, and if the growth of submerged aquatics was sustained only until the plug washed out.

CHAPTER 3. MATERIALS AND METHODS

3.1 General Approach

The backfilled canals examined by Neill and Turner (1987a; Figure 1, Table 2) in 1983/4 were re-examined to determine recent changes in (1) soils, (2) vegetative cover, and (3) fish use. A statistical model of the data was constructed using the resulting data. These backfilled canals are occasionally plugged (or at least were plugged several years ago) and represent virtually all backfilled canals in Louisiana. Hypotheses that were tested about restoration through backfilling were that success is a function of: (1) canal length, (2) canal age, (3) marsh soil organic matter content, (4) presence of a plug at the mouth of the canal, and (5) the percentage of the available spoil material returned to the canal. An additional hypothesis tested was that fish use is primarily a function of habitat cover and the availability of access (plugged or not-plugged).

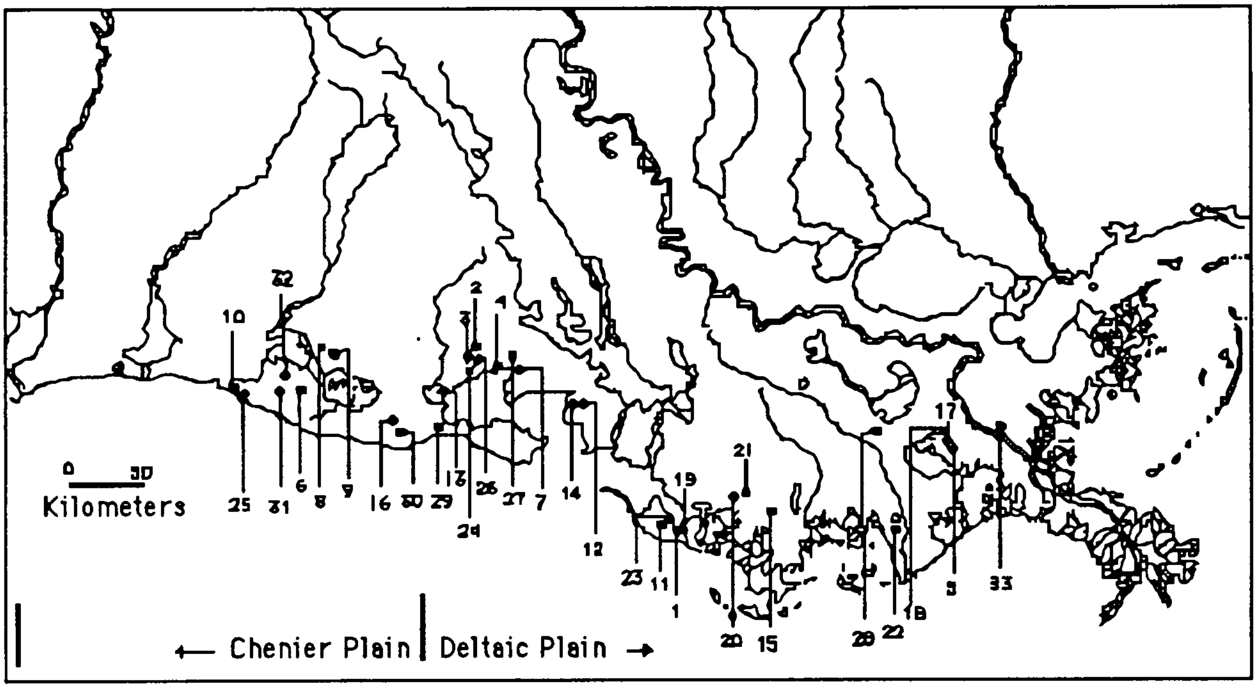

Figure 1. The backfilled canals studied, numbered as in Neill and Turner 1987a.

3.2 Methodology

3.2.1. Aerial Imagery

Field observations were made to collect information on environmental conditions influencing restoration success. All canals were photographed in color infra-red imagery in November 1990 using an aircraft-mounted large-format (5 inch x 5 inch) camera from an altitude of approximately 916 m. An 8 inch x 8 inch photograph was developed from the resulting transparency to determine the percentage of the old spoil bank area that is now marsh vegetation, upland vegetation, and open water (by planimeter). The 1990 photography was also visually compared to black and white photographs taken during the earlier study.

Table 2. The site locations, marsh type and the site characteristics in 1992.

SITE	PARISH	QUAD MAP	LAT. N.	LONG. W.	MARSH TYPE	PLUG in 1992	DISTURBED AREA (ha)
1 Hellhole Lake	Terrebonne	251B	29° 12.1'	91° 06.0'	Salt	Intact	13.4
2 Boston Bayou N.	Vermilion	209D	29° 49.5'	92° 03.0'	Brackish	No	1.9
3 Boston Canal	Vermilion	209D	29° 49.3'	92° 03.9'	Brackish	Intact	nd
4 Tigre Lagoon	Iberia	208C	29° 49.3'	91° 55.6'	Brackish	No	2.5
5 Golette Bay	Jefferson	233D	29° 34.3'	90° 00.7'	Brackish	Gone	4.6
6 Grand Lac L'Huit	Cameron	211C	29° 45.8'	92° 39.0'	Fresh	Gone	4.8
7.5 Bayou Carlin	Iberia	208D	29° 51.0'	91° 49.8'	Intermediate	Gone	3.7
8 Mallard Bay W.	Cameron	211A	29° 53.8'	92° 38.2'	Fresh	Intact	3.5
9 Mallard Bay E.	Cameron	211A	29° 53.7'	92° 38.1'	Fresh	Intact	5.3
10 Mermentau Riv.	Cameron	213D	29° 45.2'	93° 04.3'	Brackish	Breached	5.3
11 Mosquito Bay	Terrebonne	247C	29° 16.0'	91° 12.3'	Brackish	No	2.7
12 Lake Point Bayou	St. Mary	227B	29° 42.0'	91° 34.0'	Fresh	No	6.5
13 Vermilion Riv.	Vermilion	209C	29° 46.5'	92° 09.0'	Intermediate	Gone	6.5
14 Bayou Long	St. Mary	227B	29° 40.5'	91° 36.2'	Intermediate	No	4.9
15 Four Isle Bay	Terrebonne	246D	29° 16.0'	90° 49.0'	Salt	Gone	6.9
16 Pecan Island W.	Vermilion	224C,D	29° 35.5'	92° 22.5'	Brackish	Gone	12.6
17 Lafitte	Jefferson	233D	29° 36.9'	90° 02.7'	Brackish	Gone	2.1
18 Dupree Cut	Jefferson	233D	29° 36.0'	90° 04.4'	Brackish	Gone	1.3
19 Buckskin Bayou	Terrebonne	247D	29° 16.8'	91° 02.2'	Brackish	Intact	5.9
20 Lake Decade	Terrebonne	246B	29° 23.7'	90° 49.3'	Intermediate	Breached	4.1
21 Falgout Canal	Terrebonne	246B	29° 26.5'	90° 49.0'	Intermediate	Intact	4.7
22 Catfish Lake	Lafourche	244B	29° 23.7'	90° 20.6'	Brackish	Breached	4.1
23 Fourleague Bay	Terrebonne	247C	29° 19.3'	91° 11.0'	Brackish	No	2.8
24 Intrcstl/Oaks Cnl.	Vermilion	208C	29° 49.9'	91° 58.8'	Brackish	Yes	4.4
25 Lower Mud Lake	Cameron	213D	29° 45.1'	93° 02.5'	Salt	Breached	2.0
26 Boston Bayou S.	Vermilion	209D	29° 49.0'	92° 02.5'	Brackish	No	7.0
27 Iberia Canal	Iberia	208B,D	29° 52.2'	91° 51.9'	Intermediate	Yes	6.3
28 Delta Farms	Lafourche	232D	29° 36.9'	90° 17.9'	Fresh	Breached	4.5
29 Rainey Refuge	Vermilion	225C	29° 36.6'	92° 14.1'	Brackish	Breached	1.8
30 Pecan Island E.	Vermilion	224D	29° 35.5'	92° 21.5'	Brackish	Gone	8.4
31 Superior Bridge	Vermilion	223A	29° 43.3'	92° 40.0'	Intermediate	Breached	5.1
32 Long Island	Cameron	212D	29° 45.8'	92° 45.9'	Fresh	No	3.7
33 Point a la Hache	Plaquemines	234D	29° 37.0'	89° 49.75'	Brackish	*	5.7

*no aerial photography was available to determine the condition of a plug, if present

3.2.2. Canal Depth, Vegetation and Soils

Canal depth and vegetation cover were estimated by field visits in 1991 and 1992. Point measurements of water depth were made at 10 m intervals up the canal axis. Because water level records are not available for widely scattered locations, we measured elevation relative to mean elevation of adjacent marsh rather than to mean water level (as previously). Sasser (1977) found that mean marsh elevation was not distinguishable statistically from mean water level for marshes composed of most important Louisiana marsh plant species.

The percent cover of marsh vegetation in the canal and on the old spoil banks was taken as a measure of how well the canal was restored to marsh. Zero percent cover of marsh plants indicated no restoration, and 100 percent cover indicated complete restoration. Cover was determined from tracings of the aerial photographs, using a planimeter. We determined the percent cover of emergent marsh vegetation reestablished in the backfilled canal and on the regraded spoil bank from the aerial photographs.

We determined the presence/absence and species of submerged aquatic vegetation from ground observations. Changes in vegetation and water surface area were made by comparing measurements made in 1983/4 and 1991.

Three replicate soil samples were taken at each canal from spoil banks at non-backfilled canals, regraded spoil banks, and inland marsh (50 m inland from the edge of the canal) using a 50 cc piston core (Swenson 1983). These soil samples were used to determine water content (by drying cores to a constant weight at 85^{o} C.) and organic matter content (measured as the loss on ignition for four hours at 550^{o} C.).

The recovery of organic matter content or water content for a spoil bank was judged to be complete if values for the backfilled spoil bank and adjacent undisturbed marsh were not significantly different (t-test, $p<0.05$). Recovery was judged to be zero if values for the backfilled spoil bank were not significantly different from unfilled spoil. If the values for the backfilled spoil bank were significantly different from both unfilled spoil and undisturbed marsh and lay somewhere between these values, recovery was judged to be partial.

3.2.3. Plug Condition

Both aerial photographs and ground observations were used to determine the status of the plug at the mouth of the canal (plugged, unplugged, partially plugged), and, the percentage of the spoil bank returned to the canal during backfilling from aerial photographs and ground observations.

3.2.4. Fish Surveys

Fish and invertebrate populations in 13 of the backfilled canals examined by Neill and Turner (1987b) were examined using a 3.1 x 1.9 - m seine of 3.2 mm mesh in summer. An attempt was made to keep fishing effort similar between sites and all work was performed by the same field investigator(s). Seining in each canal was for 15 minutes and consisted of 3 approximately 10 m tows. Sampling was from representative areas of deep, shallow, vegetated, and unvegetated portions of each canal. All fish collected were preserved in 10 percent formalin and returned to the laboratory for enumeration and identification.

Fish species were divided into two categories: permanent residents and migrants. Species that completed their entire life cycle in shallow estuarine areas are classified as permanent canal residents (fishes classified as freshwater or estuarine; McHugh 1967), others are classified as migrants if they spawn outside the estuary or in larger estuarine waterbodies and move to shallow areas as post-larvae or juveniles (fishes classified as estuarine-marine; McHugh 1967). Differences in numbers of species in open and semi-open canals compared with plugged canals were examined using the Student T-statistic ($P<0.05$) adjusted for unequal sample sizes and unequal variances (Ott 1977).

3.2.5. Descriptive Statistics

The effects on restoration of marsh type, hydrologic unit, presence of a plug, and whether mitigation was for the dredged location (on-site mitigation) or for one at another location (off-site mitigation) were examined by calculating mean values for depth, plant cover, and spoil returned for each marsh type, hydrologic unit, plug and mitigation circumstance. The canals examined represented a high proportion of all existing backfilled canals and therefore represented a finite population. The standard error of the mean (S.E.) for each category was calculated as:

$$\text{S.E.} = \sqrt{\frac{s^2}{n}\frac{(N-n)}{N}}$$

where N equals the number of all existing backfilled canals, s equals the sample variance and n equals the number of canals sampled (Snedecor and Cochran 1967). A standard error of zero indicates that all existing canals in that category were sampled and the mean was determined exactly. These data were used in the statistical analysis (below).

3.2.6. Statistical Models

We developed multiple regression models to investigate the factors affecting the success of marsh restoration by canal backfilling. Success was measured by canal depth and by cover of marsh vegetation on the restored canal and spoil bank. We hypothesized success to be a function of: (1) canal length, (2) canal age at backfilling, (3) marsh soil organic matter content, (4) presence of a canal plug, (5) whether backfilling was performed for mitigation upon abandonment (on-site mitigation) or away from the permitted location (or off-site mitigation), and (6) the percentage of the available spoil material that was returned to the canal.

Two separate models were developed using the same independent variables (1-6 above). The dependent variable in one case was canal depth, and in the other case, vegetation cover. The relation is given by:

$$Y_i = B_1 + B_2 X_2 + B_3 X_3 + B_4 X_4 + B_5 X_5 + B_6 X_6 + B_7 X_7$$

where:

Y_i = canal depth in meters, <u>or</u> percent cover of marsh vegetation on the backfilled spoil bank,

and,

X_2 = canal length in m,
X_3 = age of canal at time of backfilling (in months),
X_4 = percent soil organic matter,
X_5 = presence of a canal plug 1, if plug present; 0, if plug absent
X_6 = permit conditions 1, if backfilled off-site; 0, if backfilled as on-site mitigation
X_7 = percent of spoil area cleared and returned to the canal during backfilling

and,

B_i = the non-dimensional coefficient for each variable "i', 1 to 7

Data for the model consisted of information on the 23 canals for which all X- and Y-data were available.

The statistical model used vegetation cover on the spoil banks of backfilled canals as a measure of restoration success instead of vegetation cover in the canal because there was not a wide range of vegetation re-establishment in the canal. For example, in most cases, less than 10 percent of the canal was converted to marsh (Neill and Turner 1987a). In only one case was more than 50 percent of the canal area re-vegetated to marsh.

Five hypotheses (HO) were tested about the effect of backfilling.

<u>HO Canal Length:</u> Canal length was hypothesized to positively affect restoration success because more spoil material should allow for greater filling. Longer canals also were thought to allow for better vegetation re-establishment. Because backfilling is rarely used, it was thought that dredge operators did not possess the skills to expertly level spoil banks. This skill is important because if too much spoil is left unfilled, the elevation is too great for marsh plant re-colonization. Conversely, if too much spoil is backfilled, the elevation is too low for plant re-colonization. It was thought that longer canals would allow more area for operator "practice." Over the course of filling a long canal, an operator could refine his technique, allowing more precise spoil leveling and greater marsh re-establishment.

<u>HO Canal Age:</u> was hypothesized to be inversely related to filling and restoration success. In general, the older a spoil bank is, the less its volume. This results from the oxidation of highly organic marsh soils as they dry when exposed as a spoil bank, subsidence and soil compaction. Greater age and lower spoil bank volume was anticipated to decrease the level of vegetation colonization, because marsh plants are less likely to re-colonize the older, more compacted soils of old spoil banks.

<u>HO Soil Organics:</u> Soil organic matter content was thought to inversely affect canal depth and vegetation re-colonization. Most organic soils lose more volume more rapidly and lose greater total volume compared with less organic soils in spoil banks of similar age. This leaves less material as fill, and decreases the amount of vegetation re-establishment.

<u>HO Canal Plug:</u> Plugs were thought to decrease depth and increase the amount of vegetation restored by preventing fill from washing out of the canal and by preventing erosion of the vegetated banks of the canal.

<u>HO Permit Condition:</u> Backfilling was hypothesized to be more successful if the permit was issued to backfill canals off-site rather than after dry well abandonment. This was

anticipated because drillers, when doing mitigation, have a choice of which canal to fill. Thus, they might choose canals that they presume (for whatever reasons) to have a high potential for restoration success, both for filling and for vegetation re-establishment. A driller's choice of canals for restoration may, however, be motivated by economic considerations (property access, property ownership, etc.) in which case permit condition may, or may not, have little influence on restoration success.

HO Spoil Returned: The amount of spoil returned to the canal was anticipated to have a direct relationship to restoration success. The greater the percentage of spoil returned, the shallower the depth. Similarly, the more spoil returned, the lower the elevation of the spoil bank after backfilling, and the more vegetation re-establishment. This would be true up to the point when spoil was dug deeper than marsh elevation, creating more open water. Although this was a problem in some localized spots on some spoil banks, rarely was 100 percent of the spoil returned. Therefore, vegetation restoration was thought to increase with increasing spoil returned.

3.2.7. Subjective Measures of Success

The final approach was a subjective evaluation of success based on the following criteria:

1. In-filling of former canal area; establishment of emergent marsh vegetation in 25% of the canal;
2. Blending of former spoil bank with surrounding marsh (similar vegetation everywhere);
3. Establishment of hydrologic connection and natural drainage among canal, former spoil bank, surrounding marsh and nearby bodies of water;
4. The conversion of former spoil bank to open water was less than 10% for complete success.

Each of the four categories were examined and a rank of 0 to 3 applied to each of them, representing the perceived range of values for the sites if complete restoration occurred, or not. The individual 4 scores were summed to obtain an overall ranking of restoration success.

CHAPTER 4. CHANGES FROM 1983/4 TO 1990/3

4.1 Site Size

Each sampling site was of nearly identical size in the two sampling periods (1983/4 and 1992/3; Figure 2). This result was fortunate because of a concern for the sparse distribution of fixed landmarks in the aerial imagery from both periods. Because of these similarities among sites, the results from two photographic analyses can be compared to each other.

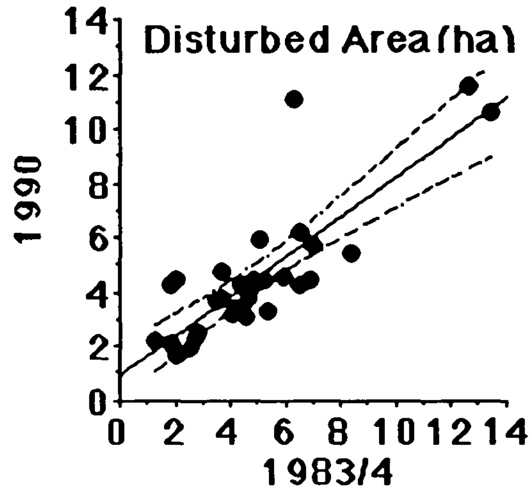

Figure 2. A comparison of the estimate of the disturbed area from the 2 studies (1983/4 and 1990/2). A linear regression of the two variables is the solid line. The 95 percent Confidence Interval for the true value of the y intercept is shown with the dotted line. There is no difference in the size of the areas from one study period to the next.

4.2 Water Depth

There was no measurable increase or decrease in water depth from the 1983/4 period to the 1992/3 sampling period (Figure 3). However, the data set was limited to 7 sites with measurements in both periods. Several canals were too shallow to penetrate because of low water or floating aquatics (principally hyacinth). An additional methodological issue was that the measurements were made down the throat of the canal. Several sites had obviously filled in along the edges of the canal or had streams cutting into or across the former canal spoil bank (Figures 4 and 5) and the average depth was impossible to determine using the techniques of Neill and Turner (1987a). Therefore the data set has a rather limited usefulness for comparative purposes.

The average water depth at each site was empirically related to the time between dredging and backfilling (Figure 6). The depth initially rose with increasing time, but then declined after about 5 years. This result is consistent with the hypothesis that the dredged spoil material is washing away or oxidizing as it is exposed to air after placement on the wetland, and that there is subsequently less to return to the canal with time. The declining depth after 5 years is probably related to the filling in of the canal *before* backfilling. That is, the canal was filling in before backfilling.

This long-term annual fill rate was about 5.8 cm•yr^{-1} (Figure 7). Later, in the statistical modeling section (Section 5.1), we estimate the fill rate to be about 4.2 cm•yr^{-1}, when the influence of all other factors is normalized through statistical analyses. We subtracted this long-term rate (4.2 cm•yr^{-1}) from the total depth, to derive the fill-rate from backfilling alone, over time (Figure 8). Values below zero are an artifact of the calculation method, and indicate canals that are filled in. The results indicate that the effectiveness of backfilling continues for about 2 decades after dredging. Backfilling probably will not have much influence on canal depth beyond 2 decades.

4.3 Canal and Spoil Bank Restoration

The overall average percent vegetation in the canals, on the spoil banks, and total area remained unchanged from 1983/4 to 1990 (Table 3). A discussion of the vegetation in the overall study site follows in section 4.4.

The percent of marsh restoration in the canals was relatively unchanged during the intervening years (Figure 9). This result is consistent with the slow or stable canal infilling during the interval. Vegetation does not re-colonize until water depths are less than 0.5 m and the percent cover is higher with a plug, than without (Figure 10).

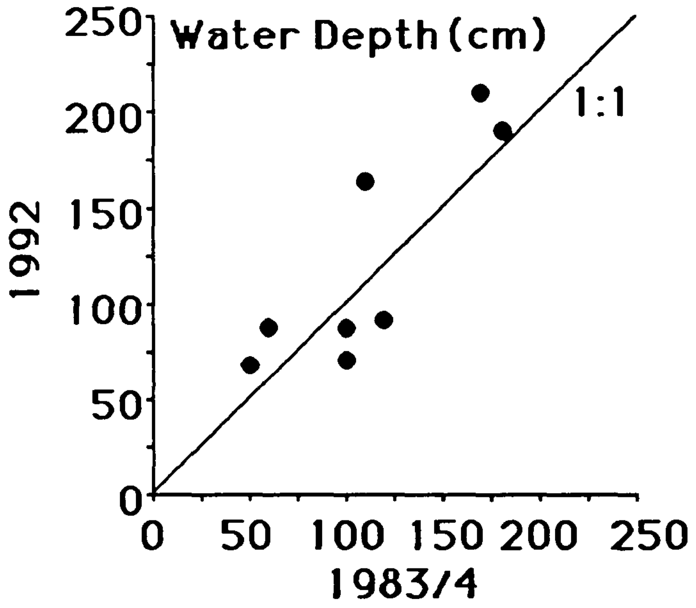

Figure 3. The average water depth in the canal for 8 canals in the two different study periods. The straight line is a 1:1 ratio, or a line of no change.

Figure 4. An aerial infrared image of the backfilled canal at Vermilion River (site #13).

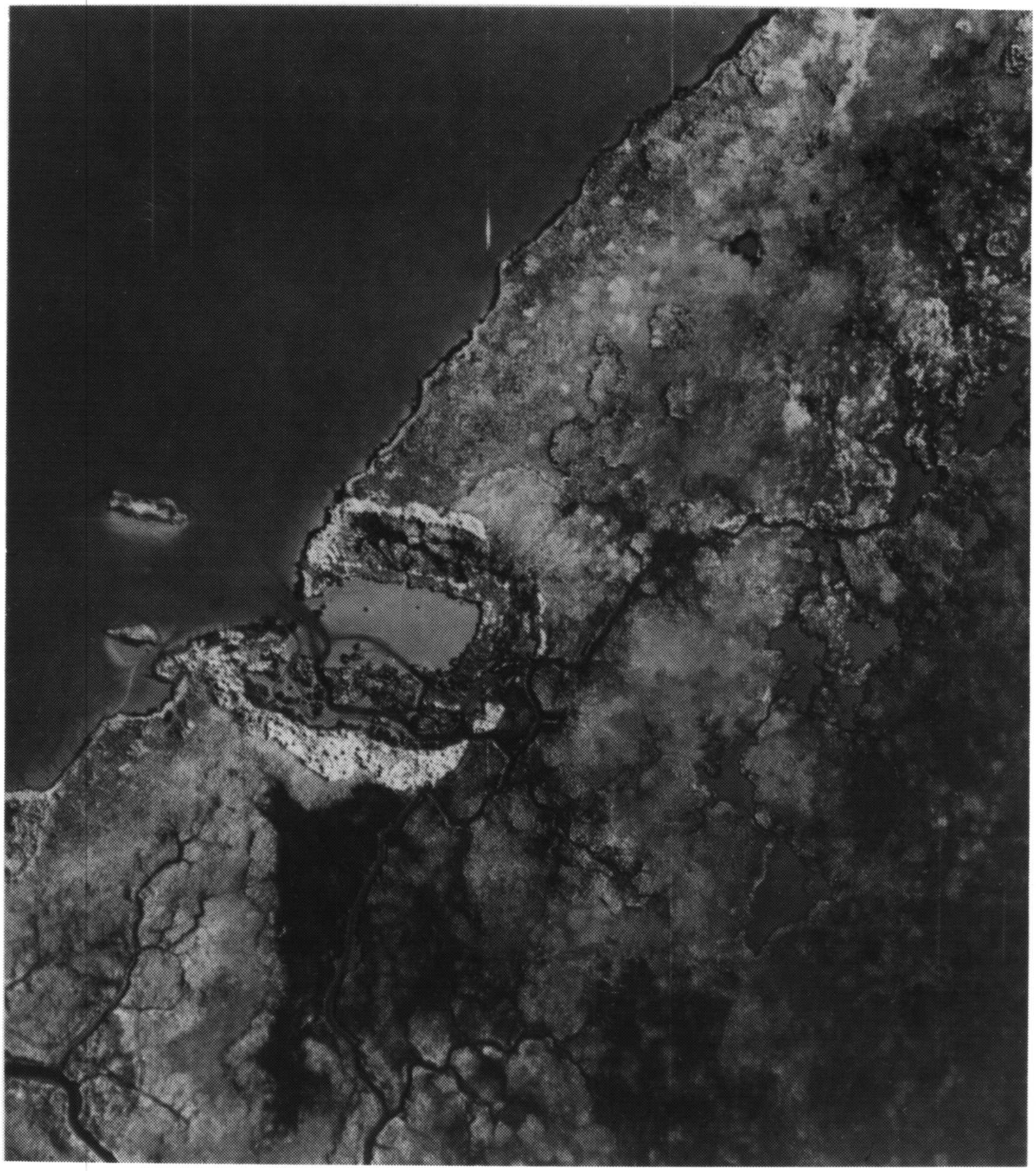

Figure 5. An aerial infrared image of the backfilled canal at Lower Mud Lake (site #25).

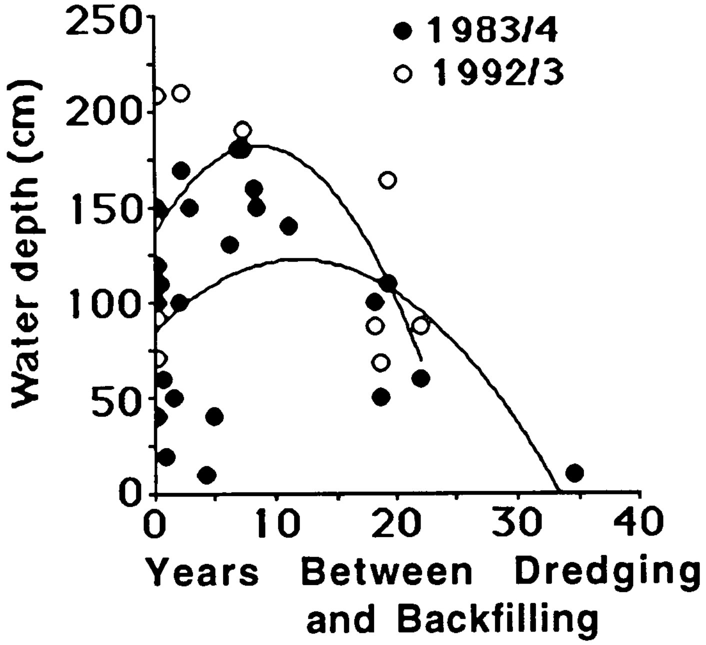

Figure 6. Water depth in 1983/4 and in 1992/3 versus the years between the original dredging and backfilling.

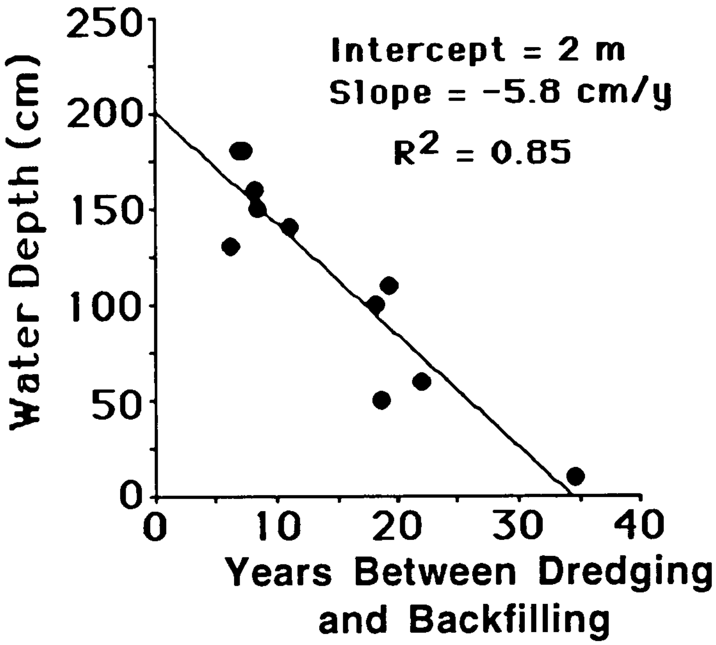

Figure 7. Water depth in 1992/3 versus the years between the original dredging and backfilling. Only sites that were dredged >5 years before backfilling are shown. The straight line is a linear regression of the two variables.

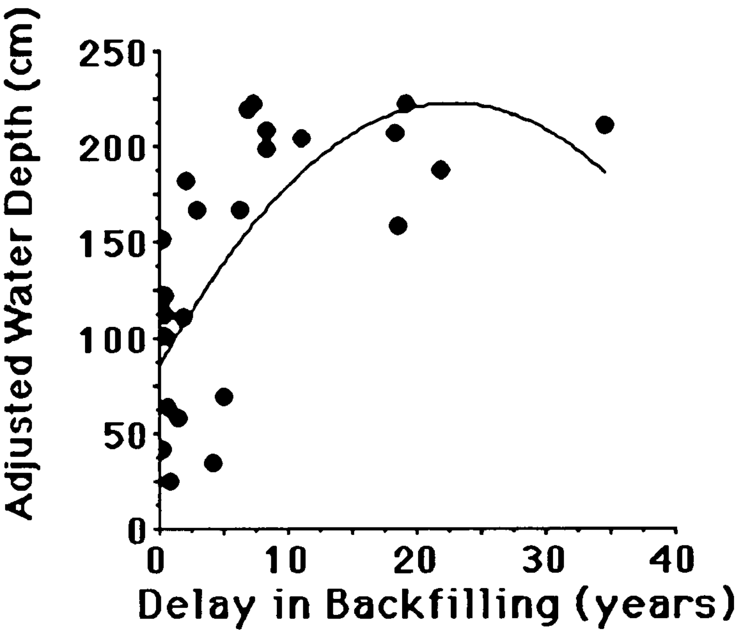

Figure 8. The estimated water depth versus the years between the original dredging and backfilling, corrected for the long-term fill rate. Only sites that were dredged less than 10 years before backfilling are shown. The actual water depth was adjusted for filling in of canal without dredging time between by subtracting the fill rate of the previous figure. The curved line is a polynomial regression of the two variables.

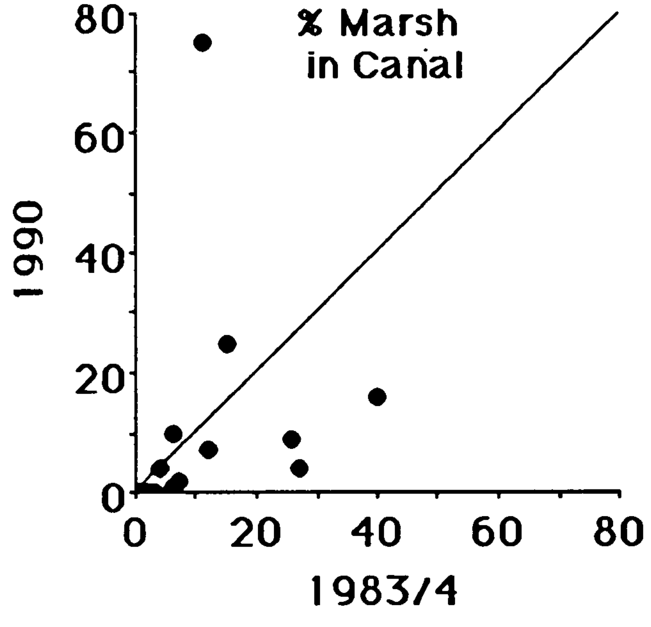

Figure 9. The percent marsh in the canal in the two different study periods. Note the change in scale. The straight line is a 1:1 ratio, or a line of no change.

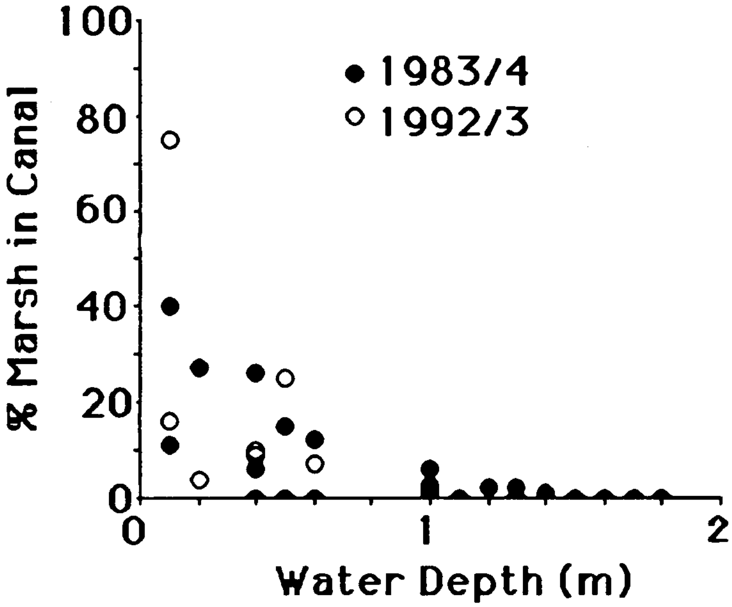

Figure 10. The relationship between the percent vegetation in the canal and water depth for the two studies.

Table 3. The mean and +/- 1 Standard Deviation for paired sites (number = 30) in the two study periods.

	Mean	Std. Dev.
Percent Marsh in Canal		
1983/4	5.3	9.8
1992/3	5.1	14.4
Percent Marsh on Spoil		
1983/4	47.2	27.1
1992/3	50.7	23.6
Percent Open Water on Spoil		
1983/4	24.4	23.0
1992/3	23.3	20.5
Percent Upland Vegetation on Spoil		
1983/4	28.4	26.5
1992/3	25.5	23.3

4.4 Vegetation Restoration for the Entire Study Site

There were no statistically-meaningful differences in vegetation restoration in the canal or on the spoil bank between the 1983/4 and 1990 surveys (Figure 11). The wetland area on the spoil is the dominant location of wetland area at the sites.

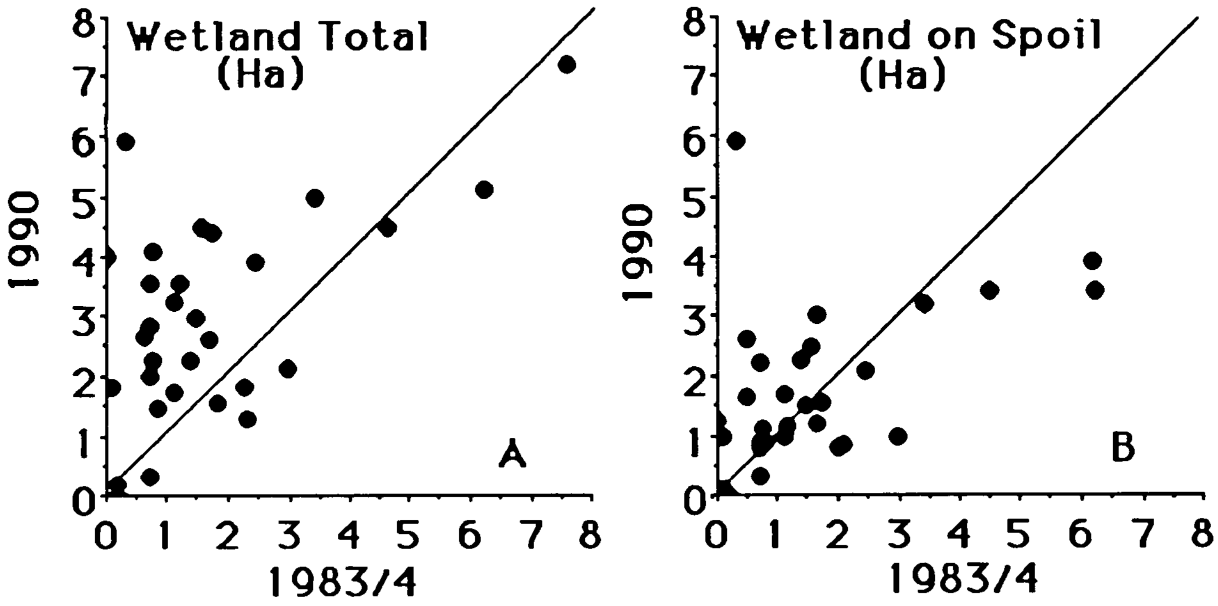

Figure 11. The area of wetland vegetation as the study site for 1983/4 compared to 1990. A. The total wetland for the entire study site for the 2 study periods. A line of equal values passes through the graph from lower left to upper right. B. The total wetland area for the study sites and wetland area on the spoil banks. Several points lie beneath each other.

4.5 Measures of Success

The subjective ranking of restoration success at all sites varied greatly, and no site showed 100 percent restoration success (Figure 12). Some remained virtually unchanged since the survey of Neill and Turner (1987a). Others had enough sedimentation to prohibit boat traffic. Site rank and water depth were inversely related (Figure 13).

4.6 Fish Surveys

There were no statistically significant differences in fish and invertebrate populations as the various combinations of field sites (backfilled vs control; plug, semi-plugged and no plug). These results are therefore in the Appendix.

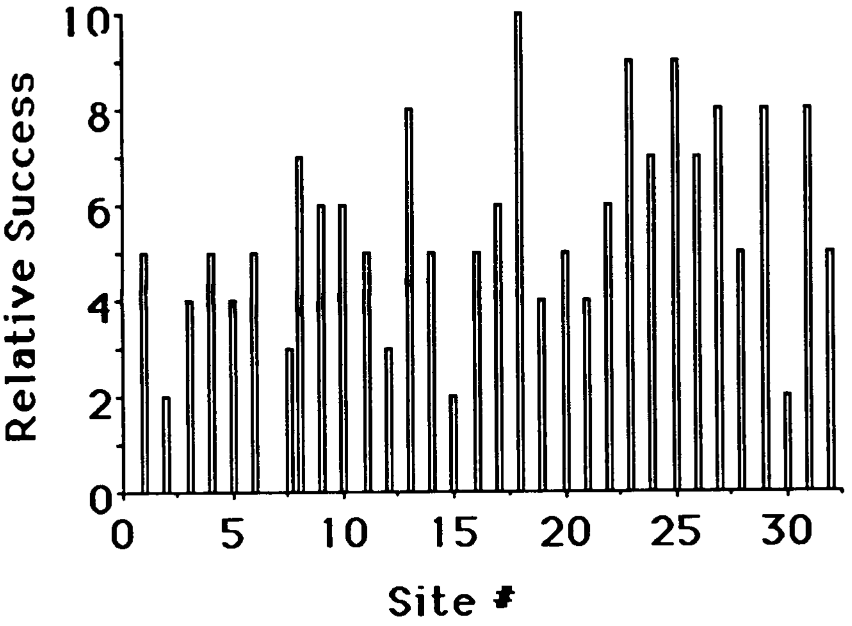

Figure 12. The ranking of backfilling success using an arbitrary scale for hydrologic connection, re-vegetation, and vegetation cover. A "12" is 100% restoration success.

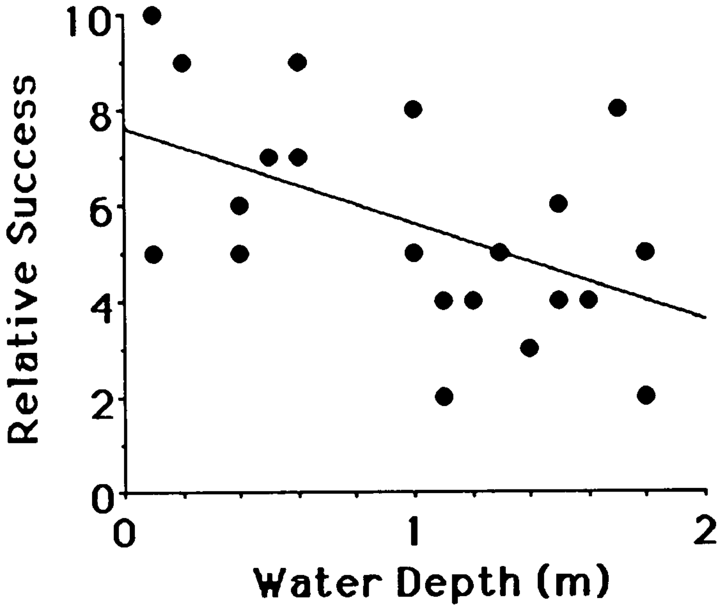

Figure 13. The relationship between the subjective ranking of backfilling success and the average water depth of the backfilled canal (the coefficient of determination for the linear regression is 0.27; $p<0.01$).

CHAPTER 5. STATISTICAL MODELS OF CHANGES

5.1 Results from the Canal Depth Model

The results obtained from the statistical model of canal depth are presented in Table 4 and the results are discussed below. All hypothesis tests were performed at the 95 percent significance level.

Table 4. Results of the model to predict canal depth.

d.f.=17; R^2=0.55

Variable	Beta	Std. Error	T Value	
X_1 Intercept	0.47			
X_2 Length	0.0001	0.001	0.96	NS
X_3 Age	-0.0035	0.0013	2.75	*
X_4 Percentage Organic	0.015	0.0055	2.73	*
X_5 Plug	-0.0085	0.27	.31	NS
X_6 Permit Condition	0.58	0.28	2.06	*
X_7 Percent Returned	-0.0029	0.0067	.43	NS

*significant at the 95% level

The coefficient for canal length indicates that length had little effect on depth and we failed to reject the null hypothesis that B_2=0. We therefore conclude that canal length had no influence on restoration success in terms of canal depth.

The coefficient for age (X_3) indicates that age is inversely related to depth. A one month increase in the canal age at backfilling results in a 0.35 cm decrease in canal depth, or 4.2 cm·yr. This rate is slightly lower than the rate of 5.8 cm·yr estimated from a less sophisticated approached used earlier (Figure 7). We rejected the null hypothesis that B_3=0 and conclude that restoration success increases with time.

Each percent increase in soil organic matter (X_4) content results in an increase in canal depth of 1.5 cm. We rejected the null hypothesis that B_4=0 and concluded that soil organic concentration influences restoration success.

Plugged canals (X_5) are 4 cm shallower than unplugged canals, but we fail to reject the null hypothesis that B_5=0, and conclude that plugs have no effect on canal depth.

The coefficient for Permit Condition (X_6) indicates that canals backfilled as mitigation away from the permitted site (off-site mitigation) are 0.6 m shallower than canals backfilled after dry hole abandonment (on-site mitigation). We rejected the null hypothesis that B_6=0.

The amount of spoil returned (X_7) had little effect on the depth of the canal. We fail to reject the null hypothesis that B_7=0 and conclude that the variability in spoil return was not a significant influence on the variability in canal depth. This result should not be interpreted to mean that backfilling *any* amount of spoil bank material has no influence on canal depth -- something that is counter-intuitive. The model results probably mean that variability in the amount returned at the time of backfilling is not as important as the variability in the other factors, e.g., the variability in site characteristics.

The sign of the coefficient for age (B_3) differs from the hypothesized relationship. Older canals appear, on average, to be shallower than younger ones. This may result from the natural slumping and filling in of older canals, which may offset the effect of decreased spoil volume that is thought to accompany greater age. Results of the model suggest that backfilling will be more successful at older canals.

The graphical analysis showed (Figure 6) that depth increases with canal age up to some intermediate age (approximately 5 years) and then begins to decrease as canals progressively fill in. Changing the functional form of canal age by addition of a new variable (age ^{2}) changed the amount of variation explained by the model only slightly (R^2=0.55 compared to R^2=0.59).

Soil organic matter content has an important effect on canal depth. Results indicate that canal depth decreases 15 cm for every 10 percent decrease in marsh soil organic matter content. There is a wide range of soil organic matter contents in Louisiana marshes, ranging from approximately 5 to 75 percent. On average, there is an approximately 1 m difference in canal depth at these extremes, if everything else is held constant. The model suggests that permits requiring backfilling would be more successful in marshes with less organic soils. These marshes tend to be near the coast or next to major rivers or bayous--precisely the areas in which alterations to hydrology by dredged canals are probably most severe. Backfilling these canals would help alleviate these harmful modifications and have a greater chance of successful restoration. Managers could use existing soil organic matter maps to evaluate backfilling permits.

Backfilled canals are 58 cm shallower if the driller had a choice of canals to backfill off-site. This suggests that an effective strategy for issuance of permits may be to allow a choice of canals to be filled for mitigation. However, backfilling after abandonment appears to be an effective conservation strategy, despite the chance for greater restoration success at another location.

5.2 Results from the Vegetation Cover Model

The results obtained from the statistical model of vegetation restoration are in Table 5 and the results discussed below. All hypothesis tests were performed at the 95 percent significance level.

The coefficient for length indicates that each m increase in canal length results in an 13 percent increase in cover for each 100 m increase in length (over the size range of canals sampled). We rejected the hypothesis that B_2=0. Therefore, vegetation cover appears to be influenced by canal length.

The coefficient for age indicates that older canals have less vegetation restoration on the former spoil banks than younger canals. We could not reject the null hypothesis that B_3=0. We cannot explain this result to our satisfaction, especially in view of the stable composition of the vegetation cover between the 2 surveys.

Each percentage increase in soil organic matter resulted in a decrease of 0.21 percent in vegetation cover, but again we fail to reject the null hypothesis that $B_4=0$ and conclude that the differences with age were not statistically significant.

Plugged canals had 13 percent less vegetation cover on the spoil bank, but we failed to reject the null hypothesis that $B_5=0$, and conclude that the differences with age were not statistically significant.

Canals backfilled as mitigation had 11 percent more vegetation cover than canals backfilled after abandonment, according to the estimate of B_6. However, we failed to reject the null hypothesis that $B_6=0$.

According to the estimate of B_7, each percentage increase in spoil returned to the canal resulted in a 0.64 percent increase in the percentage cover of vegetation. We rejected the null hypothesis that $B_7=0$.

Table 5. Results of the model to predict vegetation restoration.

d.f.=19; $R^2=0.55$.

Variable	Beta	Std. Error	T Value	
X1 Intercept	-7.78			
X2 Length	0.13	0.041	3.2	**
X3 Age	-0.125	0.045	2.77	**
X4 Percent Organic	-0.21	0.22	0.97	NS
X5 Plug	-12.9	10.8	1.19	NS
X6 Permit Condition	10.9	12.2	0.89	NS
X7 Percent Returned	0.64	0.28	2.25	*

*significant at the 95% level
**significant at the 99% level

It appears that the most important factors influencing vegetation re-establishment are the canal length and the percentage of the spoil bank returned to the canal during backfilling. Both of these factors are probably related to the skill of the dredge operator. The more precise the operator's work, the more spoil can be returned without gouging the marsh or causing the marsh surface elevation to be too low. Also, the coefficient for length suggests that the hypothesis that longer canals allow dredge operators to learn better technique may be correct.

The model results indicate that permits for backfilling would be more effective for longer canals. So few canals are presently being backfilled that it is unlikely that any one operator would have any backfilling experience. If that situation changed, one might expect operator experience to have a greater effect on restoration success. The model results also suggest that monitoring to ensure that as much of the existing spoil material is backfilled as possible would aid in increasing the success of restoration.

5.3 Detection of Interdependence of Independent Variables

For various reasons, we may expect some of the independent variables to be related to each other. For instance, we expect canals backfilled after well abandonment to be younger than canals backfilled as mitigation. The pair-wise correlation between X_3 and X_6 (age and permit condition, respectively) is 0.64. Canal age and length had a pair-wise correlation of 0.51, indicating that older canals tend to be longer. This is probably related to tighter restrictions on new canal construction. There were no pair-wise correlations above 0.8, a level that indicates serious multi-colinearity.

Regressions of each explanatory variable against all other explanatory variables revealed that 44 percent of the variation in length can be explained by a linear combination of the other variables and that the only variable in this model with a slope that is significantly different from zero at the 95 percent level was canal age (Table 6).

Table 6. Regressions of each explanatory variable against all others.

	Variables with Slopes	
Dependent Variable	R^2	No. where t = 0 at 95 percent Level
X_2 length	0.45	X3, age
X_3 age	0.60	X_2, length; X_6, permit
X_4 percent organic	0.08	----
X_5 plug	0.07	----
X_6 permit	0.55	X_3, age
X_7 return	0.36	----

Sixty percent of the differences in age could be explained by a linear combination of the other variables. Slopes of length and permit condition were significantly different from zero. Fifty-five percent of the variation in permit condition was explained by a combination of the other variables, and the slope of canal age was positive and significantly different from zero at the 95 percent level.

Only 6 percent of the variation in organic matter content, 7 percent of the variation in the presence of a plug, and 36 percent of the variation in spoil returned could be explained by linear combinations of the other X-data.

Clearly, the greatest interdependence exists between length, age, and permit condition.

5.4 Sensitivity Analysis

Tests of the addition and deletion of observations were performed to evaluate the sensitivity of the model to the given set of data. Deletion of 3 observations changed the coefficients and R^2 little and did not change the interpretation of the results (Table 7).

The addition of 4 observations to the depth model resulted in a decrease in the amount of variation in depth explained. The slopes of age and organic matter remained different from zero at the 95 percent level, but B_6, the coefficient for permit condition changed, and we fail to reject the hypothesis that it equals zero (Table 8).

The addition of 4 observations to the vegetation restoration model changed the R^2 from 0.61 to 0.50. The slope of spoil returned (B_7) remained different from zero, but addition of observations changed the slope of canal length, which we no longer reject as being different from zero.

Table 7. Effect of deleting three observations to the depth and vegetation restoration models.

Depth Model

R^2=0.63

Variable	Beta	Std. Error	T-Value	
X_1	-0.0710	0.7374	0.096	NS
X_2	0.0001	0.0001	1.290	NS
X_3	0.0045	0.0014	-3.128	**
X_4	0.0149	0.0051	2.942	**
X_5	-0.0695	0.2221	-0.313	NS
X_6	0.8245	0.2966	2.780	*
X_7	0.0014	0.0076	0.184	NS

Vegetation Restoration Model

R^2=0.75

Variable	Beta	Std. Error	T-Value	
X_1	-16.8444	28.8714	-0.583	NS
X_2	0.0106	0.0039	2.727	*
X_3	-0.0870	0.0557	-1.561	NS
X_4	-0.2364	0.1989	-1.188	NS
X_5	-11.3691	8.6963	-1.307	NS
X_6	13.0507	11.6166	1.124	NS
X_7	0.7631	0.2992	2.550	*

*significant at the 95% level
**significant at the 99% level

Table 8. Effect of adding four observations to the depth and vegetation restoration models.

Depth Model

$R^2=0.46$

Variable	Beta	Std. Error	T-Value	
X_1	-0.6749	0.5781	1.167	NS
X_2	0.0001	0.0001	1.493	NS
X_3	-0.0034	0.0013	-2.528	*
X_4	0.0138	0.0048	2.859	*
X_5	-0.0813	0.2106	-0.386	NS
X_6	0.4646	0.2698	1.711	NS
X_7	-0.0060	0.0065	-0.930	NS

Vegetation Restoration Model

$R^2=0.75$

Variable	Beta	Std. Error	T-Value	
X_1	--52.2740	26.0508	-2.007	NS
X_2	0.0058	0.0039	1.503	NS
X_3	-0.0406	0.0598	-0.678	NS
X_4	-0.1816	0.2176	-0.834	NS
X_5	-17.2946	9.4829	-1.824	NS
X_6	11.8809	12.2140	0.967	NS
X_7	1.2156	0.2908	4.180	**

*significant at the 95% level
**significant at the 99% level

5.5 Tests for Autocorrelation

Tests for autocorrelation were performed using the Durbin-Watson statistic. The Durbin-Watson statistics for the vegetation restoration model (1.832) fell into the zone in which we fail to reject autocorrelation. The statistic for the depth model (1.07) fell into the range in which we reject independence of the error terms. However, this is probably an artifact of the small sample size.

5.6 Tests for Heteroscedasticity

A test was performed to examine whether variance increased with increasing canal length. Data were ranked by length. Variance was calculated separately for the 9 observations with the lowest length and the 9 observations with the greatest length. The 5 observations with intermediate length were dropped. For the depth model, the ratio of the variances was 1.06. An

F-test with 3,3 d.f. (F=5.39) causes a failure to reject the hypothesis of heteroscedasticity. The same test for the vegetation restoration model gives a ration of 4.98. An F-test again indicates failure to reject the hypothesis that the error terms have non-constant variance.

5.7 Summary of Results from the Statistical Models

Canal age, soil organic matter content, and whether restoration was done as on-site or off-site mitigation were the most important predictors of canal depth (model $R^2 = 0.59$). Canal length and percentage of spoil returned (+) had the greatest effect on vegetation cover (model $R^2 = 0.61$).

Backfilled canals were shallower if they were older, in soils lower in organic matter, and backfilled off-site. Vegetation cover increased with increased canal length and percentage of spoil material returned. These results can be used to establish guidelines that will improve the overall success of backfilling.

CHAPTER 6. SUMMARY AND CONCLUSIONS

Backfilling canals is a positive restoration measure for coastal Louisiana wetlands. The majority of the backfilled canal have retained the same amount of vegetation in 1990 that was there in 1983/4. This result alone shows that the restoration achieved earlier has some stability. Further, many canals increased the area of vegetative cover between 1983/4 to 1990. The canal profiles are, in many cases, changing from a rectangular shape to channels with sloping sides, even though the land has subsided about 8 cm in the last decade (Turner 1991). However, some backfilled canals show little restoration, and even deterioration. One backfilled canal (Mallard Bay; Site 9) was re-dredged between 1983/4 and 1990. Another has lost most of the marsh around it and will probably not have vegetation in the canal soon, if at all.

The major factors determining backfilling restoration success are the depth of the canal, soil type, canal dimensions, locale, dredge operator skill, and permitting conditions (Table 9). Plugging the canal has no apparent effect on water depth or vegetation cover, with one exception. Neill and Turner (1987a) noted that submerged aquatic vegetation was more frequently observed behind backfilled canals with plugs than in backfilled canals without plugs. The decisions managers can constructively make when requiring backfilling is to choose among those candidate canals that are in low organic soils, longer, and near sources of suspended sediment supply. Canals in the Chenier Plain of southwestern coastal Louisiana may have a higher restoration success than in the Deltaic Plain region. However, all canals with a healthy wetland around them should be included as potential backfilled sites. Even canals that are 20 years old may benefit from backfilling.

Table 9. Factors promoting restoration in backfilled canals.

Factor	Influences Promoting Restoration
Physical/Biological	
Canal Depth	time between backfilling and dredging; up to 20 years shows benefits time since backfilling (decades)
Canal Length	longer canals have higher re-vegetation rates, perhaps because dredge operators have more time to develop skills
Soils Condition	wetland organic content is inversely related to canal depth
Surrounding Wetland	stability of surrounding wetland
Sediment Supply	proximity to sediment sources
Dredging Operation	
Operator Skill	longer canals have higher re-vegetation rates, perhaps because dredge operators have more time to develop skills
Management	
Plug or No Plug in Canal	no apparent differences with or without plug
Permitting Stipulations	canals backfilled for mitigation are shallower than those backfilled after abandonment; one explanation is related to the choice of sites by the dredge operator, or, the land manager. Off-site mitigation offers more choices to dredge operators.

If complete wetland restoration back to a pristine state were the goal of backfilling, then that goal has not been achieved. In the majority of cases marsh vegetation has not re-colonized the backfilled canal areas. The old spoil banks, in most cases and in varying degrees, have been re-vegetated by marsh vegetation. However, most also support some upland vegetation at the outer portions that were not backfilled or on spots that were not backfilled to marsh elevations. There are also many examples of open water where spoil banks were backfilled below marsh elevation. Eight to ten years after backfilling, it is still a simple matter to discern the original configuration of the canal and spoil banks from aerial imagery. In other words, the backfilled spoil areas are still distinct from the surrounding marsh habitat.

However, there have been benefits. Restoration of a more natural hydrological cycle has been achieved. Marsh areas which have been partially or completely impounded by spoil banks have fewer but longer periods of flooding and drying and reduced water exchange when compared to unimpounded marshes which respond more readily to the meteorologically and astronomically forced levels of estuarine waters (Swenson and Turner 1987). Visual studies of the aerial imagery of the backfilled canals shows that many have developed dendritic drainage patterns that connect the marsh, former spoil banks, backfilled canals and (in cases where the canals were not plugged or where the plugs have eroded) the connecting waterways. Often, meandering channels are discernible in the backfilled canals. The interconnection of these components allows for the flux of material from and into the marsh area. Formerly impounded marsh areas can thus be the recipients of resuspended sediment from the bays and bayous, an important component in marsh accretion in subsiding marshes (e.g., Reed 1989). By contrast, backfilled canals with intact plugs are clearly not receiving the suspended sediment that is available in the adjacent waterways. Plugged canals tend to be more uniformly deep and to have more aquatic vegetation. The aquatic vegetation in plugged canals offers good habitat for waterfowl and for fish, although the presence of an intact plug inhibits the movement of migrant fish species into and out of the canals.

Backfilling cost were estimated using the assumptions shown in Table 10. Backfilling restores wetlands at a cost of $1,200 to $3,400/ha, depending on whether only the direct, or also the indirect impacts, respectively, where included. The cost of dredging the original canal is in the neighborhood of $25,000/ha. The restoration costs compare favorably with funded restoration projects in south Louisiana (compared in Turner et al. 1994). For example, marsh management plans under the Coastal Restoration Act, 1990, cost approximately $1,000 to $90,000/ha. Marsh management plans may be somewhat unpredictable or even damaging (Cowan, et al. 1988; Cahoon and Groat 1990), whereas these backfilled sites are based on empirical results. The estimated costs of river diversions are in the same cost range (>$10,000/ha), but we have little experience with the reasonableness of the restoration estimates and the maintenance infrastructure is scheduled for 20 years. There are limited opportunities for building small river diversions, or splays, at the Mississippi River delta, although their cost is even less expensive (about $200 to $400/ha). Strategic cuts in spoil banks range around $10 to $200/ha restored (Turner et al. 1994).

In summary, backfilling is a technique to manage the legacy of canals and spoil banks in coastal Louisiana and demonstrates stability (and even some improvement) within a few years, but also over decades. It is a reasonably easy and quite management action, requiring simple equipment and no on-site maintenance. Fish and waterfowl habitats are produced. There are tens of thousands of hectares of canal and spoil banks available for backfilling today. Many more will become available as the oil and gas field close down.

Table 10. Cost assumptions for calculating the cost of backfilling and its success.

Item	Calculation Basis	Comments/Notes
Cost:	\$1.20 per m^3	Industry based estimate. Ignores mobilization costs that may be substantial for one effort, but trivial if multiple sites competitively bid.
Canal Area	1.3 ha	median value of 31 backfilled canals
Spoil Area	3.0 ha	median value of 31 backfilled canals
Spoil Length	880 m	400 m canal length, 2 sides continuos spoil bank, and 80 m width at one end
Spoil Bank Width	34 m	median value for 31 backfilled canals
Spoil Elevation	0.3 m	assume the peak of a triangle with a base of 34 m
Indirect impacts	1.85 ha/ha canal	Bass 1993
Restoration	1.6 ha	median value for 31 backfilled canals

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APPENDIX A. Fish Catch Data

There were no distinguishing characteristics of the backfilled plugged, partially plugged or unplugged canals in terms of the presence of resident and migrant fish and invertebrates (Figure A.1 and A.2). This result may be for several reasons, including the sample size or the season.

The sample size was small because of the few canals with intact plugs. The 13 canals with plugs in 1983/4 were reduced to 8 by 1992/3. The same ten canals with breached plugs in 1983/4 were reduced to 5 by 1992/3. The plugs were clearly eroding over time and this afforded spaces and avenues for access during high water. Second, the late June and July sampling are also the time of higher water levels. The general absence of migratory species (see Tables A.1 and A.2) indicates that the distribution of fish and decapods in the estuary determined the results, not the selection of habitats by the species present.

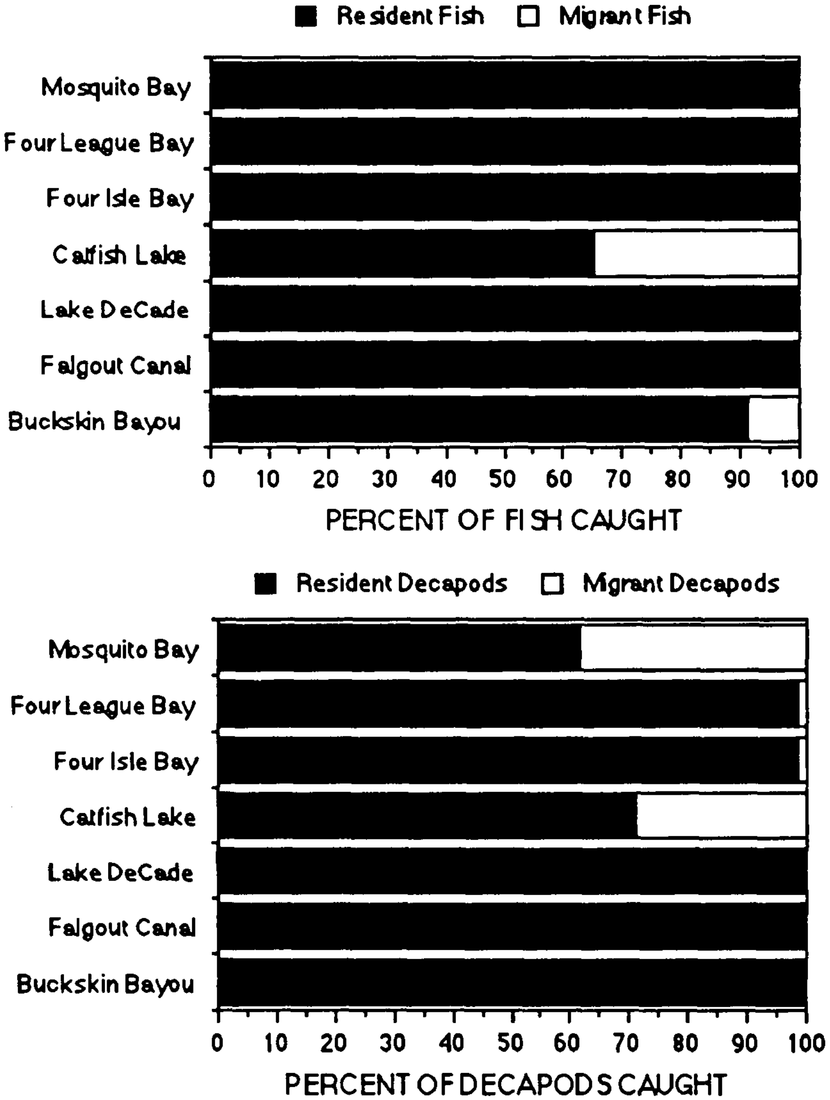

Figure A.1. The percent of resident and migrant fish (upper panel) and decapods (lower panel) caught in open (no plug; MB< FLB, FIB), semi-open (deteriorated plug; CL, LDC) and closed (plugged; FC, BB) backfilled canals.

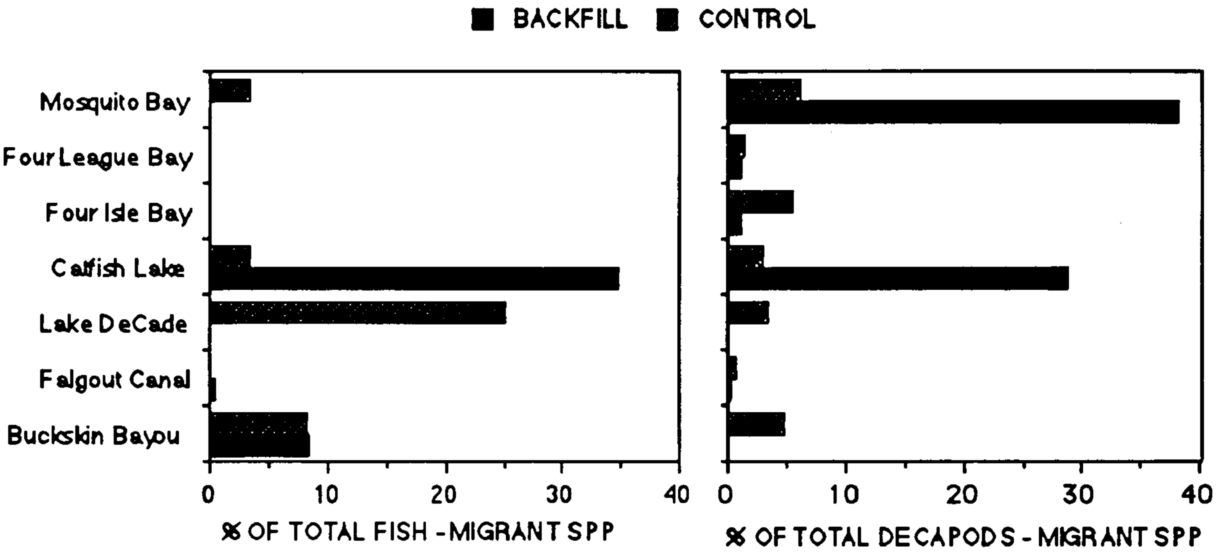

Figure A.2. The percent of the fish and decapods classified as 'migratory' that were caught at the backfilled sites and nearby reference sites that were open (no plug; MB< FLB, FIB), semi-open (deteriorated plug; CL, LDC) and closed (plugged; FC, BB).

Table A.1. Occurrence of resident and migrant species in Louisiana backfilled canals. Key: BB = Buckskin Bayou; FC = Falgout Canal; LDC = Lake DeCade; CL = Catfish Lake; FIB = Four Isle Bay; FLB = Four League Bay; MB = Mosquito Bay.

Species	Plugged canals		Semi-open canals		Open canals		
	BB	FC	LDC	CL	FIB	FLB	MB
Resident Species							
Cyprinodon variegatus			58		91	2	54
Lucania parva		55			560	21	
Adinia xenica					1		15
Fundulus grandis				6	164	25	71
Fundulus jenkinsi				3	77	2	1
Fundulus pulvereus					22		1
Fundulus chrysotus		12	4				
Poecilia latipinna	31	12	201		14	1	4
Gambusia affinis	18	43	2079				
Heterandria formosa		40	576				
Menidia beryllina		58		85	97		
Syngnathus floridae		4					
Syngnathus scovelli				6	1		
Gobiosoma bosc	5	3		168	85		
Microgobius gulosus		10		9	1		
Lepomis macrochirus		2					
Lepomis punctatus		1					
Lepomis symmetricus		2					
Lepomis sp.		13					
Procambarus sp. ?		2	8				
Palaemonetes sp.	120	1063	378	300	1920	1341	110
Xanthidae				6			
Migrant Species							
Anchoa mitchilli				139			
Cynoscion nebulosus				5			
Mugil cephalus	5	obs					
Opsanus beta				3			
Penaeus aztecus				13	14		26
Penaeus setiferus				108	1		2
Callinectes sapidus		2		2	8	16	40
Number of fish species							
Resident	3	13	5	6	11	5	6
Migrant	1	1	0	3	0	0	0
Number of decapod species							
Resident	1	2	2	2	1	1	1
Migrant	0	1	0	3	3	1	3
Total numbers of fish							
Resident	54	255	2918	277	1113	51	146
Migrant	5	1	0	147	0	0	0
Total numbers of decapods							
Resident	120	1065	386	306	1920	1341	110
Migrant	0	2	0	123	23	16	68

Table A.2. Occurrence of resident and migrant species in non-backfilled (control) canals. Key: BB = Buckskin Bayou; FC = Falgout Canal; LDC = Lake DeCade; CL = Catfish Lake; FIB = Four Isle Bay; FLB = Four League Bay; MB = Mosquito Bay.

	Non-backfilled canal adjacent to site						
Species	BB	FC	LDC	CL	FIB	FLB	MB
Resident Species							
Cyprinodon variegatus				4			
Lucania parva		3	2	46	599		
Fundulus grandis	25			17	6	2	17
Fundulus jenkinsi					9		
Poecilia latipinna				1	3		1
Heterandria formosa			15				
Menidia beryllina	2			5	1		1
Syngnathus scovelli				30	17		
Gobiosoma bosc	11	1	7	91	45		37
Gobionellus boleosoma	7						1
Microgobius gulosus			2		21		
Micropterus salmoides		3					
Lepomis macrochirus			9?				
Lepomis punctatus			1				
Lepomis sp.?		51?					
Palaemonetes sp.	2831	286	57	166	1385	702	2153
Xanthidae		1		2			
Migrant Species							
Anchoa mitchilli			12	1			2
Cynoscion nebulosus				1			
Symphurus plagiusa	3						
Opsanus beta				5			
Oligoplites saurus	1						
Penaeus aztecus	4			2	77	1	53
Penaeus setiferus	5					1	53
Callinectes sapidus	130	2	2	3	3	8	35
Number of fish species							
Resident	4	4+	6+	7	8	1	5
Migrant	2	0	1	3	0	0	1
Number of decapod species							
Resident	1	2	1	2	1	1	1
Migrant	3	1	1	2	2	3	3
Total numbers of fish							
Resident	45	58	36	194	701	2	57
Migrant	4	0	12	7	0	0	2
Total numbers of decapods							
Resident	2831	287	57	168	1385	702	2153
Migrant	139	2	2	5	80	10	141

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Minerals Revenue Management** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.