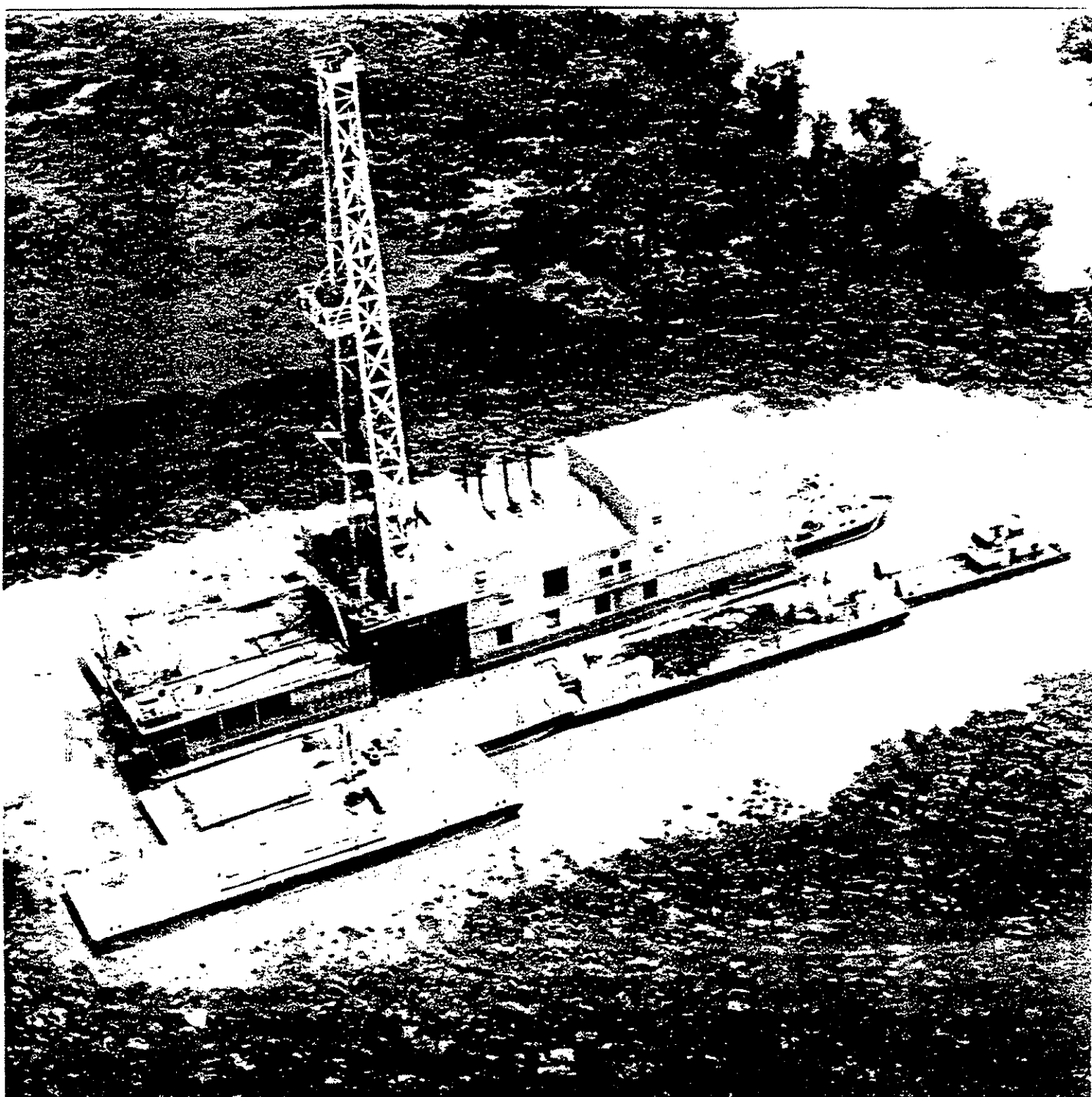
ONSHORE OIL AND GAS ACTIVITIES ALONG THE NORTHERN GULF OF MEXICO COAST:

A WETLAND MANAGER'S HANDBOOK



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A WETLAND MANAGER'S HANDBOOK

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DISCLAIMER NOTICE

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This document is provided as guidance for Clean Water Act (CWA) §404 permit applicants involved in oil and gas exploration and production in coastal Louisiana. Due to increased emphasis on other issues prior to contract completion, this document should not be considered to reflect every concern Region 6 has with existing or proposed oil and gas exploration and production facilities in wetland areas. It does, however, provide guidance to CWA §404 permit applicants regarding a majority of concerns which CWA §404 applicants could expect Region 6 to express.

PREFACE

This handbook evaluates the impacts to coastal marshes in Louisiana related to the various operational methods used in oil and gas exploration and development projects (i.e., exploration, site access, site preparation, drilling, production, pipeline installation, spill control and cleanup, and site closure) and presents techniques for avoiding, minimizing, and restoring these impacts through the process of regulatory review. The lead chapter discusses the values and functions of wetlands. Subsequent chapters discuss impacts to these values and functions by different operational procedures and refer directly to the first chapter.

The discussion of compensation for unavoidable environmental impacts (i.e., offsite mitigation) is beyond the scope of this handbook. Compensation for impacts remaining after all regulatory steps have been taken to avoid, minimize or restore can be determined only on a case-by-case basis. Factors that must be considered include marsh type, local hydrologic regime, degree of avoidance, minimization, restoration already achieved, technological limitations, suitable off-site locations for mitigative work, and economics. More importantly, compensatory policy varies widely among agencies, depending on the agencies' regulatory mandate. It is recommended that the reader review the offsite mitigation literature for a fuller understanding of this issue.

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Several corporations provided valuable information on industry procedures and techniques. Cajun Exploration provided informative discussions of modern seismic exploration activities for Chapter 2. Berry Brothers General Contractors Inc. discussed the methods and costs associated with modern bucket dredging while Aztec Development Company provided information on an alternative dredging methodology (Chapters 3 and 4). Central Industries discussed the procedures for constructing road dumps and board roads in coastal Louisiana wetlands.

The following corporations and organizations contributed to our discussion of pipelines (Chapter 7). Tennessee Gas Pipeline, United Gas Pipeline, ENRON, and Louisiana Resources Company provided access to field personnel who monitor construction operations and personnel from their environmental divisions. Discussions with these corporate representatives provided insights on the historic evolution of pipeline construction techniques, practical problems and advantages associated with the use of differing types of equipment, establishing rights-of-way, and dam construction and maintenance. These corporations also provided many of the photographs that are used for illustrative purposes herein. Woodson Construction of Lafayette, La, provided the cost estimates for the various construction alternatives discussed in the chapter. Transco provided informative discussions on wetland recovery projects initiated within their pipeline system.

TABLE OF CONTENTS

Page

PREFACE v
ACKNOWLEDGMENTS vii
LIST OF FIGURES xvii
LIST OF TABLES xix

CHAPTER 1. WETLAND FUNCTIONS AND VALUES
1.1. Structure and Setting of Coastal Marshes 1
1.1.1. Development of Louisiana's Delta Marshes 2
1.1.2. Louisiana's Coastal Topography 2
1.1.3. System Couplings 3
1.2. Influence of Hydrology on Wetland Ecological Processes 4
1.2.1. Hydrologic Functions 4
1.2.2. Influence of Hydrology on Substrate 4
1.2.3. Influence of Substrate on Biota 6
1.2.4. Influence of Biota on Hydrology 7
1.3. Mechanisms of Wetland Loss 7
1.4. Wetland Values 9
1.4.1. Population Values 9
1.4.2. Ecosystem Values 9
1.4.3. Global Values 10
1.4.4. Management Priorities 10
1.4.5. Management Objectives 11

CHAPTER 2. EXPLORATION
2.1. Introduction 13
2.1.1. History 13
2.1.1.1. Transportation 14
2.1.1.2. Environmental Regulatory Policy 14
2.1.2. Modern Seismic Survey Procedures 15
2.2. Impacts on Wetland Values and Functions 15
2.2.1. Alteration of Habitat 18
2.2.2. Influence on Hydrology 18
2.3. Influence on Wetland Loss 18
2.4. Managing Impacts through the Regulatory Process 18
2.4.1. Avoiding Impacts to Surface Features and Functions 21
2.4.1.1. Alternate Transportation Methods 21
2.4.1.2. Timing of Exploration 22
2.4.2. Minimizing Impacts to Surface Features/Functions 22
2.4.2.1. Route Selection 22
2.4.2.2. Minimize Marsh Buggy Activity 22
2.4.3. Restoring Impacts to Surface Features/Functions 22
2.4.3.1. Filling Marsh Buggy Tracks 22
2.4.3.2. Barriers at Waterway Crossings 23
2.4.4. Suggestions for Implementing Management Techniques 23

CHAPTER 3. DRILLING SITE ACCESS
3.1. Introduction 25
3.2. Canals 25
3.2.1. Introduction 25

3.2.1.1. History 26
3.2.1.2. Procedure 26
3.2.2. Impacts on Wetland Values and Functions 29
3.2.2.1. Alteration of Habitat 29
3.2.2.2. Influence on Hydrology and Water Quality 32
3.2.3. Influence on Wetland Loss 32
3.2.3.1. Cause-effect Relationships 32
3.2.4. Managing Impacts through the Regulatory Process 33
3.2.4.1. Avoiding Impacts 33
3.2.4.2. Minimizing Impacts 35
3.2.4.3. Avoiding and Minimizing Techniques Combined 41
3.2.4.4. Suggestions for Implementing Management Techniques 43
3.3. Road Dump 43
3.3.1. Introduction 43
3.3.1.1. History 43
3.3.1.2. Procedure 44
3.3.2. Impacts on Wetland Values and Functions 47
3.3.2.1. Alteration of Habitat 47
3.3.2.2. Influence on Hydrology 50
3.3.3. Influence on Wetland Loss 51
3.3.3.1. Cause-effect Relationships 51
3.3.4. Managing Impacts through the Regulatory Process 51
3.3.4.1. Avoiding Impacts 51
3.3.4.2. Minimizing Impacts 52
3.3.4.3. Avoiding and Minimizing Techniques Combined 54
3.3.4.4. Suggestions for Implementing Management Techniques 54
3.4. Hovercraft and Helicopters 55

CHAPTER 4. SITE PREPARATION
4.1. Introduction 57
4.2. Canal-Keyhole 57
4.2.1. Introduction 57
4.2.1.1. History 57
4.2.1.2. Procedure 58
4.2.2. Impact on Wetland Values and Functions 58
4.2.2.1. Alteration of Habitat 58
4.2.2.2. Influence on Hydrology and Water Quality 59
4.2.3. Influence on Wetland Loss 59
4.2.4. Managing Impacts through the Regulatory Process 59
4.2.5. Suggestions for Implementing Management Techniques 60
4.3. Road Dump/Ring Levee 60
4.3.1. Introduction 60
4.3.1.1. History 60
4.3.1.2. Procedure 60
4.3.2. Impacts to Wetland Values and Functions 61
4.3.2.1. Alteration of Habitat 62
4.3.2.2. Influence on Hydrology 63
4.3.3. Influence on Wetland Loss 63
4.3.4. Managing Impacts through the Regulatory Process 63
4.3.4.1. Avoiding Impacts 63
4.3.4.2. Minimizing Impacts 63

CHAPTER 5. DRILLING
5.1 Introduction 65
5.1.1. History of Oil Drilling 65

5.1.2. Modern Drilling Methods 66
5.1.3. Directional Drilling 67
5.2. Impacts on Wetlands Values and Functions 69
5.2.1. Alteration of Habitat 69
5.2.2. Influence on Hydrology 69
5.3. Managing Impacts through the Regulatory Process 71
5.3.1. Avoiding Impacts of Drilling Operations 71
5.3.2. Minimizing the Impacts of Drilling Operations 71
5.4. Suggestions for Implementation of Management Procedures 71

CHAPTER 6. PRODUCTION
6.1. Introduction 75
6.1.1. History of Oil and Gas Production 75
6.1.2. Modern Techniques of Production 76
6.1.2.1. Reservoir Types 76
6.1.2.2. Stimulation Techniques 76
6.1.2.3. Processing Techniques 76
6.1.2.4. Workovers 79
6.1.2.5. Secondary and Enhanced Recovery Techniques 81
6.2. Impacts on Wetland Values and Functions 81
6.2.1. Alteration of Habitat for Production Facilities 81
6.2.2. Influence on Water Quality 83
6.3. Influence on Wetland Loss 83
6.3.1. Influence of Subsidence Caused by Drawdown 83
6.3.2. Influence of Brine Disposal 83
6.4. Managing Impacts through the Regulatory Process 83
6.4.1. Avoiding Impacts 83
6.4.2. Minimizing Impacts 84
6.4.3. Combining Regulatory Programs 84
6.5. Future Trends 84
6.5.1. Future Need for Increased Processing Facilities 84
6.5.2. EOR—The Future Effects on Habitat 85

CHAPTER 7. PIPELINE INSTALLATION
7.1. Introduction 87
7.1.1. History 88
7.1.2. Pipeline Construction Techniques 88
7.1.3. Right-of-Way Restoration Techniques 91
7.1.3.1. Marsh Habitat 91
7.1.3.2. Beach Habitat 95
7.1.3.3. Seagrass Beds 95
7.1.4. Dams (Bulkheads) 96
7.1.5. Ancillary Facilities 96
7.2. Impacts on Wetland Values and Functions 97
7.2.1. Direct Impacts 97
7.2.2. Indirect Impacts 98
7.3. Managing Impacts through the Regulatory Process 99
7.3.1. Avoiding Impacts to Surface Features 99
7.3.1.1. Route Selection: Upland 99
7.3.2. Minimizing Impacts to Surface Features 99
7.3.2.1. Route Selection: Wetlands 99
7.3.2.2. Pipeline Corridors 100
7.3.2.3. Equipment Usage 100
7.3.2.4. Construction Techniques 100
7.3.2.5. Pipeline Diameter 100

7.3.3. Restoring Impacts to Surface Features 100
7.3.3.1. Plantings 100
7.3.4. Suggestions for Implementing Management Techniques 101

CHAPTER 8. SPILL CONTROL AND CLEANUP
8.1. Introduction 103
8.1.1. Petroleum Spills 104
8.1.1.1. Sources 104
8.1.1.2. Substances 104
8.1.2. Impacts of Petroleum Hydrocarbons on Estuarine Biota 105
8.1.2.1. Impacts on Vegetation and Fauna 106
8.1.2.2. Factors Affecting Impacts 106
8.1.3. Emergency Response Procedures 107
8.1.4. Protection Measures 107
8.1.4.1. Existing Control Features 108
8.1.4.2. Skirt and Fence Booms 108
8.1.4.3. Sorbent Booms 108
8.1.4.4. Improvised Booms 108
8.1.4.5. Earth and Rigid Barriers 109
8.1.4.6. Permeable Barriers 109
8.1.4.7. Sorbents 109
8.1.4.8. Wildlife Deterrents 110
8.1.5. Cleanup Measures 110
8.1.5.1. Natural Cleaning 110
8.1.5.2. Removal and Collection of Oil 110
8.1.5.3. Handling of Contaminated Materials 110
8.1.5.4. Bird Cleaning 113
8.2. Influence on Wetland Values and Functions 113
8.2.1. Impacts Associated with Protection Measures 113
8.2.2. Impacts Associated with Cleanup Measures 113
8.2.2.1. Traffic 115
8.2.2.2. Flushing 115
8.2.2.3. Sorbents 115
8.2.2.4. Cutting 115
8.2.2.5. Soil Removal 115
8.3. Managing Impacts through the Regulatory Process 115

CHAPTER 9. SITE CLOSURE
9.1. Introduction 117
9.2. On-site Restoration of Impacted Wetland Values and Functions upon Abandonment of Well-Canal-Keyhole 118
9.2.1. Restoring Spoil Bank and Canal Habitat to Marsh 118
9.2.1.1. Typical Backfilled Canal 118
9.2.1.2. Factors Affecting Backfilling Success 121
9.2.2. Restoring Alterations to Hydrology and Sediment Distribution 124
9.2.2.1. Plug Canal with Earthen Dam 124
9.2.2.2. Construct Gaps in the Spoil Bank 126
9.2.2.3. Open-Blocked Waterways 127
9.2.2.4. Combinations of the Above 127
9.2.2.5. Suggestions for Implementing Management Techniques 127
9.3. On-site Restoration of Impacted Wetland Values and Functions upon Abandonment of Well-Road Dump/Ring Levee 128
9.3.1. Restoration of Habitat 128
9.3.1.1. Regrade Drill Site 128
9.3.1.2. Removal of Drill Pad Material 129

9.3.1.3. Removal of Road Surface 129
9.3.1.4. Removal of Road Dump 130
9.3.2. Restoration of Surface Hydrology and Maintenance of Water Quality 130
9.3.2.1. Open Blocked Streams 130
9.3.3. Suggestions for Implementing Management Techniques 130

CONVERSION TABLE 133
GLOSSARY OF TERMS 135
REFERENCES CITED 145
TOPICAL INDEX 151

LIST OF FIGURES

Page

Figure 1.1. Map of the Mississippi River Deltaic Plain showing the hydrologic units. 2
Figure 1.2. Conceptual diagram illustrating the coupling of delta marshes to other ecosystems. 3
Figure 1.3. Conceptual model of the direct and indirect effects of hydrology on wetlands. 5
Figure 1.4. The influence of tidal flooding on marsh soil transformations. 6
Figure 1.5. Simplified diagram illustrating the influence of hydrology on the source-sink nature of nutrient cycling in wetlands: (a) sink of inorganic nutrients; (b) source of organic matter. 7
Figure 1.6. Diagram illustrating the general effect of wetlands on stream flow. 10
Figure 2.1. A view of marsh buggies parked along the bank of a waterway during seismic survey operations. 14
Figure 2.2. A cross-sectional view of subsurface geologic formations and upland seismic surveying procedures. 16
Figure 2.3. Truck-mounted rotary drill rig used for upland seismic survey operations. 16
Figure 2.4. Pontoon sled-mounted rotary drill rig used for seismic survey operations in marshes. 17
Figure 2.5. Pontoon sled-mounted rotary drill rig used for seismic survey operations in swamps and other forested wetlands. 17
Figure 2.6. Aerial view of marsh showing linear feature of marsh buggy tracks. 18
Figure 2.7. Aerial view of marsh in the vicinity of a salt dome in southern Plaquemines Parish showing numerous parallel marsh buggy tracks resulting from intense seismic surveying. 19
Figure 2.8. Close-up view of fresh tracks created by a tracked marsh buggy in a salt marsh of southern Lafourche Parish. 19
Figure 2.9. A ground view of marsh buggy tracks crossing a natural streamside levee. 20
Figure 2.10. Aerial view of the marsh showing fresh and old marsh buggy tracks. 20
Figure 3.1. Modern submersible barge platform. 26
Figure 3.2. Cross-section view of a typical access canal and slip. 27
Figure 3.3. Plan view of a typical keyhole showing the position of the drilling barge. 28
Figure 3.4. Aerial view of drill barge on location. 28
Figure 3.5. Cross-section and plan view of a typical parallel slip. 29
Figure 3.6. A view looking along the length of a canal showing the relationship of canal, berm, and spoil bank. 31
Figure 3.7. Aerial view of canal and keyhole with forested spoil bank. 31
Figure 3.8. An interconnected system of canals resulting in a partial impoundment. 37
Figure 3.9. Aerial view of canal with discontinuous spoil bank. 38
Figure 3.10. Basic spoil bank configurations. 39
Figure 3.11. Aerial view of channel dredged in open water with gapped subaerial spoil banks. 40
Figure 3.12. Channel alignment and spoil placement in an open water habitat designed to promote marsh creation. 41
Figure 3.13. Jet-spray swinging ladder dredge excavating a keyhole. 42
Figure 3.14. Jet-spray swinging ladder dredge spraying spoil across marsh. 42

Figure 3.15. View of the bank of a canal dredged by a Jet-spray swinging ladder dredge. 43
Figure 3.16. Spreader-head attachment used to deflect pumped spoil upward on conventional hydraulic dredge. 43
Figure 3.17. View of dredged material being deflected upward by spreader head and sprayed onto marsh. 44
Figure 3.18. Cross-section of road dump and borrow ditch. 46
Figure 3.19. Dredged material piled to create road dump through open water area. 46
Figure 3.20. Plan view of typical road dump and staggered alternating borrow ditches. 47
Figure 3.21. Examples of road dump side slopes. 47
Figure 3.22. Aerial view of board road and ring levee/drill pad in forested wetlands. 48
Figure 3.23. View of road dump in Figure 3.19 with boards recently put in place. 48
Figure 3.24. Completed board road, ground view. 49
Figure 3.25. Completed board road, aerial view. 49
Figure 3.26. Board road with bridge crossing. 50
Figure 3.27. Canal versus road dump/board road–acres altered. 51
Figure 4.1. Illustration of keyway showing plan and cross-section views. 58
Figure 4.2. Illustration of typical design of foundation pad for a drill barge or production platform made from shell or limestone. 59
Figure 4.3. Road dump access route with ring levee drill site. 60
Figure 4.4. Board road accessed drill site. 61
Figure 4.5. Cross-section and plan view of typical ring levee/drill pad. 62
Figure 5.1. The rotary drilling process. 66
Figure 5.2. Schematic of example rig circulating system for drilling fluids. 67
Figure 5.3. The numerous applications of controlled directional drilling. 68
Figure 5.4. Simple kick directional well. 68
Figure 5.5. S-shaped directional well. 68
Figure 5.6. Comparison of two sets of well configurations 72
Figure 6.1. Heater treater at wellhead. 77
Figure 6.2. Stock tanks for oil storage. 78
Figure 6.3. Oil processing facility. 78
Figure 6.4. Diagram of field operations. 79
Figure 6.5. As water is injected into the water bank, the water bank expands outward and pushes petroleum ahead toward offsetting production wells. 80
Figure 7.1. Dragline mounted on wide-track marsh buggy. 89
Figure 7.2. Backhoe dredge mounted on wide-track marsh buggy. 89
Figure 7.3. Typical push ditch canal prior to backfilling. 90
Figure 7.4. Pipeline crossing a waterway, with two slips on either side of the waterway. 91
Figure 7.5. Push method of pipe installation. 91
Figure 7.6. Bulkhead dam near shoreline intersection. 92
Figure 7.7. Pipeline lifted by a cradle so that a new pipeline can be laid under it. 92
Figure 7.8. Jet dredge, which pushes material away from existing intersecting pipeline. 93
Figure 7.9. Lay barges being pushed across a waterway. 93
Figure 7.10. Example of a properly backfilled and restored pipeline right-of-way. 94

Figure 8.1. Schematic of a typical boom. 108
Figure 8.2. Small flotation boom deployment at production platform to contain minor spill caused by collapse of brine storage tank. 109
Figure 8.3. Rope mop skimmer and vacuum pump assembly. 111
Figure 8.4. A. Weir skimmer attached to vacuum pump. B. Boom skimmer-combination of pressurized chamber boom and weir skimmers. 112
Figure 8.5. Weir skimmer attached to vacuum pump. 113
Figure 9.1. Schematic representation of a typical oil and gas drilling site canal before and after backfilling. 118
Figure 9.2. Examples of backfilled canals in south Louisiana. 119
Figure 9.3. Illustrations of a typical plug design used in closing a drilling site access canal, showing plan and cross-section views of the plug, canal, and borrow area. 125
Figure 9.4. Earthen plug installed at mouth of canal. 126
Figure 9.5. Aerial view of plugged canal/slip, showing the relationship between the canal, slip, berm, spoil bank, and plug. 127
Figure 9.6. Aerial view of a plugged canal/slip with gaps dredged every 500 feet in the spoil bank. 128
Figure 9.7. Aerial view of restored road dump and ring levee in coastal fresh marsh. 129

LIST OF TABLES

Page

Table 2.1. Observed and hypothetical impacts of marsh buggies on coastal marsh habitats and wetland loss. 21
Table 3.1. Estimates of the amount of dredging and acres of marsh altered for access canals of various sizes. 30
Table 3.2 Observable and hypothetical cause-effect relationships between canals and marsh alterations and loss. 34
Table 3.3. Suggested procedure for implementing management techniques during permit review. 45
Table 3.4. Observable and hypothetical cause-effect relationships between board roads and marsh alteration. 53
Table 5.1. Observable and hypothetical cause-effect relationships of drilling operations on coastal marsh habitats and wetland loss. 70
Table 6.1. Possible leaks and discharges in production operations. 80
Table 6.2. Observable and hypothetical cause-effect relationships of production operations on coastal marsh habitats and wetland loss. 82
Table 7.1. Observable and hypothetical cause-effect relationships between pipeline construction and habitat alteration for push-pull pipelines. 98
Table 8.1. Oil classification, diagnostic properties, and control/cleanup potential. 105
Table 8.2. Observable and hypothetical cause-effect relationships of protection techniques. 114
Table 8.3. Observable and hypothetical cause-effect relationships of cleanup techniques. 114
Table 9.1. Characteristics of a typical backfilled canal. 120
Table 9.2. Restoration of depth, vegetation, and soil properties for 35 backfilled canals. 120
Table 9.3. The influence of plugs on the presence of aquatic vegetation. 121
Table 9.4. Factors encouraging backfilled canal restoration for seven marsh components. 123

CHAPTER 1

WETLAND FUNCTIONS AND VALUES

by
Donald R. Cahoon

1.1. STRUCTURE and SETTING of COASTAL MARSHES

Coastal marshes develop in estuaries that are the boundary between land and ocean. The terrestrial (riverine) and marine processes impinging upon the regional climate and geologic setting of the estuary control marsh development. Consequently, marshes exhibit characteristics of both terrestrial and marine communities: their development is plastic and highly influenced by water, sediment, and vegetation. For example, in salt marshes many organisms are terrestrial in nature, especially the plants, and vegetational processes can lead to the development of soils with horizons similar to terrestrial soils (Wiegert et al., 1981). The same marsh displays aquatic attributes in that water circulates throughout the system distributing organic and inorganic matter, providing a medium in which many organisms live. Wiegert et al. (1981) summarized the structure and function of the water, sediment, and vegetation of a tidal salt marsh, but the following generalities apply as readily to brackish and fresh marshes: a) tidal creeks and water flowing over the marsh—predominantly aquatic organisms and aerobic processes; b) soils and sediments—attributes of both terrestrial soils (marsh surface) and aquatic sediments (water bottoms), and therefore both aerobic and anaerobic processes occur; and, c) emergent vegetation—predominantly terrestrial organisms and terrestrial processes (i.e., primary production, mortality, decomposition, herbivory) (Wiegert et al., 1981).

1.1.1. Development of Louisiana's Delta Marshes

In Louisiana's low energy Gulf coast shoreline, the Mississippi River has created an extensive deltaic system during the past 5,000-6,000 years. Numerous delta lobes have been formed as the river changed course and sought the route of least resistance to the Gulf (Fisk and McFarlan, 1955; Frazier, 1967). Each delta goes through a cycle of growth, abandonment, and destruction. The sequential growth and abandonment of delta lobes has led to the development of major interdistributary basins that now form the primary drainage basins of the Lousiana coast (**Figure 1.1**). These drainage basins constitute the basic functional unit in the coastal landscape. The development of marshes in these basins is controlled by and directly related to the delta cycle.

In early stages of development, the emergent delta is composed of fresh marshes and mineral soils as a result of the overwhelming influence of the river. The marshes expand as the delta grows, but that expansion is not uniform. Subdeltas become isolated from stream flow, marine processes become more important, and brackish and salt marshes eventually develop. When the river abandons its course, the seaward edge of the delta is reworked by marine processes into barrier islands and reefs that shelter the inland portions of the delta. In addition, riverine hydraulic energy and riverborne sediment load are greatly reduced. As mineral sediment input declines, marsh development depends increasingly on peat production by vegetation, especially at the landward edge of the delta far from the source of reworked marine sediments. Thus, as the delta ages, fresh marsh soils that were originally formed on riverborne mineral soil become more organic, while salt marsh sediments maintain a fairly high mineral content from marine reworking. In general, the mineral content of the soil decreases with distance from the river source in active deltas but in abandoned deltas decreases with distance from the marine sediment source. The development of a Mississippi River delta lobe and its associated wetlands has been summarized by Gosselink (1984).

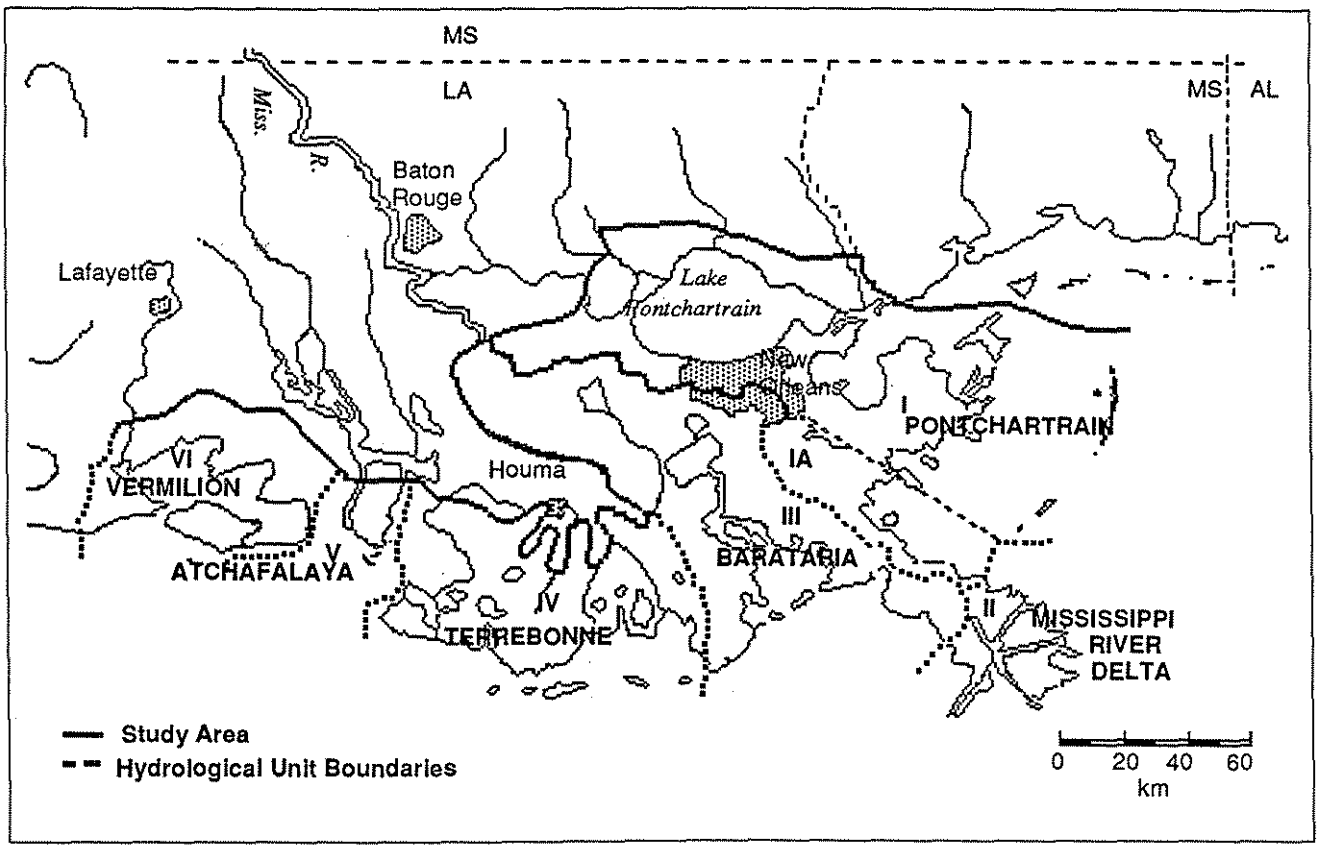


Figure 1.1. Map of the Mississippi River Deltaic Plain showing the hydrologic units (adapted from Wicker, 1980).

1.1.2. Louisiana's Coastal Topography

In a deltaic landscape, the predominance of river flow over marine inflow creates a gently sloping terrain. For example, delta expansion in the Barataria basin covers 50 miles from Gulf to

upland with a mean water slope of only 0.08 inches/mile (Byrne et al., 1976). The slope of the wetlands is also very small since marsh elevation is directly related to local water elevations (Sasser, 1977; Baumann, 1980). Within the gentle waters of the Gulf of Mexico, the tidal regime is small (12 inches) and easily influenced by meterological events. The gradual slope of the delta means that wind and storm events can push flood waters far inland and hold them over large portions of the drainage basins for prolonged periods.

There is also a gentle slope within the marsh starting at the edge of tidal streams and heading inland. A natural creekbank levee (usually several inches high) forms when water overflows the streambank on flood tides and deposits most of its coarse grain sediment near the streambank as it loses velocity. Eventually, a tidal creek can only flood the marsh when its water level exceeds that of the marsh by several inches. This means that not all water can flow directly back into the stream on the ebb tide. Instead, it must flow across the marsh to small natural channels of slighlty lower elevation that eventually take it through the natural levee back to the creek. This slight slope is significant not only for its role in sediment distribution but also because it causes a gradient in inundation that influences water/soil chemistry and biotic productivity.

1.1.3. System Couplings

Louisiana's coastal marshes and the basins of which they are a part are open systems that are strongly influenced by surrounding systems because of their position in the coastal landscape between upland and sea. This coupling means that surrounding systems affect wetland development through the hydrologic exchange of materials and energy in the form of biota and gaseous, dissolved, and particulate organic and inorganic matter. It also means that the value of wetlands extends beyond the boundaries of the basin. Therefore, a full understanding of the role and value of marshes and how best to manage them can only be achieved by viewing marshes in the context of their surroundings (**Figure 1.2**).

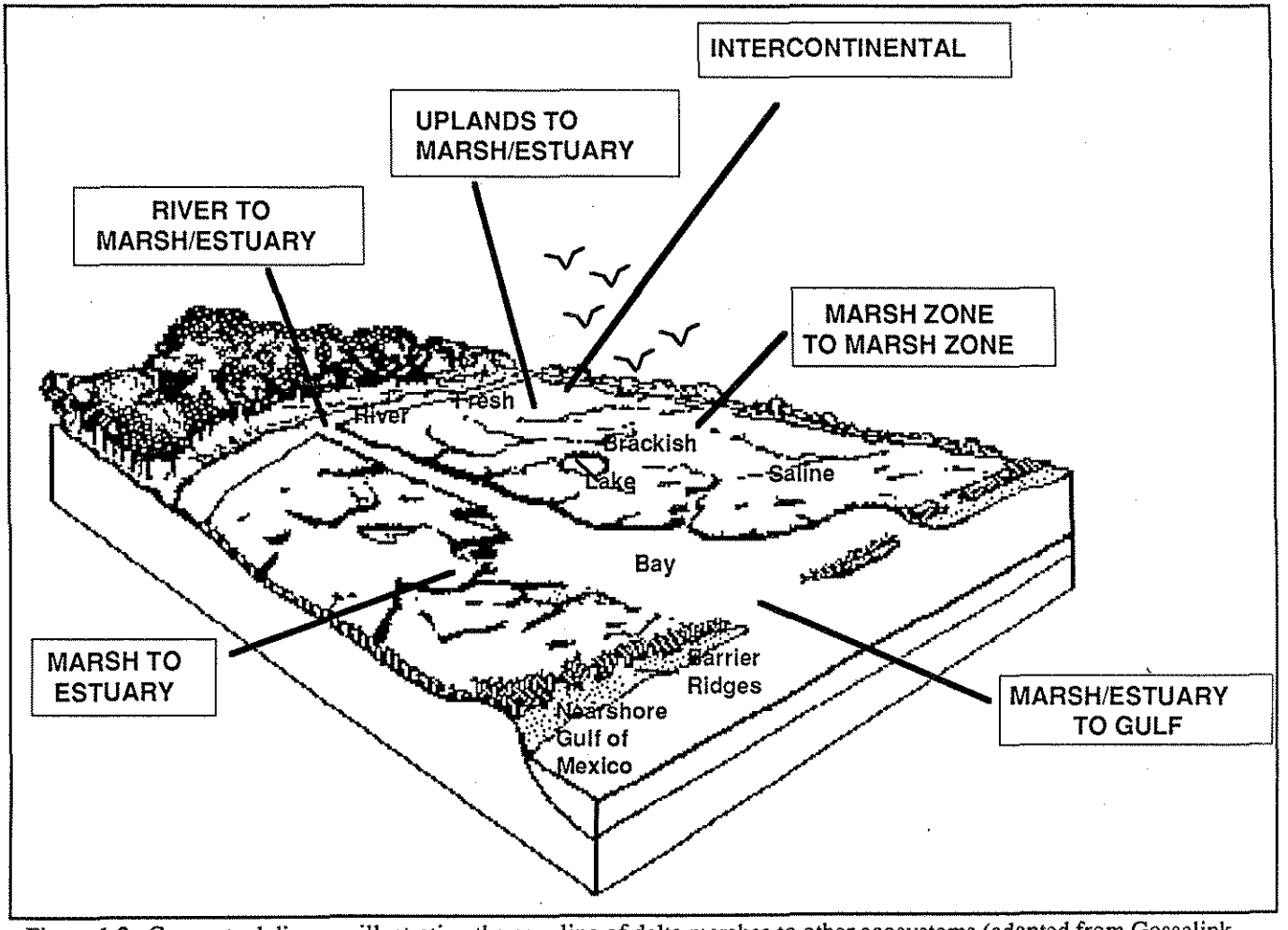


Figure 1.2. Conceptual diagram illustrating the coupling of delta marshes to other ecosystems (adapted from Gosselink, 1984).

The development of marshes is controlled by two major processes external to the coastal basin: upland runoff (river flow) and marine inflow. Annual or episodic variation in these two processes (i.e., changes in riverflow, Gulf water level, and salinity or channel switching by the river) can strongly influence the function and structure of the marsh. Gosselink (1984) describes four basic couplings between the marsh and surrounding ecosystems: marsh zone to marsh zone; marsh to estuary; marsh/estuary to Gulf, river, and adjacent uplands; and, intercontinental couplings. He classifies the first three into intra- and extra-basin couplings (see **Figure 1.2**).

An example of intra-basin coupling is the coupled subsystem of marsh, bay, and stream (Gosselink, 1984). Basins are typically organized along a gradient from fresh to saltwater—fresh marshes are nearest to the upland or riverine sources and salt marshes are nearest to tidal influences. Salt marshes are more typically dissected by channels because of the influence of tidal energy. Some species of biota, such as waterfowl and nektonic organisms, are restricted to specific portions of an environmental gradient and therefore occupy only a single subsystem or portion of the basin, while others are capable of moving freely between subsystems despite differing conditions.

The coupling of marsh to estuary and marsh/estuary to gulf, river, and adjacent uplands exemplifies extra-basin interactions. A recent study demonstrating the dependence of marine-spawned fish on estuaries for the completion of their life cycles is an excellent example of a marsh-estuary coupling (Turner, 1977). While almost all of the commercially important fish in the Gulf of Mexico are spawned and live as adults in the Gulf, their juvenile development is completed in the marshes. Many upland species, such as birds, deer, and other mammals, use wetlands for feeding grounds. The transcontinental migrations of waterfowl between Louisiana and Canada/Alaska exemplify an intercontinental coupling.

1.2. INFLUENCE of HYDROLOGY on WETLAND ECOLOGICAL PROCESSES

Hydrology plays a very important role in the function of wetlands by influencing marsh biogeochemistry and the rates of ecological processes, such as vertical accretion (mineral soil deposition and peat formation) and primary production. All wetlands are characterized by saturated soils and emergent vegetation adapted to growing in an anaerobic environment. Wetlands differ, however, in biota, species richness, productivity, rate of organic matter accumulation, and degree of coupling. These differences are caused by hydrologic forces (Gosselink and Turner, 1978).

A conceptual model of the role of hydrology in wetland ecosystems is presented in **Figure 1.3**. Within the constraints of the local climatic regime and geologic setting, hydrology indirectly influences the biotic response by directly influencing characteristics of the substrate. The loop is closed when biotic components of the wetland exert their influence on hydrology. This is why marsh development is plastic in nature.

1.2.1. Hydrologic Functions

The hydrology-substrate-biota relationship is different for low and high energy systems (i.e., different local climatic and geologic settings). Tidal flood waters deliver and remove sediments, nutrients, salts, and toxins to the basin (**Box 1** in **Figure 1.3**). The velocity of the tidal flood waters determines the renewal rate or flux of these materials and thus directly influences basin physiography. In high energy systems (i.e., high tidal velocities), erosion usually occurs, which, in turn, influences hydrology and changes basin physiography. In both systems, the hydrologic influences on basin physiography modify and determine the chemical and physical properties of the substrate.

1.2.2. Influence of Hydrology on Substrate

Flooding influences the rate and state (reductive or oxidative) of chemical transformations in marsh soils (**Box 2** of **Figure 1.3** and **Figure 1.4**). Anaerobic conditions develop in wetland soils when water fills the pore spaces because oxygen diffuses 10,000 times more slowly through water than air. Such reduced soil conditions prevent aerobic root respiration and strongly influence the availability of plant nutrients and soil toxins. For instance, phosphorus is more soluble under reduced than oxidized conditions (Delaune et al., 1981) and nitrogen, the primary limiting nutrient in marshes, is reduced to the readily available ammonium ion form. Some elements essential to plant growth may be converted to toxins. The reduced forms of manganese and iron are much more soluble than oxidized forms and can accumulate to toxic levels in the soil. Under strong reducing conditions, sulfate (present in saline flood waters) is reduced to highly toxic sulfide. Even plant species specially adapted to anoxic conditions experience reduced growth rates and even death in highly reduced environments.

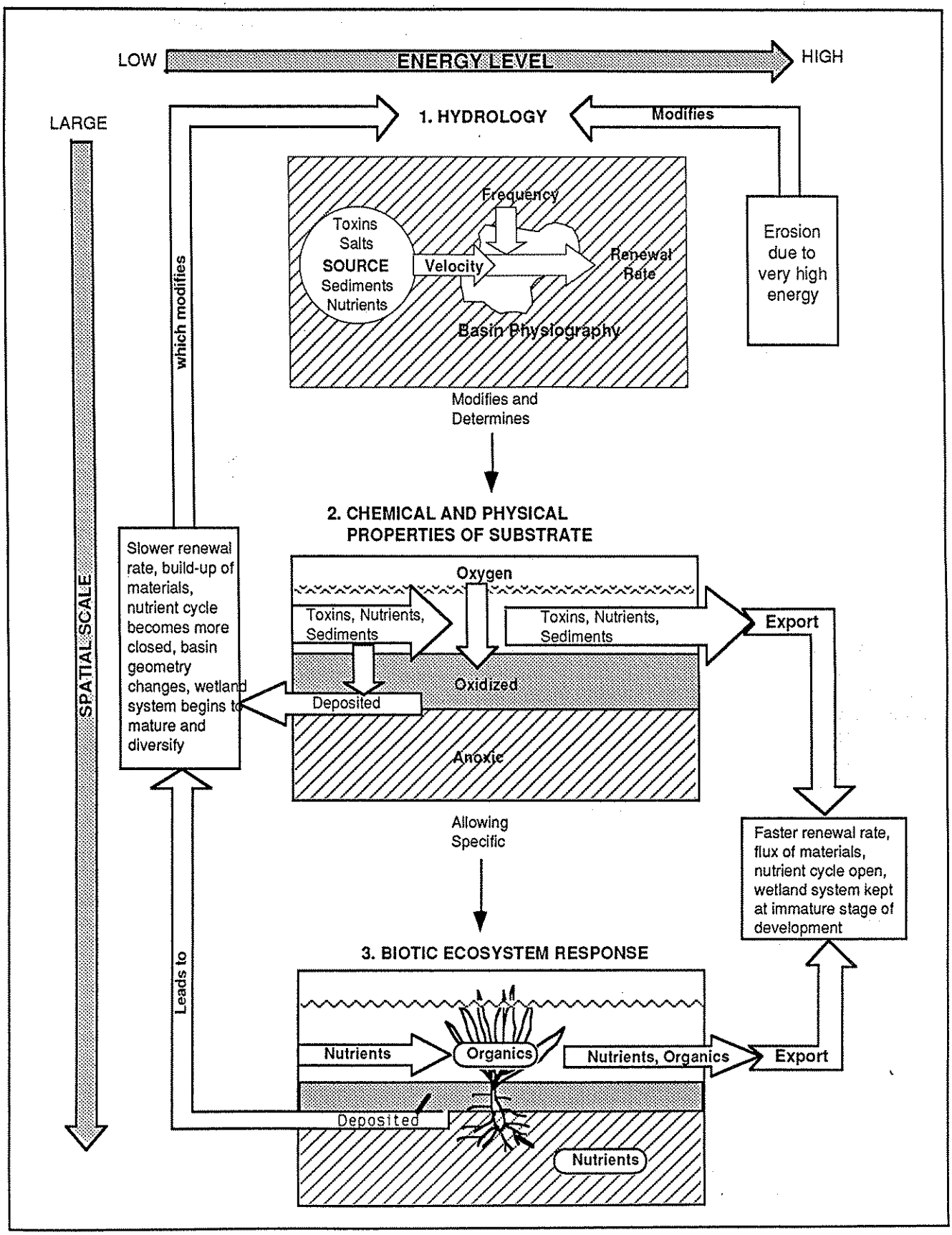


Figure 1.3. Conceptual model of the direct and indirect effects of hydrology on wetlands (adapted from Wicker et al., 1982, after Gosselink and Turner, 1978).

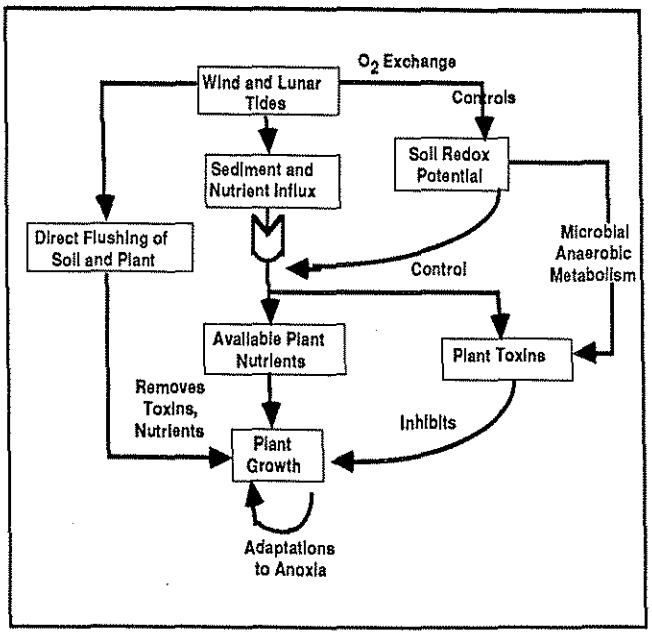


Figure 1.4. The influence of tidal flooding on marsh soil transformations (adapted from Gosselink, 1984).

Marsh soils are not usually totally anaerobic. A thin oxidized layer (often less than 0.4 inches) usually forms at the soil surface where oxygen diffuses from the overlying surface waters or atmosphere at low tide levels. Also, a thin oxidized layer is formed around the roots and underground rhizomes (stems) of those plant species that have developed aerenchyma tissue (tissue with large air spaces) which allows the diffusion of oxygen from aerial plant parts into the roots. The presence of this thin oxidized layer next to the reducing conditions of the anaerobic layer is very important in the chemical transformations and nutrient cycling that occur in wetlands. The cycling of many of the major plant nutrients, such as nitrogen, sulfur, and carbon, depend on this close association of oxidizing and reducing conditions (see Mitsch and Gosselink, 1986, for a review).

1.2.3. Influence of Substrate on Biota

The chemical and physical properties of the substrate have direct and specific impacts on the biota of the ecosystem (**Box 3** of **Figure 1.3**). Major plant population attributes, which largely determine the visual aspect of the coastal landscape (e.g., plant species composition, zonation, and growth), are controlled by the substrate.

Species composition of a marsh can be modified by the influence of the hydrologic regime on spatial diversity. Floodwaters may reduce spatial heterogeneity by mixing dissolved or suspended matter and distributing it more or less uniformly across the marsh through sheet flow. Indeed, many marshes are dominated by monospecific stands of vegetation such as *Phragmites australis* or *Spartina alterniflora* (Gosselink and Turner, 1978). Or flooding can lead to variations in elevation and substrate and, thereby, increase spatial diversity. For example, water flooding tidal creeks loses velocity and deposits sediment, creating a gradient in elevation and sediment grain size. Plant zonation occurs along that gradient and is generally a function of flooding depth and duration. Thus, depending on the local situation, hydrology may lead to uniformity or diversity.

Hydrology and substrate characteristics have a demonstrable effect on primary production. The hydrologic regime enhances productivity in certain regions of the marsh and in some marshes more than others. These effects are visually discernible in the coastal landscape and are called the edge effect and the tidal subsidy effect, respectively.

Plants growing on the edge of tidal streams have higher growth rates than plants growing in inland marshes, a phenomenon known as the edge effect and the result of the natural topography and substrate characteristics of the streamside habitat. As described above in the section on coastal topography, streamside locations experience higher flooding velocities and therefore have greater and coarser sediment deposits than inland locations. This has several consequences. A natural creek bank levee is formed with a surface elevation higher than the inland marsh. This levee substrate experiences shorter periods of inundation and is better drained (i.e., less anoxic) because of its coarser grain size. It is also more dense and has a higher nutrient content. It has a greater capacity to buffer redox changes because of the higher mineral ion content, as well as lower levels of toxins caused by less reduced conditions and better flushing by tidal action. All of these conditions favor plant growth along the streamside.

Plant productivity is also directly correlated with tidal amplitude (Steever et al., 1976; Odum, 1978). The auxiliary energy input to the marsh in the form of tidal circulation mixes nutrients, food, and waste products within the system, thereby maintaining more than adequate concentrations and fluxes of nutrients while reducing the stress associated with salts and waste products (Odum, 1978). Thus marshes with large tidal amplitudes (energy subsidies) are more productive.

The biotic ecosystem response regarding the cycling of nutrients between biotic and abiotic components and organic matter flux is also controlled by hydrology. Some marshes are trans-

formers of nutrients (i.e, have closed nutrient cycles), assimilating inorganic forms, such as carbon dioxide and ammonium, converting them into carbohydrates and proteins, and then re-mineralizing them *in situ*; marshes with open nutrient cycles are either sources (exporters) or sinks (importers) of inorganic nutrients, depending on hydrologic and substrate conditions. At present, it is difficult to classify general wetland types as sinks, sources or transformers because of conflicting evidence. However, the following hypotheses, based on the influence of hydrology, are in vogue. Organic matter is deposited and builds up as peat in low energy systems (**Figure 1.5a**). The re-mineralization of this matter into inorganic nutrients and subsequent uptake again by the plants means these systems could be viewed as nutrient sinks or, if inputs were cut off, nutrient transformers. Conversely, high energy systems exporting organic matter (**Figure 1.5b**) can be viewed as sources of nutrients. In either case, hydrology plays a dominant role in the cycling of nutrients and organic production of wetlands.

1.2.4. Influence of Biota on Hydrology

Lastly, the vegetative component of wetlands exerts considerable control over hydrology. The build-up of peat and the trapping of sediment alter basin physiography and hence the flooding regime. Increased stem densities cause more sediment to fall out of the water column (Gleason et al., 1979), and plant roots anchor it in place. The nutrients bound to the sediment enhance plant production. High rates of organic matter (peat) production and accumulation, combined with vertical accretion, change the marsh surface elevation and contours. Also, plant transpiration can influence water levels in the marsh over a short time scale.

To summarize, hydrology controls the mechanics of marsh development by its influence on the substrate (water content, oxygen availability, nutrient availability, and accumulation rate of toxins) and the degree of coupling between systems. Water is not directly limiting in flooded soils but rather regulates plant growth by influencing oxygen availability (Mendelssohn et al., 1981), which, in turn, affects nutrient availability and accumulation of toxins. In this way, the hydrologic regime of a marsh regulates or modifies the species composition, rate of primary production, nutrient cycling, and rate of organic flux (Gosselink and Turner, 1978). Apparently, structural and functional integrity of a wetland may persist for many years if the hydrologic pattern does not change (Mitsch and Gosselink, 1986).

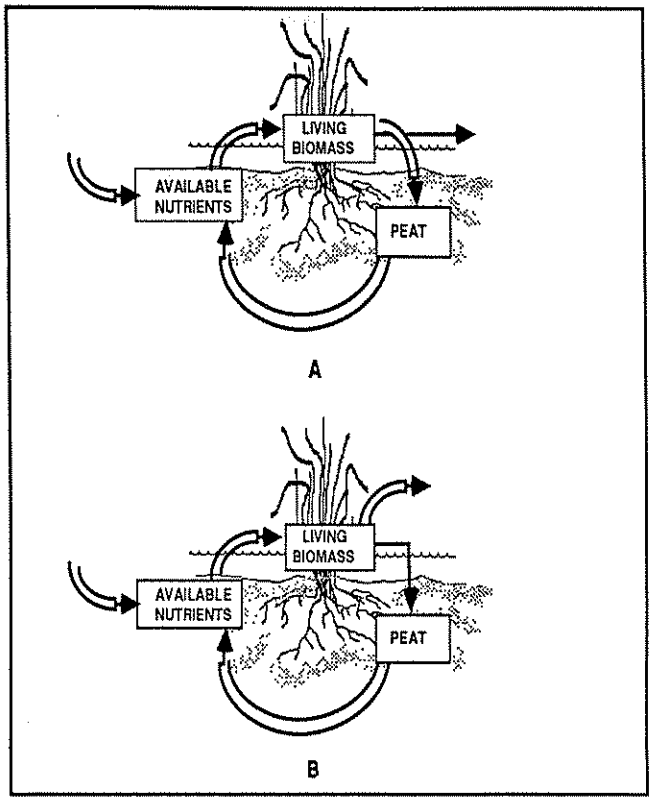


Figure 1.5. Simplified diagram illustrating the influence of hydrology on the source-sink nature of nutrient cycling in wetlands. A. Sink of organic nutrients. B. Source of organic matter (adapted from Mitsch and Gosselink, 1986).

1.3. MECHANISMS of WETLAND LOSS

In a mature delta, wetland loss and gain occur simultaneously: new deltas are formed, while abandoned ones degrade through subsidence and marine transgression. In the Mississippi River delta, the balance between gain and loss historically has been positive. Recently the balance has become negative. The sequence of delta cycles during the past 5,000 years has resulted in a gradual net progradation of the deltaic plain because land gain (marsh development) exceeded landloss. During the past 100 years, however, landloss has exceeded land gain, with the rate of landloss increasing geometrically from 6.7 square miles per year in 1913 to a current rate of approximately 40 square miles per year for the deltaic plain region (Gagliano et al., 1981). Including the chenier plain, the coastwide landloss rate is presently over 50 square miles per year, or approximately 0.8% of all Louisiana coastal wetlands, and it is increasing. The only appreciable land building along the coast occurs at the mouth of the Atchafalaya River.

Wetland loss is a complex process influenced directly and indirectly by natural and man-induced

activities. The term wetland loss refers to the conversion of wetland habitat (marsh or forested wetland) to a non-wetland habitat type, either open water or upland (spoil bank) habitat. This conversion occurs through the effects of: (1) natural and man-induced erosion of shoreline or the banks of waterways and canals; (2) dredging and filling of marshes by man; and, (3) submergence of interior marshes. Coastal submergence occurs when natural land building processes (sedimentation) lag behind geologically mediated land sinking (subsidence, compaction, consolidation). Man alters the natural balance between land building and land sinking indirectly by impacting on the mechanics of both processes.

The loss of wetlands by erosion and dredge/fill activities is caused by a direct disruption of the substrate by natural or man-induced mechanical stress (i.e., wave action, boat wakes, and bucket dredges), resulting in either open water or spoil bank habitat. The impact is immediately apparent. On the other hand, the loss of wetlands through coastal submergence is caused by an indirect alteration of the substrate (i.e., marsh surface elevation in relation to water level) and results in open water habitat, which is only gradually apparent.

To understand coastal submergence of wetlands, consider that marshes develop at the land-water interface. If the land sinks or the water level rises, the marshes must adjust to these changes or gradually become submerged. Marshes exist in very dynamic environments and continue to exist only if the rate of adjustment can keep pace with the rate of change. In other words, wetland loss can be viewed as the inability of wetlands to maintain themselves. In deltaic systems, subsidence (sinking) of land surfaces is high, and the continued existence of marsh depends in part on its ability to maintain its elevation within the tidal range through vertical accretion (Delaune et al., 1986). The structural and functional integrity of a wetland prevails only if the downward displacement of the land surface in relation to the water surface (relative sea level rise) and vertical accretion (land building) are in balance.

The marsh surface elevation can change in relation to the surrounding water level for two reasons: (1) the marsh surface sinks or (2) the water level rises. The former results in isostatic sea level rise (colloquially called subsidence) and is caused by isostatic compensation. The latter is referred to as eustatic sea level rise and is due to changes in the volume of the ocean. The sum of eustatic and isostatic sea level rise is termed relative sea level rise. On the other side of the scale is vertical accretion, which is the upward growth of a sedimentary deposit. The surface of a marsh accretes by two processes, the deposition of sediment carried in suspension in the water column and the accumulation of organic matter in the substrate through plant growth. Thus, the land building/sinking relationship can be stated as follows:

Relative Sea Level Rise ≈ Vertical Accretion
or
Eustatic + Isostatic Sea Level Rise ≈ Mineral + Organic Matter Accumulation

and, if the equation is in balance, marshes will persist. However, if the rate of either of the four processes changes dramatically, it could significantly impact the ability of marshes to adjust and maintain themselves. Oil and gas extraction activities in marshes can affect all of these processes except for eustatic sea level rise.

Isostatic sea level rise can be directly affected by drilling. Fluid withdrawal from oil and gas wells contributes to the total process of subsidence. The removal of groundwater from hydrocarbon-bearing sands creates a void into which water from adjacent clay layers moves. The dewatered compressible clays become compacted. Subsidence caused by fluid withdrawal makes up a small part of isostatic sea level rise, but it may be very important on a local scale, particularly in large oil fields. It may also impact organic matter accumulation by lowering the water table, which may promote saltwater intrusion and affect plant growth (Gosselink et al., 1979).

Oil and gas activities have a greater potential to affect the other side of the equation, vertical accretion. As stated in the previous section, hydrology has a significant effect on ecological processes in wetlands. Consequently, any activity (levee, road, or canal construction) that affects local hydrology influences mineral and organic matter accumulation. For example, levees (spoil banks) affect the duration and frequency of tidal inundation (Swenson and Turner, 1987), which, in turn, may affect sediment and nutrient supply, as well as the availability of nutrients, oxygen, and toxins, which ultimately influence plant growth and peat buildup. This is particularly true for areas that inadvertently become partially or totally impounded and no attempt is made to manage (i.e., manipulate) the hydrological regime.

Land building-sinking processes are not in balance in Louisana's wetlands. Relative sea level rise varies between hydrologic basins, with the averages ranging from 0.5 to 0.4 inches/year. Eustatic sea level rise for the Gulf of Mexico averages 0.09 inches/year, while subsidence ranges from

0.32 to 0.42 inches/year. Thus, subsidence (isostatic rise) is the major contributor to relative sea level rise, particularly in the recently abandoned delta lobes of the deltaic plain. As for landbuilding, vertical accretion rates in Louisana's coastal marshes generally are less than 0.4 inches/year and most often fall in the range of 0.28 to 0.31 inches/year, significantly less than what is required to balance the rate of land sinking. Thus, Louisiana is experiencing an aggradation deficit, which means that coastal (interior) wetlands are disappearing. [See Penland et al. (1986), Delaune et al. (1986), and Boesch et al. (1983) for reviews of subsidence, vertical accretion, and landloss in coastal Louisiana.]

The cumulative effect of natural and human activities on wetland loss is often greater than the sum of the individual impacts. For instance, canal dredging has a direct impact on wetland habitats by converting them to open water and spoil bank habitats. However, if the canal influences local hydrology (i.e., alters surface water flow or introduces saline water into the region), it can affect the rate of coastal submergence of interior marshes. Therefore, any evaluation of human activities on wetland loss must consider all present and potential impacts within the basin.

1.4. WETLAND VALUES

Wetlands, like every ecosystem, have intrinsic ecological values defined by the functional processes occurring within them, such as trapping atmospheric CO_2 through photosynthesis and thereby providing the energy to drive all other ecosystem processes within the marsh. In addition to these ecological values, wetlands perform many services for man, services derived from the functional processes already described. It is these values, the benefits that man derives from wetlands, that are reviewed here. The unique ability of wetlands to perform these services should be a leading principle in their management.

Wetland values can be considered at three levels: (1) populations that depend on wetland habitats for survival, i.e. population values; (2) the functional processes of ecosystems; and, (3) the influence of wetlands on global ecological processes (Odum, 1978; Mitsch and Gosselink, 1986).

1.4.1. Population Values

The most readily perceivable and easily quantifiable value of wetlands is man's harvest of useable materials from populations that inhabit them. The commercial value of wetlands expressed in terms of the annual harvest of furs, pelts, fish, shellfish, waterfowl, timber, fibers, and hydrocarbons is clearly established in the market place.

The natural resources of Louisiana's vast coastal environment (5.3 million acres with 3.5 million acres of wetlands) support an economic system of national and global importance. Louisiana has long been a leader in production of non-renewable fossil fuels, ranking first in natural gas and second in oil and total energy produced (Louisiana State Planning Office, 1979), with nearly 75 percent of this production coming from coastal parishes (Maruggi and Hartl, 1981). Louisiana is also a national leader in several renewable resources. In 1982, Louisiana's fishermen landed 1.7 million pounds of fishery products, more than twice as much as second-ranked Alaska (Horst, 1983). Louisiana is first in wild fur production: 1.6 to 3.2 million fur pelts were harvested annually from the coastal zone between 1974 and 1982, with a market value ranging from $8.5 to 18.2 million (Louisiana State Planning Office, 1983). Louisiana's wetlands also provide habitat for 66 percent of the Mississippi Flyway's wintering waterfowl. In all, Louisiana provides a wide variety of natural resources for human use, the utilization of which requires proper management in order to avoid conflicts in resource use.

1.4.2. Ecosystem Values

Ecosystem values are not as readily perceivable nor as easily quantifiable as population values, but they may be more important (Odum, 1978). Wetland ecosystems modify hydrological events in ways that benefit man (Odum, 1978; Larson, 1982; Gosselink, 1984; Sather and Smith, 1984; Mitsch and Gosselink, 1986). They mitigate flooding of rivers and streams by intercepting storm runoff and storing the storm waters. In this way, they moderate runoff and attenuate storm discharge over a longer period of time compared to non-wetland sites (**Figure 1.6**). The water storage capacity of wetlands provides an inexpensive method of protecting human settlements from flooding. Wetlands also protect man's property by buffering the impacts of coastal storms. When storms first make contact with the shore, the energy of their impact is absorbed by the coastal islands and marshes, thereby dissipating much of the storm's energy before it reaches upland cities and towns. In addition to flood and storm protection, wetlands influence the groundwater supply by intersecting groundwater flow. Research shows that, in some circumstances, wetlands may recharge aquifers, but recent evidence indicates that

wetlands are more likely to be discharge points for groundwater (see Sather and Smith, 1984 for a review).

Wetlands play a major role in improving water quality through the removal or trapping of organic and inorganic nutrients and toxins. Wetlands are generally considered to be chemical sinks and have a major influence on chemicals that flow through them. Wetlands are sediment traps, accumulating compounds bound to sediment particles. Large quantities of nitrogen (N) and phosphorus (P) are taken up by the vegetation and subsequently buried in the sediments when the plants die. Louisiana deltaic marshes have a high capacity for storing nutrients because of the high rate of subsidence. Through anaerobic processes, marshes release large quantities of gaseous N to the atmosphere. In the presence of saltwater, many chemicals flocculate out of the water column when they reach the marsh

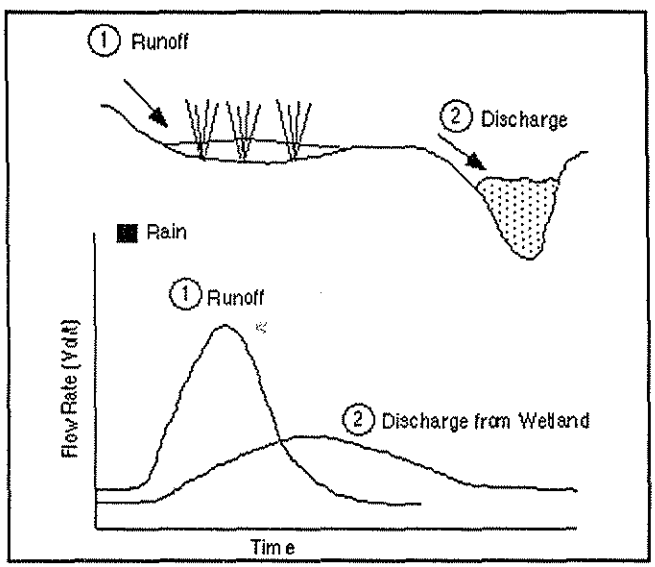


Figure 1.6. Diagram illustrating the general effect of wetlands on stream flow (adapted from Mitsch and Gosselink, 1986).

or estuary. This ability to assimilate wastes and excess nutrients makes marshes valuable as tertiary treatment sources for sewage (Kadlec, 1979) and other human wastes, such as waste from fish processing plants (Meo et al., 1975).

In addition to hydrologically based values, wetlands are valued by man for their aesthetics (Reimold et al., 1980). They provide diversity in the landscape, recreational and educational opportunities, and information on our cultural heritage (e.g., sites of archaelogical significance). The uniqueness of certain wetland environments makes them valuable from a biological, geological, or historical perspective, as well as potential sites for research.

1.4.3. Global Values

The influence of wetlands on nutrient cycling goes far beyond the boundaries of the ecosystem. Wetlands present oxidizing and reducing environments in close proximity to one another. This, combined with the fact that many are chemical (nutrient) sinks, makes them important sites of denitrification (the gaseous release of N from the soil). Wetlands have recently been recognized as a major source of gaseous N and therefore play an important role in the global N cycle. The anaerobic substrate also traps atmospheric sulfur washed down by rain in the form of hydrogen sulfide (H_2S), making wetlands important sinks in the global sulfur cycle. Also, the enormous quantities of peat stored in wetlands around the world make wetlands an important source-sink of carbon, depending on the oxidative-reductive state of the world's peat deposits. The draining of wetlands causes the oxidation of peat deposits, which increases atmospheric CO_2.

1.4.4. Management Priorities

The population value of marshes accrues directly to the landowner (often a private citizen or corporation), while ecosystem and global values provide public amenities that are external to the market place and of no commercial value to the landowner. Herein lies the source of conflict in multiple resource use in wetlands. The issue is compounded in that many uses of wetlands negatively influence other values. For instance, dredging access channels with spoil banks for oil and gas development in the wetlands provides the landowner with a direct population value (harvest of organically derived petroleum products) but alters other population values through habitat alteration as well as ecosystem values through its impact on hydrology. Thus, no use or activity in wetlands can be viewed in isolation because of the interrelated nature of wetlands values and functions.

The concept of resource use conflict between private ownership and public service is particularly germaine to wetlands for three reasons: (1) development pressures are increasing in coastal areas; (2) marshes are open systems that must be viewed in their regional setting and not as isolated systems; and (3) alteration of marshes is essentially irreversible (Gosselink, 1984). Population values make up a small part of the total value of wetlands (Odum, 1978), but, because they have obvious economic value, initial attempts to manage wetlands focused on them. Present attempts to manage or regulate impacts to wetlands must consider all wetland

values, which means that management objectives (i.e., enhancement of population values, and maintenance of ecosystem and global values) must be clearly established.

1.4.5. Management Objectives

Wetlands are managed primarily for three reasons: (1) to enhance population values, such as wildlife production; (2) to modify ecosystem values, as in using marshes as tertiary treatment sources; or (3) to maintain the status quo of any value by passive (i.e., preservation, such as state parks) or active (i.e., restoration, such as diverting fresh water through levees) methods. The type of regulatory constraints employed in managing oil and gas activities in Louisiana's wetlands will depend on the objectives of the Environmental Protection Agency (EPA) and Section 404(b)(1) of the Clean Water Act (CWA), as amended 1980. The stated purpose of the revised guidelines of the CWA is "...to restore and maintain the chemical, physical, and biological integrity of waters [by definition this includes wetlands] of the United States through the control of discharges of dredged or fill material" (USEPA, 1980: 85345). Therefore, the recommendations in this handbook—avoiding and minimizing impacts to wetland values and functions associated with oil and gas development—are designed to maintain the status quo of any impacted value or function.

CHAPTER 2

EXPLORATION

by Donald R. Cahoon

2.1. INTRODUCTION

The first step in developing petroleum resources is to locate underground reserves by studying the visual and physical characteristics of the earth's crust. The search for petroleum includes broad reconnaissance methods and site-specific surveys. Broad reconnaissance methods, such as inspection of aerial and satellite photographs and magnetometer surveys, cover large regions of the earth's surface and require little or no direct site contact. These techniques have no significant effect on the environment. Therefore, the following discussion on selecting drilling site locations will deal with site-specific exploration methods used to intensively survey areas several miles long. The method used most commonly today along the Gulf Coast is seismic exploration.

2.1.1. History

From 1901 to 1924, oil was discovered along the northern Gulf of Mexico coast in the vicinity of salt domes, indicated only by a slight change in surface elevation on an otherwise very flat coastal plain environment. When all these surface irregularities were developed, it was presumed that the oil had played out and the boom was over. However, by 1924, geophysicists had developed methods to "see" below the earth's surface, so that during the next 10 years three times as many salt domes (which had no surface expression) were discovered as during the previous 23 years (Meyer 1934). Geophysical methods include analyses of variations in the earth's magnetic and gravitational

fields, as well as seismic reflections created by man-made explosions. The newly developed torsion balance (gravitational method) and reflection seismograph techniques worked equally well in marsh or upland environments (Flude, 1936), but surveying coastal habitats required unusual forms of transportation to move equipment across the unstable marsh substrates interlaced with waterways.

2.1.1.1. Transportation. Early exploration crews used whatever means possible to traverse the marshes, swamps, and bayous along the Texas and Louisiana coasts. Since 1924, seismic crews have travelled through the marsh and waterways by foot, boat, mule, float plane, helicopter, raft, and marsh buggy (Flude, 1936; The Lamp, 1948; Samuel, 1949; State Times, 1953). The marsh buggy was originally developed in the late 1920's to carry hunters across the marshes of Louisiana's Chenier Plain, but geophysical crews quickly adapted it to survey use. By 1936, marsh buggies were considered essential for marsh exploration (Flude, 1936), with nine petroleum-related firms developing models over the next 20 years. They have been used extensively on Louisiana's Deltaic Plain, however, since the end of World War II (Detro, 1977). During the 1940's and 1950's, they were used often in conjunction with helicopters (Samuel, 1949; State Times 1953).

Initially, the marsh buggies used on the Chenier Plain were made from a truck chassis with over-sized, wooden-slatted wheels. This made them well-suited to crossing the firm marsh substrates of this geologic province. In the "trembling marsh" of the Deltaic Plain, marsh buggies were built with large balloon or flotation tires. These buggies were capable of crossing marsh and waterways with equal ease, even when carrying a thirty-man seismic crew and its equipment (approximately 9,600 pounds) (Detro 1977). The large tires tore up the soft marsh surface, leaving large, water-filled ruts which were slow to recover. Modern marsh buggies employ caterpillar tracks revolving around flotation pontoons that distribute the weight more evenly and cause less damage to the marsh surface (**Figure 2.1**). They often tow heavy equipment behind them on pontoon sleds.

2.1.1.2. Environmental Regulatory Policy. Until the 1960's, the only environmental regulations governing oil and gas development in Louisiana's coastal wetlands were related to wildlife and fisheries resources. When seismic exploration became popular in the 1930's, Texas and Louisiana required a conservation agent to accompany each seismic crew to observe the effects of explosions on fish populations (Flude, 1936). There was no governmental regulation of the wetlands

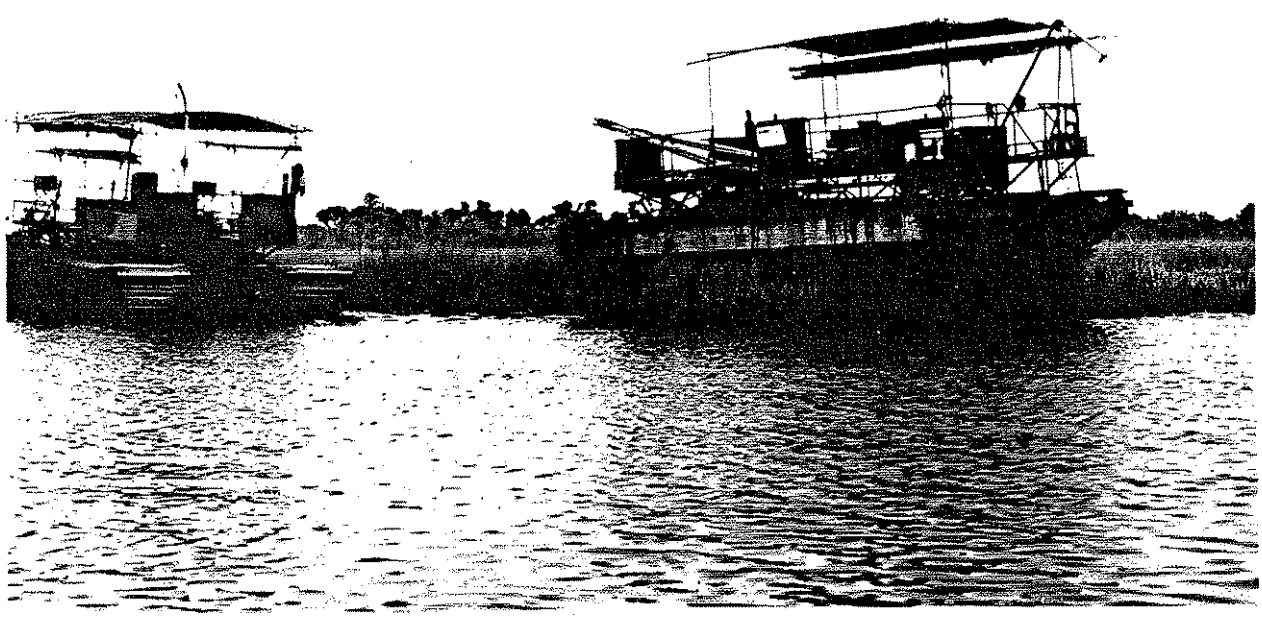


Figure 2.1. A view of marsh buggies parked along the bank of a waterway during seismic survey operations. Note the caterpillar-type tread wrapped around pontoons and the ability of the buggy to stay afloat on marsh and water. (Photograph by W. Sikora.)

buggies criss-crossing the marshes in ever-increasing numbers or the impacts they exerted on the marsh. Eventually, a "range war" broke out between trappers (who claimed that the buggy wheels badly damaged the marsh, destroyed their trap sets, and crushed muskrat and nutria habitat) and geophysical survey crews (Detro, 1977). To minimize damages, the geophysical companies agreed to follow the same trails repeatedly. This, however, usually led to the formation of deep, continuous gullies that often became permanent streams causing erosion, ponding, salinity changes, and vegetation alteration.

The petroleum industry switched exclusively to tracked vehicles by 1960 because of the severe impacts of wheeled marsh buggies (Detro, 1977; Sikora et al., 1983). This new technology lessened the impacts but did not eliminate them, and the practice of following the same trails is still used today. As in the days when the buggies were first developed, there are no governmental regulatory policies specifically regarding the operation and use of marsh buggies in coastal wetland habitats, even though the impacts are clearly visible and long-lasting. Therefore, it is essential that any review of 404 permit applications identifies all activities requiring the use of marsh buggies and that the consequences of their use be considered in all permit decisions.

2.1.2. Modern Seismic Survey Procedures

Reflection seismography calculates the attitudes, configuration, and depth of subsurface rock strata by producing sound waves belowground. In wetland environments, dynamite is used to create the sound waves, and the speed and angle at which the wave is reflected back to the surface are measured with sensors called geophones (**Figure 2.2**). Knowing this, and the typical velocity of waves, subsurface structures can be accurately mapped. These subsurface contour maps are used by the petroleum geologist, in conjunction with existing data from the region (e.g., well logs from other wells in the vicinity, other seismic surveys, known structures like salt domes, and surface features) to determine where petroleum reserves may be located and where best to position the drilling rig on the surface. The final step in exploration is to drill a wildcat well to see if there really is any hydrocarbon present. If so, development (production) wells are drilled, and an oil field is established.

Seismic surveying is performed by "shooting lines" many miles long in a straight path across the earth's surface. First, the line is surveyed and staked. Then, drilling crews drill shot-holes along the line in which to place explosive charges. Sensing cables are laid along the line, leading back to a recording station (**Figure 2.2**). When the explosives detonate, the sound waves are recorded. In upland areas, the cables are swung forward to the next section of the line by trucks and the entire process repeated. Specially adapted trucks are used to drill the shot-holes (**Figure 2.3**), and the recording equipment is kept in a van to facilitate transit (**Figure 2.2**).

In coastal wetlands, the marsh buggy is used to set up seismic surveying because it can travel in a straight path across both marsh and open water. First, the survey crew is transported along the line. Two or three drilling crews, each using a marsh buggy to tow a drill rig mounted on a pontoon sled (**Figures 2.4 and 2.5**), follow the same path. Then, another crew (or crews) traverses the line, laying the cable from a pontoon sled towed behind a marsh buggy. After each shot, the 1,320 foot-long cable is swung by boat, rather than marsh buggy, to save time and money. An experienced seismic crew can survey approximately 2 miles per day in Louisiana's coastal marshes. In all, each segment of the line is traversed a minimum of three times by marsh buggies and heavy equipment sleds.

2.2. IMPACTS on WETLAND VALUES and FUNCTIONS

Seismic exploration by marsh buggies creates long, linear scars in the marshes and swamps along Louisiana's coast (**Figure 2.6**) that may remain visible for decades. There is virtually no area of the coast that has not been surveyed, and areas with proven reserves have been heavily surveyed (**Figure 2.7**). Whitehurst and Blanchard (1977) analyzed aerial photography of a major oil field and navigation channel in the saline marsh of southern Lafourche Parish for signs of marsh buggies. It was not possible to determine how many times a route was retraced, but researchers measured over 1,500 miles of tracks within a 6.11 square mile area. Assuming an average track width of 4 feet, this means 18.5 percent of the wetland habitat was crushed by the vehicles (Sikora et al., 1983). The areal extent of marsh buggy impacts on Louisiana's coastal zone has never been quantified, but these long-lasting scars influence wetland values and functions through the alteration of both marsh habitat and local hydrologic regime.

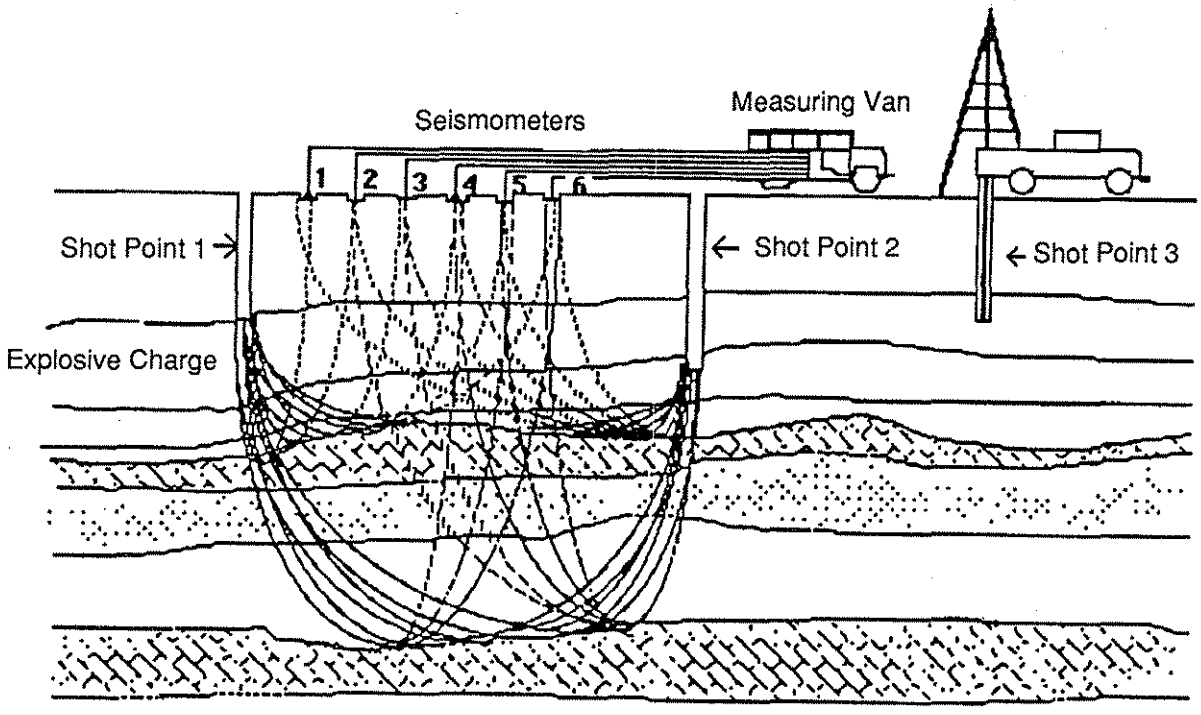


Figure 2.2. A cross-sectional view of surbsurface geologic formations and upland seismic surveying procedures. Operational procedures are the same for wetland habitats, only the trucks are replaced by marsh buggies and pontoon sleds. An explosion creates shock waves that are reflected by subsurface geologic structures to sensors (geophones) on the ground surface. The waves are recorded as lines on photographic paper in a central, mobile recording station (adapted from Petroleum Extension Service, 1981).

Figure 2.3. Truck-mounted rotary drill rig used for upland seismic survey operations. (Photography by D. Cahoon.)

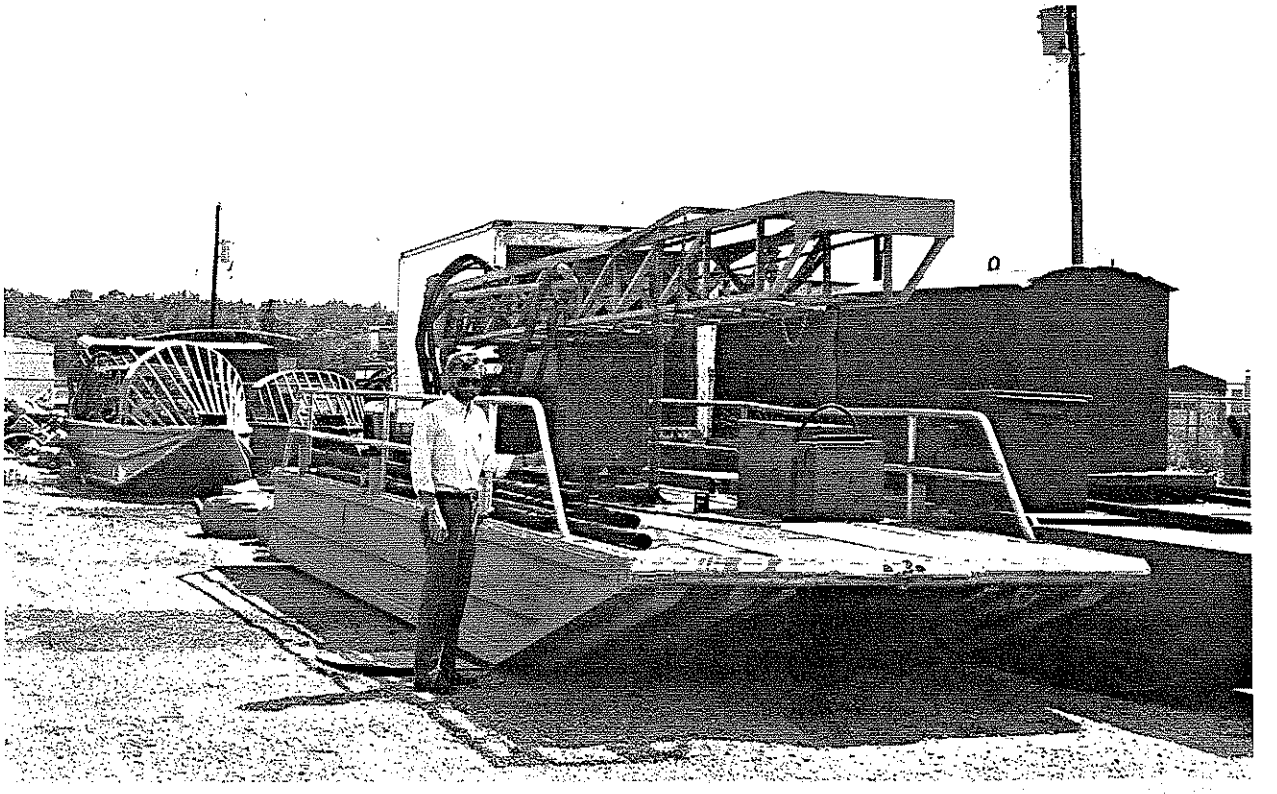


Figure 2.4. Pontoon sled-mounted rotary drill rig used for seismic survey operations in marshes. This is towed through the marsh by a marsh buggy. (Photography by D. Cahoon.)

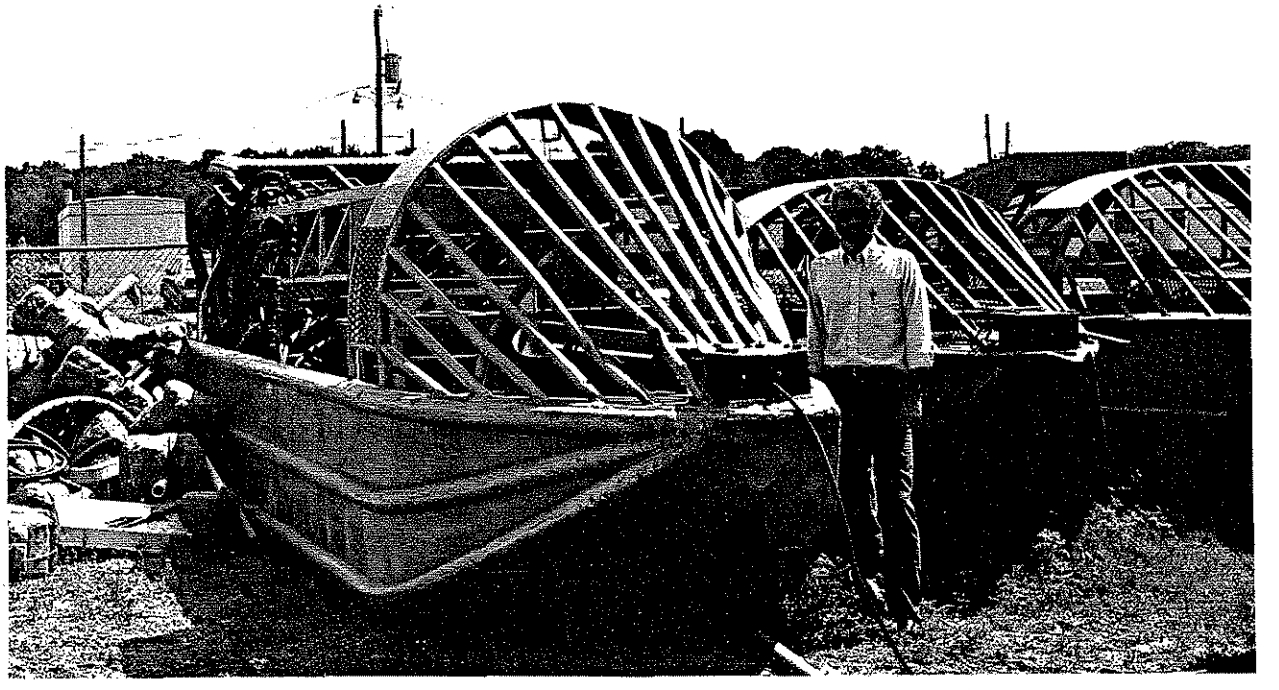


Figure 2.5. Pontoon sled-mounted rotary drill rig used for seismic survey operations in swamps and other forested wetlands. Note that this sled is narrower, with a heavily protected and pointed bow, in order to facilitate travel through wooded habitats. (Photography by D. Cahoon.)

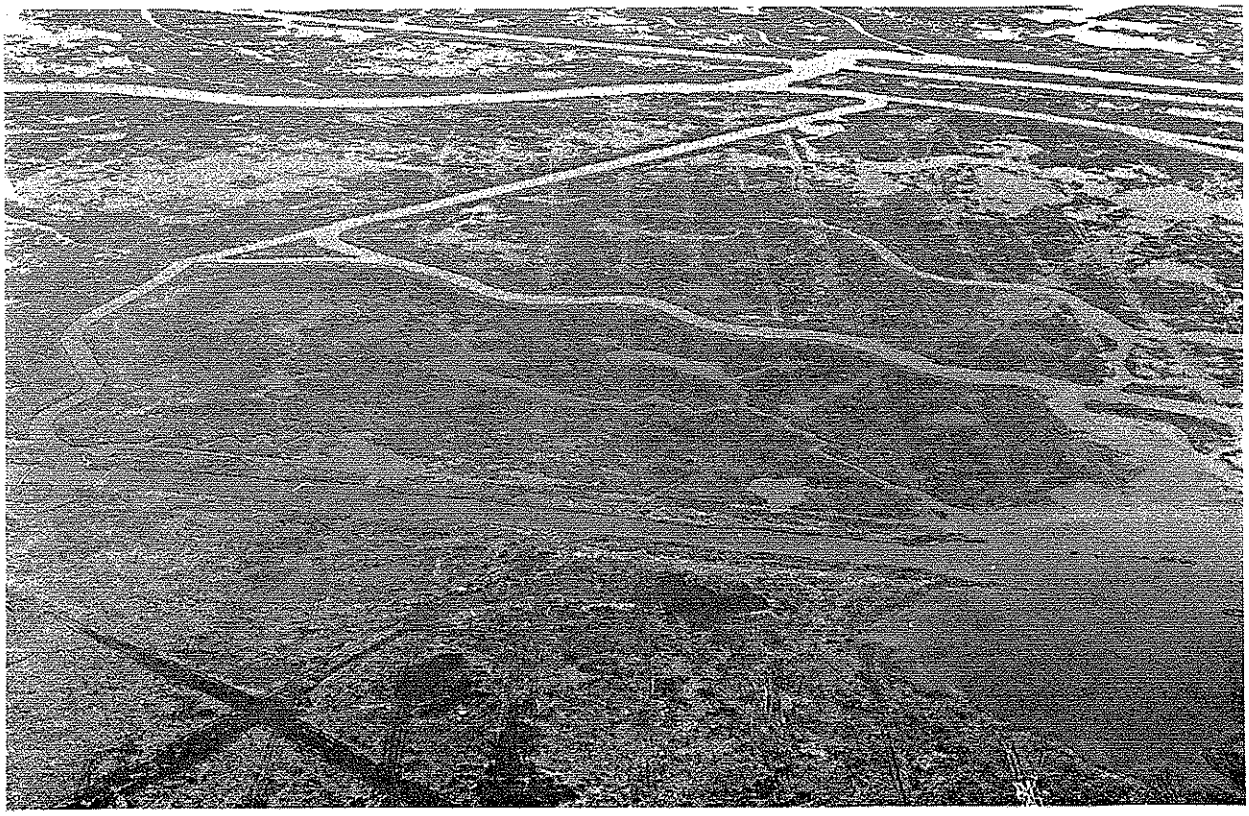


Figure 2.7. Aerial view of marsh in the vicinity of a salt dome in southern Plaquemines Parish showing numerous parallel marsh buggy tracks resulting from intense seismic surveying. Note, again, that the edges of natural streams exhibit less damage. (Photography by D. Cahoon.)

Figure 2.8. Close-up view of fresh (less than 4 weeks old) tracks created by a tracked marsh buggy in a salt marsh of southern Lafourche Parish. A portion of the area in the center of photograph has been denuded of vegetation, and the remaining plant stems have been crushed and killed. (photography by W. Sikora.)

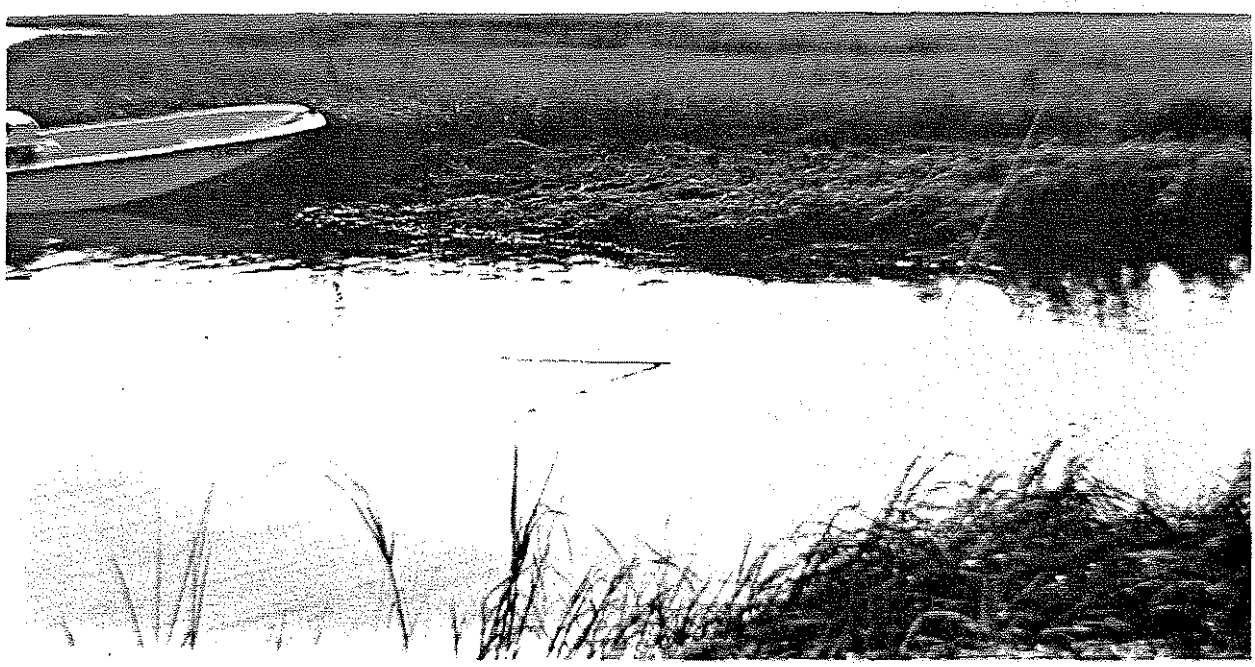


Figure 2.9. A ground view of marsh buggy tracks crossing a natural streamside levee. Note that the vegetation has been crushed flat. (Photography by W. Sikora.)

Figure 2.10. Aerial view of the marsh showing fresh and old marsh buggy tracks. The upper set of tracks are the same as those in Figures 2.8 and 2.9. The lower set of tracks are much older. Note that the impact of the tracks on the streamside levee is still visible for the fresh (i.e., upper) tracks but no longer visible for the older tracks. Also, note that the interior marsh has not recovered, even for the older tracks. (Photography by W. Sikora.)

Table 2.1. Observed and hypothetical impacts of marsh buggies on coastal marsh habitats and wetland loss.

ACUTE ENVIRONMENTAL CONSEQUENCES
Habitat Alteration — Physical Impact Change in Marsh Surface Elevation (Gullies), Including Breaks in Natural Hydrologic Barriers Noise, Commotion during Exploration
Habitat Alteration — Ecological Impact Immediate Loss of Marsh Vegetation
Impact on Biota Destruction of Biota (Vegetation and Sessile Organisms) Crushing of Muskrat Houses New and Different Habitat New Avenue for Movement of Aquatic Organisms In/Out of Marsh
CHRONIC ENVIRONMENTAL CONSEQUENCES
Habitat Alteration — Altered Physical Process Surface Hydrology and Drainage
Habitat Alteration — Physical Impact Avenue for Water Exchange and Saltwater Intrusion
Habitat Alteration — Ecological Impact Changes in Plant Growth, Organic Matter Accumulation, Sediment Distribution

wetland environments is directly related to timing and the mode of transportation used. Outlined below are some techniques for avoiding, minimizing, and restoring the impacts of marsh buggy operations. As described in Chapter 1, the management objective of these techniques is to minimize changes to the status quo of the wetland system in question, in accordance with Section 404 regulations. As a general policy, the use of wheeled marsh buggies should not be permitted.

2.4.1. Avoiding Impacts to Surface Features and Functions

This section describes methods for avoiding marsh buggy impacts through alternative transportation methods and appropriately scheduling field activities.

2.4.1.1. Alternate Transportation Methods. Modes of transportation that do not impact the marsh substrate should be considered for any activity requiring regular transit across the marsh because of the marsh buggy's potential for environmental damage. Two alternatives exist, neither of which is currently in use, mainly for economical reasons. However, the use of these more expensive alternatives should be justifiable if the potential for damage to an area is high. One is the helicopter with pontoons, which was used in the 1950's for transporting survey crews and drilling equipment, as well as swinging cables (Samuel, n.d.; State-Times, 1953). All heavy equipment was slung beneath the helicopter between the pontoons. Helicopters were faster and more efficient than marsh buggies, especially travelling between the line and the base camp.

The other alternative is the air-cushioned vehicle (ACV) or hovercraft, which can traverse land and water as easily as a marsh buggy, but which has, on average, only 14 percent of the loading intensity of a standard marsh buggy (Sikora et al., 1983). It can be transported to a work site by truck or barge. Like a helicopter, it would have little or no effect on the marsh substrate and speed would most likely be a considerable advantage over a marsh buggy. Even though ACVs have been developed for numerous commercial and military purposes and are capable of carrying far more equipment and personnel than is required for a geophysical survey, no research has been done on their feasibility for seismic surveys in Louisiana's marshes. They could be used for surveying the line and swinging the cable without having to be modified, and it is not hard to envision one being modified for use in drilling the shotholes. At present, the major drawback of this alternative is that there is no substantial ACV industry in Louisiana.

The financial consequences of using either of these alternative transportation methods could be substantial, particularly for ACVs because there is no commercial infrastructure in Louisiana. If used in conjunction with a marsh buggy, both alternatives involve an added piece of equipment and, therefore, expense. To use either alone would require tooling up a new use for two exisiting industries, but the use of helicopters has already been tested and proven feasible.

2.4.1.2. Timing of Exploration. The noise and commotion associated with marsh buggy and drilling operations are capable of disrupting breeding and nesting activities of bird colonies. This coincident impact can be avoided if nesting areas are avoided and surveys conducted during the nonbreeding season. The location of shore and wading bird nesting populations along the Louisiana coast and their breeding schedule are presented in Keller et al. (1984). Scheduling surveys during the nonbreeding season should not be a difficult condition for geophysical exploration companies to meet. The financial consequences of avoiding this impact should be negligible.

2.4.2. Minimizing Impacts to Surface Features/Functions

If standard exploration and transportation methods are employed, marsh buggy impacts on wetland values and functions can be minimized through careful route selection and decreased marsh buggy activity.

2.4.2.1. Route Selection. Although the location and length of the shot-line may be fixed by geological constraints, there are three ways to reconcile transportation impacts with surface ecological features. The shortest route possible should be taken when approaching the line or bypassing any obstacles along the line. Repeated use of the same route should be avoided to the maximum extent possible, and all sensitive habitats should be avoided.

Shortest Route Possible. Marsh buggies should be transported by truck or barge to an embarkation point that will minimize travel in wetlands. Once surveying begins, marsh buggies should be kept to the line and take the shortest route around any insurmountable features of the terrain, such as pipelines, platforms, or any other manmade or natural barriers. This is not only a wise ecological decision but also a prudent financial one.

Avoid Repeated Use of the Same Route. Every seismic survey requires at least three trips along the line by a marsh buggy, often with a heavy equipment sled in tow. Some of these trips can be avoided if an alternative mode of transportation is used, such as a helicopter (see **Section 2.4.1.1.** above for the environmental and financial implications).

If alternatives are not available, each marsh buggy trip along the line should not follow the tracks left by the previous trip so as to avoid creating deep ruts in the marsh surface. The financial consequences of this action should be negligible.

Avoid Sensitive Habitats. Seismic lines should be selected to minimize transportation impacts on unique archaeological sites (e.g., shell middens), shallow waterbottom habitats (e.g., oyster reefs), nesting bird colonies, and any other unique habitat resources located in the marsh. This includes avoiding muskrat homes during marsh buggy operations. These impacts can be minimized at little or no additional financial expense to the operator.

2.4.2.2. Minimize Marsh Buggy Activity. Whenever possible, boats or helicopters should be used to swing cables or carry equipment to the next set-up. The use of boats for swinging cables in wetland environments is common because it is usually quicker and more efficient. Also, using boats to carry equipment reduces marsh buggy activity and, therefore, results in a cost savings to the operator.

2.4.3. Restoring Impacts to Surface Features/ Functions

To date, the authors know of no attempts to restore marsh buggy impacts on wetland values and functions. Consequently, there are no tested restoration methods. However, if marsh function is to be restored to pre-project conditions, marsh surface elevations in the tracks will have to be raised to that of the adjacent marsh. If this is not feasible, measures should be taken to restore local hydrologic patterns. Techniques for doing both are proposed below.

2.4.3.1. Filling Marsh Buggy Tracks. Along the edges of navigable waterways, it is feasible to deposit dredged material in marsh buggy tracks as a means of restoring marsh surface elevations. Suction dredges, which dispose of dredged mate-

rial by spraying it, would be well-suited to this task, especially high-pressure spray dredges. This restoration method is restricted, however, to the edge of waterways (a maximum of 250 feet). Restoration of interior marshes would not be feasible. Any attempt to restore interior marshes would probably cause additional damage to the substrate. The financial consequences for this type of restoration would be substantial unless it could be combined with an existing dredge job.

2.4.3.2. Barriers at Waterway Crossings. If restoring marsh surface elevations is not possible, local hydrologic conditions can be restored and saltwater intrusion prevented by blocking any gullies that have breached the banks of waterways. It appears that natural streamside levees are often capable of recovering from the passage of a marsh buggy. However, if the levee is breached so that it does not recover, placing a weir, earthen plug, riprap or similar structural device at the waterway crossing will close the long avenue to hydrologic transport. The cost of construction in the remote regions of the Louisiana coast can be substantial.

2.4.4. Suggestions for Implementing Management Techniques

There are no existing federal or state policies to regulate the mode of transportation employed by seismic operators. The State of Louisiana requires that: (1) seismic operators apply for permission to work in the coastal zone; (2) all regulations of the Departments of Wildlife and Fisheries and Natural Resources be strictly adhered to; and, (3) all unique ecological, archaeological, and cultural resources be avoided during surveying. However, the state does not review the transportation methods nor make any specific transportation requirements of the operators. The Army Corps of Engineers (USACE), makes even fewer demands on the seismic industry. The USACE has waived its requirement that seismic operators apply for permission to operate in the coastal zone as long as they meet the conditions for survey activities under the Nationwide Permit (Federal Register, 1986). If the conditions are met, the Nationwide Permit satisfies the requirements of Section 10 of the Rivers and Harbors Act of 1899, Section 404 of the Clean Water Act, and Section 103 of the Marine Protection, Research and Sanctuaries Act. Consequently, neither federal or state agencies have regulatory procedures specifically designed to avoid or minimize transportation impacts of seismic exploration activities on wetland.

Regulatory mechanisms do exist (i.e., conditioning a permit) to restore marsh buggy impacts. The recommendations presented above for restoring marsh buggy impacts can be implemented by conditioning subsequent permits to restore unavoidable wetland impacts associated with previous oil and gas development activities in Louisiana's coastal zone.

CHAPTER 3

DRILLING SITE ACCESS

by
Donald R. Cahoon and Joseph C. Holmes, Jr.

3.1. INTRODUCTION

The advent of geophysical exploration techniques in 1924 enormously increased oil and gas development in Louisiana's coastal marshes (Meyer, 1934, Posgate, 1949). Oil and gas companies were confronted with the problem of accessing drilling locations in terrain where no one had ever worked. Transportation techniques developed for moving drilling equipment on land or water were not suitable for this hybrid terrain. Therefore, new methods of accessing drilling sites in remote marsh locations were developed. The techniques that evolved in south Louisiana have become the industry standard worldwide. Today, the oil and gas industry accesses wetland drilling locations mainly by dredging canals or constructing board roads. In 1984, site access and preparation accounted for 5-8 percent of the total cost of drilling a well (IPAA, 1987).

This chapter presents an overview of the history, construction methods, impacts on wetland values and functions, and appropriate techniques for managing the impacts of accessing wetland drilling sites via canal dredging and board road construction.

3.2. CANALS

3.2.1. Introduction

This section describes the standard and traditional techniques used to construct the vast majority of drilling site access canals in south Louisiana marshes during the past 50 years. The impact of

these standard construction techniques on wetland values and functions is reviewed, including an analysis of the cause-effect linkages between canal construction and wetland loss. The final section explains appropriate techniques for managing canal construction activities and thereby reducing their impact, including discussions of alternative canal construction techniques.

3.2.1.1. History. The upper portion of marsh soils is very unstable because of its high water and organic matter content and, thus, cannot bear the load of the heavy equipment used to drill oil and gas wells. In the early days of petroleum exploration in south Louisiana, the first drilling sites in wetlands were accessed by canals and natural waterways or board roads constructed from adjacent upland areas (Williams, 1929). During the 1920's, access to wetland sites was an expensive procedure regardless of the method. Therefore, canals and roads were both used; roads in firmer marshes and canals where roads could not be supported. When accessed by a canal, wetland drilling sites were constructed on wooden mats on the marsh surface or on pilings in open water sites. The expense associated with this site preparation led to the invention of the floating barge rig in 1931 (Williams, 1934a, Posgate, 1949). This was quickly replaced by the submersible drilling barge in 1934 (Williams, 1934b). The invention of the submersible barge platform changed the industry's perspective. Suddenly there was a cheaper, more efficient, routine method of accessing wetland drilling sites.

The submersible barge platform quickly became an industry standard. What was needed next was an efficient method of dredging access canals through the marsh for distant drilling sites. There is some question of when the first petroleum-related canal was dredged (Davis, 1976, McGee, and Hoot, 1963), but, in any event, by 1938 barge-mounted draglines were being used to dredge petroleum access canals in south Louisiana. The following discussion of dredging history in coastal Louisiana is excerpted from Cahoon and Cowan (1988).

Early dredge barges consisted of land-based draglines temporarily mounted on the deck (McGhee and Hoot 1963). These dredge barges were not well-suited to working in all regions (i.e., soil types) of the coast because of their small size. In some areas, the spoil could not be deposited a sufficient distance from the waters edge to prevent the material from collapsing the canal bank and sliding back into the water (Williams, 1944). Consequently, hydraulic dredges utilizing suction and spray disposal of spoil also were used to dredge drilling site access canals. During the 1930's and 1940's, hydraulic dredges were as, or more, common than bucket dredges. Sometimes both dredge types were used in combination in marsh areas where the vegetation was too thick to remove by suction dredge. The bucket dredge would remove the vegetation layer and then the hydraulic dredge would remove the underlying substrate (Williams, 1944). By the mid-1950's, however, conventional bucket dredging technology had improved and the machines enlarged to the extent that they became more efficient than hydraulic dredges. New machines with longer reaches, requiring less manpower to operate, became more cost effective and by the early 1960's had nearly eliminated hydraulic dredging in south Louisiana. Conventional bucket dredges and their associated spoil banks remain common to this day in coastal Louisiana.

The combination of the submersible barge platform and the barge-mounted dragline opened the entire coastal zone of Louisiana to exploration and production by the petroleum industry. The use of canals to access drilling sites became the industry norm in the 1930's and 1940's, and remains so today.

3.2.1.2. Procedure. The modern submersible barge platform is typically only 45 to 55 feet wide so that it can pass through the system of locks in south Louisiana. It is 180 to 220 feet long to accomodate the narrow width and heavy weight of the equipment and drilling tower and draws approximately 8 feet of water **(Figure 3.1)**. Lacking

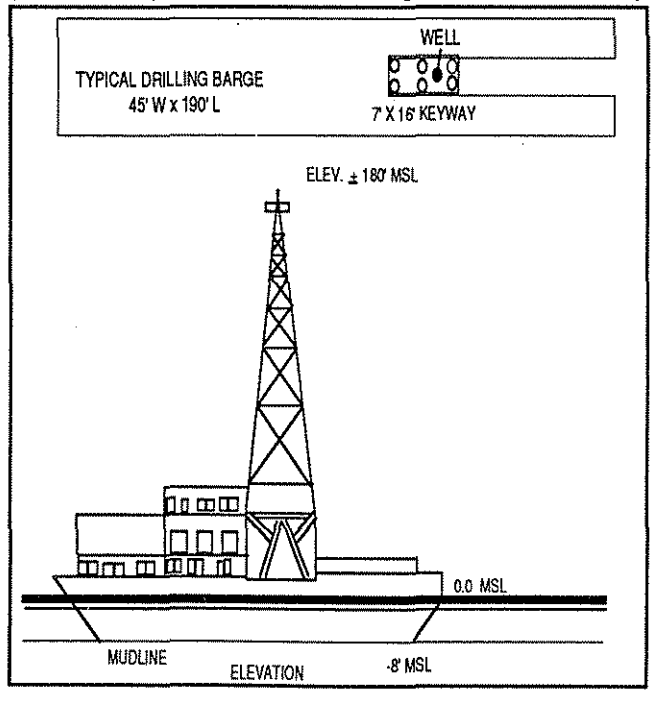


Figure 3.1. Modern submersible barge platform.

self-propulsion, it must be pushed to its location by a tugboat. Today, the barge-mounted bucket dredge is still the industry's workhorse for dredging access canals for submersible barge platforms. The bucket dredge works usually with a 6 to 10 cubic yard clamshell bucket and is capable of dredging 7,000 to 15,000 cubic yards of material a day (350 to 700 feet/day), depending on the substrate.

Access canals are dredged with a bottom width of 70 feet and to a depth 8 feet below mean sea level to accomodate the drilling barge. The mean tidal elevation in south Louisiana ranges between +0.5 to +1.5 feet above mean sea level, so the average water depth in the canal is approximately 9 feet. The top width of the canal can be greater than 70 feet depending on the stability of the substrate and the slope of the banks. The spoil is piled continuously along the banks of the canal and creates a spoil bank approximately 70 feet wide on each side of the canal with a 25-foot berm between the canal bank and the spoil (**Figure 3.2**). At its terminus, the canal is 160 feet wide so that the drilling barge can be offset, thus leaving room for work barges to tie up alongside to deliver pipe, concrete, and drilling mud. Because of its shape, the terminus is often nicknamed the keyhole (**Figure 3.3**). The keyhole is typically 345 feet long with a 90-by-90-foot wing to allow the drill barge to be pushed into place and pulled off location upon completion of drilling. **Figure 3.4** shows the typical configuration of a 500-foot slip, illustrating the relationship of the drilling barge and auxillary vessels.

When the proposed drilling site is located in a waterway or old canal, the actual drilling location must be offset to facilitate navigation. Thus, a slip parallel to the waterway is constructed to accomodate the drilling barge and auxiliary service vessels (**Figure 3.5**). It is typically 120 feet wide and up to 375 feet long, although it can be as short as 200 feet.

The cost of dredging an access canal varies widely depending on the distance the dredge and its tug must travel, the type of substrate being dredged (which determines the speed of dredging), the volume of the job, the amount of clearing involved (e.g., clearing forested wetlands to allow the boom to swing from side to side), the ease of ingress and egress (e.g., along existing waterway, such as crossing sensitive water bottoms), the cost of constructing a keyway and tie up clusters (a keyway is a 7- by 16-foot timber protective structure constructed around the wellhead), and many other factors. The cost of dredging a 1500-foot canal, including daily rental for a dredge and tug combined with construction and other costs, could run as much as $75,000 to $100,000 in the delta, or more in the hard clays of the chenier plain or forested swamp and bottomland hardwoods habitats. However, considering that the cost for completing all eight operational procedures for a single

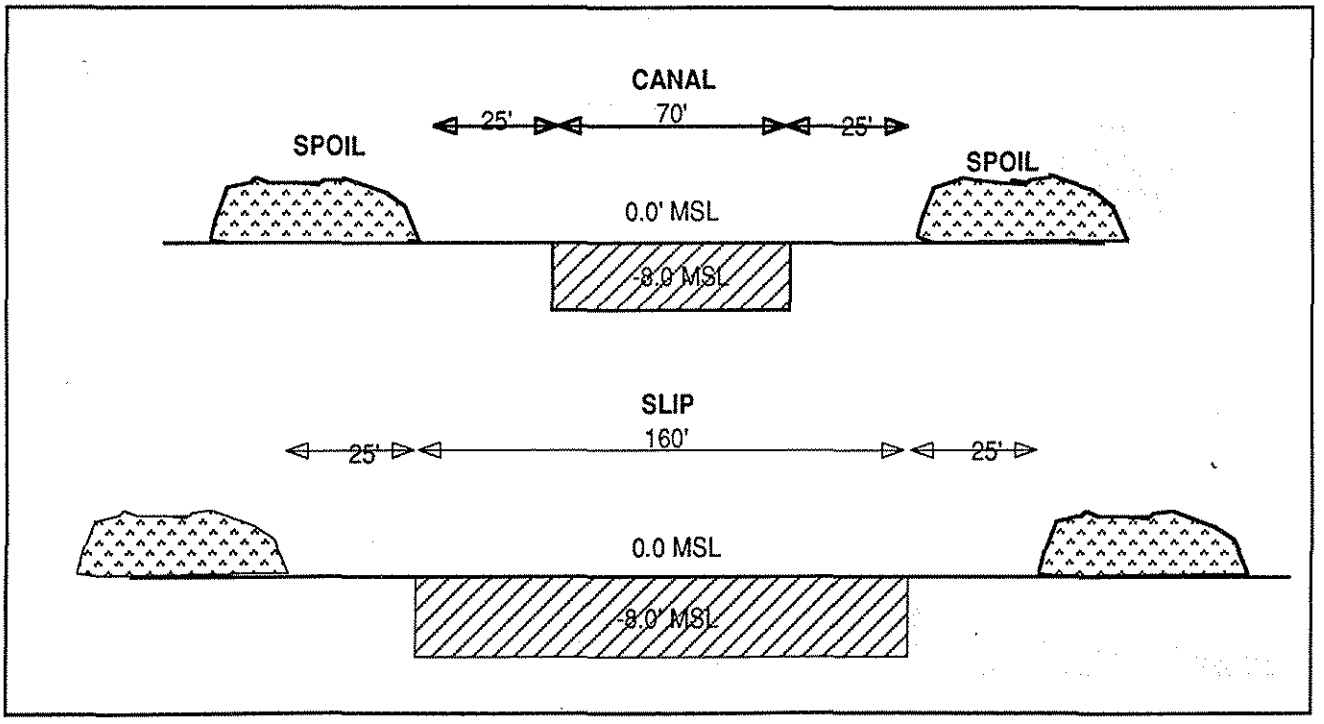


Figure 3.2. Cross-section view of a typical access canal and slip. Spoil width varies.

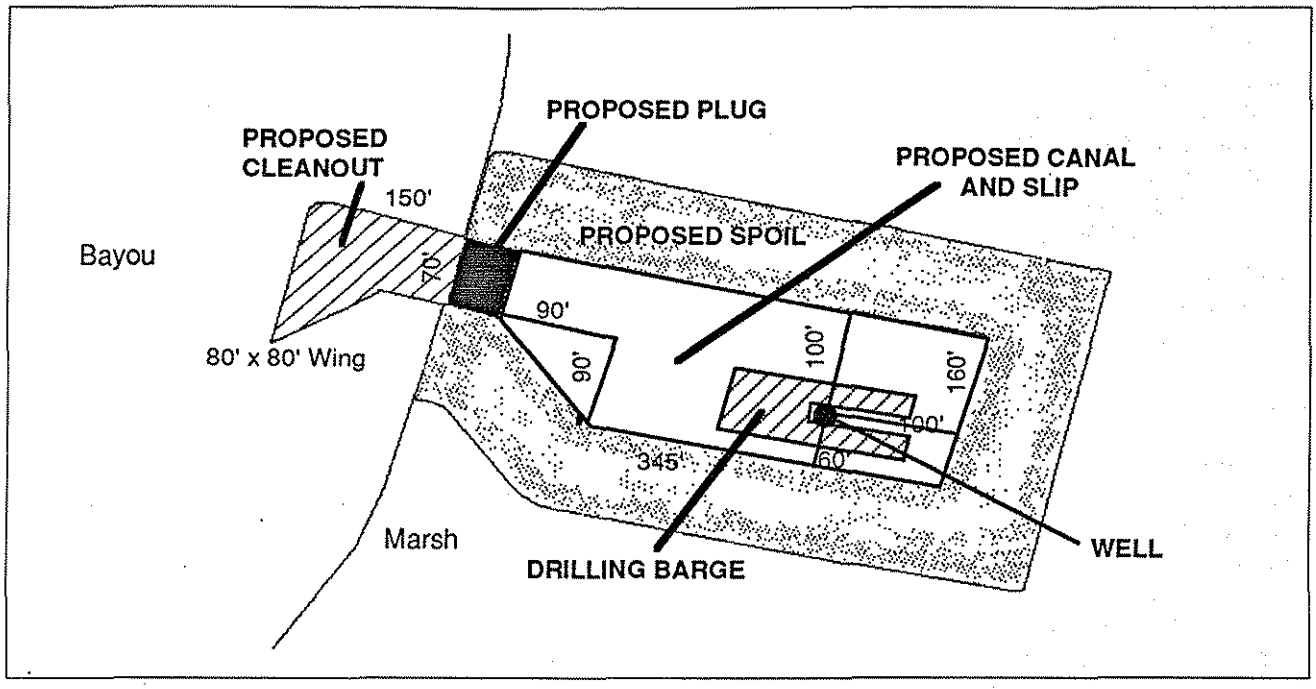


Figure 3.3. Plan view of a typical keyhole showing the position of the drilling barge.

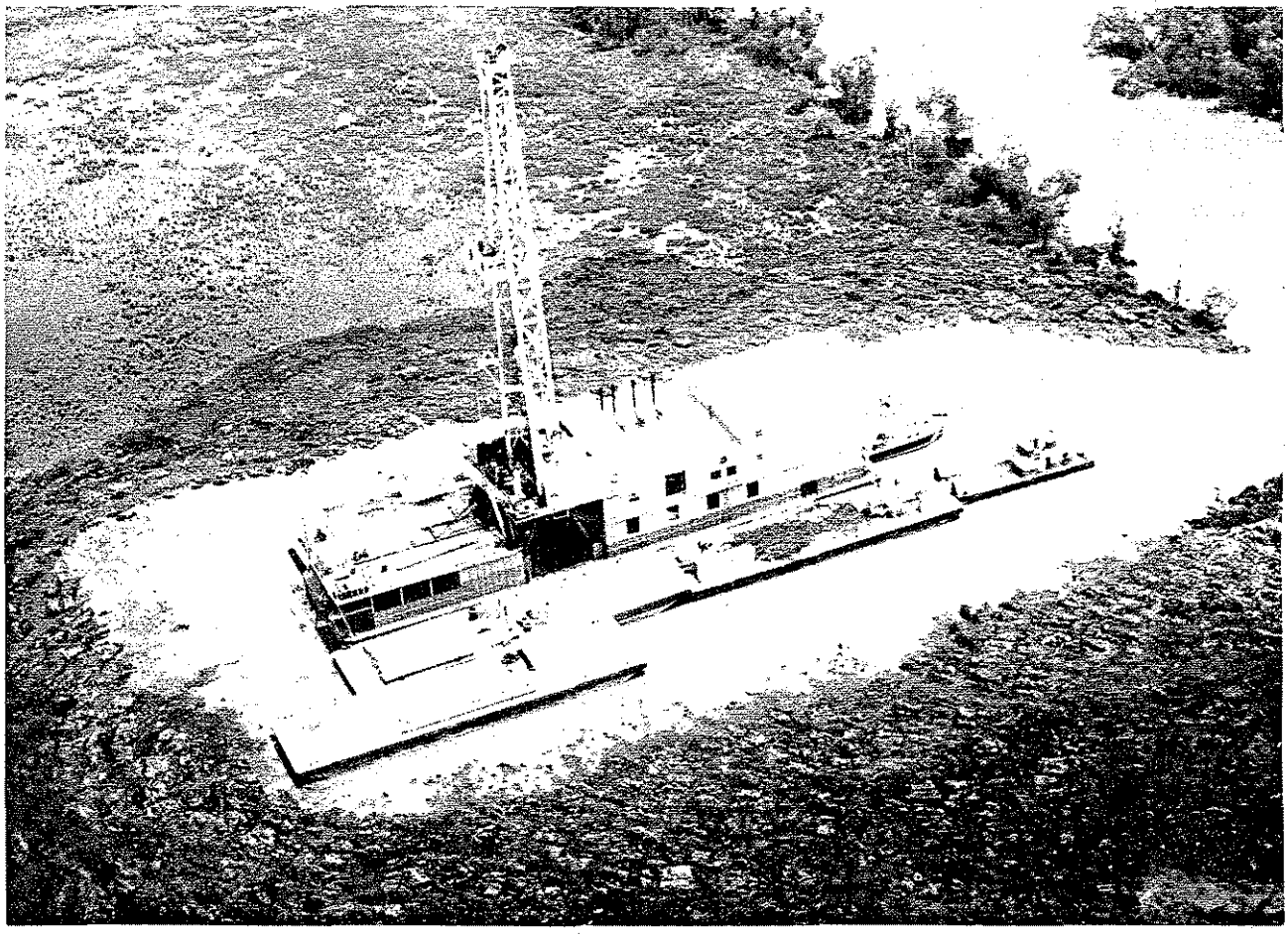


Figure 3.4. Aerial view of drill barge on location. Note configuration of keyhole, spoil banks, and auxiliary service vessels (barges and work boats). (Photography by D. Cahoon.)

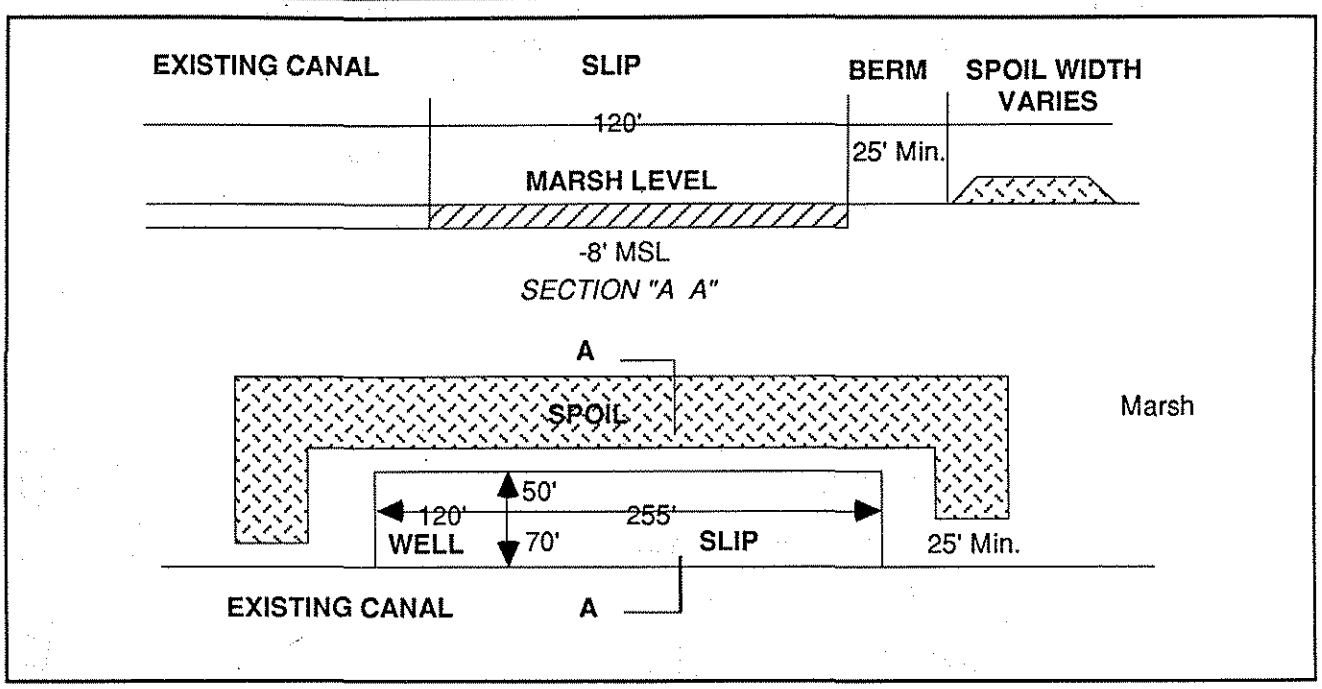


Figure 3.5. Cross-section and plan view of a typical parallel slip.

well runs into millions of dollars, even for a shallow well the cost of site access is minimal (<5 to 8 percent) and of little importance in a company's decision to proceed with the well. Conversely, the use of a more expensive alternative access method or canal construction technique would add proportionately little to the total cost of the well.

3.2.2. Impacts on Wetland Values and Functions

In the nearly fifty years since canals have become the traditional means of access to drilling sites, Louisiana's coastal zone has been crisscrossed with an extensive network of access canals situated over subterranean petroleum reserves. On the scale of a human lifetime, these canals are permanent. Canals dredged for navigation in the late 1700's and early 1800's are still an obvious feature of Louisiana's landscape. By the late 1960's, there were over 4,500 miles of canals in Louisiana's coastal zone (Barrett, 1970). Today, canals cover 192,000 acres of coastal habitat (Lindstedt and Nunn, 1985). Petroleum access canals make up a large part of this total, particularly in areas of large petroleum reserves (Gagliano et al., 1973). This canal network influences wetland values and functions through: (1) conversion of marsh habitat to open water and spoil bank habitat; and, (2) alteration of the hydrologic regime of coastal marshes.

3.2.2.1. Alteration of Habitat. The dredging of an access canal results in the immediate conversion of marsh habitat to open water and spoil bank habitat. Of the total area impacted by a single canal (channel and spoil bank area), the spoil bank alters more than twice the area of marsh than the channel **(Table 3.1)**, and the ratio increases directly with canal length. This is because spoil banks alter an area more than twice the width of the canal, on both sides of the canal, resulting in a total impacted area 5.5 times as wide (Monte 1978). McGinnis et al. (1972) estimate that 48 to 56 acres of wetlands may be altered for every mile of access canal. Turner (1985) estimates that the total area of all canals (i.e., navigation, pipeline, and access canals), including spoil banks, equals the total area of natural drainage channels in south Louisiana.

The conversion of marsh habitat does not end when dredging is completed. Wave erosion continuously widens canals. In the Leeville, Louisiana, oil fields, the rate of widening of access canals ranges from 3.1 to 7.4 feet/year, depending on the frequency of boat traffic (Johnson and Gosselink, 1982). Estimates of widening rates for five major canals in Louisiana range from 2 to 15 percent annually (Turner, 1985), indicating a doubling of the canal width every 5 to 35 years. Turner (1985) estimates that enlargement of old canals nearly equals the area of new canals added each year. The direct conversion of marsh habitat to open water accounts for 5 to 10 percent of the total coastal

Table 3.1. Estimates of the amount of dredging and acres of marsh altered for access canals of various sizes. Values in parentheses represent the percent of total acres altered.

	Dredging	Acres Altered		
Length of Canal/Slip	Cubic Yards[a]	Open Water	Spoil[b] Bank	Total
375'[c]	13,500	1.0 (35)	1.8 (65)	2.8
500'[d]	22,000	1.6 (35)	2.9 (65)	4.5
1000'	32,400	2.4 (32)	5.0 (68)	7.4
1500'	42,800	3.2 (31)	7.1 (69)	10.3
2000'	53,200	4.0 (30)	9.2 (70)	13.2
3000'	74,000	5.6 (29)	13.4 (71)	19.0
5000	115,600	8.8 (29)	21.8 (71)	30.6

[a] Approximately 10,400 cubic yards of material is excavated per 500' segment of a 70' w x 8' d canal. The amount dredged per slip varies according to slip design and dimensions.
[b] Calculations are based on a 95' wide disposal zone (25' berm, 70' spoil bank) adjacent to the canal
[c] Parallel slip (Figure 3.4).
[d] Figure 3.3

landloss rate each year (Turner 1985, Scaife et al., 1983), and this rate may be doubled within the next 20 years by canal widening (Turner, 1985).

The new habitats created by dredging differ importantly from the surface features and drainage channels originally existing at the site. The natural channel berm or levee is replaced by a spoil bank or levee. This artificial levee has a lower soil organic content, a higher bulk density, and is typically as much as an order of magnitude wider than the natural channel berm. Spoil banks begin to shrink in bulk immediately after construction because of dewatering and oxidation of organic matter and may decrease in volume by 50 percent within the first six months following deposition (Nichols, 1959). Most importantly, in an environment in which a half-inch change in surface elevation can significantly influence hydrology and plant succession, the final elevation of 1 to 3 feet of a continuous 75-foot wide spoil bank represents a major change in topography (**Figure 3.6**). These new raised habitats are quickly invaded and dominated by terrestrial species, with plant succession eventually climaxing in a bottomland hardwood forest (Monte 1978) (**Figure 3.7**). In forested wetlands, newly constructed spoil banks should be planted with one-year-old seedlings after the spoil bank has dewatered. Plantings must be done during the dormant season (i.e., winter) and within 60 days of construction, if possible.

The wide, firm substrate of an established spoil bank is a formidable barrier to sheet flow and drainage of surface waters across the marsh. The drainage of the marsh surface on a falling tide depends on small natural channels flowing around or through small openings in the natural levee (see **Chapter 1**). Continuous artificial levees do not permit such drainage and therefore can delay or prevent surface drainage from the surrounding marsh. This results in prolonged inundation (Swenson and Turner, 1987), which affects soil/water chemistry and plant growth. In addition, spoil banks affect subsurface water flow and drainage. The weight of the spoil compresses the surface organic layer of the marsh to approximately 60 percent of its original thickness (Nichols, 1959). This means that the belowground flow of water not only has a smaller cross-sectional area through which to flow but the medium is much more compressed, which further reduces the flow rate. Lastly, besides blocking or altering water flow, spoil banks interrupt the feeding and spawning activity of fish and other aquatic life that routinely move between the marsh and the natural waterways.

The new open water habitat created by dredging a 9-foot deep, straight canal differs importantly from the habitat provided by sinuous natural shallow channels. Natural and canal waterways both allow migration of aquatic organisms, but little is known about secondary production (e.g., fish and macrobenthic communities) in canals. Water turnover rates and, hence, water quality can differ drastically depending on alignment (e.g., dead-end versus open-end) of the canal and whether or not the canals have been dammed or closed with a weir. Oxygen depletion resulting from lack of water turnover and accumulation of organic debris has caused fish kills in semi-open or closed canals (Adkins and Bowman, 1976). In the marshes of

Figure 3.6. A view looking along the length of a canal showing the relationship of canal, berm, and spoil bank. (Photography by D. Cahoon.)

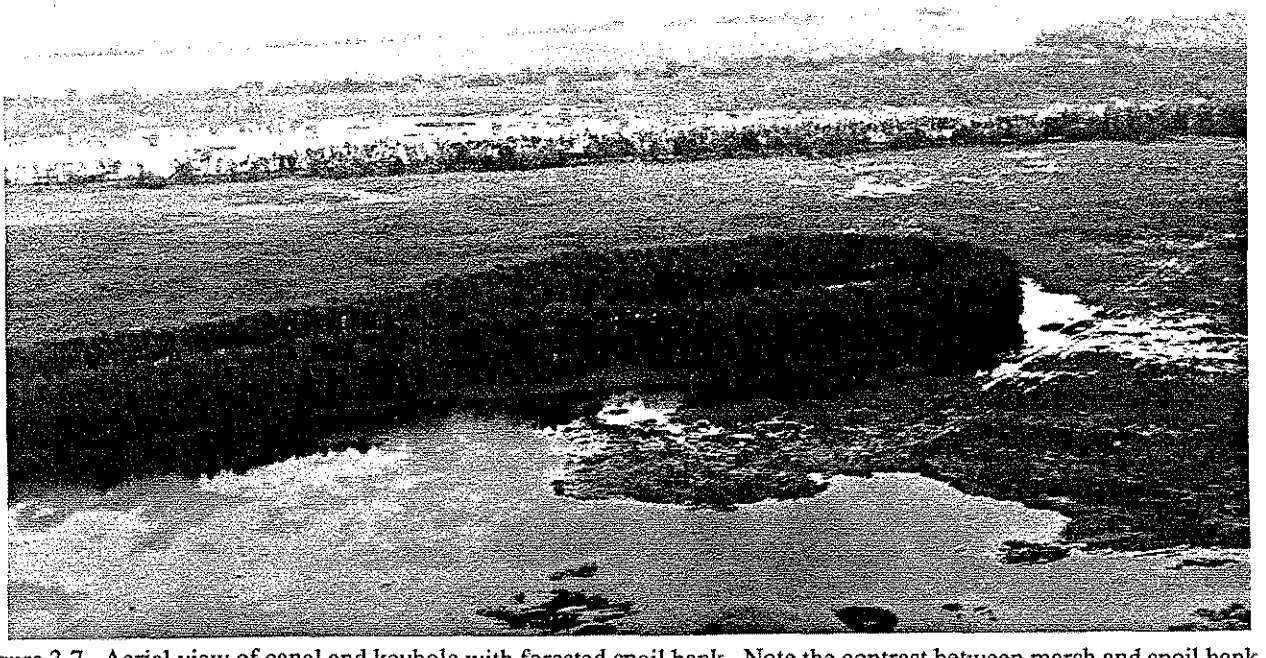


Figure 3.7. Aerial view of canal and keyhole with forested spoil bank. Note the contrast between marsh and spoil bank habitat. (Photography by D. Cahoon.)

Terrebonne Parish, organisms in closed canals are larger and fewer in number than organisms sampled at adjacent stations, but they also are effectively taken out of commercial production because they cannot be harvested (Adkins and Bowman, 1976). Lindstedt (1978) demonstrated that the mean number of macrobenthic organisms within a salt marsh was 50 percent lower in canals of the Leeville oil field than in control waterways. On the other hand, May (1977) found no difference in mean abundance of killifishes between canals of the Leeville oil field and control sites, although the total catches were substantially lower in the canal sites.

3.2.2.2. Influence on Hydrology and Water Quality. Hydrology is a dominating influence on wetland structure and function. It controls wetland development, regulates the rate and direction of ecological processes, and forms the basis of most wetland values. The construction of a criss-crossing network of access canals of the type described above has severely altered the natural hydrologic regime of the coastal marshes of the Mississippi River deltaic plain. Straight canals deeper than the sinuous natural channels have been superimposed on the drainage systems of the coastal basins. These canals are hydrologically more efficient and, consequently, capture waterflow from the natural channels and allow more rapid runoff of freshwater.

This hydrological change has several consequences for water quality and the health of the marsh. Nutrient and pollution-laden runoff is shunted through the canals more quickly than natural channels, and, thus, the cleansing processes of the marsh are bypassed. This contributes to eutrophication of the lower part of the estuary, which is normally buffered from upland runoff by the marshes. Also, the increased runoff efficiency results in more rapid water level fluctuations and lowers the water table. This causes more frequent and prolonged drying of the marsh, which directly influences the rate and redox state of soil/water chemistry (see **Chapter 1**). The interconnected channels also provide an avenue for saltwater to move further inland, changing the marsh communities to more saline types. These last two impacts can directly influence organic matter production and accumulation.

Intrusion of saltwater affects marsh and aquatic communities by changing the type and resource value of a habitat. The inland encroachment of higher salinities is evidenced by the changing distribution of vegetative communities and oyster-growing areas. As saltwater moves inland, the salt marsh vegetation zone near the coast expands landward at the expense of low-salinity and fresh marsh communities. Freshwater forested wetlands (e.g., cypress swamps) and flotant marsh communities are usually converted to open water while fresh and brackish marshes change into brackish and saline marshes, respectively. The associated changes in wildlife and fishery habitat are important and must be considered when developing a plan for managing hydrologic impacts.

Spoil banks block sheet flow and thus increase flooding duration. Additionally, spoil banks decrease the amount of tidal flooding of marshes and hence may reduce sediment and nutrient supply to the marsh. Therefore, spoil banks may affect the rate of vertical accretion by influencing sediment input and organic matter production and accumulation.

The dredging of marsh sediments to a depth of 8 feet returns many nutrients, noxious substances (H_2S), and pesticides to the marsh surface. This has a direct effect on water quality in the marsh. The potential impact of toxic or acidic substances leached from the spoil bank on plant growth and soil/water chemistry within the immediate vicinity needs to be investigated.

3.2.3. Influence on Wetland Loss

The dredging of oil and gas access canals contributes to the wetland loss problem in south Louisiana by directly converting marsh to open water and spoil bank habitat (5 to 10 percent of the total land lost each year). This contribution increases to perhaps 10 to 20 percent if canal widening effects are included. However, canals have been blamed for as much as 90 percent of the annual landloss (Craig et al., 1979, Scaife et al., 1983, Turner et al., 1981, Turner et al., 1983) because of their influence on coastal submergence. Analysis of aerial imagery has revealed a high correlation between canal development and subsequent wetland loss in the immediate vicinity. Scaife et al. (1983) demonstrated that where canal-spoil bank density is high, landloss is high; where the density is low, landloss is low; and where the density is nearly zero, landloss is nearly zero. The influence of canals and their associated spoil banks on local hydrology has been proposed as the causal mechanism to explain this statistical relationship.

3.2.3.1. Cause-Effect Relationships. Canals can be viewed as a major indirect cause of wetland loss because of the way they influence the rate of ecological processes within the basin. In the rapidly subsiding environment of Louisiana's coast,

any alteration which impairs the ability of the marsh to maintain an adequate rate of vertical accretion contributes to wetland loss (**see Chapter 1**). Specifically, any canal impacts on hydrology that limit or reduce the sediment supply and organic matter production will negatively impact the vertical accretion rate. Hence, the marsh will gradually disappear. The impact can be cumulative. For example, marsh loss can be particularly severe in areas of high canal density, such as in major oil fields, where the web of canals and spoil banks eventually leads to the formation of numerous impounded and semi-impounded areas in which waterflow is totally or nearly totally impeded. These marsh areas almost always show rapid deterioration to open water (Turner, 1985).

The cause-effect relationships for direct and indirect mechanisms of wetland loss related to canals are outlined in **Table 3.2**. Direct effects are acute (perceived immediately) and the direct result of a physical act. Indirect effects are chronic (perceived gradually) and the result of a change in an ecological process brought about by a physical act.

The cause-effect linkages between canals and some of the ecological processes presented in **Table 3.2** cannot be fully explained in this manual. This summary is an attempt to explain the relationships between canals and wetland loss in light of current scientific knowledge, methodology, and principles. The cause-effect linkages often are complex and almost certainly synergistic. For example, no one doubts that saltwater is deleterious to the growth of freshwater plants. But how does one explain the deterioration of Louisiana's salt marshes? Saltwater intrusion cannot be the only cause. One hypothesis suggests that stresses on the vegetation caused by the combination of increased inundation that leads to increased anaerobiosis and H_2S production, coupled with a decrease in sediment supply that leads to a reduction in the supply of Fe capable of neutralizing the H_2S, result in the dieback of the vegetation. This decrease in organic matter production, combined with the already reduced sediment supply, makes it more difficult for this region of marsh to maintain its elevation through vertical accretion. The marsh eventually will sink below the water surface (caused by the naturally high rates of subsidence) making future recolonization by the orginal marsh-building species impossible. The degree to which canals influence the critical processes of inundation and sedimentation, and, hence, the biotic response, is not fully understood in all cases and is the subject of current investigations.

3.2.4. Managing Impacts Through the Regulatory Process

Managing the impacts of canals is a matter of reconciling subsurface drilling objectives and constraints with surface environmental features. In the 1920's and 1930's, wetlands were viewed as wastelands that made no important economic contribution to society. Consequently, drilling site locations and access methods were designed to facilitate achieving subsurface features with little or no consideration of the ecological value of surface features. The recently recognized values of wetlands warrant that they be considered during the siting and accessing of drilling locations. There are numerous means of reducing surface impacts during site access that are technically feasible and allow appropriate safety measures for industry personnel. Many of these methods involve standard industry techniques that, when scheduled differently or used in conjunction with existing man-made or surface features, protect the environment at no extra cost (or even less cost) to the industry.

Outlined below are some techniques for avoiding and minimizing impacts associated with oil-gas access canals. Many of these techniques can be used in combination, resulting in further environmental protection and perhaps a cost savings to the industry. As described in **Chapter 1**, the management objective of these techniques is to minimize changes to the status quo of the wetland system in question, in accordance with Section 404 regulations. The issues related to restoring functions during site closure are discussed in Chapter 9.

3.2.4.1. <u>Avoiding Impacts to Surface Features/Functions during Site Access</u>. This section describes methods for avoiding the construction of a canal by drilling from an existing slip or using an alternative access method. It also discusses techniques for avoiding coincident impacts related to canal construction. Even when road dump/board road access is used, their impacts to surface features and wetland functions can be avoided. The following discussion suggests various avoidance techniques.

Alternate Access Methods. The most obvious method of avoiding canal impacts is not to dredge a canal but instead to use an alternative access method. A detailed description of alternative methods for accessing drilling sites (board roads, hovercraft, and helicopters) is presented later in this chapter. However, each of these methods, like canal construction, has advantages

Table 3.2. Observable and hypothetical cause-effect relationships between canals and marsh alterations and loss.

	Construction Impact	
	Channel Excavation	Spoil Deposition
ACUTE ENVIRONMENTAL CONSEQUENCES		
Habitat Alteration — Physical Impact		
Direct Conversion to Open Water	√	
Direct Conversion to Spoil Bank Habitat		√
Return of Nutrients, Toxins to Marsh		√
Noise, Commotion during Construction	√	√
Habitat Alteration — Ecological Impact		
Immediate Loss of Marsh/Shallow Water Habitat	√	√
Immediate Gain of 8-foot Deep Open Water	√	
Immediate Gain of Upland Wildlife Habitat		√
Changes in Soil/Water Chemistry (increased COD); Changes in Plant Growth		√
Impact on Biota		
Destruction of Biota	√	
New and Different Habitat	√	√
Burial of Biota		√
Potential for Interrupting Fish Spawning and Feeding in Marshes		√
Potential Negative Impact on Plant Growth		√
Potential for Disturbing Avifauna Nesting by Noise	√	√
CHRONIC ENVIRONMENTAL CONSEQUENCES		
Habitat Alteration — Altered Physical Process		
Wave Action	√	
Water Circulation and Turnover: Stagnant Water	√	
Deeper than Natural Channel with Greater Hydrologic Efficiency	√	
Intercepted Freshwater Flow	√	
Interaction of Saltwater Intrusion	√	
Increased Drainage of Marsh	√	
Surface Hydrology and Drainage		√
Subsurface Hydrology and Drainage		√
Sediment Distribution		√
Interaction of Surface/Subsurface Hydrology and Sediment Distribution		√

and drawbacks and therefore may not be a suitable alternative in every instance. In such cases, dredging a canal may be unavoidable, although the impacts associated with canals are not always unavoidable. The remainder of this section discusses how to manage these impacts.

Timing of Construction. The noise and commotion associated with canal construction are capable of disrupting breeding and nesting activities of bird colonies. Such coincident impacts can be entirely avoided simply by altering the commencement date of dredging to coincide with the nonbreeding season or by moving the drilling location. The financial consequences of avoiding these coincidental impacts can range from zero to substantial. There will be no financial consequences if construction is scheduled during the nonbreeding season. If, however, the company is faced with a lease deadline that falls within the breeding season then the financial cost to the company can be great. [A lease deadline is the date by which the company must commence drilling in order to avoid a lease payment, usually a substantial sum of money.] The company will be faced with a choice of either waiting until the nonbreeding season and paying the lease royalty or moving the drilling site location.

Existing Access Routes. Use of existing waterways, natural and manmade, eliminates the need for dredging. In very few instances, however, is the subsurface location directly overlain by a waterway. More often, an existing waterway may be used to get part of the way to the desired surface location. In such cases, dredging a canal still may not be necessary if this technique is used in combination with directional drilling from an existing drill site or an alternative access method. Using existing waterways avoids environmental impacts at no additional cost.

Directional Drilling. Canal construction can be completely avoided if drilling can be performed from an existing dredged slip, upland, or other suitable location accessed through existing waterways. It is not necesary for this alternative drilling site to be located directly over the subsurface objective in order to avoid dredging a new access channel because it may be possible to achieve the subsurface objective by drilling the well at an angle. The process of intentionally drilling a well that deviates from a straight (vertical) hole is known as controlled directional drilling (Kennedy, 1983). This is done by intentionally changing the direction of the drill bit so that the bottomhole location is offset from the tophole location. The technique of directional drilling, including risks, limitations, and costs, is described in detail in **Chapter 5**, Section 5.1.3. Various applications of directional drilling technology are illustrated in **Figures 5.3., 5.4., and 5.5**.

Reconciling subsurface drilling objectives with surface environmental features depends on a thorough understanding of each. Therefore, in addition to having a biologist review surface features, each application for permission to drill a well is reviewed under the Geologic Review Procedure (Johnston and Rives, 1985) with the assistance of a qualified petroleum engineer and petroleum geologist to determine: (1) if the objective can be achieved via a vertical hole from an alternative surface location, thereby minimizing surface impacts; and, (2) the efficacy of directional drilling. It may be possible to achieve the subsurface objective via a vertical well from an alternative location, depending on the lateral extent of the reservoir. In this way, surface environmental impacts and the technical difficulties and expense of directional drilling are avoided. On the other hand, it is not always feasible to directionally drill a well, depending on the subsurface geologic constraints. This can be determined only by expert review. If directional drilling is technically feasible, the decision of whether or not to drill directionally should be based on a comparison of the increased cost, risk to life and property, and potential economic gain and need versus the value and need of the surface feature or habitat that would be impacted. Under current policy, the USACE considers directional drilling a viable alternative if the added cost is less than one-third of the cost of a straight hole.

Combining Avoidance Techniques. As already stated in the section on existing access routes, using various techniques in combination can provide the greatest environmental protection, often at little extra cost to the industry. The use of existing access routes or alternative access methods in conjunction with directional drilling is a very common and successful way to avoid the impacts associated with canal dredging and spoil deposition. In cases where dredging is unavoidable, these techniques can also go a long way toward minimizing these impacts.

3.2.4.2. <u>Minimizing Impacts to Surface Features and Functions during Site Access</u>. This section describes methods to be used when the dredging of a canal with a slip cannot be avoided. Drilling site access impacts can be minimized by using different construction techniques, particularly when used in conjunction with the avoidance techniques described above.

Canal Dimensions. Minimizing impacts through regulating canal dimensions is a matter of ensuring that the minimum feasible dimension is used. The depth, width, and keyhole dimensions are controlled by the equipment used. If the decision is to permit drilling site access by standard canal techniques, there is little that can be done to reduce the dimensions below the minimum dictated by the dimensions of the equipment. Of all the dimensions, canal length is most subject to regulation, depending on surface features and subsurface constraints.

Length. Unlike the dimensions of canal width and depth, which are determined by the size of the vessels used, canal length varies and depends on the point of origin of dredging and the subsurface drilling constraints. The use of various avoidance techniques, such as alternate access routes and directional drilling, can greatly shorten the canal.

Before legislation designed to protect and preserve wetlands was passed (e.g., National Environmental Policy Act, 1969; Clean Water Act, 1972; Coastal Zone Management Act, 1972), the length and extent of dredged access canals was not regulated by any level of government. During such time, access canals ranged from 500-foot canal/slips to several miles in length. Today, applications for canals greater than one mile long are the exception, not the rule. The average length of canal in permit applications made to the state of Louisiana between 1980 and 1985 ranged from 1,100 feet to 1,750 feet (Louisiana Department of Natural Resources, Coastal Management Division, unpublished data). An increase in the number of existing access routes and effective governmental regulation are the reasons for this reduction in canal length.

The social consequences or financial impacts to the industry resulting from employing various avoidance techniques can be minimal (see above), particularly when viewed in light of preserving wetland functions and values. The environmental advantages to shortening a canal can be great, however. Besides minimizing the direct (acute) impacts, many chronic impacts can be lessened. For instance, every attempt should be made to shorten canals if they cross hydrologic basin boundaries, connect the edge of a basin with the center, connect more saline areas with less saline areas, intersect natural streams, or impound an area (see canal alignment below).

Depth. Canal depth is determined by the size of the drilling barge used to drill the well. The standard canal depth in Louisiana is 8 feet below mean sea level (**see Figure 3.2**). If the proposed canal cannot be shortened and intersects a natural channel so that it could intercept freshwater flow or connect saline with nonsaline areas, use of a shallower canal that is closer to the depth of the natural waterway may be appropriate. In addition, if the drilling barge must cross sensitive waterbottoms en route to the access canal, use of a shallow draft barge is recommended.

There is no such thing among standard drilling equipment as a drilling barge specifically designed for shallow draft (i.e., designed to carry the same weight on a smaller hull). The depth of the hull of a drill barge, and therefore the amount of water the barge draws, is determined by the weight of drilling equipment it must carry. Drill rigs designed to drill to depths >15,000 feet usually have hulls of 12-14 feet and draw 7-8 feet of water. These dimensions are typical of drill barges used to drill wells in south Louisiana. Drill barges could draw less water if they could be built wider, but then they could not pass through the system of locks in south Louisiana and access canals would have to be dredged wider. In coastal Texas, most oil/gas reservoirs are located at <12,000 feet. Consequently, drill barges used in Texas estuaries are generally smaller (e.g., 8 foot hulls) and draw 4.5-6 feet of water.

There are two ways to get a drill barge into very shallow water, both of which require modifiying a standard drill barge. Pontoons can be attached to the barge to float it over shallow areas (the pontoons can be placed in the keyway if attaching them to the sides would make the barge too wide) or, more commonly, the barges are lightened of their load by removing equipment, water, fuel, and emptying the submersible hull of all silt and water. The equipment and supplies are then transported to the drill barge by other vessels.

Even though no specialized equipment is used, lightening the load requires additional labor and vessel operation and, thus, additional expense for the operator. This alternative has limited mitigative abilities in Louisiana because, while it is technically feasible, even an unloaded drilling barge capable of drilling >15,000 feet draws approximately 6 feet of water. In Texas, the smaller rigs can be lightened to draw only 3-4.5 feet of water. However, in such situations, the tug boat used to push the drill barge onto location usually draws more water than the barge and becomes the limiting factor in accessing the site. Nevertheless, lightly loaded drilling barges have been used to cross sensitive water bottoms, such as oyster and grass beds, along the Gulf coast.

Width. The width of the canal is determined by the size of the drilling barge and need not be any greater than 70 feet wide at the bottom. In special situations, such as sweeping out natural waterways to reach a drilling site, a bottom width of 60 to 65 feet can be used to avoid widening the natural channel. However, the cross-sectional dimensions of the standard access canal dredged through marsh (8 feet x 70 feet) cannot be reduced much below 6 feet x 65 feet and still accomodate standard drilling equipment with a reasonable safety margin.

Keyhole. Many petroleum companies have their own particular design for the keyhole, ranging from the traditional design in Figure 3.3 to a rectangle. Consequently, the dimensions can vary considerably, with the keyhole being up to 500 feet long. For normal operations, there is no need for the keyhole to be any larger than the traditional design. If drilling is anticipated to be exceptionally difficult or to great depths, the company may desire a larger than normal slip to accomodate extra equipment, but these instances should be rare and treated on a case-by-case basis.

Canal Alignment. The alignment of the proposed canal in relation to local drainage patterns, existing canals, and surface features can significantly alter the hydrology of the basin. Canals with their associated spoil levees that run perpendicular to the drainage pattern of the basin can obstruct surface sheet flow across the marsh, increasing inundation on the upstream side and decreasing it on the downstream side. Canals that create partial (2- or 3-sided) or total (4-sided) impoundments by connecting with existing canals can totally or nearly totally isolate a region of marsh from natural hydrologic flows (**Figure 3.8**). In these leveed areas,

periods of both inundation and dryness are prolonged. In total impoundments, the marsh will quickly convert to open water because of cumulative chronic impacts unless the water level is managed (manipulated) by man. Therefore, placement and alignment of the canal should not be based solely on the subsurface objective, but also on the major surface features of the basin. Avoidance techniques (e.g., use of existing waterways and directional drilling) can be used to reduce the degree of impoundment or obstruction of drainage patterns.

Canal Type. Canals can be classified into different categories, depending on their alignment in relation to neighboring waterways. The degree of associated chronic impacts depends on their position in the hydrologic landscape. For example, canals can be classified as dead-end or open-end. One is not necessarily less environmentally damaging than the other. Dead-end canals generally have a slower water renewal rate and thus are more likely to become stagnant and anoxic, particularly if the mouth of the canal is closed with a plug or weir. On the other hand, a canal that connects two water bodies (open-end) could seriously impact the marsh if it crosses basin boundaries or salinity zones, connects the center and edges of a basin, or intersects a natural stream. Therefore, each canal type must be analyzed independently each time it is proposed in light of the specific local surface features and potential cumulative impacts.

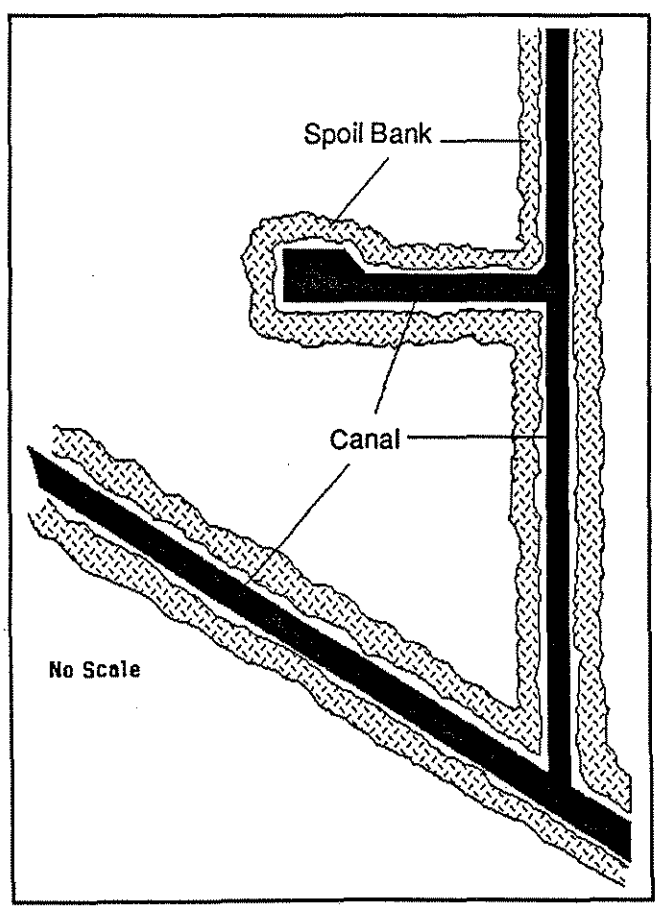


Figure 3.8. An interconnected system of canals resulting in a partial (3-sided) impoundment.

Canal slips, or keyholes, also can be classified into different categories: parallel slips and perpendicular slips **(see Figures 3.3 and 3.5)**. Parallel slips are generally smaller and hence result in the conversion of less marsh. However, if restoration of the drilling site is of primary concern, it is easier to plug a perpendicular slip than a parallel slip, because parallel slips usually are located on more heavily trafficked waterways and subject to more wave action. Thus, the selection of slip type also should be predicated on local surface features, social patterns, and potential cumulative impacts.

Dredging-Spoil Disposal Method. There are four alternative spoil disposal techniques designed to minimize the impacts of spoil banks, for use in open water and marsh habitats. They have evolved from initial attempts to minimize hydrologic impacts into standard industry techniques commonly used today. Hence, there is no standard reference source describing these techniques. Rather, each technique is applied to suit the particular environmental features of the site. The following descriptions are based on a general knowledge of these techniques, as employed by the dredging industry.

Discontinuous Spoil Bank. The spoil can be deposited so that gaps are created at regular intervals along the length of the canal and particularly at locations of small surface drainage channels to minimize or avoid the hydrologic impacts associated with continuous spoil banks **(Figures 3.9 and 3.10)**. In addition, all waterways intersected by the canal should be left open to maintain as near normal drainage patterns as possible. If there is a chance the canal will allow saltwater intrusion or is significantly deeper than the natural channel it intersects, it may be appropriate to construct a weir at the mouth of the intersected waterway in order to prevent saltwater intrusion or excessive drainage of the marsh, or to create a continuous spoil bank, rather than a discontinuous one. Both techniques, gapping the spoil and constructing water control structures, are technically feasible and in use today.

The fiscal consequence to the industry of placing gaps in the spoil is negligible, and the environmental benefits can be substantial. The gaps leave segments of the original marsh surface unburied

and uncompacted, allowing free exchange of surface and subsurface waters between the canal and the marsh. This means the ebb and flow of tidal waters will remain basically the same, thus avoiding the usual problems of altered drainage regimes and irregular flooding cycles associated with continuous spoil banks.

On the other hand, the construction of a water control structure at the intersection of a major waterway could cost a few thousand to more than $50,000 dollars, depending on the size and type of water control structure. Again, the environmental benefits can be substantial if the structure prevents saltwater intrusion or excessive drainage of the marsh.

Haul Spoil Away. The impacts of spoil banks can be completely avoided if the spoil is loaded onto barges and hauled from the site and deposited elsewhere. This technique is technically feasible but requires additional vessels, an alternative disposal site that may have to be leased or purchased, and more time to complete dredging (especially if the disposal site is far away)—all of which combined can add greatly to the cost of dredging. Acquiring an alternative suitable disposal site, preferably in open water or upland habitat, within reasonable distance of the dredge site, may be technically difficult, as well as expensive. Disposing of the dredged material at an offsite location also may be technically difficult. Depending on the disposal site and type of barge used, it may be necessary to dredge an access channel to the disposal site and to use a dredge to offload the spoil material. Employing two dredges, one at the access site and another at the disposal site, along with running barges with tugboats back and forth, can more than double the cost of dredging the access canal. Consequently, this method should be employed when it is absolutely necessary to avoid the creation of a spoil bank or if no suitable disposal site exists in the vicinity of the proposed canal. This technique probably would not be suitable in an area where the potential for saltwater intrusion is high.

Open Water Disposal. There are two basic techniques for disposing of dredged material in shallow open water habitats in wetlands. If the surrounding open water habitats are considered sensitive because of valuable oyster beds or other important benthic organisms, the spoil can be piled

Figure 3.9. Aerial view of canal (foreground) with discontinuous spoil bank. (Photography by D. Cahoon.)

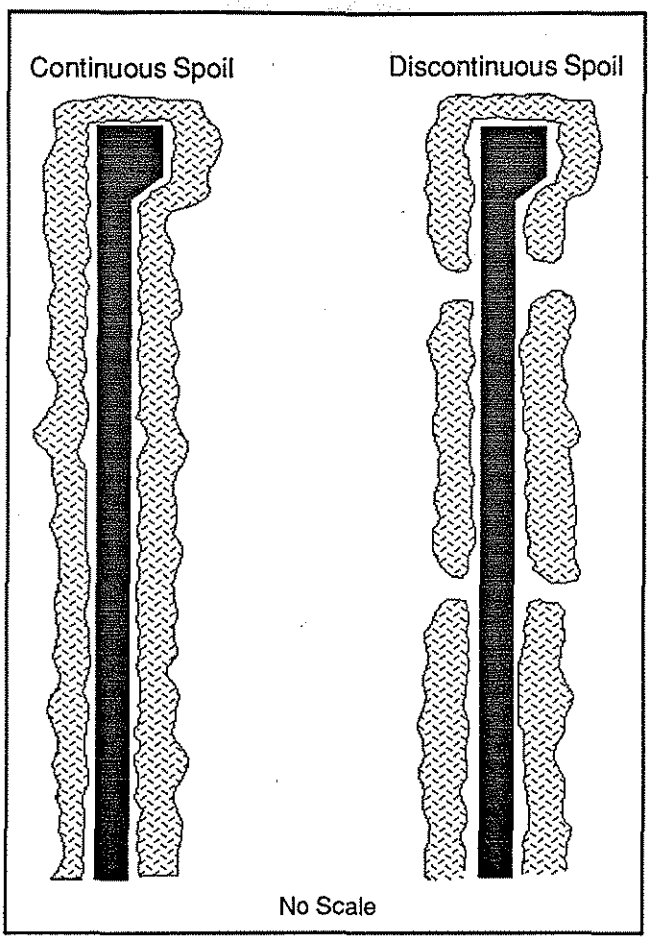


Figure 3. 10. Basic spoil bank configurations. Discontinuous spoil banks typically have 50-foot gaps spaced every 500 feet.

up along the edge of the open water channel, thereby covering as little of the waterbottom as possible (**Figure 3.11**). To prevent the spread of sediment suspended in the water column and the smothering of the oyster bed, turbidity screens can be placed around the dredge site. Also, gaps can be placed in the spoil piles to allow water circulation. The major detriment to this method of disposal is that the piles can hinder navigation, especially if they lie just below the water surface. If the surrounding benthic communities are not considered unique or valuable, but the lake or pond has a high recreational value, then spreading the spoil as thinly as possible over the bottom could be suitable, as this presents the least hindrance to navigation. Alternatively, the material could be placed in shallow water adjacent to the marsh to create new marsh (**Figure 3.12**).

Each technique is technically feasible and in use today. The difference in cost between the techniques is negligible. The only limitation to spreading the spoil is the length of the boom. Routing channels in open water near the marsh edge of ponds will encourage use of the spoil for marsh creation.

An alternative method often used by industry to access shallow open water areas is called prop-washing or wheel-washing. This involves clearing a channel through shallow water by forcefully plowing through the area with a tug boat and pushing the soft substrate aside or churning it up with the propeller. This method is preferred by industry because it avoids the necessity of mobilizing a dredge or minimizes the time required by a dredge to access a site. This can result in substantial savings on tug and drill barge rentals. However, prop-washing also results in uncontrolled re-suspension and re-deposition of bottom sediments. This can be very damaging to oyster beds or submerged vegetation communities in the vicinity. The use of prop-washing should be permitted only if it can be demonstrated that impacts to sessile bottom communities will not occur.

Hydraulic Dredging. Alternative dredging devices suitable for constructing access canals exist that work on the principle of suction. These machines cut and suck up the marsh substrate, grind it up, and spray it over the marsh. As explained earlier, the use of hydraulic dredging technology is far less common today than bucket dredging. However, there are two basic methods of hydraulic dredging in use today: (1) conventional low pressure disposal that has been in use for several decades; and (2) high pressure spray disposal that has evolved during the past decade.

Hydraulic Dredging - Jet Spray-Water Vac. A swinging ladder hydraulic dredge that utilizes high pressure spray to dispose of dredged material was developed in the late 1970's and was named Jet-Spray® (Deal, unpublished data). [The use of commercial or brand names is for illustrative purposes and does not constitute an endorsement by the U.S. Environmental Protection Agency]. This machine has a depth-adjustable cutterhead attached to a swinging ladder and is capable of accurate and precise horizontal and vertical movement. The rotation of the cutterhead slurries the spoil which is pressurized by a dredge pump. As the material enters the pump it is further slurried at the pump impeller by internal shear-action knives. The pressurized slurry is sprayed across the marsh by an accelerator nozzle (4-6 inches in diameter) at a rate of 175 to 800 cubic yards/hour. The material is well mixed (i.e., not segregated by grain size) and sprayed as a fine rain-like mist 180 to 250 feet over the marsh, depending on the clay content of the

substrate. It accumulates as a broad, thin (less than 12 inches), and not necessarily continuous, layer **(Figures 3.13 and 3.14)**.

The advantages of this technique over traditional dredging methods are numerous. The primary benefit is that no traditional spoil bank is created. The material is not deposited as a dense bank that deforms the organic substrate. After dewatering and oxidation, the final elevation is 4-7 inches (Cahoon and Cowan, 1988). Revegetation of the disposal site is by intertidal marsh vegetation. The spray can be directed to avoid particular areas of the marsh, such as natural drainage channels, leaving portions of the canal bank in a natural state (**Figure 3.15**). Thus, the density, height, and continuity of the spoil bank are greatly reduced. This likely will lessen spoil impacts on surface and subsurface hydrology.

This technology also presents other benefits. For example, turbidity is kept at a minimal level by the rapid removal of turbid waters. Runoff of sediment-laden disposal waters back into the canal also is minimized by the broadcast effect of the spray. Also, the spray can be selectively directed or the spoil piped across the marsh and sprayed onto upland, open water, distant marsh, or other suitable disposal sites if there are environmentally sensitive habitats in the vicinity. The dredge's small size, shallow draft, and lack of dependence on fixed-terrain attachments make it easy to access shallow water habitats with minimal environmental disturbance. The dredge can be disassembled and transported to the site by truck. However, at current market prices, Jet-Spray® is at least twice as expensive as traditional bucket dredging (Cahoon and Cowan 1988).

Hydraulic Dredging - Conventional Low Pressure Disposal. Conventional hydraulic dredges also have a depth-adjustable cutterhead attached to a swinging ladder capable of accurate and precise horizontal and vertical movement. However, the dredged material is pumped at low pressure, usually through a pontoon-supported pipeline (gener-

Figure 3.11. Aerial view of channel dredged in open water with gapped subaerial spoil banks. (Photography by D. Cahoon.)

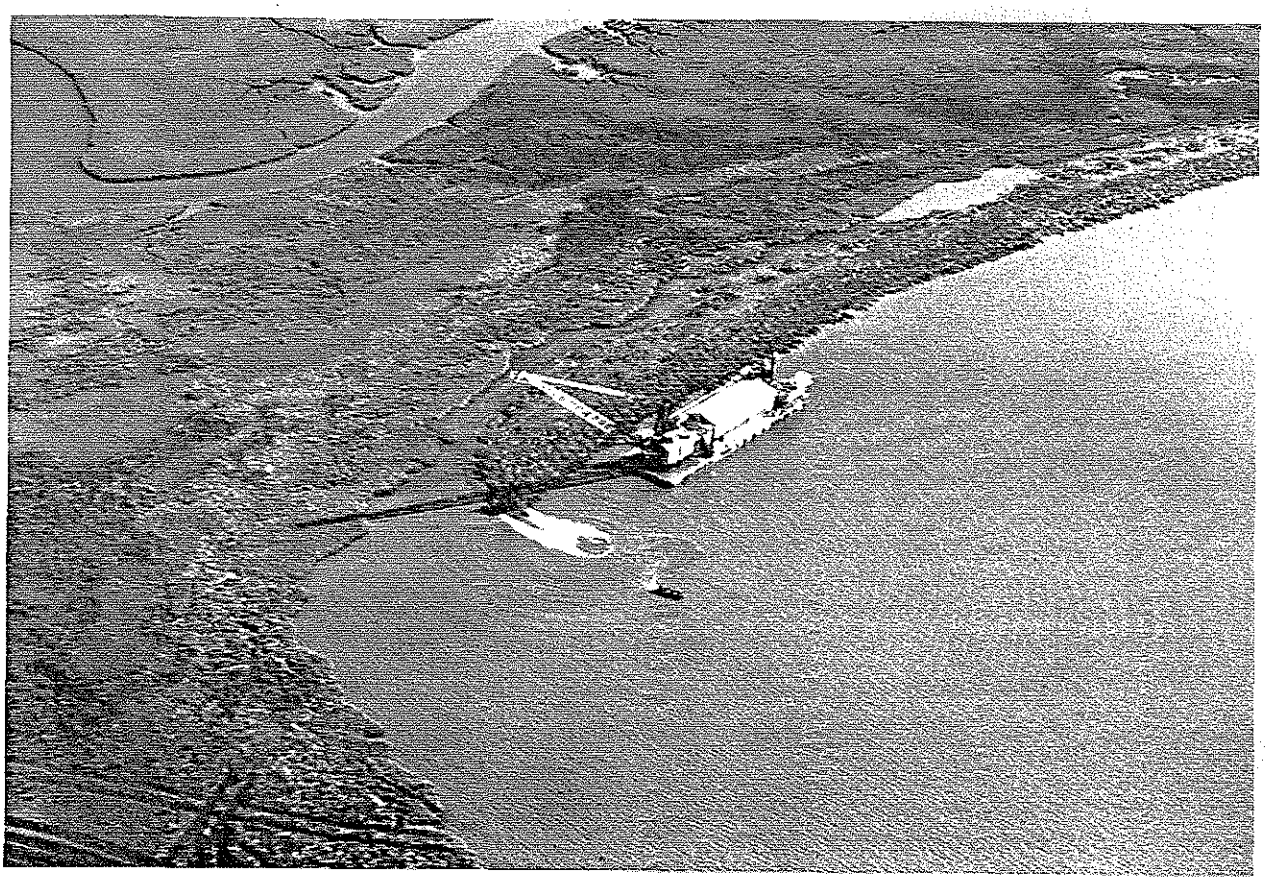


Figure 3.12. Channel alignment and spoil placement in an open water habitat designed to promote marsh creation. (Photography by P. Keney.)

ally 12 inches or greater in diameter) to a fixed disposal point. The pipeline is moved repeatedly in order to avoid the formation of large spoil mounds at each disposal point. The material is sprayed onto the marsh by use of a spreader head attached to the end of the pipeline **(Figures 3.16 and 3.17)** that deflects the material upward. The material usually segregates by grain size when travelling through the pipeline (the larger particles settling toward the bottom) and after deposition (finer particles floating away from the larger grains).

Compared to Jet-Spray®, conventional hydraulic dredges spread the material more thickly over a smaller area. The material is often not as well-mixed and not spread as far away from the waterway. The potential for increased turbidity from sediment laden runoff is high. Operation of a conventional hydraulic dredge is labor intensive (e.g., repeated movement of pipeline) and is, therefore, as or more expensive than Jet-Spray®.

Hydraulic dredging technology can perform well in virtually any coastal habitat with the possible exception of forested swamps. [Bucket dredges can remove tree-stumps whereas a second barge with a crane would be required for an hydraulic operation in a wooded swamp to remove the stumps.] In environments with very soupy substrates, hydraulic dredging may be better suited than mechanical dredges. However, hydraulic dredges may not be best-suited in areas where a substantial spoil bank is needed to check saltwater intrusion or control some other aspect of the hydrologic regime. The major drawback of hydraulic dredging (both low and high pressure) is the increased expense.

3.2.4.3. <u>Avoiding and Minimizing Techniques Combined</u>. The most effective means of managing the cumulative chronic impacts associated with canal construction is to combine the various techniques described above whenever possible. For example, alternate tophole locations, canal alignment, and alternative spoil disposal methods can result in significant reductions in acute and chronic impacts greater than any one technique could provide. The best access route (and even drilling location) from an environmental and industrial point of view can be determined only

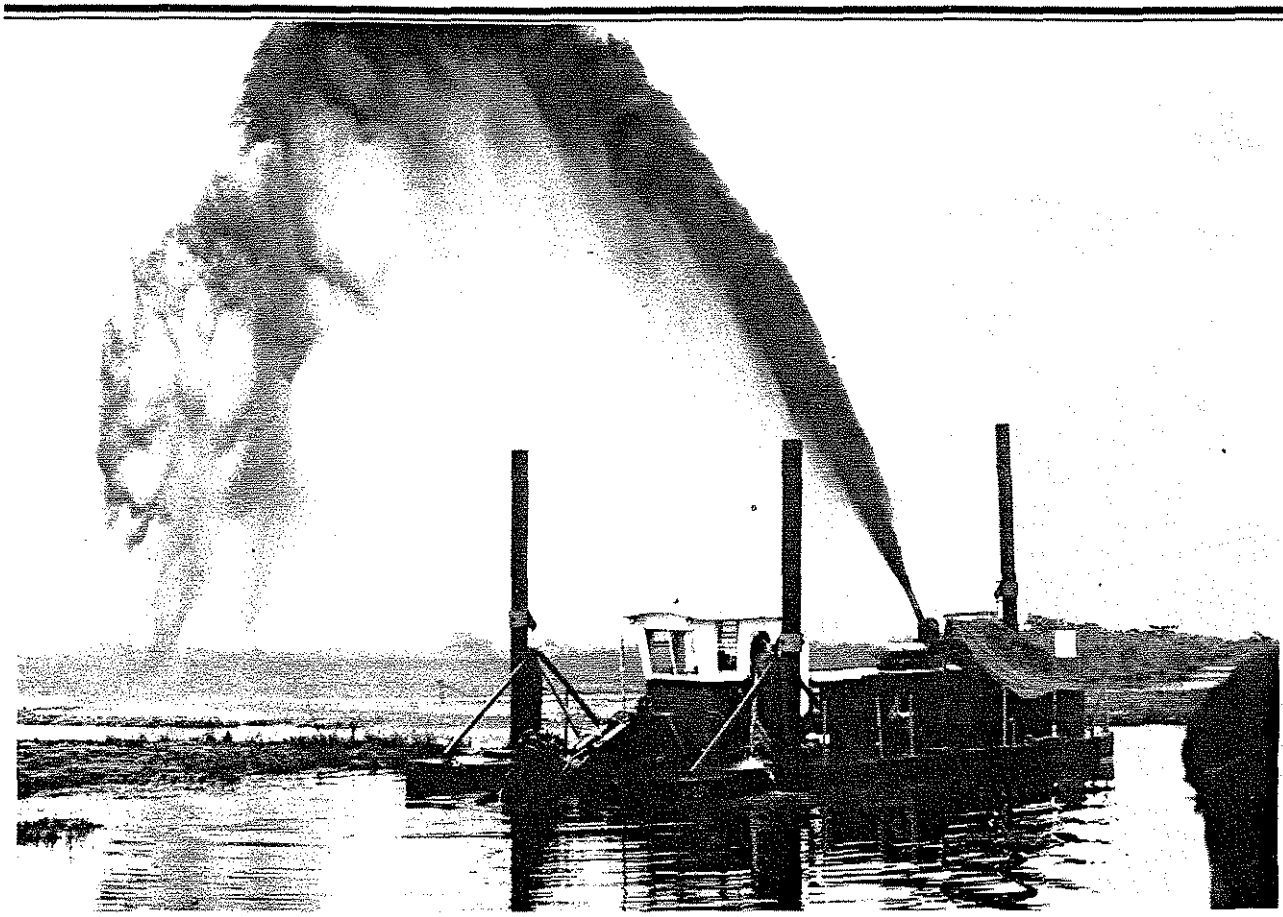


Figure 3.13. Jet-Spray® swinging ladder dredge excavating a keyhole. (Photography by D. Cahoon.)

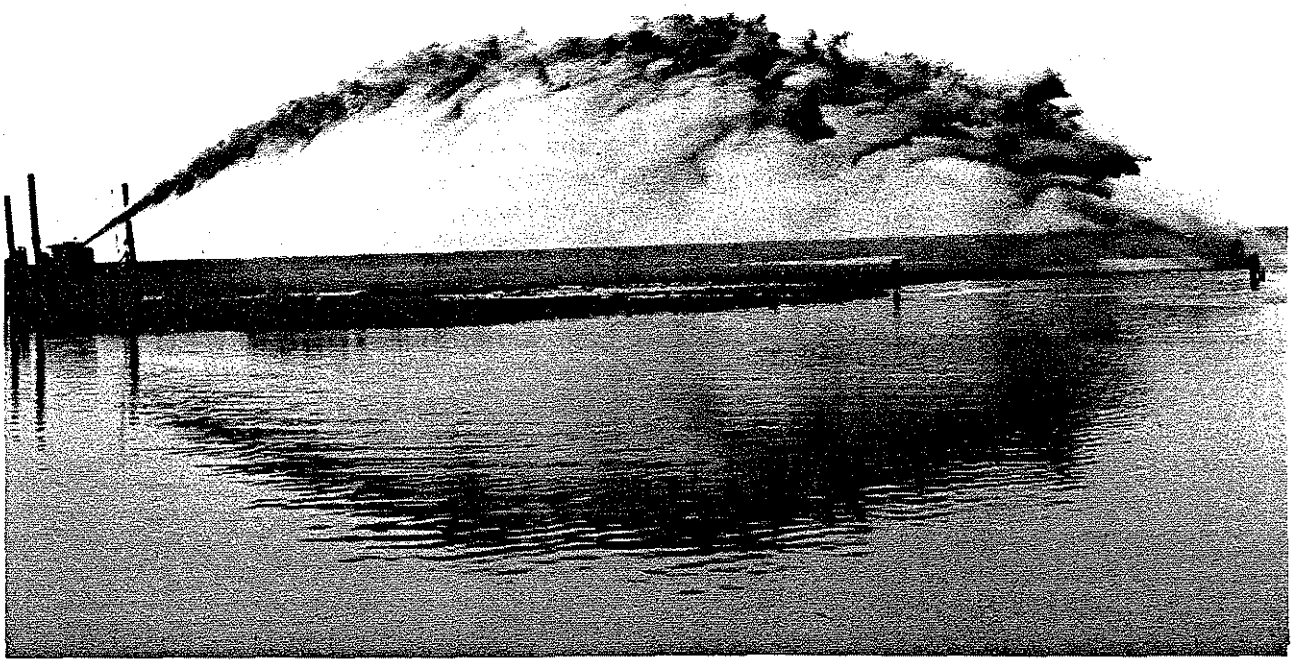


Figure 3.14. Jet-Spray® swinging ladder dredge spraying dredged spoil across a marsh. (Photography by D. Cahoon.)

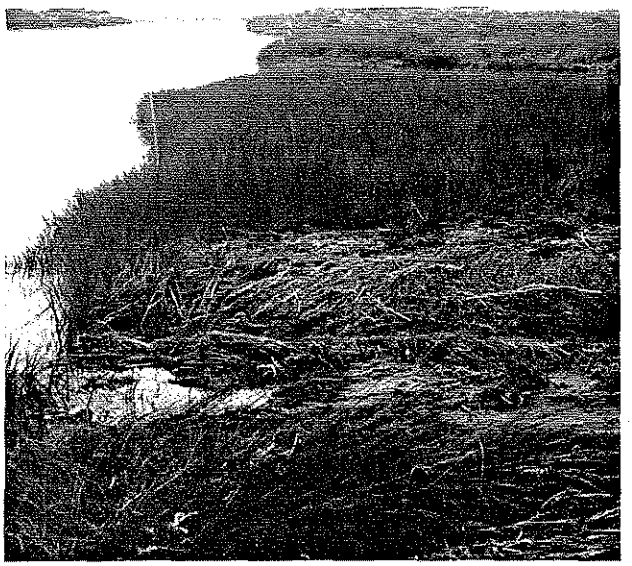


Figure 3.15. View of the bank of a canal dredged by a Jet-Spray® swinging ladder dredge. Note that only a portion of the bank has spoil sprayed upon it, and the spoil occurs as a thin layer through which plant stems are protruding. (Photography by D. Cahoon).

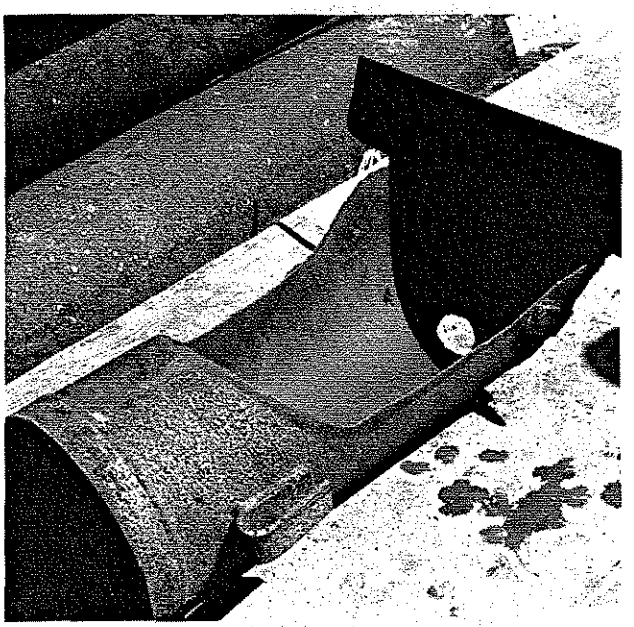


Figure 3.16. Spreader-head attachment used to deflect pumped spoil upward on conventional hydraulic dredge. (Photography by D. Cahoon.)

after a careful review of all surface and subsurface features and consideration of all alternative construction techniques.

3.2.4.4. Suggestions for Implementing Management Techniques. A general procedure to follow in reviewing permit applications for accessing drilling locations in wetlands is presented in **Table 3.3.**

3.3. ROAD DUMP

3.3.1. Introduction

A land route to access a drill site in a wetlands environment is normally constructed using dredged fill material as a base, surfaced by boards. The simplest description of the process is that a dragline dredges fill from the wetland surface and "dumps" it to create a linear surface raised above the surrounding wetlands. Layers of boards are hand-placed atop the road dump to produce a road capable of supporting drilling equipment. Initial costs of road/dump board road access are greater than canal access costs, but service to a producing well with board road access is cheaper in the long run. Land access is preferred by the industry over a canal if the drill site is located near uplands or existing board roads. The safety factor is worthy of consideration when weighing road versus canal access as transportation to hospitals and access for fire fighting equipment is quicker by road than by canal. Mixed operations (board roads built off of a canal, hence a mixed land-water operation with trucks barged to the site) are more expensive and less safe than land operations.

Standard construction techniques and typical cost variables are described below. Design requirements for NOD-13 General Permit sanction from the USACE also are discussed. The acute and chronic impacts on wetlands are examined along with methods to reduce impacts.

3.3.1.1. History. As stated previously, early prospects for oil and gas exploration in the coastal wetlands of Louisiana focused initially on topographic highs or "islands. These areas, created from the uplifted sediments of diaperic salt movement (i.e., salt domes), were recognized as promising sites for oil and gas. One of the earliest areas of interest was Hackberry Island, on the south bank of Black Lake, in Cameron Parish, where exploratory drilling begin in 1902. Access to this dome was by land and water, and the dome was developed from both barges and roadways.

Early accounts of the development of the old Hackberry Dome state that both shell and plank roads were used to access well sites on the edge of the marsh. These plank roads consisted of 2-by-8-inch or 2-by 12 inch boards placed across 6-by 8-

Figure 3.17. View of dredged material being deflected upward by spreader head and sprayed onto marsh. (Photography by D. Cahoon.)

inch timber stringers laid directly on the marsh (Williams, 1930). Accounts of development in the Lockport field in Calcasieu Parish prior to 1930 tell of "...miles of board roads, supported by plank matting resting on the unbroken marsh carpet connecting all parts of the field..." (Williams, 1930). Neither of these early methods of site access utilized dredging of the marsh to construct a road dump base as is the common practice today. In fact, in the Lockport field preserving the marsh root mat was recognized as necessary for site access by land.

An additional access method of a piling–supported board road was used in some areas, often to reach a drill site in open water from nearby land. By far most drill sites were accessed by water, at first in and along natural streams and then more frequently by dredged canals. Written accounts of land access methods are lacking. However, early photographs of drilling operations show planks supported by logs laying on the swamp surface (Franks and Lambert, 1982). Aerial photographs of Cameron Parish from 1953 (the earliest set of Agricultural Stabilization and Conservation Service aerial photographs with marsh coverage) show that a dredged road dump/board road access method much like the type in use today had been used for some time.

3.3.1.2. Procedure. Drilling rigs and all ancillary equipment used for hydrocarbon exploration and development on land can be dismantled and transported on federal, state, and parish highways to the marsh locale. Movement off existing roadways usually requires preparation of a temporary road, commonly referred to as a road dump with a board road. In upland areas, particularly on the Pleistocene terrace surface or on chenier ridges, preparation may involve only placing a shell or limestone base and/or boards to access the drill site. In marsh areas where water access is not used, a road dump is constructed of material "borrowed" (i.e., dredged) from the adjacent marsh or swamp and surfaced with boards.

There are very few locales (1 out of 100) along the Louisiana-Texas coast where soil conditions are too poor to permit construction of a road dump. The specific site conditions rather than the general marsh type are the controlling factors of construc-

Table 3.3. Suggested procedure for implementing management techniques during permit review.

(A) Receipt of Application to Dredge Standard Canal

Review surface features/ascertain potential environmental impacts
Methods - inhouse review of data bases
- field investigation of site

Review - environmental/biological features (natural resources)
- cultural features (archaeological sites)
- social infrastructure (roads, waterways, etc.)

(B) Determination that Potential for Impacts Is High

Reconcile impacts to surface environmental features with subsurface objectives
Method -meeting with applicant

Review - subsurface objectives and constraints (geologic data)
- techniques for avoiding and minimizing impacts
- techniques for restoring ecological habitat or function, if necessary
- techniques for compensating for unavoidable impacts (impacts remaining after avoiding, minimizing, and restoring measures have been taken), if necessary

(C) Permit Decision
Review Benefits and Impacts In Context of Authorizing Legislation

Methods - if decision is made to issue, incorporate changes in project design from step B into permit

tion and, ultimately, the cost of this method of site access. Specific site conditions (i.e., depth to an underlying clay layer and percent organic matter of the sediment), dictate the completed dimensions of the road dump, borrow pits, and size of disturbed area. Standard construction procedure uses a dragline moving over the marsh surface on wooden mats placed under the dragline treads as temporary supports. These mats consist of timbers generally 1 by 16 feet long wired together to form a mat 4 to 6 feet wide and 16 feet long.

As the dragline progresses along the route, it moves the mats forward and "walks" across the marsh. The dragline generally dredges marsh material from one side and deposits it on the other to form the road dump. Usually one dragline is used, but if conditions for construction are "poor" (i.e., little clay and high water and organic matter content), two draglines may dredge, one on either side of the route.

Current dragline rental commonly costs $1,000 per day. If conditions are favorable for road dump construction, work may progress at 300 feet per day. In poor conditions, construction may proceed at 100 feet or less per day, thus increasing the cost of this phase of construction threefold. If two draglines are required, costs for road dump construction generally double.

The fill is piled to create a road dump 5 feet above the surrounding marsh level. The width of the crown or level road dump surface on which boards will be placed is 20 feet **(Figures 3.18 and 3.19)**. The borrow ditches generally are 30 feet wide, 5 feet deep, and a maximum of 300 feet long, alternating on either side of the road dump **(Figure 3.20)**. The marsh surface between the borrow ditch and the toe of the road dump is called the berm and is necessary to prevent the newly deposited fill material from slumping into the just created borrow ditch and to maintain a stable foundation for the road dump **(Figure 3.20)**. The berm area is normally the location over which the dragline moves during construction. The quality (organic content, water content, and particle size) of the fill or dredged material determines the angle of the side slopes and the final width of the road base. In areas with good (favorable) conditions, typical side slopes may be 1:2 (i.e., 1 foot of elevation increase for every 2 feet of width), whereas in poor conditions slopes may be 1:6 or 1:8 **(Figure 3.21)**. In such poor soils, the overall width of the road dump may greatly exceed the width of the 20-foot

crown. Additionally, the width and depth of the borrow ditches increases as more fill is required for road dump construction. It should be noted, however, that the dimensions described in this paragraph are standard design criteria and may vary substantially depending on local conditions.

Construction in a forested wetland is slightly different from a marsh because the access route must be cleared of standing trees (**Figure 3.22**).

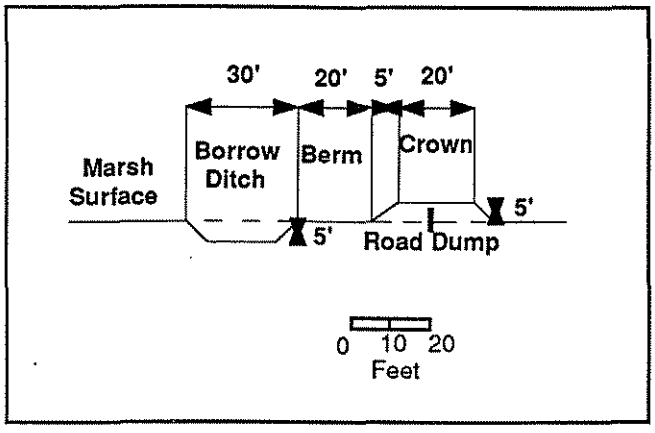


Figure 3.18. Cross-section of road dump and borrow ditch.

The route from outside borrow ditch to outside borrow ditch is hand–logged. Stumps in the borrow ditch site must be removed prior to dredging. The stumps on the road dump site are left in place to help support the fill and board road.

After dredged fill has been deposited to form the road dump, filter cloth that allows water but not sediments to pass through, or plastic sheeting, is placed on the fill (**see Figure 3.19**). It is desirable to allow the newly deposited road dump time to dewater and form a hard "crust" before board installation.

Several layers of boards are hand-placed at right angles on the crown of the road dump to provide a firm surface for equipment passage (**Figures 3.23, 3.24, and 3.25**). The boards are generally 4 -by 8- inches by 16 feet. The first layer (the mud boards - laid directly on the fill material) is placed lengthwise to the direction of travel and may be staggered. The next layers of boards are placed at right angles to the underlying layer. Three or four layers are normally used before the top layer (the runners or tread boards) is placed in the direction of travel. The tread boards are normally positioned five to a side where the truck tires

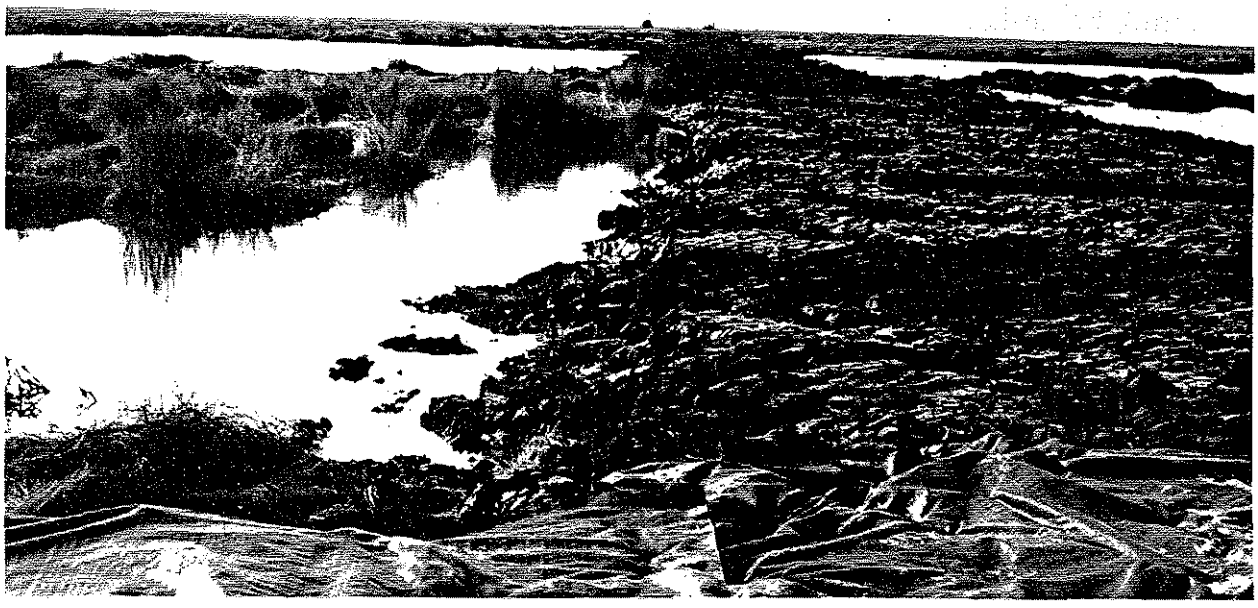


Figure 3.19. Dredged material piled to create road dump through open water area. Note filter cloth in the foreground (Photography by D. Clark.)

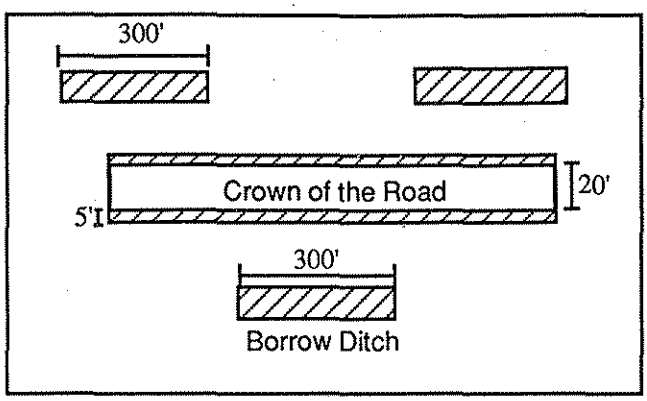


Figure 3.20. Plan view of typical road dump and staggered alternating borrow ditches.

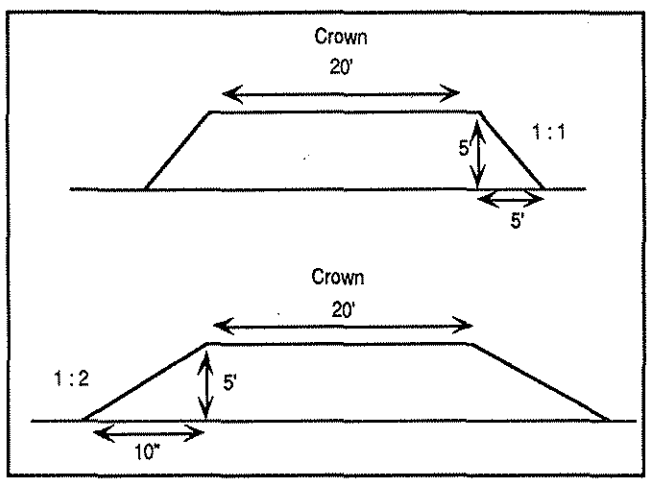


Figure 3.21. Examples of road dump side slopes. The bottom width of the road is determined by the width of crown plus side slope (1:1 = 30-foot bottom width; 1:2 = 40-foot bottom width).

will travel. The final number of layers of boards depends on the soil conditions and the size of the drilling rig. Consequently, costs increase as more boards and labor are required. The boards are rented by the drilling company for a 90-day period with three 30-day renewal options. If the operation extends beyond 180 days before a site is abandoned or the road is made permanent, there is no additional cost for board rental. However, the boards remain the property of the rental company. Typical costs (at current market prices) for a board road with three layers is $8.50 per linear foot. Additional layers of boards incur additional expense because of the greater amount of hand labor required for placement as well as the total number of boards used. If four layers, plus the runners, are required, board rental and placement costs may be $12.00 per linear foot. If the location requires a "mixed" operation, i.e., the site is accessed by barge and a road dump/board road, the cost for the lumber rental is generally doubled to cover the increase in transportation costs.

When water courses are encountered, they must be re-routed or culverts installed through the road dump to maintain natural flow. If larger streams must be crossed, bridges may be required (**Figure 3.26**). Bridge construction costs vary, with cost per linear foot decreasing as length increases. A "short" bridge, 40 to 50 feet long, costs approximately $600 per linear foot, while at current market prices, longer bridges may cost $500 to $475 per foot.

Perhaps the most significant consideration when evaluating road dump/board road versus canal access is the restoration process. Board road access is designed to be removed in the event of a dry hole or site abandonment. Financial incentives exist for both the drill site operator/owner and the road dump/board road construction company. For the former, payment of rental fees for the boards ceases, and for the latter an additional contract to remove and restore the site will be negotiated in addition to having the boards available for another contract. Boards are commonly reused three or four times.

A road to a producing well is made permanent by placing shell or limestone directly on top of the boards. Additional deposits of shell or limestone are laid down as needed for routine maintenance during the life of the well.

3.3.2. Impacts on Wetland Values and Functions

Access routes to drill sites using road dump construction prior to 1953 are visible on aerial photographs from Cameron Parish. These earlier routes normally used a continuous borrow ditch, a technique that promotes mixing between hydrologic regimes. Abandoned sites from this time show little evidence of restoration of the road dump or borrow ditches; however, the routes are re-vegetated. While some of the continuous borrow ditches may have developed into boat routes and remain evident in the landscape, many road dumps have re-vegetated and are identifiable only as an elevated linear vegetation anomaly. Road dumps, like access canals, influence wetland values and functions through: (1) conversion of marsh habitats to open water and upland habitat; and, (2) alteration of the hydrologic regime of coastal marshes.

3.3.2.1. Alteration of Habitat. Road dump construction results in the immediate conversion of marsh habitat to open water and potential spoil habitat. Unlike canal spoil banks, the ratio of area altered by the borrow ditches equals the area al-

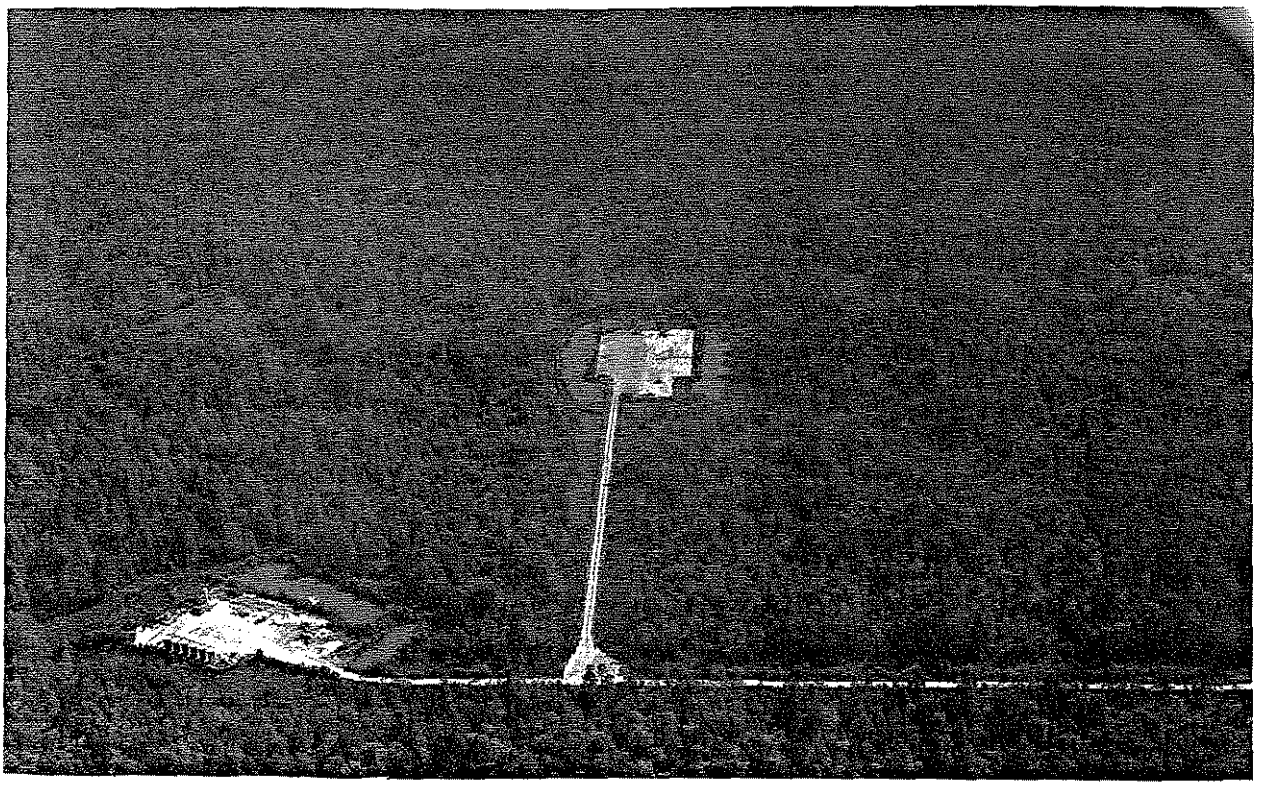


Figure 3.22. Aerial view of board road and ring levee/drill pad in forested wetland. Note width of cleared area: ring levee is larger than 400 by 400 feet. (Photography by D. Cahoon.)

Figure 3.23. View of road dump in Figure 3.19 with boards recently put in place. Note bundles of planks in foreground ready to be installed. (Photography by D. Clark.)

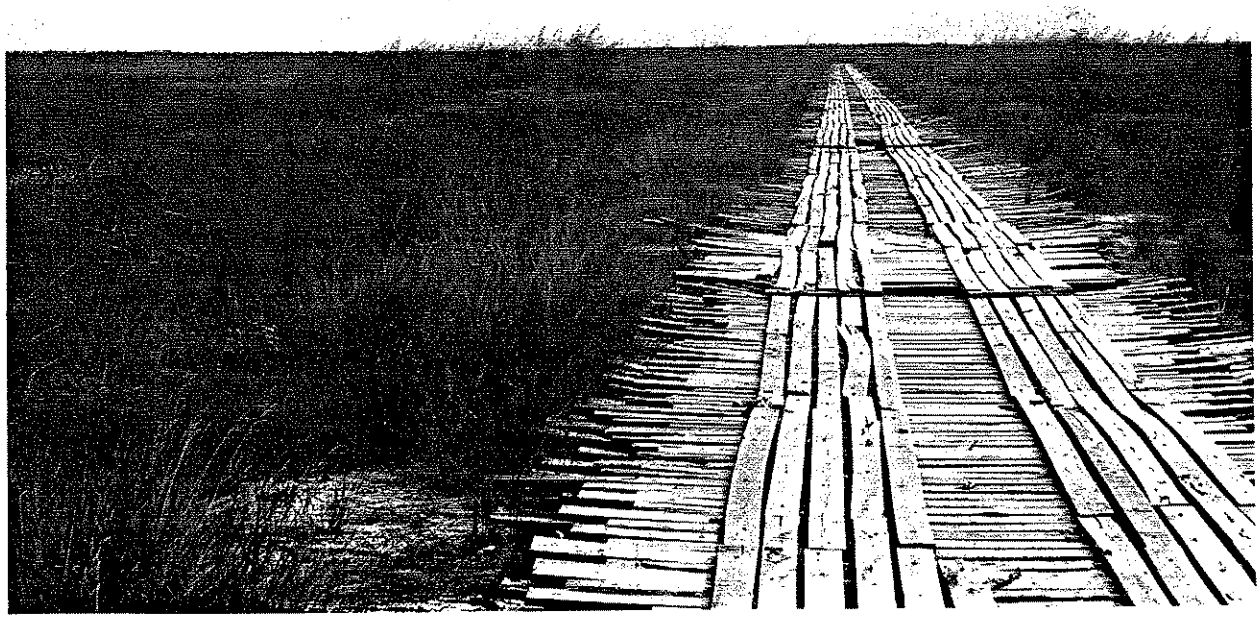


Figure 3.24. Completed board road, ground view. (Photography by P. Keney.)

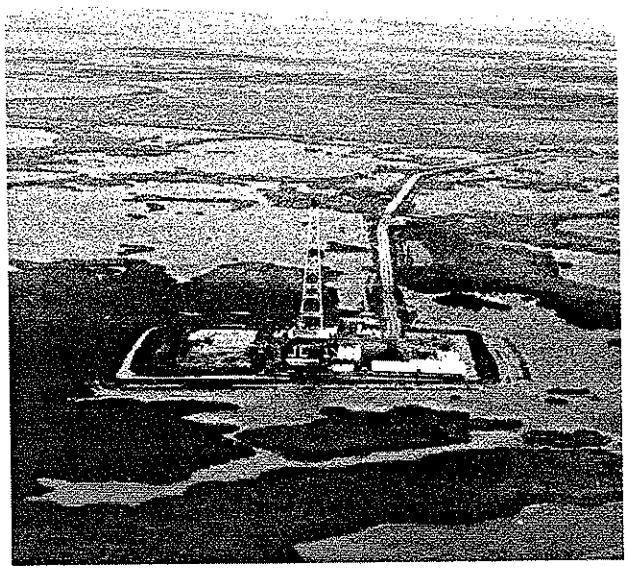


Figure 3.25. Completed board road, aerial view. Note configuration of road, staggered borrow ditches, ring levee, and drill pad. (Photography by D. Cahoon.)

tered by the road dump. The standard road design produces a borrow ditch equal in area to the road dump even though the borrow ditch alternates along the road dump route. The borrow ditches and the road dump may be larger than the standard design dimensions, but pond environments created by the borrow ditches are shallower (5 feet vs 8 feet) and not as continuous as the deeper, linear channels created by canal construction. Using the dimensions of a road dump as described in Section 3.3.1.2 (30–foot wide road dump and 30-foot wide borrow ditch) every 100 feet of road dump alters 0.137 acres of marsh. For a 1,100 foot access road (the maximum length allowed under the USACE General Permit NOD-13, **see Section 3.3.4.4**), approximately 1.5 acres of marsh are altered to provide access to a drill location. With the addition of the area altered by the ring levee/drill pad (400 by 400 feet) the altered area increases to 5.2 acres. When compared with the 10.3 acres altered by a 1,500-foot canal/slip, (**Table 3.1**), the area altered by a road access is about 50 percent less (**Figure 3.27**). [NOD-13 dimensions were revised during re-authorization of the general permit in 1988. Maximum ring levee size is 400 by 400 feet, with

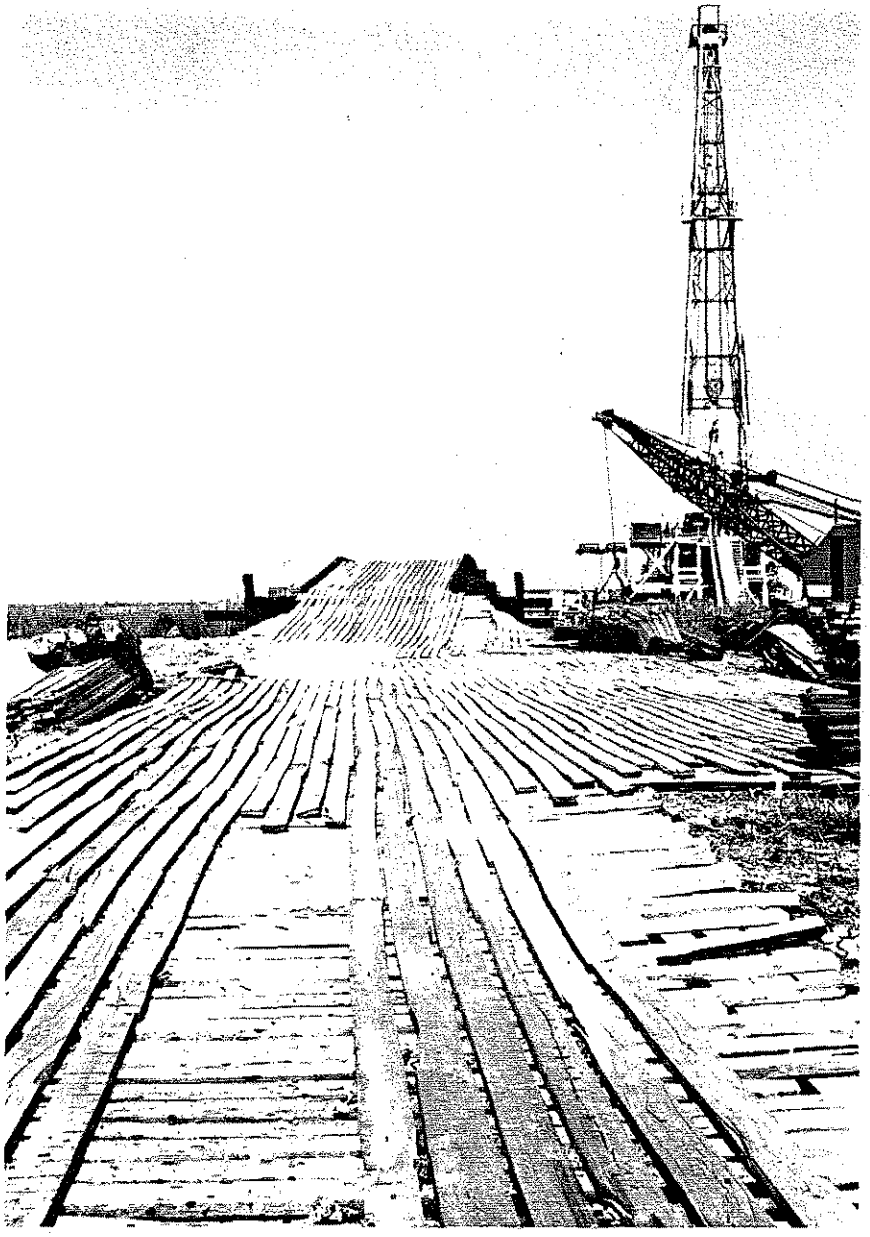


Figure 3.26. Board road with bridge crossing. (Photography by P. Keney.)

300 by 300 feet preferred. This will reduce substantially the impacts of an NOD-13 authorized boardroad. All board roads and ring levees ≥ 300 by 300 feet will require a geologic review.] Also, the difference in impacts increases with the length of access. Therefore, a 5,000-foot canal/slip alters 30.6 acres, while a road dump/ring levee of the same length alters only 10.0 acres, or 67 percent less.

3.3.2.2. Influence on Hydrology. Impacts to adjacent marsh surfaces may continue through the alteration of existing hydrologic regimes after road dump construction has been completed. Such alterations are chronic rather than acute. The newly created road dump acts much like a canal spoil bank: as a linear, elevated feature it is a barrier to sheet flow across the marsh. Orientation of the road dump affects the degree to which this occurs, but unlike canal spoil banks, a road dump is not a continuous solid barrier to water movement. The required installation of culverts at periodic intervals insures water movement across the marsh surface. Such movement probably creates new channels because water becomes funneled to these sites. Also, natural channels crossed by the road dump remain connected by culverts or, if navigation is required, by bridges. Even with these gaps,

some interruption of the natural hydrologic regime is inevitable. If the road dump is perpendicular to water movement, a hydrologic head may develop alternately on either side in response to rising and falling tides. The periodicity of inundation and drainage may be altered, thus impacting plant and animal species inhabiting the marsh (see Section 1.2).

Subsurface water flow and drainage are altered by the weight of the road dump compressing the underlying organic layer. The reduction in subsurface, cross-sectional flow area and the increase in the density of the substrate reduce flow rate.

Feeding and spawning habits of aquatic organisms are likely to be interrupted because of the linear barrier of the road dump, but this is probably less severe than with canal spoil banks because the barrier is not continuous. Excavation and deposition alter turbidity and water quality. Silt veneers may bury sessile organisms and cause death or hinder recolonization. Reintroduction of toxic substances and nutrients in runoff from the road dump may impact the surrounding marsh and organisms.

3.3.3. Influence on Wetland Loss

The construction of road dump access routes for oil and gas exploration and development contributes to wetland loss in south Louisiana primarily by the direct conversion of marsh habitat to shallow open water ponds and biologically nonproductive industrial sites with upland shrub/scrub vegetation. The alteration of hydrologic regimes caused by improper route selection or construction techniques potentially impacts a much greater area than the actual road dump.

No quantitative data are available on the total area directly converted from wetlands to road dump/board road and borrow pits; however, scars of active, abandoned, and partially restored sites are distinct on aerial photography of coastal wetlands. This is particularily true in the Chenier Plain of western Louisiana.

No data are available for the actual number of road dump/board road access routes that have been restored. Partial restoration is more common than complete restoration. Even when total restoration of an access route has been attempted, impacts to the wetlands remain. The presence of restored sites visible on aerial imagery indicates that impacts to wetlands have been lessened but are still present.

3.3.3.1. Cause-Effect Relationships. Like canals, road dump/board road access routes disrupt ecological processes and, thus, indirectly cause significant wetland alteration or loss (**Table 3.4**). As a barrier to water movement, road dumps alter inundation and sediment distribution patterns. Borrow ditches that connect differing salinity regimes may promote saltwater intrusion into fresher

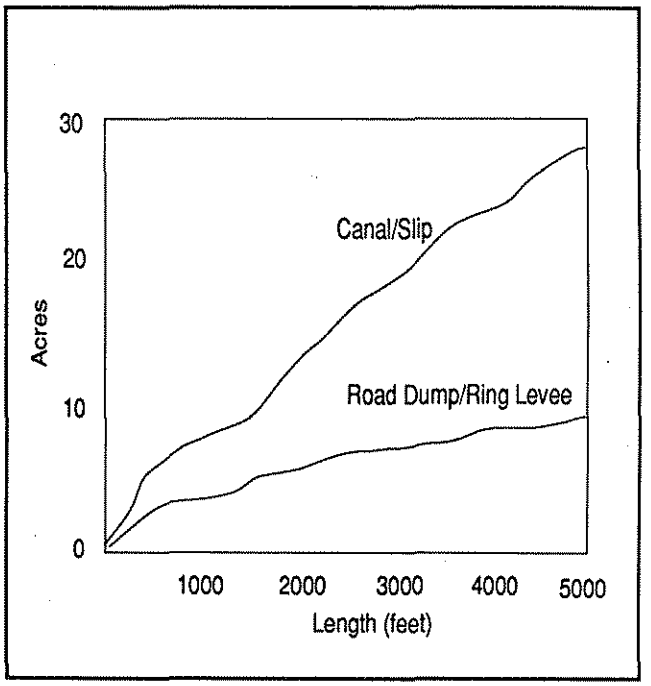


Figure 3.27. Canal versus road dump/board road—acres altered (adapted from Vinzant, 1986).

marsh areas. These impacts reduce organic production and therefore vertical accretion and local marsh submergence. **Table 3.4** presents the cause-effect relationships for direct (acute) and indirect (chronic) wetland loss related to road dump/ring levee construction.

3.3.4. Managing Impacts through the Regulatory Process

Various techniques developed to minimize change to the wetland system can be employed during the construction of a road dump/board road and ring levee. Encouraging land access rather than canal access can reduce impacts by tens of acres of wetlands for a small increase in the initial financial investment. If exploration is successful, expenditures during the life of the well will be less if land access is chosen. Furthermore, acute and chronic environmental impacts of road dump access are less than those of canal access.

3.3.4.1. Avoiding Impacts to Surface Features and Functions. This section discusses methods for avoiding impacts associated with road dump/board road construction by using an existing

road dump route, a natural elevated access route, existing public or private roads, or an alternate access method.

Road dump access is the standard alternative to canal dredging. Direct impacts (acute) to a wetland site are reduced substantially by using this method (see **Figure 3.23**). Indirect impacts are also reduced. Although generally unpopular for logistical and financial reasons, "mixed" land-water operations can be used as a viable alternative access method in selected locales. Even when road dump/board road access is used, impacts to surface features and wetland functions can be avoided.

Timing of Construction. The noise and commotion associated with road dump/board road construction may be disruptive to nesting and breeding bird colonies. Timing construction activities to occur during nonbreeding seasons avoids such impacts. See Timing of Construction in **Chapter 3.2.4.1** for financial impacts.

Existing Access Routes. The necessity of dredging the marsh surface to provide fill for road dump construction can be avoided or reduced by using existing road dumps, public or private roads, or other elevated routes, such as cheniers, levees, or existing spoil banks. This can also result in substantial cost savings to the operator. If combined with relocation of the drill site and directional drilling techniques, the use of existing access routes may totally avoid additional site access impacts.

Alternate Drill Site. Relocation of the drilling site location may result in: (1) reducing the length of the necessary access route; or, (2) using a drill site or upland site with existing access from outside the wetland area. The use of an alternative drilling location, coupled with directional drilling techniques, may thereby reduce or avoid entirely access impacts. **See Section 3.2.4.1** for financial implications.

Directional Drilling. Road dump/board road construction impacts may be reduced or completely avoided by directional drilling from an existing drill site or an upland site. **See Section 3.2.4.1** for a discussion of directional drilling.

Combining Avoidance Techniques. By using road dump rather than canal access, several direct and indirect impacts to wetlands can be avoided. The only way to avoid further impacts is to use an existing drill site or upland location. Combining road dump access with existing access routes and drill sites, alternate drilling sites, and directional drilling techniques significantly reduces and may even avoid completely access impacts in wetlands, often at little or no additional cost. Even if the costs are greater, the increased potential for restoration of a road dump access route may outweigh them.

3.3.4.2. Minimizing Impacts to Surface Features and Functions. Road dump/board road access has less impact on wetland values and functions than canal access. Further reductions can be achieved through the combination of minimizing techniques with the before–mentioned avoidance techniques.

Width. The width of road dumps is dictated by the size of the heavy equipment trucks that carry the dismantled drill rig to the site. A crown width of 20 feet is necessary and an industry standard. The height of the road dump base may be established by tidal range. Keeping the elevation of the road dump base as low as feasible reduces the width of the side slopes. This in turn reduces the amount of required fill, and the size of the borrow ditches, and thereby minimizes impacts. Any request for a board road crown width of more than 20 feet should not be considered without significant justification.

Length. Total length of the road dump may be reduced by selecting an alternate drill site or by directional drilling. Although decreasing road dump length does not reduce impacts as greatly as decreasing canal length, some lessening of impacts is achieved, 0.137 acres of wetlands for every 100 feet.

Minimizing road dump length to 1,100 feet has been encouraged since the inception of the NOD-13 General Permit in 1981. The Louisiana Department of Natural Resources (unpublished data) has recorded more than 600 instances in Louisiana's coastal zone where road dump length was designed to comply with the General Permit requirements .

Road Alignments. Impacts to local drainage patterns, both channel and overland sheetflow, are minimized through road dump alignment. Alignment parallel to sheetflow lessens changes in the hydroperiod of the area and prevents excessive inundation or drainage. Maintaining the status quo of the hydrology of the area enables natural sedimentation rates, subsidence, and organic production rates to continue. Also, fewer culverts may be required to move water through the road dump, thus reducing construction costs.

Road dumps that result in enclosed or partially

Table 3.4. Observable and hypothetical cause-effect relationships between board roads and marsh alteration.

	Construction Impact			
	Excavation		Deposition	
	Road Dump	Ring Levee	Road Dump	Ring Levee
ACUTE ENVIRONMENTAL CONSEQUENCES				
Habitat Alteration — Physical Impact				
Direct Conversion to Open Water	√	√		
Increase in Turbidity (Local Scale)	√		√	√
Loss of Forested Wetland	√			
Direct Conversion of Marsh/Swamp to Biologically Non-Productive Industrial Site/Potential Upland Shrub/Scrub Created by Linear Feature in Landscape			√	√
Return of Nutrients, Toxins to Marsh Surface (in Form of Road Dump)			√	√
Noise, Commotion during Construction	√	√	√	√
Habitat Alteration — Ecological Impact				
Immediate Loss of Marsh/Shallow Water Habitat	√			
Immediate Gain of Open Water Ponds	√	√		
Redeposition of Particulates/Local Increase in Suspended Sediment Load	√			
Reduced Photosynthesis	√		√	√
Possible Suspended Pollutants/Hydrogen Sulfide/Heavy Metals/ Excess Nutrients	√		√	√
Immediate Loss of Forested Wetland Habitat	√			
Potential for Upland Spoil Bank Habitat			√	√
Disruption of Natural Surface Drainage Pattern			√	
Changes in Soil/Water Chemistry			√	√
Changes in Plant Growth			√	√
Impact on Biota				
Destruction of Biota	√			
New and Different Habitat	√		√	√
Silt on Water Bottom Reduces Interstitial Oxygen, Reduced Water Circulation	√			
Interferes with Behavior/Physiology of Aquatic Organisms, Submerged Vegetation			√	√
Burial of Biota			√	√
Habitat Diversity			√	
Potential for Interrupting Fish Spawning and Feeding			√	√
Interferes with Movements of Estuarine Organisms			√	
Potential Negative Impact on Plant Growth			√	√
Potential for Disturbing Avifauna Nesting	√	√	√	√
CHRONIC ENVIRONMENTAL CONSEQUENCES				
Habitat Alteration — Altered Physical Process				
Sediment Distribution	√			
Forest Succession	√			
Surface Hydrology and Drainage			√	√
Subsurface Hydrology and Drainage			√	√
Sediment Distribution			√	
Habitat Alteration — Physical Impact				
Sediment -Nutrient Trap	√			
Potential for Rapid Colonization by Invader Species	√			
No Chronic Impact due to Levee Construction/ Subsequent Hydrologic Isolation for Surrounding Wetlands		√		
Changes in Hydroperiod and Surface Drainage Patterns			√	√
Loss of Hydraulic Head Downslope due to Altered Sheetflow			√	
Potential Increased Frequency of Saltwater Intrusion due to Loss of Hydraulic Head			√	
Potential Increased Upflow Water Levels			√	
Compacted Marsh Surface and Restricted Subsurface Flow			√	√
Diminshed and Irregular Sediment Distribution Regime			√	
Habitat Alteration — Ecological Impact				
Reduced Vertical Accretion in Surrounding Marshes	√			
Potential Succession to Shallow Water Wetland Community	√			
Potential for Different Ecological Community (e.g., cypress replaced by willow)	√			
Changes in Soil/Water Chemistry			√	√
Changes in Vegetation Dynamics: Species, Composition, Organic Matter Production/Accumulation			√	√
Changes in Mineral Accretion and Soil Nutrition			√	
Changes in Vertical Accretion Rate			√	

enclosed areas should be avoided. The combined synergistic impact of such barriers heightens adverse impacts to the enclosed marsh surface and results in marsh breakup and conversion to an open water environment. Surface features, i.e., natural streams, forested wetland areas, cheniers, lakes, levees, roads, and upland areas must be considered, as well as the desired top hole location and existing access routes when planning route alignment.

Culverts and Bridges. Every attempt should be made to minimize disruptions to the existing hydrologic regime along the access route. Culverts with at least a 24–inch diameter should be installed through the road dump at the proper marsh elevation for all natural streams crossed by the route. If that diameter is insufficient to maintain normal flow, larger culverts should be used. Additionally, 24–inch diameter culverts should be installed at least every 500 feet along the route to maintain sheetflow across the marsh. Culverts must not connect alternating borrow pits.

Borrow Pit Alignment. Continuous borrow pits may connect areas having different salinity regimes. Intrusion of saline water into a fresh marsh results in species dieback and marsh breakup. Additionally, continuous borrow pits provide avenues for boat traffic to enter wetlands. Wake action widens the borrow pit, resulting in additional marsh loss and increased maintenance of the road dump route. Borrow ditches 300 feet in length alternating along the road dump route minimize the interconnection of different salinity regimes and hinder boat travel. **See Figure 3.19.** If alternating or staggered borrow ditches are not possible, there should be a minimum of 50–foot gaps between successive pits.

Re-routing Streams. Flow in streams and natural channels is normally maintained by culverts or bridges. If this is not feasible, a water course may be re-routed around the end of the road dump and associated ring levee drill site by dredging. Dredged material should be incorporated into the road dump and/or ring levee and not deposited as a spoil bank along the re-routed stream. The artificial water course should reproduce the width and depth of the original stream to the extent possible.

3.3.4.3. Avoiding and Minimizing Techniques Combined. As an alternative to canal dredging, road dump/board road access to wetland oil and gas drilling sites is an effective impact management technique when coupled with avoidance and minimizing measures. Alternate drill site locations, directional drilling possibilities, and alignment of access route must be considered for each site. However, the combination of these variables can achieve reductions in the acute and chronic impacts of oil and gas access methods.

Some situations exist where canal access is more suitable and may have less impact than road dump access. For example, in a developed canal network, dredging a parallel slip has less adverse impact and is more economical than constructing a lengthy road dump access across the wetlands.

3.3.4.4. Suggestions for Implementing Management Techniques. Access by road dump/board road should be promoted as the preferred method because it is designed to be restored and also has less accute and chronic impact than canal access. The implementation of management techniques as outlined in **Table 3.3** is also applicable in road dump/board road permit applications.

The NOD-13 General Permit is an administrative vehicle that lessens adverse impacts and reduces applicant costs by decreasing the time between application and receipt of a construction permit. The following section discusses the design requirements for conformance with the NOD-13 General Permit.

NOD-13 Standards. A standard construction design for road dump/board road access has been adopted in the USACE, New Orleans District, General Permit NOD-13, implemented in March 1981. USACE permission may now be obtained without the public notice process by using the standard size dimensions as described in the NOD-13 and conforming to the other requirements. The dimensions of this permit represent an idealized standard. As stated earlier, final road dump dimensions are determined by the quality of the fill material at the site.

The standardized design **(Figure 3.21)** consists of a road formed by placing dredged fill on the marsh surface to create an elevated road dump 5 feet above the surrounding marsh with a crown width of 20 feet and side slopes a maximum of 5 feet wide. The completed road dump then has an overall width of 30 feet. Fill to construct the road dump is excavated from adjacent borrow ditches staggered on either side of the road **(Figure 3.21)**. The borrow ditches are excavated 20 feet from the edge of the road dump and may be a maximum of 300 feet long, 20 feet wide, and 5 feet deep. If the borrow ditches are not staggered on alternating sides, they must be discontinuous with gaps at least 50 feet long between the segments. Culverts,

usually corrugated metal pipe with at least a 24-inch diameter, must be installed through the road fill at the original surface level at least every 500 feet in addition to all crossings of streams, ditches, and sloughs and must be of sufficient diameter to maintain existing flows in all water bodies.

Overall length of the road dump and the ring levee which surrounds the drill site may not exceed 1,500 feet (See **Chapter 4.3.** for a description of ring levee construction procedures.) [NOD-13 dimensions were revised during re-authorization of the general permit in 1988. Maximum ring levee size is 400 by 400 feet, with 300 by 300 feet preferred. All board roads and ring levees ≥ 300 by 300 feet will require a geologic review.] Variations in this design are permitted in special circumstances. Other requirements regarding location and required restoration must be met in order to use this general permit.

3.4. HOVERCRAFT and HELICOPTERS

The United States military has developed hovercraft and helicopters capable of carrying heavy loads over relatively inaccessible terrain. The use of hovercraft as an alternative to marsh buggies in exploration activities has been preliminarily evaluated (Sikora et al., 1983; Sikora, 1988). The transportation of heavy drilling equipment across the marsh and water surfaces of coastal Louisiana by large hovercraft has been discussed but has not received serious consideration by industry as a viable alternative to canals and boardroads because technological developments are lacking. However, there are hovercraft capable of carrying loads heavier than land-based drill rigs (Sikora, 1988). It is not difficult to imagine hovercraft being adapted to drilling purposes. Incentives should be provided to the oil industry to develop this technology.

Presumably, hovercraft have little impact on the marsh surface because their loading ratio is low and any impacts that do occur are apparently not permanent (Sikora et al., 1983; Sikora, 1988). Therefore, their use as an alternative to canals and boardroads should be evaluated. However, transporting drilling equipment to the drill site by hovercraft or helicopter has never been tried. Hence, the cost of these site access methods is not known and their feasibility not tested. Still to be determined is how best to establish a stable foundation for the drilling equipment while keeping costs competitive. At the moment, the cost of both of these methods appears to be prohibitive. Until technological improvements are developed that make the use of hovercraft and helicopters routine, their use to access drill sites should be recommended only in situations where the use of current technology is not acceptable.

SITE PREPARATION

by
Donald R. Cahoon and Joseph C. Holmes, Jr.

4.1. INTRODUCTION

The evolution of technologies for preparing drilling sites in wetland environments closely parallels that for accessing those sites. In the 1920's and 1930's, oil and gas companies were confronted with the problem of supporting enormously heavy equipment (the derrick, boilers, mud tanks, and drilling equipment) on marsh soils with only one-tenth the load-bearing capacity of upland soils (Herbert and Anderson, 1936) or providing platforms for drilling in open water. Again, new methods were developed that became the industry standard worldwide for drilling in coastal environments. Today, the industry employs a submersible drilling barge for all sites accessed by a canal and a boarded drill pad surrounded by a ring levee for all sites accessed by road dump.

This chapter presents an overview of the history, construction methods, impacts on wetland values and functions, and appropriate techniques for managing impacts of site preparation techniques related to canal and board road access.

4.2. CANAL-KEYHOLE

4.2.1. Introduction

This section describes the standard techniques used to prepare a wetland drilling location accessed by canal. The history, procedures, environmental impacts, and techniques for managing impacts are discussed.

4.2.1.1. History. Prior to the development of the barge rig in 1931 and the submersible drilling barge in 1934, drilling derricks were constructed

on pilings in open water (Williams, 1929) or on wooden mats in shallow water (Williams, 1934c) and marsh locations (Williams, 1929, 1930; Herbert and Anderson, 1936). Even when accessed by a canal, the actual drilling location was situated on the marsh surface and supported by wooden mats (Williams, 1929). The expense of constructing piling and mat foundations, coupled with the difficulty in getting the rig equipment to the location, led to the development of the barge rig in 1931 (Williams, 1934a; Posgate, 1949). The barge rig consisted of a derrick and other drilling equipment permanently affixed to a floating barge. The barge had a 4-foot wide slot or "bay" in the center to allow the barge to be removed from around the well head. As heavier equipment was required to drill wells of ever-increasing depth, these floating drilling platforms became more and more unstable (i.e., top-heavy). Hence, in 1933 the submersible drilling barge was invented (Williams, 1934b). It resembled the floating drilling barge, except that it could be submerged at the site to provide better stability. The submersible drilling barge revolutionized coastal drilling and quickly became the industry standard for drilling in man-made canals and open–water lakes and ponds.

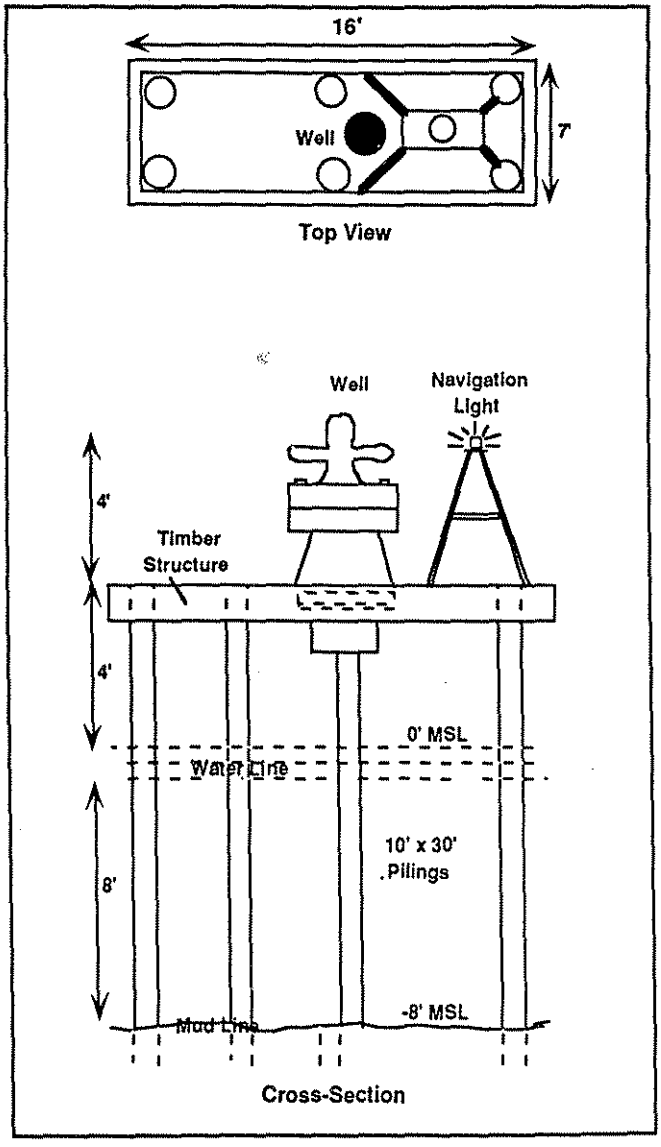


Figure 4.1. Illustration of keyway showing plan and cross-section views.

4.2.1.2. Procedure. The first step in preparing a modern drilling location in wetlands that have been accessed by a canal is to dredge a keyhole at the end of the canal. The keyhole (see **Chapter 3** for description) provides room for the drill barge and auxiliary service vessels at the end of the canal **(see Figures 3.3 and 3.4)**. Mats or pile-supported structures are not required because the drill barge provides a suitable foundation for all equipment. The only structure that must be constructed is the keyway, which surrounds the wellhead and fits within the slot on the drill barge **(Figures 3.1 and 4.1)**. The keyway protects the wellhead and guides the drill barge. If the waterbottom is soft or unstable, it may be necessary to construct a shell pad for the submersible barge to rest on **(Figure 4.2)**. The shell may be placed directly on the bottom or the bottom may be dredged to provide a level base for the shell pad and to lower the elevation of the barge. Once the drill barge and auxiliary vessels are on location, site preparation is complete.

4.2.2. Impact on Wetland Values and Functions

Most operations associated with preparing a drilling site have little impact on wetland values and functions. Some may even provide an indirect environmental benefit. The major exception to this is the impact of dredging a keyhole at the end of the canal.

4.2.2.1. Alteration of Habitat. The dredging of a slip and the deposition of spoil directly converts marsh to open water and spoil bank habitat. The extent of the impact of this site preparation activity on coastal marsh habitats is described in **Chapter 3, Section 3.2.2.1**. The construction of a keyway and shell pad, associated with installation of a submersible drill barge, should have no detrimental impact on wetland habitats. The construction of a shell pad may even provide an environmental benefit by creating potential shell reef habitat in shallow water areas.

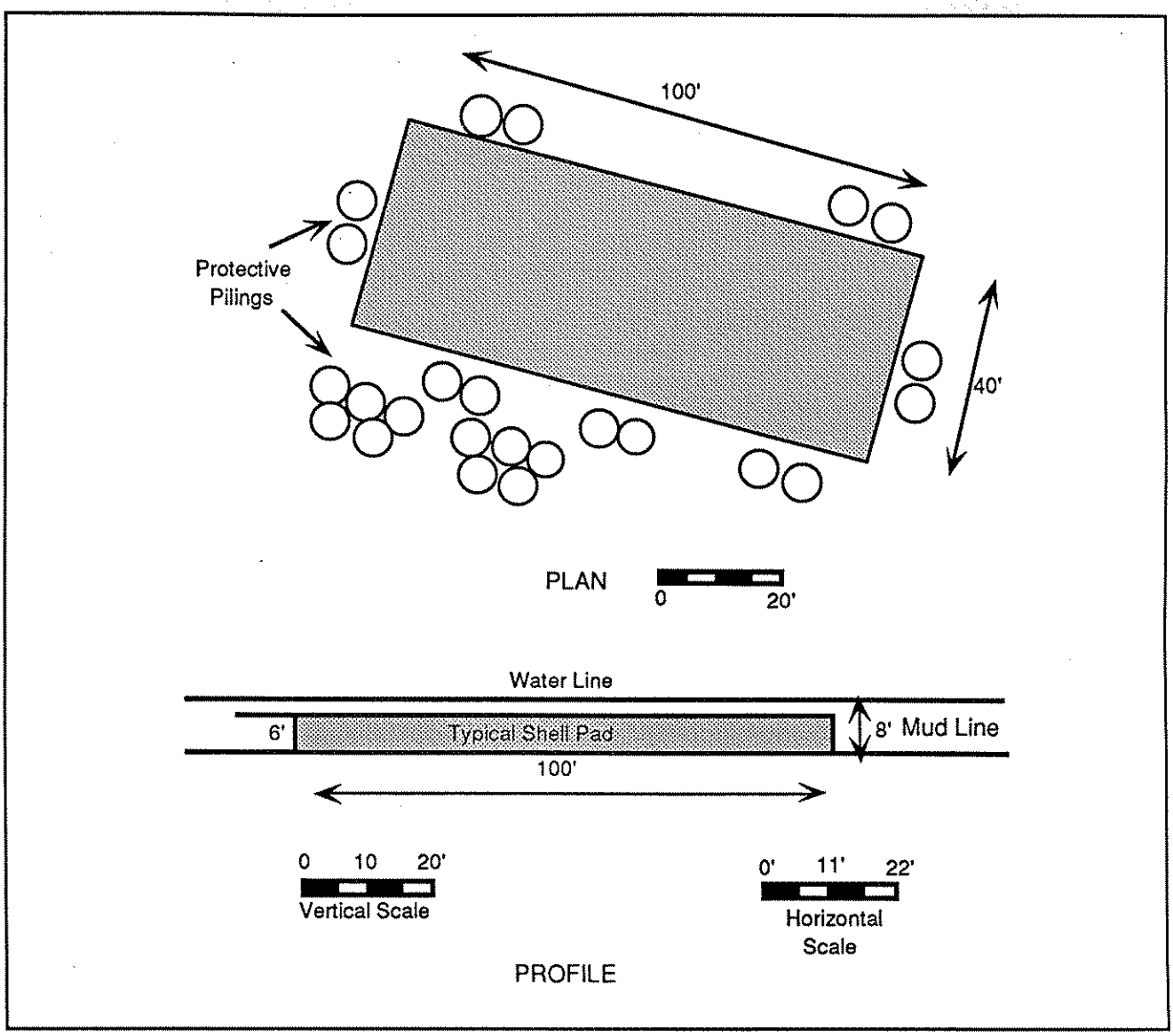


Figure 4.2. Illustration of typical design of foundation pad for a drill barge or production platform made from shell or limestone. The dimensions may vary up to 250 feet in length to 225 feet wide under the NOD-13 general permit.

4.2.2.2. <u>Influence on Hydrology and Water Quality</u>. The only site preparation activity that significantly influences hydrology and water quality is dredging the slip at the end of the canal. The impact of this activity on hydrology and water quality is fully described in **Chapter 3, Section 3.2.2.2.** All other site preparation activities have a negligible impact on hydrology and water quality, although dredging associated with shell pad construction may cause short-term local turbidity maxima. This could create a problem at open water sites in the vicinity of oyster reefs or other important bottom communities.

4.2.3. Influence on Wetland Loss

The dredging of a keyhole, or slip, directly contributes to wetland loss. The cause-effect relationship between dredging and wetland loss is described in Section 3.2.3. All other site preparation activities have no appreciable influence on wetland loss.

4.2.4. Managing Impacts through the Regulatory Process

Methods for managing impacts associated with dredging a keyhole are explained in **Section 3.2.4.**

Impacts to nesting birds can be avoided by appropriate timing of construction (**Section 3.2.4.1**), and wetland loss can be reduced by minimizing slip dimensions (**Section 3.2.4.2**). Turbidity associated with shell pad construction can be minimized if the shell pad dimensions are kept to the smallest practical size.

4.2.5. Suggestions for Implementing Management Techniques

The procedure for reviewing canal/slip dredging applications is reviewed in **Table 3.3**. As for shell pad construction, regulatory review has been streamlined by the development of a general permit. The New Orleans District of the USACE has developed General Permit NOD-3, authorizing construction of foundation (shell or limestone) pads (up to 250 feet in length and 225 feet wide) for drilling barges and oil and gas production facilities in open water bodies and man-made oil field canals.

4.3. ROAD DUMP/RING LEVEE

4.3.1. Introduction

This section describes the preparation of a wetland drilling site accessed from land by a road dump /board road. Construction of the pollution control levee (i.e., ring levee), drill pad, and reserve pit are described. The acute and chronic impacts to the construction site and surrounding wetlands are evaluated, as well as methods for minimizing impacts.

4.3.1.1. History. Drill site locations in marsh environments were accessed initially by boat or barge from natural water bodies or canals. Wooden drilling derricks were erected on 2–to 3–foot high wood cribbing on wood mats placed on the marsh surface. Such mats may have had as many as three criss-crossed layers of timbers 12 inches wide and 30 feet long and occupied a 40–square foot area. Larger derricks and greater loads required for deeper drilling changed this earlier practice. By the mid–1930's drilling rigs in the marsh areas of coastal Louisiana were commonly constructed on pilings elevated above the marsh surface. Access to the drilling location was by a canal dredged specifically to the site or an access road constructed on mats on the marsh surface or on elevated pilings, depending upon the local conditions. Levees were often constructed around the drilling site to protect them from flooding. Today's drilling equipment consists of portable land drilling rigs, pumps, power generators, and mud shakers, and usually requires an area of operation of 160,000 square feet (nearly 4 acres). A portion of this area is a ringing levee designed to prevent flooding of the drill site and contain any potential pollution within the area of operation.

4.3.1.2. Procedure. The dragline used to prepare the road dump/board road is retained to prepare the drilling sites at the end of the road dump/board road route (**Figure 4.3**). The proposed drilling depth and required drilling rig size are factors that affect the overall size of the drilling site (**Figure 4.4 and 5.6**). The minimal area required for a drilling rig capable of drilling to 10,000 feet is 250 square feet. Rigs capable of attaining depths of 20,000 feet need a larger drilling site. **(See Chapter 5, Section 5.3.2 and Figure 5.6.)**

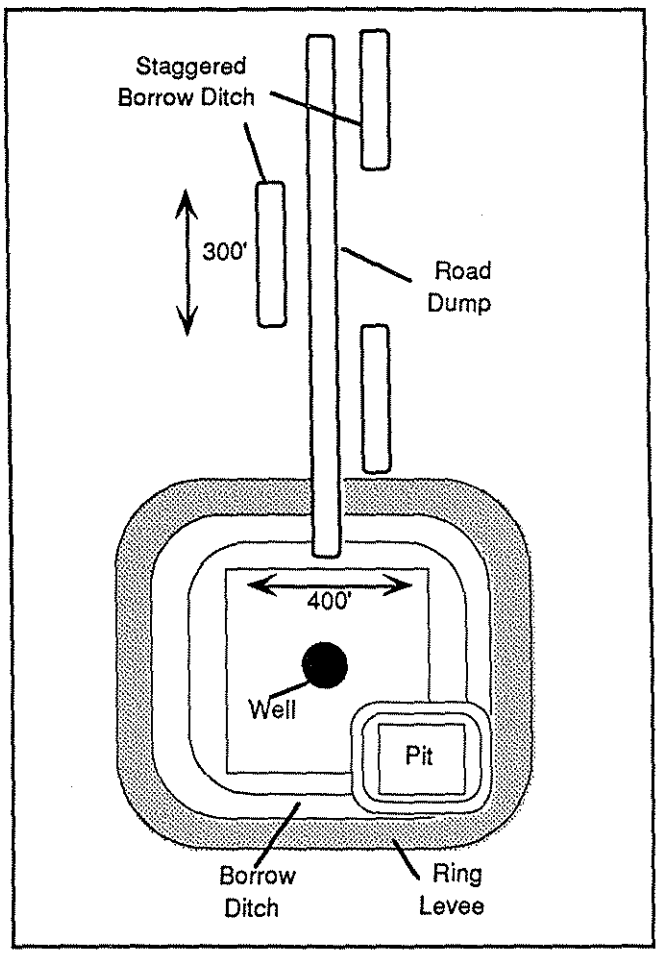


Figure 4.3. Road dump access route with ring levee drill site.

During the last decade, standard construction design has been a 400 by 400 foot perimeter ring levee with a 2–foot wide crown elevated 3 feet above the adjacent marsh level. Recently, however, the Environmental Protection Agency (EPA),

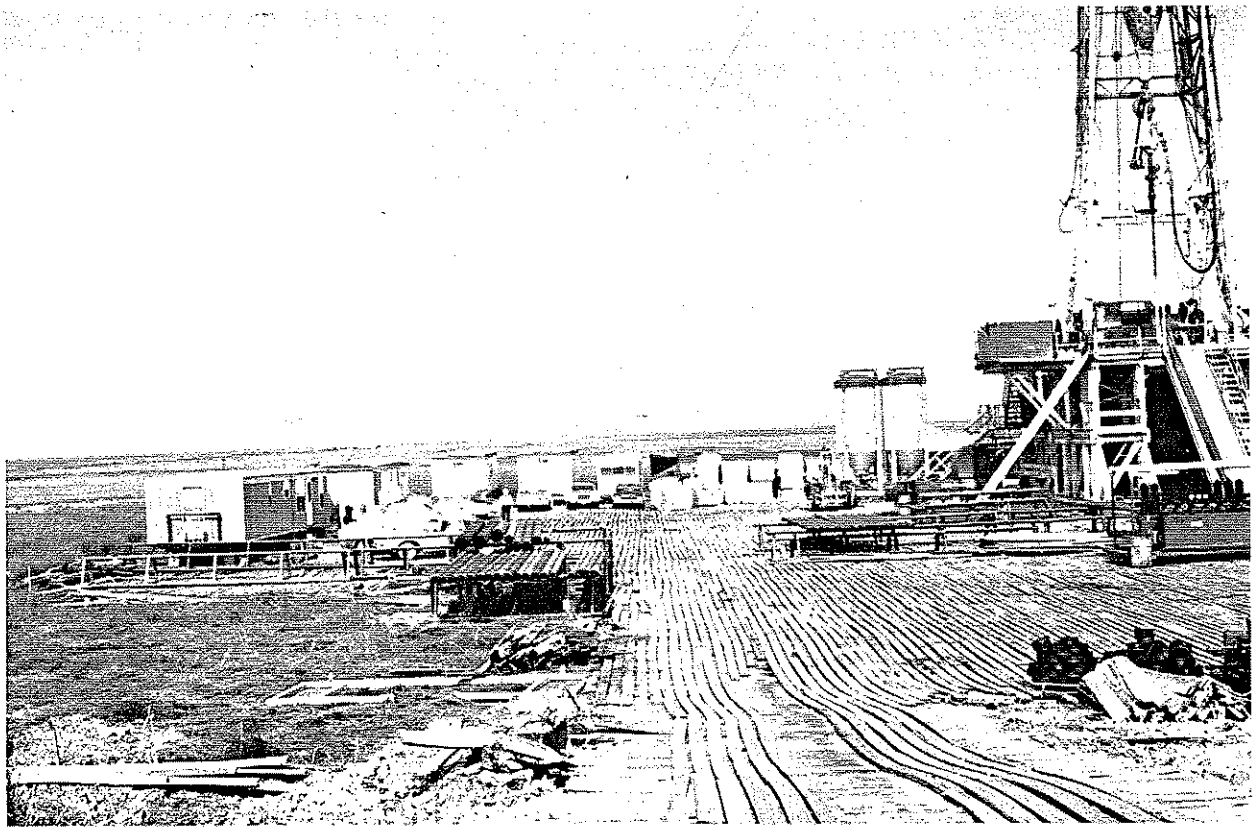


Figure 4.4. Board road accessed drill site. Note boarded drill pad area, drill rig support equipment, and ring levee (far left). (Photography by P. Keney.)

USACE, Louisiana Department of Natural Resources (LDNR), and industry have been moving toward smaller ring levee dimensions. New ring levee dimensions of 300 x 300 feet to 350 x 350 feet are currently being recommended by the regulatory community with a maximum of 400 by 400 feet.

The overall width of the levee is commonly 8 feet (**Figure 4.5**). Fill for the ring levee is excavated from a continuous borrow ditch within the surrounding ring levee. Within the ring levee, a reserve or mud pit is excavated to a depth of 3 feet below the marsh surface. The pit, surrounded by a pit levee, commonly occupies up to one quarter of the area within the ring levee. The remaining area is the actual drill pad and typically occupies about 45,000 square feet. The pad is normally elevated 3 feet above the natural ground level by fill removed from the mud pit. The drill pad is covered with boards (placed by hand) to form a stable supporting base for the drilling rig. Natural wood pilings are usually driven into the marsh under the drill pad to provide additional support for the drilling rig.

An alternative construction method is employed if soil conditions at the drilling location are suitable. After the ring levees are constructed, water is pumped from the site, filter cloth is placed on the marsh surface, and boards are placed on the filter cloth.

4.3.2. Impacts to Wetland Values and Functions

Evidence of ring levee drill sites is easily discernable on aerial photographs of wetlands. Active drill sites often appear as square or rectangular plots at the termination of linear features (road dump/ board road access routes). Abandoned drill sites often look like geometric variations in vegetation surrounded by solid or broken marsh, forested wetlands, or open water. Restored or partially restored ring levee drill sites may appear as rectangular open water sites or as rectangular areas of solid or broken marsh. Aerial photographs from as early as 1953 in Cameron and Terrebonne Parishes confirm these sites. As with canal drilling slips and both canal and road dump access routes, ring levee drill sites influence wetland values and functions by (1) the direct conversion of wetlands from productive wetlands into initially non-bio-

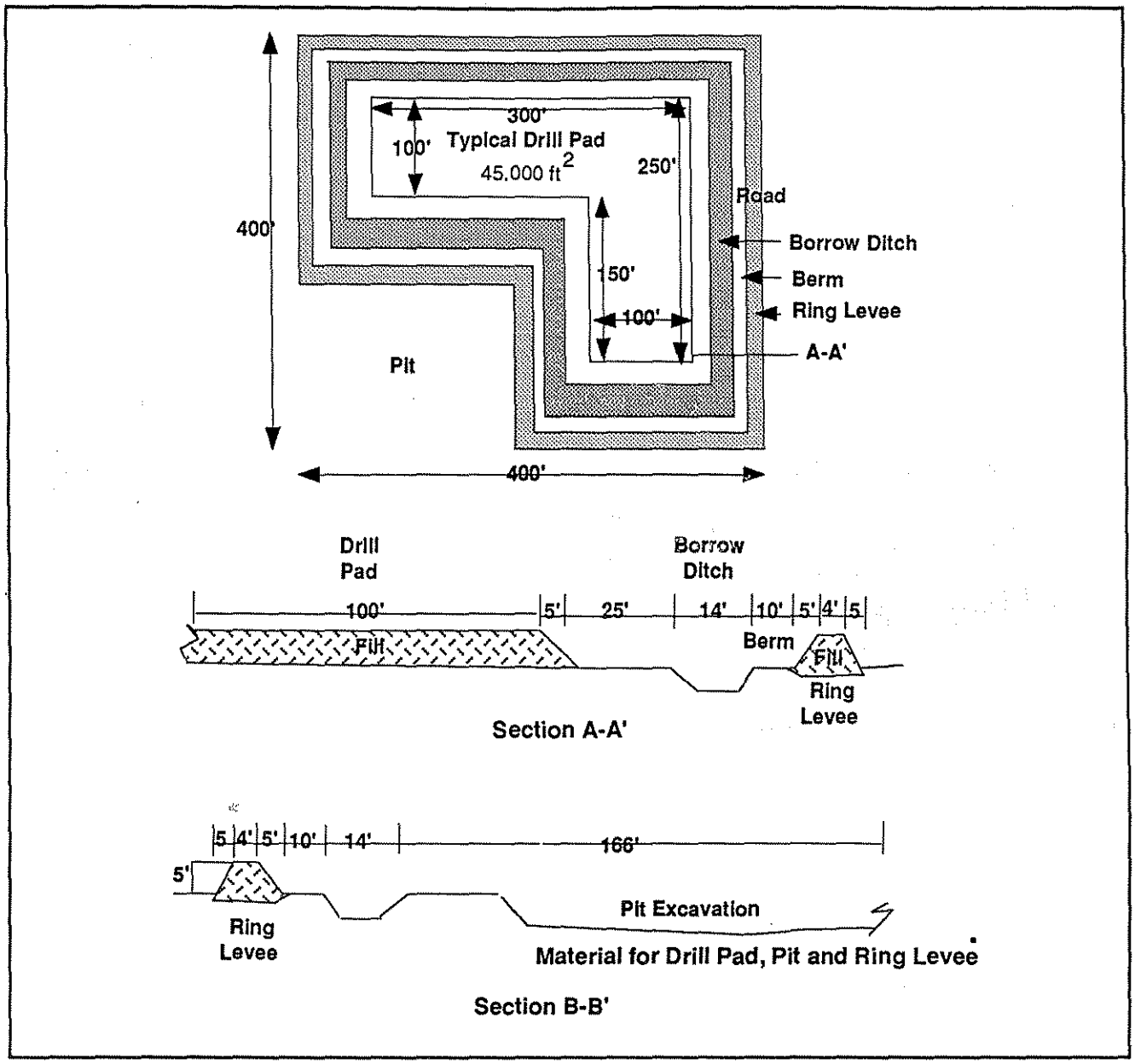


Figure 4.5. Cross-section and plan view of typical ring levee/drill pad.

logically productive industrial sites and potential upland shrub/scrub sites; and, (2) alteration of the hydrologic regime of the area.

4.3.2.1. Alteration of Habitat. The construction of a perimeter ring levee effectively removes all the land within it from the wetland ecosystem. Although a loss to the total area of wetlands and thus a loss to the total potential biomass production, the ringing levee serves a beneficial function. It offers protection to the surrounding wetlands from toxic substances, (e.g., diesel fuels and lubricants, acid muds, and hypersaline waters) associated with drilling operations (**Chapter 5**). This benefit is actually a by-product of site construction since the original purpose of the levee was to isolate and alter the enclosed wetlands to accomplish drilling. Legislation to preserve wetlands and waters has contributed to the evolution of the ring levee into a pollution containment structure.

Within the ring levee, deeper pits that contain drilling muds and saltwater produced from the well are lined with an impermeable material to prevent seepage and contamination of subsurface water. After construction, the area occupied by and contained within the ring levee ceases to be wetlands. This loss may be short lived if the site is nonproductive and promptly restored, or permanent (20 or more years) if exploratory drilling results in a producing well. Productive wetlands may be totally or partially re-established at a restored site.

4.3.2.2. Influence on Hydrology. The ring levee drill site is an extension of the partial barrier to the existing hydrologic regime created by the construction of the road dump access route with three significant differences: (1) the ring levee is a much wider (generally 400 feet) barrier; (2) unlike the road dump, there are no passage ways to allow uninterrupted flow in natural channels that cross the site; and, (3) sheetflow is impeded by the site. Like canal spoil banks and road dumps, the weight of the dredged sediments resting on the marsh surface compresses the underlying materials and reduces the sub-surface, cross-sectional flow area. During excavation and deposition of the marsh surface to create the ring levee, local turbidity can increase beyond (i.e., outside) the ring levee. Natural streams located at the drill site have to be re-routed around the ring levee.

4.3.3. Influence on Wetland Loss

As the ring levee drill site is an extension of the linear access road dump, the acute and chronic impacts on wetland loss can be considered essentially the same. **Table 3.2** details the cause and effect relationships of the impacts of ring levee construction.

4.3.4. Managing Impacts through the Regulatory Process

Adverse impacts to wetland ecosystems caused by ring levee drill site construction can be reduced by combining avoidance and minimizing techniques. Many of the alternate techniques for access route construction are applicable.

4.3.4.1. Avoiding Impacts to Surface Features and Functions. This section describes the potential of four techniques for avoiding impacts to wetland values and functions.

Alternate Access Methods. Because a ring levee is constructed at the termination of the access route, use of an alternative method to access the selected drill site is not a method of reducing impacts unless the drill site is removed from the wetlands to an existing or an upland location.

Timing of Construction. The same impact to avifauna is likely to occur from ring levee construction as with canal or road dump construction. Consequently, the same avoidance techniques are applicable. **See Section 3.2.4.1.**

Existing Access Routes. The use of existing access routes, while highly recommended, has little impact on ring levee construction unless the drill site location has been judiciously located. Dredging and area impacts may be reduced by incorporating an access route as one side of the boundary of an existing ring levee.

Directional Drilling. Wetland alteration may be completely avoided through directional drilling (see **Section 3.2.4.1** for a discussion of directional drilling techniques). If the down–hole objective can be obtained by a deviated hole from an existing or upland drill site, no alteration of wetlands need occur. Additionally, the impacts associated with accessing the drilling site may be reduced or completely avoided.

4.3.4.2. Minimizing Impacts to Surface Features and Functions. The construction of a 300 by 300 foot ring levee/drill site results in the direct alteration of 2.1 acres of wetlands. A larger ring levee/drill pad may be justified if the planned depth requires an abnormally large drilling rig, or in cases of geo-pressured formations or geologic abnormalities, or if safety or pollution potential are considerations. Larger ring levees may be permitted under the NOD-13 General Permit if the overall length (access route and ring levee) does not exceed the maximum allowable and sufficient data are presented to the USACE District Engineer to justify a large ring levee. A NOD-13 General Permit is not granted for ring levees larger than 400 by 400 feet.

The size of a ring levee/drill pad may be reduced by using an existing or abandoned drill site, decreasing the areal size of the mud and/or reserve pits, or using a containerized mud pit. (See Section 5.3.2). Short of using an existing or abandoned drill site or moving the drill site to an upland location, a reduction of the 300 by 300 foot standard ring levee is difficult and may be technically impossible. If a natural stream course is interrupted by the location of the ring levee/drill site, the stream must be re-routed. This results in the alteration of additional wetlands, but maintaining the hydrologic regime probably reduces chronic impacts and therefore is less destructive than the additional acute impacts that result from the dredging to re-route the stream. Impacts associated with the re-routing of a natural stream around the ring levee/drill site can be held to a minimum by: (1) making the artificial channel the same dimensions as the natural channel; and, (2) placing the dredged material on or within the ring levee.

CHAPTER 5

DRILLING

by
Brian J. Harder and W. Kent Webb

5.1 INTRODUCTION

The process of petroleum exploration ends with drilling. New drilling technology, which is constantly being improved, allows wells in wetland areas to be directionally drilled. Environmental concerns have caused the development of technology designed to limit discharges of waste materials and to reduce the area disturbed by drilling activities. This chapter presents an overview of the history of drilling technology, modern and directional drilling methods, impacts on wetland values and functions, techniques for managing impacts, and suggestions for implementing management procedures.

5.1.1. History of Oil Drilling

Early wells were drilled with a primitive cable tool rig, one of the first types of drilling rigs. Cable tool rigs had one major impact on the environment—the disposal of drill cuttings removed from the hole and dumped in an open pit. This pit also served as the refuse pit for the drilling location and all foreign material (e.g., human refuse, hydraulic fluids, oil, machinery) was disposed in it. In wetland areas the cuttings were discharged directly into open water bodies, and rig refuse was also placed in open water or marsh next to the drill site. Released drill cuttings and oils caused localized contamination of drinking water resources and destruction of wildlife habitat. However, because the total amounts of fluid produced at cable tool locations was small the impact on surrounding habitat was minimal.

Spindletop, the first well to use modern rotary drilling, caused major changes in how oil and gas wells would impact surface habitat. Because wells around the salt dome at Spindletop were under substantial pressure, new drilling methods were needed to control this pressure. Drilling mud was used in a new process called rotary drilling to control the downhole pressure and prevent a blowout that could affect human safety and the surrounding environment. These drilling muds were disposed into an open pit or a body of water. The fact that rotary drilling was more effective and more economical in wetland areas increased its use in the Gulf Coast Region. Modern drilling operations at board road locations still use open pits to contain drill cuttings and mud. At open water and canal drilling sites, cuttings and mud are stored on shale barges. However, closed loop systems are being used increasingly to prevent environmental contamination caused by drilling fluids.

5.1.2. Modern Drilling Methods

Modern wetland drilling operations use two different types of rigs: the standard land rig **(Figure 4.4)** and the barge-mounted rig **(Figure 3.4)**. All the rigs used in wetland areas use a rotary drilling system. These rigs, the space they need and the surface environmental impacts associated with drill-site preparation are described in **Chapters 3 and 4.**

Modern drilling operations should have minor environmental impacts on habitat, provided that the drilling contractor follows current environmental regulations. An illustration of the rotary drilling process is shown in **Figure 5.1**. The major impacts on wetland environments are caused by the storage and discharge of cuttings and drilling fluids and the noise associated with operations.

The fluid circulated throughout the wellbore is called drilling mud, which is a fluid made by suspending weighting agents (particles of material) in a base fluid. The weighted material consists of a variety of natural and man-made materials. Some examples are lignite, lignosulfonates, hematite, bentonite and barite. These materials are agitated into solution with the base fluid. Chemical additives and extenders are added to help the base fluid entrain more solids and keep the present solids in solution. Chemicals are also used to control downhole mud properties. The base fluid in most cases is fresh water, although salt water and oil are also used as base fluids. This fluid serves several other functions besides removing cuttings: cleaning the drill bit, exerting sufficient hydrostatic pressure to contain formation fluids, cooling and lubricating the bit, and conditioning the walls of the hole.

As the mud exits the well, it flows into a series of solids control equipment. This equipment consists of shale shakers and other devices to remove inert solids from the mud. A diagram of the mud circulating system is shown in **Figure 5.2**. The inert solids include such minerals as sand, silt, limestone, feldspar, and barite. With the exception of barite which is added to increase mud density, these solids are considered undesirable in mud and need to be removed from the drilling mud (Bourgoyne et al., 1986).

The shale shaker, the primary solids control device, can remove the larger solids from the mud but is unable to remove very small particles called colloidal solids. Failure to remove colloidal solids causes stuck pipe, excessive pipe drag, and loss of circulation. These problems can seriously affect the safety of the drilling operation. If control of the well is lost, serious adverse impacts to the surrounding surface habitat may occur.

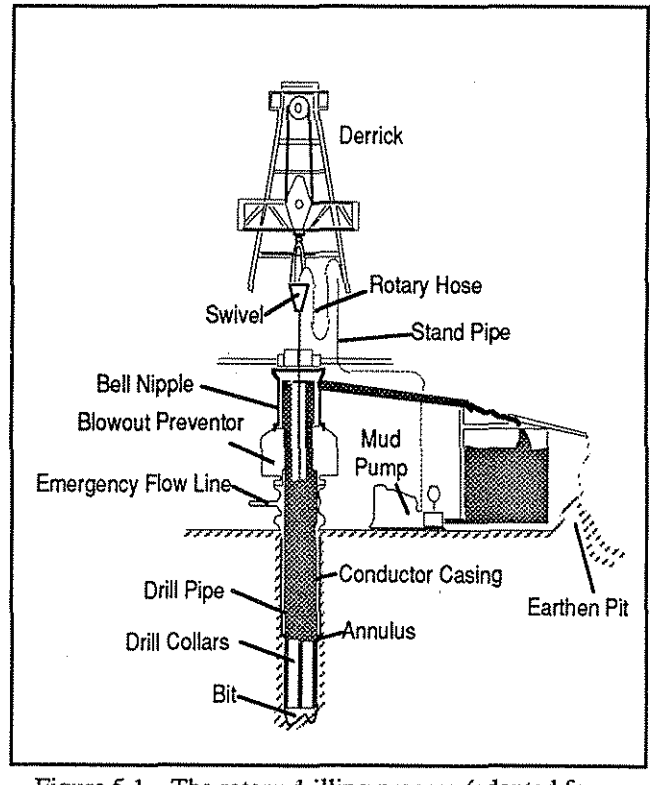


Figure 5.1. The rotary drilling process (adapted from Bourgoyne, 1986).

Mud properties deteriorate with the increase of inert solids that cannot be removed. A dilution process is performed to reduce the solids concentration, which requires discarding some of the mud to the reserve pit. The remaining mud is diluted

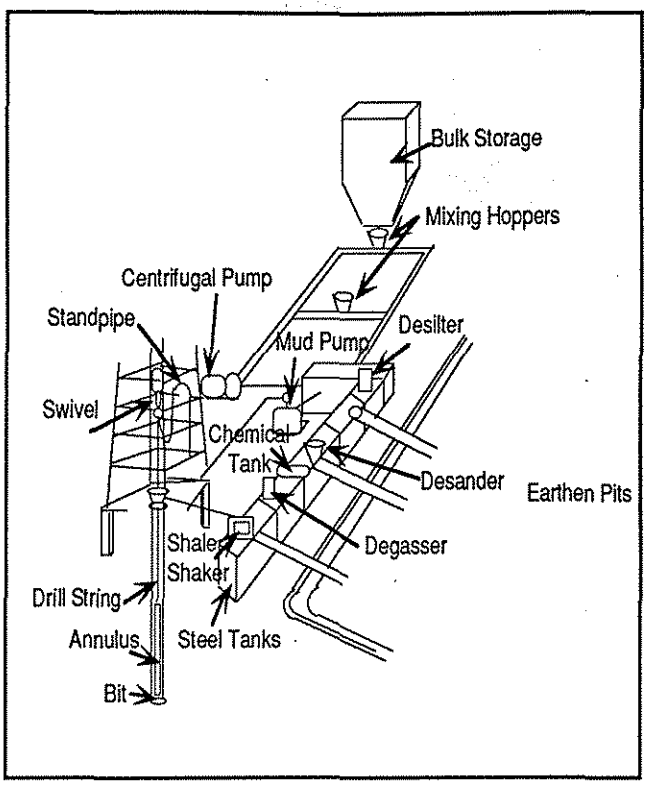


Figure 5.2. Schematic of example rig circulating system for drilling fluids (adapted from Bourgoyne et al., 1986).

with water or the base fluid. Then more chemicals and weighting material must be added to restore the desired mud properties.

Present industry practice uses an open pit to contain waste fluids and solids for all board road locations. This pit is dredged inside a ring levee when the location is built **(see Figure 4.5).** The average size for reserve pits in wetland areas varies from 150 by 100 feet to 340 by 100 feet for a location, depending on ring levee size. Barge mounted rigs use a shale barge to contain all drilling by-products.

The size of the reserve pit depends on the number of dilutions by the mud system. The deeper the well the more material that will be discarded in the reserve pit. For a typical well in south Louisiana, 10,000 to 30,000 barrels (i.e., 1,930 to 5,790 cubic yards) of material will be dumped in the pit. (Note: one barrel equals 42 US gallons.) One reason for this large volume is the "swell" effect. Drilling solids, such as clays, are originally deposited in a marine environment, and after compaction by geologic pressure and temperature they undergo mechanical destruction by the bit. While being transported by the mud column to the surface the clays absorb water and swell. More water is absorbed when dilution material is added to the open pit. This can cause a 600 to 900 percent increase in particle volume (Neidhardt, 1985).

During drilling operations, various planned stoppages in operations occur. The most important is the setting of surface casing to protect shallow fresh water sands from contamination by the drilling fluids. Surface casing is heavy steel pipe cemented to the walls of the hole. If the downhole pressure should exceed the mud pressure, surface casing and the blowout preventors will not allow the formation fluids to reach the surface. The minimum depth for surface casing is set by the state governmental agency that oversees drilling operations.

5.1.3. Directional Drilling

Directional drilling is a process that directs the wellbore along some trajectory to a planned target area. Some of the reasons for drilling a kicked or directional well include avoiding population centers, salt domes, and surface environmental features. **Figure 5.3** illustrates the numerous situations in which controlled directional drilling is applied. Directional drilling is technically more difficult, and the risks associated with directional drilling are greater than with a vertical hole, especially when drilling through high or low pressure. The increased torque and drag, combined with the greater probability of losing mud circulation, experiencing differential sticking of pipe, and kickback (blowout), result in greater potential for loss of life or property. Also, directional drilling usually takes longer than a vertical well. Consequently, controlled directional wells can cost 15 to 75 percent more than a vertical well or, on average, approximately 30 percent more.

Directional drilling is different from standard rotary drilling. There are two basic types of angled well bores: simple kick and S-shaped kick. The most common type is the simple in which the deviation is controlled, and the wellbore approaches the objective on an angle to the vertical plane **(Figure 5.4)**. For wells evaluated under the Geologic Review Procedure in coastal Louisiana the maximum angle of a simple kick well is 30° from vertical achieved at a rate of no more than 2° per 100 feet. The horizontal radius (i.e., the maximum distance the surface location can be offset from the subsurface objective) of a simple well depends on the total depth and the point at which deflection can begin.

The second type of directional well is the S-shaped well shown in **Figure 5.5**. S-shaped wells are used when the bottomhole location is offset from the surface location, but subsurface geologic

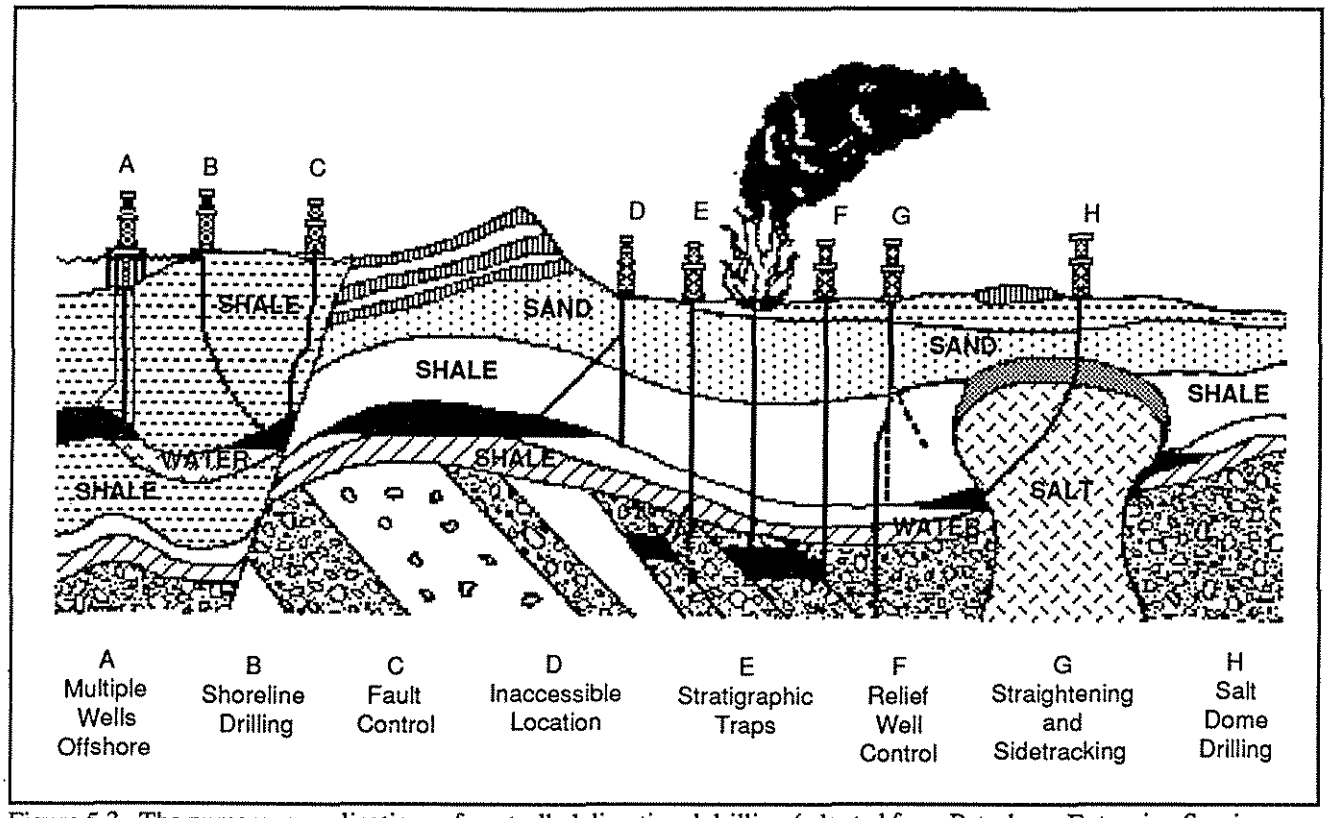


Figure 5.3. The numerous applications of controlled directional drilling (adapted from Petroleum Extension Service, 1981).

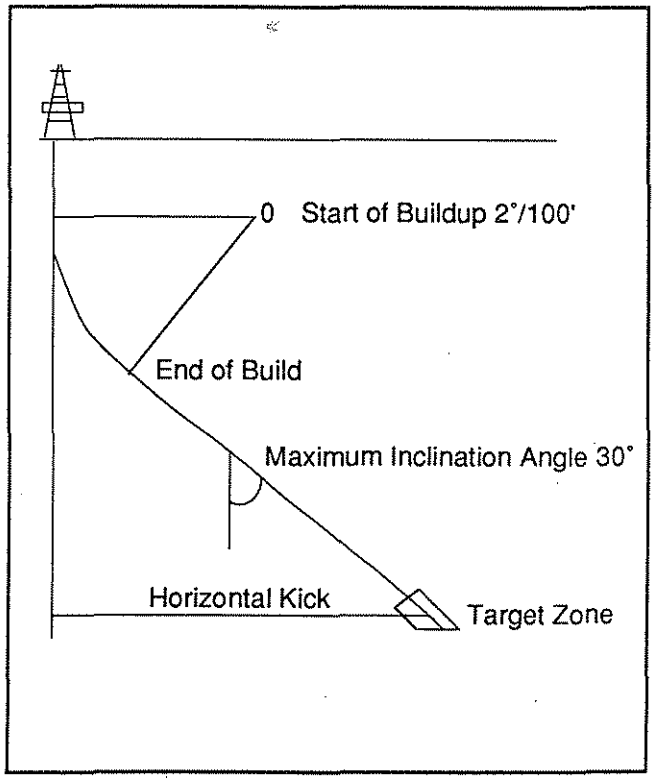


Figure 5.4. Simple kick directional well.

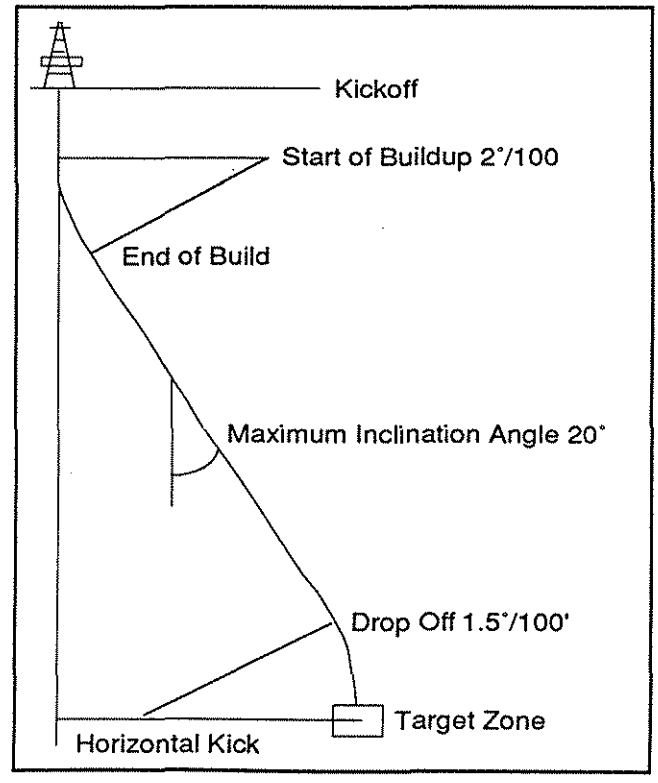


Figure 5.5. S-shaped directional well.

constraints require that the objective be achieved via a vertical borehole. These wells require two deviations, and the maximum angle is limited to 20°. The build angle is limited to 2° per 100 feet, and the drop angle is limited to 1.5° per 100 feet for these wells. These limitations cause the horizontal displacement for the S-shaped well to be much less than for a simple kick well. The horizontal radius (i.e., the maximum distance the surface location can be offset from the subsurface objective) is dependent on the depth at which the well must be vertical and the point at which deflection can begin.

5.2. IMPACTS on WETLAND VALUES and FUNCTIONS

The major impacts on wetland values are caused by (1) discharge of drilling mud into open water; (2) open pit storage of toxic material and migration of these materials into the ecosystem; (3) noise and commotion during operations; (4) alteration of the hydrologic regime; and, (5) conversion of marsh to open water or uplands. Evidence of past drilling operations is found in aerial photographs and at existing production sites. An estimated 12,000 open pits exist in Louisiana from past drilling and production operations (Osterman et al., 1987). No accurate count of pits in wetland areas is available, but a significant number exist.

5.2.1. Alteration of Habitat

The major alterations to habitat from drilling operations are caused by building the drillsite, the storage and disposal of drilling mud and cuttings, and noise during operations. The alterations caused by construction of the drillsite are described in **Chapters 3 and 4** of this manual. The noise and commotion generated by drilling operations can disrupt the breeding and nesting activities of bird colonies. The impacts of drilling operations on coastal wetland habitats are summarized in **Table 5.1**.

Drilling by-products are stored in open pits at land locations (e.g., board roads), while water locations (e.g., barge locations) contain the drill cuttings on a shale barge. Drilling mud chemical additives and contaminants are the main source of EPA priority pollutants in drilling mud. These pollutants include heavy metals (arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver and zinc), organics (oil and grease), and soluble salts (EPA, 1987a). Also included are other waste materials, such as hydraulic fluid lubricating oils, pipe dope, and rig wash water, which are disposed of in the open reserve pits.

Migration of drilling mud chemicals into the ecosystem through the soil is possible from open reserve or waste pits. Studies done in New Mexico using production pits (characteristic of pits used throughout the natural gas industry for disposal) show contamination by long-chained hydrocarbons to a depth of four feet below the original pit bottom (Eiceman et al., 1986). Closer to the surface an increase in more volatile hydrocarbons was shown. The samples were taken from five different geologic regimes, from uplands to wetlands. This fact is significant because in south Louisiana the water table ranges from three to six feet. Because most pit material (e.g., heavy metal ions, chloride ions, and hydrocarbon residuals) and mud additives are highly mobile in a water environment, movement into groundwater aquifers is possible. Chlorine and sodium ions are the most mobile faction in drilling waste, with migrations of several hundred feet recorded. Elevated levels of metal concentrations were also present in soils and plants near disposal sites. However, the actual migration distance by the metal ions was small (Moseley, 1983).

Besides soil migration, pollutants may enter the environment directly via runoff from drill sites. Reintroduction of toxic substances and nutrients in run-off may directly impact surrounding marsh and organisms on a local scale. This may result in direct impacts to vegetation, fish, and wildlife outside the ring levee (Moseley, 1983).

5.2.2. Influence on Hydrology and Water Quality

The present practice of discharging drilling mud into waterways is the major impact of drilling operations on local water quality. Present regulations for pit closure and cleanup in wetland areas allow the treatment of non-toxic muds and the discharge of their liquid portions into waterways. Current Louisiana Department of Environmental Quality policy permits whole mud and cuttings discharge into brackish open water areas and large water bodies with direct hydrologic connection to the Gulf of Mexico. No discharge is allowed within 1300 feet of an oyster bed. No oil based muds may be discharged. No cuttings from oil or water based systems may be discharged if a visible oil sheen is present (L. Wellman, Louisiana Department of Environmental Quality, 1988, *personal communication*).

Even though water based mud is non-toxic, discharge of this material alters water quality. The major impact of suspended solids is the loss of fisheries habitat. Fish yields are impaired when

Table 5.1. Observable and hypothetical cause-effect relationships of drilling operations on coastal marsh habitats and wetland loss.

	Activity		
	Mud Storage	Fluid Discharge	Drilling Activities
ACUTE ENVIRONMENTAL CONSEQUENCES			
Habitat Alteration – Physical Impact			
Reduction in Water Quality	√	√	
Return of Nutrients, Toxins to Surroundings	√	√	
Inhibition of Rainfall Penetration	√		
Noise, Commotion during Drilling			√
Habitat Alteration – Ecological Impact			
Increase in Suspended Solids		√	
Changes in Soil/Water Chemistry	√	√	
Changes in Plant Growth	√	√	
Impact on Biota			
Destruction of biota		√	
Potential for Interrupting Fish Spawning/Feeding in Marshes		√	
Potential for Disturbing Avifauna Nesting by Noise		√	
CHRONIC ENVIRONMENTAL CONSEQUENCES			
Habitat Alternation – Altered Physical Process			
Alteration of Surface Hydrology and Drainage	√	√	
Subsurface Hydrology and Drainage	√	√	
Sediment Distribution		√	
Interaction of Saltwater Intrusion		√	
Habitat Alteration – Physical Impact			
Suspended Solids Lead to Decreased Nutrient Availability		√	
Increased Sediment Distribution from Discharges		√	
Anoxia		√	
Habitat Alteration – Ecological Impact			
Loss of Marsh Habitat	√		
Altered Soil/Water Chemistry:			
Possible Negative Influence on Aquatic/Benthic Organisms		√	
Changes in Mineral Accretion and Soil Nutrition	√	√	

levels of suspended sediments are high (Hall et al., 1987).

One of the few studies relating shellfish mortality directly to suspended solids tested survival rates of two crab species exposed to the discharge of 9.1 pounds per gallon of lignosulfonate mud (Bookhout et al. 1982). The results showed survival rates of approximately 4 percent in 50 percent suspended solid particulate phases (SSP), and 31 percent survival rates in 5 percent SSP mud.

The major chronic impact to wetland habitat is the alteration of the sheet flow of coastal marsh environments. Subsurface water flow and drainage are altered by the weight of the boarded area and pit that compress the underlying organic layer. This reduction in cross-sectional flow area causes an increase in substrate density and a reduction in flow rate. Over time this effect alters vegetation and causes changes in habitat. Areas downstream from the location are impacted by the leveling of seasonal flows. The alteration of these flows can alter the composition of the present vegetation. Channelization of flow around the drillsite alters seasonal flows, causing drier conditions that are more favorable for upland vegetation. In forested wetlands these factors may cause loss of shellfish and finfish habitat (Hall et al., 1987).

Drilling mud pits are a long-term liability. The potential for contamination of surrounding areas always exists if open pits are used. The pit material should be totally removed as soon as possible after completion of drilling.

Contrary to popular opinion, drilling mud is essentially sterile and contains little or no plant nutrients, although it has some calcium. Since it is essentially very fine clay, it inhibits rainfall penetration if spread over soil. Its two agricultural values are in increasing water holding capacity of very sandy soils and in sealing leaking pond dams. (Taylor, 1983)

5.3. MANAGING IMPACTS through the REGULATORY PROCESS

Drilling operations are the essence of petroleum exploration and production. Operational impacts on the wetlands are directly related to the location size, time spent on location, and regulations that govern waste disposal.

5.3.1. Avoiding Impacts of Drilling Operations

The only way to totally avoid the impacts of drilling operations is to not drill the well. Because this is not a reasonable alternative, other avoidance techniques have been developed. These include the use of alternate access routes (**Chapter 3**) and directional drilling from outside the marsh. In cases where the well needs to be drilled in a wetland area, impacts to known bird colonies can be avoided by altering operation schedules during breeding and nesting activities.

The use of a closed-loop or containerized mud system should be required to prevent possible contamination of water resources. These systems, if properly used, can completely contain pollutants used in drilling operations. In addition, closed loop systems reduce the total volume of waste produced. The liquid discharge for a closed-loop system is clean water that can be discharged depending on its salinity. This system removes the direct impact to water quality and turbidity if discharge rates are kept low. High discharge rates cause short-term turbidity problems (National Research Council, 1983).

5.3.2. Minimizing the Impacts of Drilling Operations

Enforcement of existing noise regulations for drilling rigs would reduce the noise associated with drilling operations and, in turn, would reduce the impact of noise and commotion on wildlife.

The use of a closed-loop mud system reduces environmental impacts in wetland areas. A well-designed closed loop system requires less total area than a standard open pit well. A comparison of two sets of well configurations is shown in **Figure 5.6.** A closed loop system requires a site 400 by 350 feet for wells over 15,000 feet deep (**Figure 5.6b**). For wells less than 15,000 feet, the configuration is shown in **Figure 5.6a.** The savings for the deep well is 0.46 acres over the standard 400 by 400-foot location and 1.26 acres for the 10,000-foot well. This translates to a significant savings in valuable wetland habitat and reduces the direct impact of this location by 12.5 percent for the deep well and 34 percent for the well of intermediate depth. See **Chapter 4** for discussion of drill site preparation. The reduced area translates into reduced impacts on habitat and sheet flow. Sheet flow is impacted by the weight of the location compressing the subsoil and preventing natural flow. If the direction of sheet flow can be determined, the short side of the location can be placed perpendicular to the flow to minimize impacts.

The best method to minimize impacts of drilling operations on water quality is to discharge only clean water. Closed loop systems run drilling mud through a high-speed centrifuge or, on some systems, a pressure filter system. The resulting liquid should be available for re-use in drilling operations or discharge as clean water. The resulting damp solids are stored until disposal. Some companies stabilize the solids with cement, potash or limestone and bury this stabilized product on location. This procedure immobilizes the chemical constituents and prevents migration of free ions into ground water. There is no environmental impact because the material's physical and chemical properties are essentially the same as its downhole properties (Hinds et al., 1986; Neidhardt, 1985).

Proper treatment and disposal of drilling waste have been addressed by current regulations. Louisiana Statewide Order 29-B sets specific guidelines for pit closure and waste disposal. Specifically operators shall prevent the placing of produced brine, waste oil, refuse, or any material that could adversely affect the clean-up of the pit or the surrounding environment (Section XV 2.4 B. 3.). Pits must be closed to protect soil, surface, and groundwater resources. Prior to closure, the pits must be tested for proper pH, heavy metals content, percent oil and grease, soluble salt and cationic distribution (Section XV 2.6). If the pit material tests under guidelines, pit closure may be attempted, depending on the type of surface environment, by one of the following methods: burial or trenching, solidification, subsurface injection or land farming. If the pit material exceeds guidelines, the options are to treat the waste for onsite disposal or offsite disposal at an approved site (Section XV 2.7)

5.4. SUGGESTIONS for IMPLEMENTATION of MANAGEMENT PROCEDURES

The federal government has recently increased emphasis on enforcement of existing environmental regulations pertaining to oil and gas activities. The U.S. Army Corps of Engineers (COE) and the Environmental Protection Agency (EPA), two agencies charged with responsibilities for these

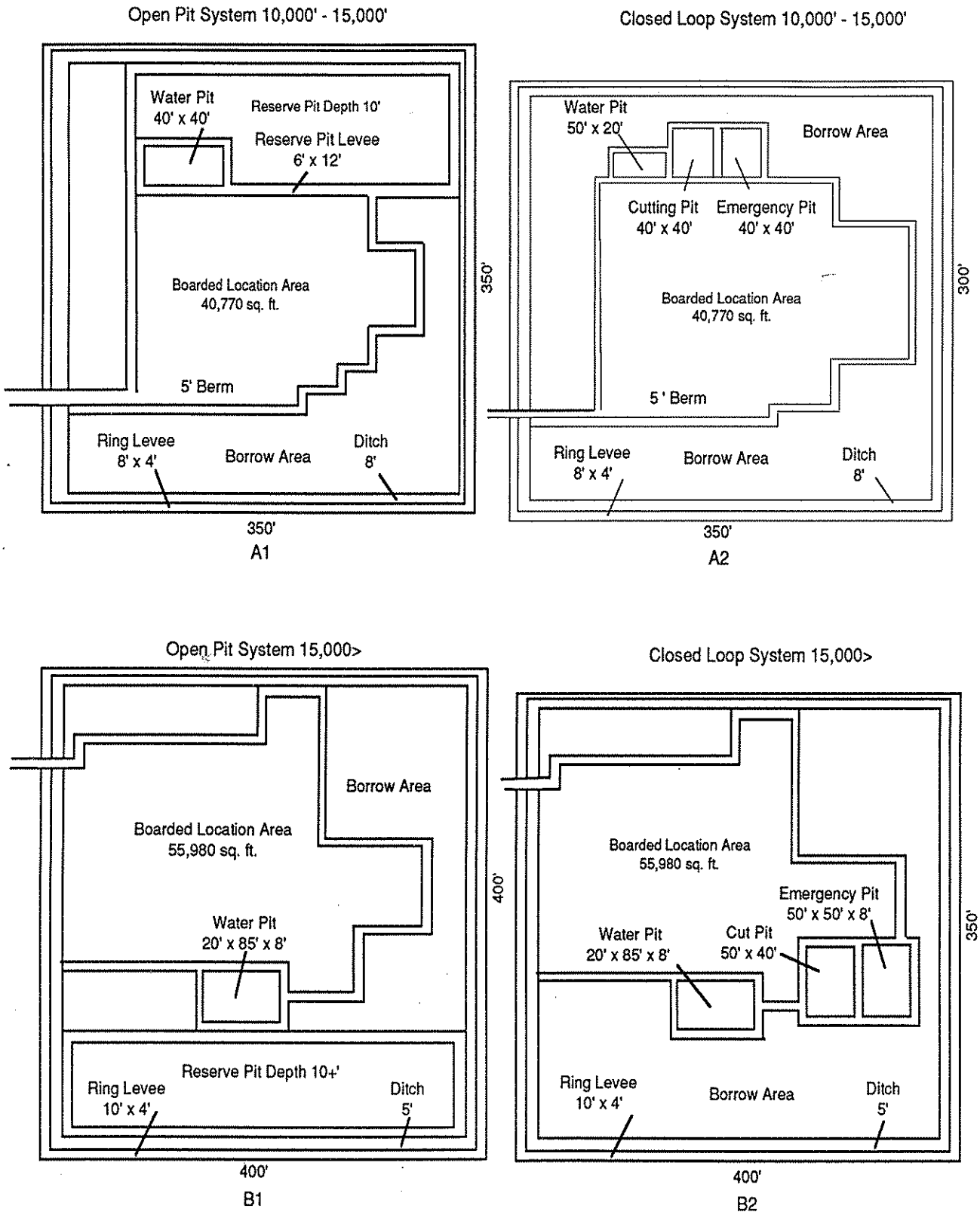


Figure 5.6. Comparison of two sets of well configurations.

activities, have increased their scrutiny of current wetlands operational techniques under Section 404 of the Clean Water Act.

The agencies need to review each project and, using present regulations (1) control and eliminate mud discharges; (2) reduce location size under the regulatory powers granted over dredge and fill operations; and, (3) reduce noise and commotion associated with drilling operations by cooperation with OSHA in inspecting drilling rigs for noise violations. The authority to reduce these impacts exists under the Coastal Zone Management Act, which controls activities in the coastal zone and Sections 402 & 404 of the Clean Water Act. Enforcement of present regulations and increased interagency cooperation will reduce the impacts of present and future drilling operations.

The Geologic Review Procedure is an example of interagency cooperation that works. This procedure was begun in 1982 at the request of the director of the Coastal Management Division (CMD) of the Louisiana Department of Natural Resources. The Louisiana Geological Survey developed the procedure, in conjunction with the CMD, for a case-by-case review of oil and gas permit applications involving environmental damage, within the jurisdiction of either the Coastal Management Division of the State of Louisiana or the New Orleans District of the Army Corps of Engineers. In the Geologic Review Procedure, a thorough evaluation is performed on lease and regulatory information, geologic, engineering, and economic data, and future plans that relate to the permit application. There are three possible outcomes to this procedure. The well may be directionally drilled from an existing site, an upland site or from a less environmentally damaging site. In cases where directional drilling is unsafe, the well may be moved to a geologically equivalent location that is less environmentally damaging. If the first two options are unfeasible, efforts will be made to minimize impacts through the use of alternate access routes (**Chapter 3**) and reduction of location size by using a closed loop mud system.

PRODUCTION

by
Brian J. Harder and W. Kent Webb

6.1. INTRODUCTION

Production is implemented after the successful completion of exploration activities. Production involves getting the oil and gas product out of the ground, processing it, and then transporting it to the buyer. Sophisticated techniques have been developed to minimize environmental damage caused by production facilities, and they are being improved constantly.

This chapter presents an overview of oil and gas production techniques and how they impact wetland habitat values and functions, techniques for managing habitat impacts, and a brief summary of future trends.

6.1.1. History of Oil and Gas Production

Early production was allowed to blow out the well in a gusher and the hydrocarbon was collected by placing a levee around the location. Produced hydrocarbons were stored in earthen levees called stock tanks. This early method of storing produced hydrocarbons was unsafe and directly altered wetland habitat. Open pits allowed oil to seep from the pits into groundwater aquifers, allowed spills to contaminate the surrounding vegetation and created a fire hazard to the surrounding environment (natural gas was considered a nuisance and burned in a flare resulting in numerous grass and forest fires). Hydrocarbon production in wetland environments was hampered by the inability to create sufficient leveed areas for storage. Consequently, wooden barrels and tanks were used in wetland areas to store products until steel and iron tanks

came into use in the early 20th century. The wetland area required for storage was leveed and pumped dry.

Early oil producers used the force of gravity to disassociate produced water and oil. The well product flowed into a separator where the oil, gas, and water were allowed to separate. The oil then flowed to the storage tanks, the gas was flared, and the salt water was discharged into the nearest body of water. Modern production operations use steel tanks to hold production and dispose of salt water according to applicable regulations.

6.1.2. Modern Techniques of Production

Modern production depends on many factors, the most important of which is the type of reservoir. There are three major types of reservoirs, classified by their reservoir drive mechanisms: gas cap expansion drive, solution gas drive, and water drive. The envrionmental concerns related to hydrocarbon production differ with the type of reservoir.

6.1.2.1. Reservoir Types. In a gas cap reservoir, free gas exists above the oil layer. As oil is produced, the gas expands, pushing the oil up the wellbore. Because the gas cap is under tremendous pressure, drilling into this type of reservoir can result in a controlled kick or an uncontrolled blowout. A controlled kick requires that high concentrations of chemical weighting agents (barite) be added to the drilling mud. Under these conditions, concern is for human safety and the environmental effects of high concentrations of drilling chemicals **(Chapter 5)** and a blowout and subsequent spill **(Chapter 8)**. Environmental concerns of a solution gas drive (i.e., the gas is mixed with oil) are similar to those of a gas cap expansion drive.

In a water drive reservoir, the inflow of water provides the needed energy to produce the oil and gas. When the oil is produced, the water level rises and fills the voided space. Reservoir pressure remains high as long as the removed oil and gas are replaced with water. Water drive reservoirs affect the surface features in a very different way than a gas cap drive. Chances of a fiery blowout are remote. The greatest concern is a massive saltwater flow. This is much like a blowout but, instead of gas, salt water is flowing out of the well into the reserve pit. Such an occurrence would be a major environmental concern if the pit levee is breached or topped by this massive amount of fluid. Under maximal production conditions, a water drive reservoir typically produces for a long time and requires that surface facilities be in use for many years. Thus, the well will produce large amounts of salt water that need to be disposed in an environmentally safe manner.

6.1.2.2. Stimulation Techniques. To produce reservoir fluids at a maximum flowrate, stimulation techniques may be employed. The first modern stimulation technique was called shooting a well and involved detonating an explosive charge in the oil formation to increase the flow of oil and gas. This type of stimulation technique had little surface environmental effect unless the charge went off prematurely on the surface. Because of the unconsolidated nature of the geologic formations this technique is not widely used in the Gulf Coast.

Other stimulation techniques use acid or water sand mixtures to fracture the formation and allow more hydrocarbons to be produced. The affects of acid and water stimulation activities on surface habitats is covered in section **6.2.2.**

6.1.2.3. Processing Techniques. Once the fluid reaches the surface it must be processed. Sales contracts for oil and gas require the product in a marketable condition. Surface production facilities remove impurities, separate oil, gas and water, provide storage for the product, and measure the quantities produced. Production facilities are designed to conform to the field conditions present. The types of facilities used in wetland areas fall into two general categories: oil production equipment and gas processing plants.

Oil production equipment is designed to handle all the fluids produced from an oil well. These fluids are oil, gas and salt water (brine). Flowlines (pipelines ≤ 4 inches in diameter) carry crude oil from the wellhead to the processing facilities. These flowlines vary in size but usually do not exceed four inches in diameter unless extremely high flowrates are present. They are laid on top of the marsh surface by hand to prevent damage to the vegetation. Fluid flow to the processing facilities occurs by gravity drainage, gas expansion, and high pressure from the reservoir or pumping.

At the facility the flow enters a staged process to remove the impurities and to make the oil marketable. The first stage in the separation process involves a free water knockout or a heater treater. These pieces of equipment use the force of gravity or heat to remove salt water and solids from the flow stream. In marsh locations the heater-treater is at the wellhead as shown in **Figure 6.1**. The hydrocarbon-water emulsion and the free gas are piped from the free water knockout to the second stage of the separation process. This is usually a

vertical or horizontal separator where the free oil and gas are removed. The emulsion that will not separate in this phase is piped to a third stage separator, which is another type of heater-treater that breaks the emulsion using heat or chemicals. The result is a further breakdown into free oil, gas, and water.

The oil is placed in metal storage tanks called stock tanks until it is sold (**Figure 6.2**). Stock tanks serve two main purposes: to store the oil and to allow the volume produced to be measured. The complete oil processing facility is shown in **Figure 6.3.** The gas is compressed and sent through a meter to a gas processing plant for further processing. The salt water is re-injected into a disposal well or discharged in offshore and brackish areas. In a limited number of cases, fresh water is produced with the oil and usually discharged into natural water bodies. This discharge of produced fluid is the main impact on the surface environment caused by oil or gas processing facilities.

A staged process is also used at natural gas wells to separate the gas, crude oil, condensate (condensable hydrocarbons), salt water, and impurities that are produced. Gas treatment is normally required to prevent hydrate formation, to dehydrate the gas, and to remove any undesirable components. Hydrates can cause blockages in flowlines and pipelines, which can cause flowlines to break and allow oil to flow onto the marsh. To reduce hydrate formation, the gas is dehydrated prior to transporting. Liquid desiccants, such as triethylene glycol (TEG), absorb the moisture from the gas. Solid desiccants attract the water molecules and remove them from the gas. This type of desiccant is usually activated alumina (bauxite) or silica gel. The liquid TEG is toxic to most vegetation, and proper use and storage of this fluid is essential if environmental contamination is to be minimized.

Natural gas can contain other impurities, such as hydrogen sulfide (H_2S) and carbon dioxide. Both of these gases can form acids in the presence of water; therefore, they must be removed. In addition, H_2S is extremely toxic and will cause death in humans and other mammals at concentrations above 20 ppm. An alkanolamine process is used with heat stripping to process these two component gases, which are retained for sale because they are used in many industrial processes. The hydrogen sulfide will be processed to produce sulfur and fresh water, and the carbon dioxide will be sold if a market exists.

Condensable and recoverable hydrocarbons are also removed from natural gas (Gerding, 1981). The separated crude oil and condensate are sent to

Figure 6.1. Heater treater at the wellhead. (Photography by D. Cahoon.)

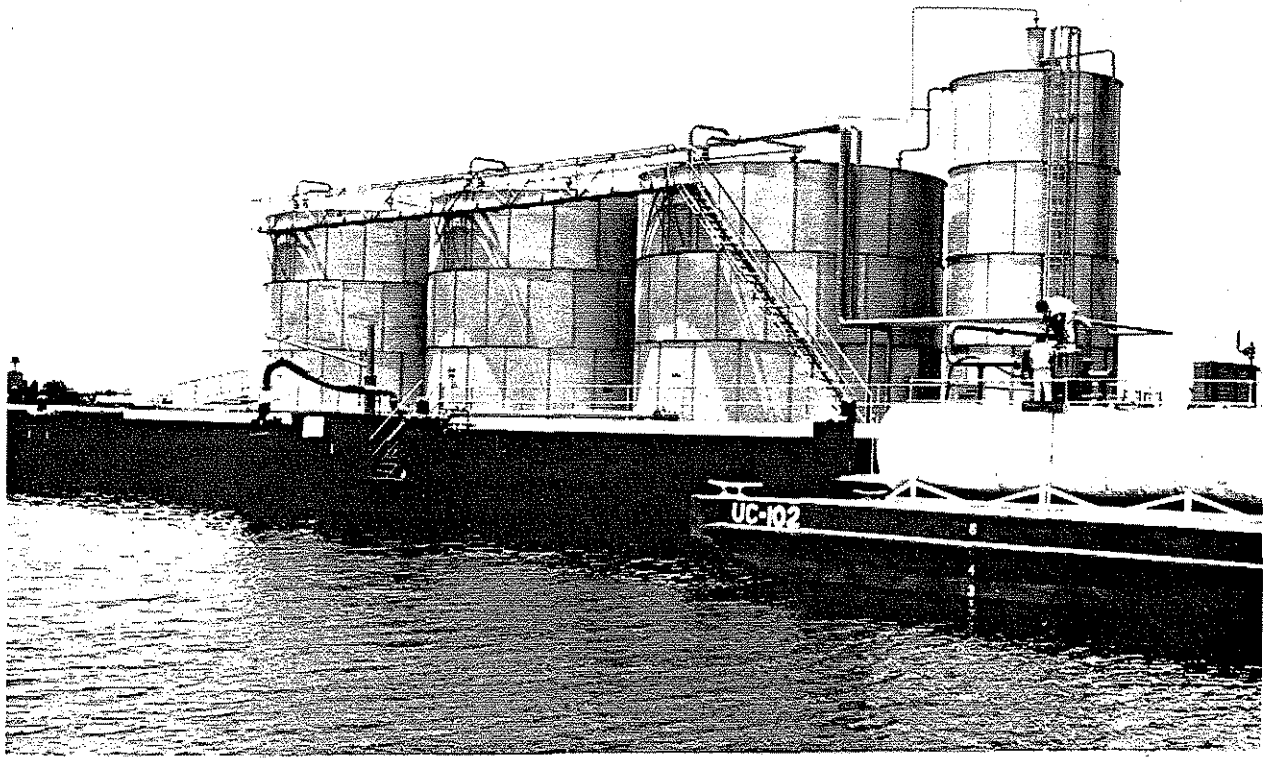


Figure 6.2. Stock tanks for oil storage. (Photography by D. Cahoon.)

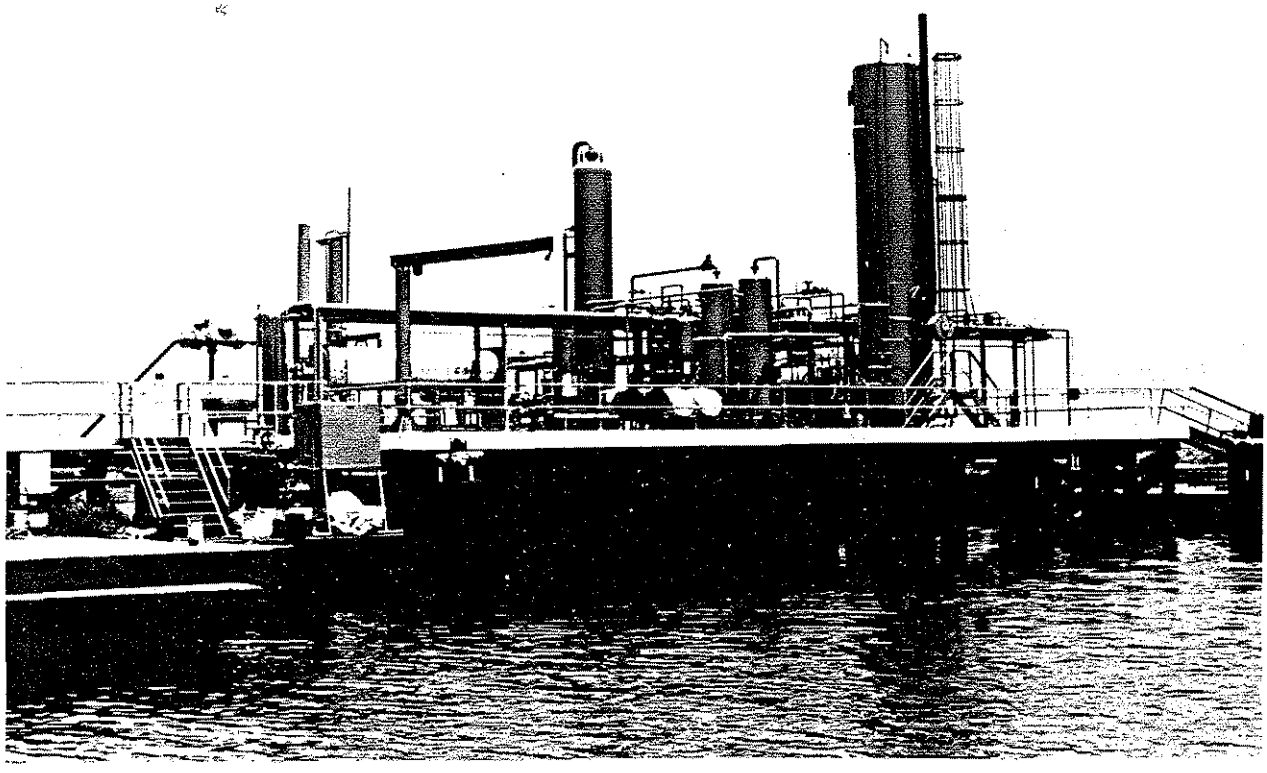


Figure 6.3. Oil processing facility. (Photography by D. Cahoon.)

an oil processing facility and processed as described above. A diagram of field operations is shown in **Figure 6.4;** this gives a general illustration of the surface impacts that wellheads, flowlines, and production facilities have on a wetland environment. **Table 6.1** summarizes the environmental effects of the different phases of production that should be reviewed during processing of the permit application.

6.1.2.4. Workovers. Periodic maintenance and servicing is needed as wells continue to produce over long periods of time. Maintenance may involve pulling sucker rods, tubing, changing subsurface equipment, and recompletion. These projects normally require a workover rig on location, which means room to maneuver this equipment is always needed at a wellhead and affects the location size of a producing well. These operations use a number of specialized fluids toxic, in many cases, to marsh vegetation and wildlife. Proper containment of these fluids and proper disposal are necessary to prevent marsh contamination.

6.1.2.5. Secondary and Enhanced Recovery Techniques. Over time the primary recovery

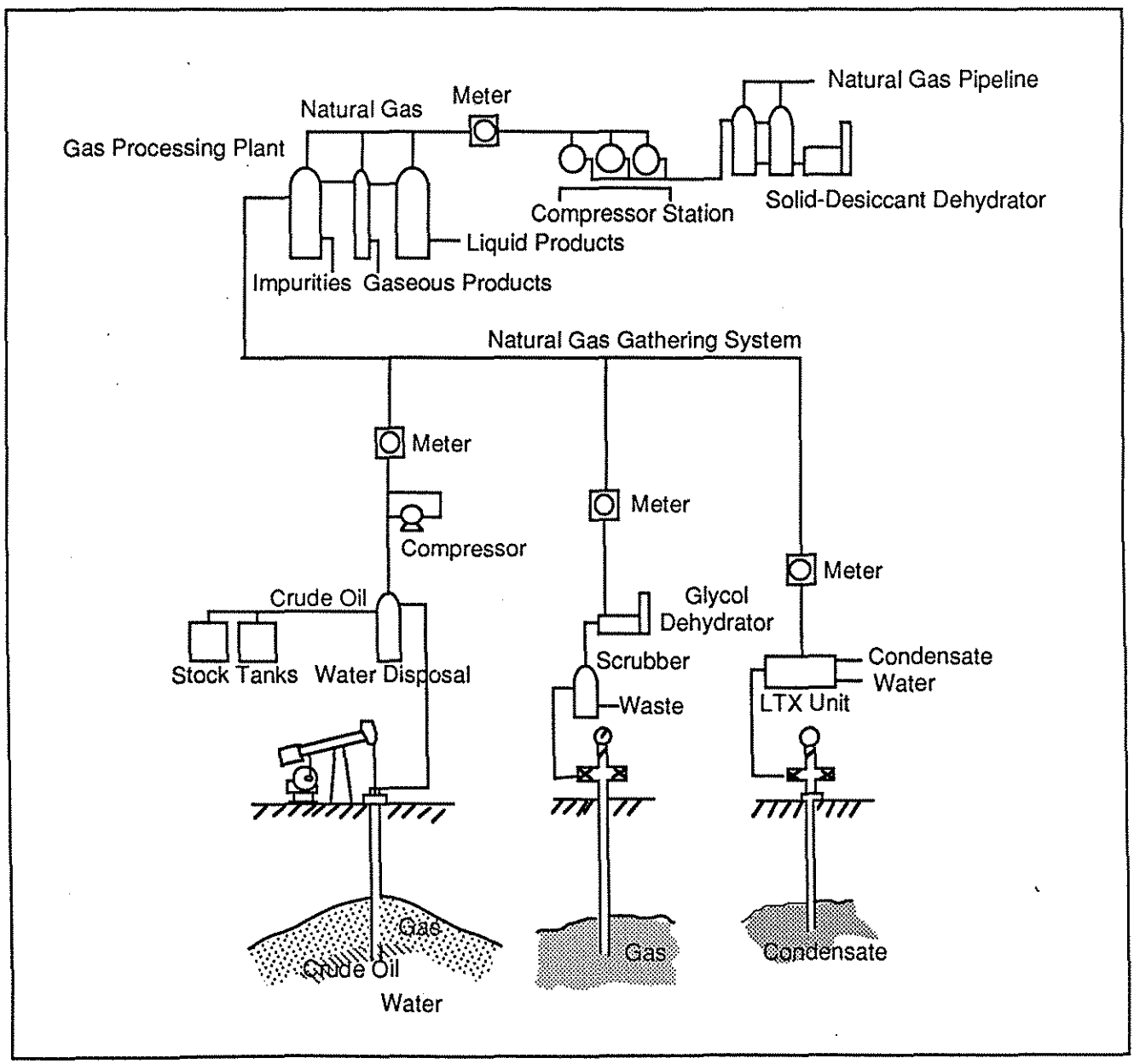


Figure 6.4. Diagram of field operations (adapted from Berger and Anderson, 1980).

Table 6.1. Possible leaks and discharges in production operations (see **Figure 6.4**).

Production Activitiy	Types of Spills/Discharges	Affected Environment
Wellhead		
	Oil	Vegetation
	Gas	Wildlife and Fish
	Salt Water	Water Quality
	Acid	
	Surfactants	
	Inhibitors	
	Polymers	
	Paraffin	Sub-soil
	Sand	
Wellhead Processing Facility		
	Oil	Vegetation
	Gas	Wildlife and Fish
	Salt Water	Water Quality
	Glycol	
	Polymers	
	Paraffin	
	H_2S	Humans
Gas Processing Facility		
	Gas	Vegetation
	Salt Water	Wildlife and Fish
	Alumina Silica	Water Quality
	CO_2	
	Sulfur	Sub-soil

processes remove a portion of the known oil and gas in a reservoir. Depending on the reservoir drive mechanism, oil and gas amounts exceeding 80 percent may still remain. When the reservoir pressure begins to decline, a pressure maintenance program may be implemented, involving secondary and tertiary (enhanced) recovery techniques.

Secondary recovery includes gas re-injection and water flooding depending on the type of reservoir. Pressure maintenance programs may involve drilling new wells to allow injection of fluids. This will adversely affect marsh habitat because, as shown in a typical 5-spot pattern (**Figure 6.5**), four injection wells are needed for each producing well. An environmental benefit is that produced salt water is injected back into the reservoir, thus solving the problem of salt water disposal.

Enhanced recovery techniques have as their objectives: (1) to increase recovery from reservoirs considered depleted by secondary recovery methods of water flooding or gas injection; and, (2) to increase recovery from reservoirs that did not respond to conventional water flooding or gas injection. Processes developed to meet the first objective are called tertiary recovery projects, but the name is ill-suited for all other methods. Thus, the term "enhanced oil recovery" (EOR) is now the generally accepted designation for all unconventional oil and gas recovery processes (van Poollen, 1980).

Three categories include the many processes of enhanced oil recovery: thermal, chemical, and miscible displacement. Thermal recovery techniques include steam stimulation, steam flooding

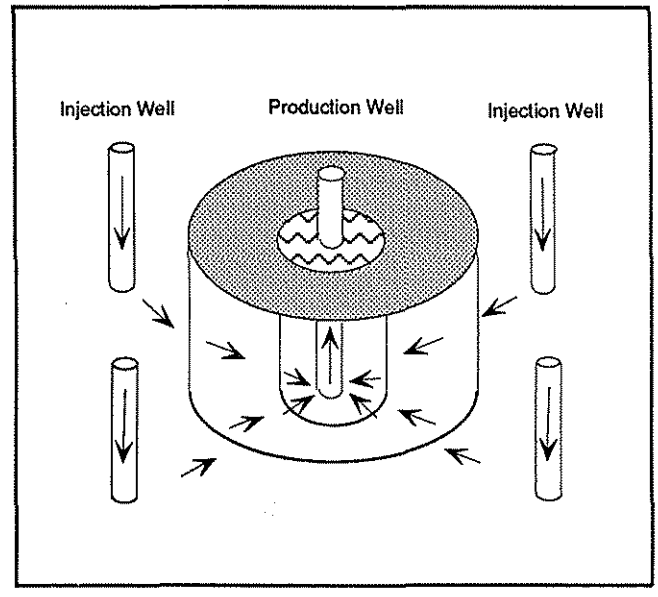


Figure 6.5. As water is injected into the water bank, the water bank expands outward and pushes petroleum ahead toward offsetting production wells (adapted from Skinner, 1981).

and in-situ combustion. These types of recovery are less environmentally damaging to the surface features of the marsh since the injection fluid is fresh water. However all enhanced recovery processes require additional well locations for injection and monitoring. Chemical recovery processes inject a water-chemical mixture to reduce the natural resistance to flow. The major types of chemical processes are surfactant-polymer injection and polymer flooding. These chemicals are usually toxic to surrounding marsh habitat. The long-term effects of enhanced recovery operations on marsh habitat is impossible to determine at this time, but it is likely that a significant area of marsh will eventually be exposed to EOR activities as the large number of wells in coastal Louisiana pass their peak of primary production.

6.2. IMPACTS on WETLAND VALUES and FUNCTIONS

The major impacts on wetland values from oil and gas production are caused by (1) permanent change in marsh elevation and habitat; (2) production pit storage of toxic materials and migration of these materials into the ecosystem; (3) noise and commotion during construction and operations; (4) alteration of surface and subsurface hydrologic regime; and, (5) effects on water quality. The relationship between production activities and wetland impacts is summarized in **Table 6.2.**

6.2.1. Alteration of Habitat for Production Facilities

Production processing facilities alter habitat in a permanent manner. As with the drilling location, an area must be prepared to station the production facilities. During the construction phase noise can disrupt nearby wildlife. After construction is completed, the noise from oil and gas processing facilities will continue to affect the character of the habitat near the plants.

In most cases, it is uneconomical to station a complete processing facility next to each wellhead. Companies create a central facility, commonly called a tank battery, where production from all nearby wells is sent. By laying flowlines from each wellhead to the processing facility, the facility can be situated anywhere. Flowlines are small diameter pipe laid by hand on the surface to move fluids between locations. Therefore, flowline construction impacts are minimal. In contrast, pipelines are larger diameter pipes buried three feet below the ground and have potentially greater impacts associated with construction **(Chapter 7).**

The facility site must be able to support the weight of the processing equipment and storage facilities. When operating in marsh surroundings, it is desirable to locate the tank battery on higher ground or a platform in open water or a canal. This minimizes or avoids habitat alteration caused by dredging and filling, which is needed to build a tank battery site. Furthermore, the use of centralized production facilities allows a reduction in the wellhead location size to a pad just large enough to service the well.

As discussed earlier, secondary and enhanced recovery techniques may be applied to increase hydrocarbon recovery. These methods inject many different types of fluid into the reservoir. Additional wells and equipment are needed to implement these techniques. This equipment may include additional pumps, compressors, and storage tanks, all of which prompt a need for additional space and may require wetland habitat areas to be altered.

6.2.2. Influence on Water Quality

Salt water is almost always associated with production of oil and gas. Because of its detrimental effects on benthic organisms (e.g., oysters) and vegetation, handling and disposal of salt water is of utmost concern. The usual techniques for salt water disposal include evaporation, discharge, and re-injection. The evaporation technique stores the produced salt water in an open pit, allowing the water to evaporate and leave the salt behind. This method is ill-suited for wetland areas of the Gulf Coast because the high humidity slows evaporation rates and abundant rainfall causes the pit to overflow into the surrounding areas. However, evaporation pits still exist in South Louisiana at this time. Presently no new evaporation pits are being built, and the old pits are being phased out under Statewide Order 29-B.

Discharge of produced brine is presently an accepted method of disposal in "tidally affected waters, brackish waters, or any other waters unsuitable for human consumption or agricultural purposes" (Louisiana Department of Natural Resources, 1986). No brine discharges are allowed in freshwater marsh areas. In 1986, 1 billion barrels of produced waters were discharged in coastal Louisiana (Louisiana Department of Environmental Quality, 1987).

Discharged brine has minute quantities of petroleum hydrocarbons, organics, and heavy metals and may have high levels of radioactive contaminants, such as radium. In addition, chemicals used in corrosion inhibitors, such as surfactants, organic

Table 6.2. Observable and hypothetical cause-effect relationships of production operations on coastal marsh habitats and wetland loss.

	Activity			
	Production of Fluids	Fluid Storage	Flowline Discharge	Construction
ACUTE ENVIRONMENTAL CONSEQUENCES				
Habitat Alteration – Physical Impact				
Noise, Commotion during Construction		√		√
Flowlines in the Marsh				√
Production Pits – Toxins to Surroundings		√	√	
Change in Marsh Elevation	√	√		
Reduction in Water Quality		√	√	
Habitat Alteration – Ecological Impact				
Saltwater Disposal – Salt Kills		√	√	
Acid Spills/Oil Spills		√		
Potential for Disturbing Avifauna Nesting by Noise		√		
Impact on Biota				
Destruction of Biota		√	√	
Potential for Interrupting Fish Spawning/Feeding in Marshes			√	
Potential for Disturbing Avifauna Nesting by Noise		√		√
CHRONIC ENVIRONMENTAL CONSEQUENCES				
Habitat Alteration – Altered Physical Process				
Noise of Processing Plants		√		
Surface Hydrology and Drainage			√	
Subsurface Hydrology and Drainage		√		
Saltwater Intrusion			√	
Changes to Plant Environment – More Saltwater Species			√	
Habitat Alteration – Physical Impact				
Anoxia			√	
Increased Localized Subsidence	√			
Habitat Alteration – Ecological Impact				
Loss of Marsh Habitat		√	√	
Altered Soil/Water Chemistry:				
Possible Negative Influence on Aquatic/Benthic Organisms		√	√	

polymers, and ethylene diamine tetracetic acid (EDTA), can be discharged with the produced brine (EPA, 1987b). Produced oilfield brine has high concentrations of chloride (Cl), sodium (Na), calcium (Ca), magnesium (Mg) and potassium (K) ions in decreasing amounts (Collins, 1975).

Stimulation techniques, such as acidizing and fracturing, may adversely affect wetland habitats. Concentrated acids, such as hydrochloric and hydrofluoric, are used to open the pore-spaces in the formation. Fracture acidizing uses large volumes of these fluids, and small spills occur during operations. These acids can mix with water present on the location and be transported into the surrounding marsh habitat. Major spills of these chemicals are possible but unlikely. A major acid spill would contaminate the surrounding water habitat and destroy localized fauna and wildlife. This adverse effect would continue until dilution of the acids or bases by rain water brings soil conditions back to a level that could support growth.

Fracturing uses a base fluid, water, acid or oil, and sand pumped at high pressure to fracture the formation and prop the the fractures open to increase well production. The high pressures used increase the risk of accidental discharge during fracturing operations. The environmental effects of fracturing are determined by the composition of the base fluid. The effects of a water frac are minimal. When acid is used as a base fluid and a spill occurs, the effects on habitat are similar to those described above. The most damaging type of spill that can occur is if an accident or unplanned release of material occurs while an oil frac is being

performed. The high pressure can cause dispersion over a wide area, thus increasing the potential for environmental impacts

6.3. INFLUENCE on WETLAND LOSS

Hydrocarbon production may influence wetland loss through subsidence caused by fluid removal and salt water impacts on vegetation that holds the soil together.

6.3.1. Influence of Subsidence Caused by Drawdown

Fluids occupy space between sand grains, cracks, and other areas of subsurface formations. Production of this fluid and depletion of the reservoir pressure cause surface subsidence. The weight of the overlying rock compacts this empty space and lowers the surface elevation. (Bourgoyne et al., 1986).

The Minerals Management Service (U.S. Department of the Interior) has developed a subsidence prediction model for oil and gas production. Fluid withdrawal from oil and gas reservoirs appears to have a localized influence on subsidence, amounting to as much as 80 centimeters (2.62 feet) of settlement directly above the reservoirs (Suhayda, 1988). Subsidence is the major long-term component of relative water level rise in the wetlands. The conclusion is that most oil and gas production does not seem to have significantly influenced subsidence.

6.3.2. Influence of Brine Disposal

Little research has been done on the effects of brine on wetland loss. However, most plant species and benthic organisms will not survive direct exposure to hypersaline brine (120 to 140 ppt). Therefore, every attempt should be made to prevent brine from contacting marsh vegetation. Brine should not be directly discharged into vegetated marsh because it can directly contribute to wetland loss (USFWS, 1978). However, brine is much denser than low salinity water and hence sinks to the bottom of waterways. The effect of open water disposal of brine in well-flushed estuarine areas on wetland loss remains to be determined. The Minerals Management Service is presently conducting an investigation of the environmental effects of produced waters and their role in wetland loss. This study also addresses the potential for radioactive contamination associated with brine disposal.

6.4. MANAGING IMPACTS through the REGULATORY PROCESS

The regulatory process can manage most environmental impacts associated with production. Production impacts are directly related to location size and discharge regulations for that area. By instituting a review process for production facilities and by enforcing existing regulations, impacts to wetland habitat can be decreased.

6.4.1. Avoiding Impacts

Major facilities impacts can be avoided by moving production facilities from the marsh to upland sites when feasible. The use of a Production Review process, modeled on the Louisiana Geological Survey Geologic Review procedure, would allow wetland managers to make an informed decision on these matters. Stationing processing facilities on higher ground eliminates the need for dredging and filling.

Flowlines to move the production to the central or upland facilities can be laid along the spoil banks or board roads to avoid impacting virgin marsh. Currently, flowlines are laid straight across the marsh to the production facilities; however, a process to combine the number of flowlines laid in a single corridor may be beneficial.

The impacts to surrounding marsh from spills of acid and frac fluids is minimal, but locations can be designed to prevent almost all spills from impacting surrounding marsh. Almost all of the acidizing and fracturing occurs during the initial phase of production and completion. Therefore, the impact of these dangerous fluids is minimal. Once the initial production and completion work is finished, the drilling ring levee is leveled. However, in some cases, it is necessary to acidize or frac the well after the drilling ring levee is removed. This means that any spilled material can enter the restored areas and connect with the un-impacted marsh. To prevent run-off of completion fluids, a 1- to 2-foot berm around the production pad should be constructed. This also protects the surrounding habitat from leaks of produced fluids at the wellhead. The construction of these small dikes is already common around most production facilities. Extending this practice to each wellhead should not be difficult or unreasonably expensive.

The greatest impacts on marsh habitat are caused by the discharge of produced fluids. Salt water is the major fluid associated with production of oil and gas. Because of its detrimental effects on the

environment, handling and disposal of salt water need to be carefully regulated. In south Louisiana discharge of salt water into streams, bayous, lakes, and the Gulf of Mexico is standard practice; however, discharge of salt water is an impact that can be totally avoided. Technology exists and is used in every oil producing state to re-inject produced waters into the ground. Re-injection costs more than discharging but has less environmental impact.

6.4.2. Minimizing Impacts

Impacts of production facilities on the environment can be minimized through the proper choice of location, layout, and size. Reducing the location size for the processing facilities reduces adverse effects associated with building a site. These effects were discussed in **Chapter 4.** Utilizing the central facility concept, which most companies implement, allows wellhead areas to be reduced dramatically. Construction of dikes around the production and wellhead facilities can minimize impacts to the surrounding areas. Efforts to consolidate flow lines and prevent them from being placed in un-impacted areas would minimize impacts, as would limiting production facilities to the minimum number needed. It may be possible to reduce facilities through a Production Review process. As the wetland oil and gas fields mature, more reworking of wells will be needed to keep production rates at reasonable levels, and careful review on a case-by-case basis can produce dramatic results in minimizing impacts.

In cases where the wellhead and production facilities must be in a wetland area, care can be taken to avoid known bird colonies, and operations may be restricted during breeding and nesting phases. This reduces the impact of noise and commotion on wildlife.

6.4.3. Combining Regulatory Programs

The U.S. Army Corps of Engineers (COE), the Environmental Protection Agency (EPA), National Marine Fisheries Service (NMFS), and the United States Fish and Wildlife Service (USFWS) are federal regulatory agencies concerned with wetland resources. These federal agencies, in cooperation with state agencies concerned with wetland resources, such as Louisiana Department of Natural Resources/Coastal Management Division, Louisiana Geological Survey, Louisiana Department of Environmental Quality, and Louisiana Department of Wildlife and Fisheries, could begin a Production Review modeled on the Louisiana Geological Survey Geologic Review procedure. This process would identify methods to avoid and minimize environmental impacts associated with oil and gas production activities. The regulatory agencies could use this process to eliminate produced water discharges, reduce location size, consolidate flowlines, and implement construction requirements that minimize damage caused by production operations. The authority to reduce these impacts exists under current state and federal regulations.

6.5. FUTURE TRENDS

The Gulf Coast region of the United States is becoming a mature producing region, which will have great impact on future operations in this area. Although oil and natural gas are still plentiful, finding new reserves will be increasingly more difficult. Future trends include drilling deeper wells in an attempt at new discoveries, horizontal wells (i.e., 90° wells) in existing fields to prevent decline, increased secondary recovery activity, new evaluation technologies for abandoned fields, and enhanced recovery techniques for the oil still in-place. These trends have one common theme—increased access in wetland areas. How the regulatory agencies allow this access is the question for the future.

New technologies in the drilling and production fields will allow increased access to undiscovered oil and gas reserves. Successful projects just completed have shown increased oil and gas reserves at deeper depths. Since the present trend in the United States is to use natural gas as an energy source, demand for gas will continue to grow, and, therefore, the trend for deeper wells in the Gulf Coast will continue to grow. The increased pressures found at these depths can prohibit horizontal and directional drilling on safety grounds. The need to explore for these reserves will put increased pressure on our coastal wetland surface features and resources.

6.5.1. Future Need for Increased Processing Facilities

The gas recovered from these deep formations will cause a demand for increased gas processing and production facilities. Once produced, oil and natural gas must be treated, but processing facilities need not be located at the immediate well site. These fluids could easily be transported via flowlines to facilities that are located in a more suitable

area. Cooperation between regulatory agencies and the producing companies can lead to decreased impacts caused by these facilities.

6.5.2. EOR–The Future Impacts on Habitat

After the partial depletion of reservoir energy, secondary and tertiary recovery or pressure maintenance techniques may be initiated. In addition, as oil and gas become increasingly harder to find, techniques to improve recovery of known and abandoned reserves will be initiated. The future use of secondary recovery, enhanced recovery and enhanced evaluation techniques in south Louisiana is dependent on the price of oil. The lower the price the less activity that will occur in the near future. Some of these activities will occur regardless of future price trends for oil and gas. The higher the price the more activity that will occur in the near term.

These enhanced recovery methods require more equipment and consequently more area. Efficient use of existing prepared sites or impacted sites, re-injection of salt water, and optimal stationing of central facilities can avoid or reduce unnecessary effects of these recovery techniques. Efficient utilization of existing drilling and production sites can minimize habitat alteration.

PIPELINE INSTALLATION

by
Robert H. Baumann and Donald R. Cahoon

7.1. INTRODUCTION

The pipeline system along the Gulf Coast of Texas and Louisiana is the most intensive oil and gas transport system in the world. To date, the region has provided over 90 percent of the Outer Continental Shelf (OCS) hydrocarbons produced (Slitor and Wiese, 1988), 40 percent of the nation's natural gas supply (EIA, 1988), and nearly 33 percent of the nation's refinery capacity. The only deep water offshore receiving terminal (LOOP) in the U.S. is located here, as well as the vast majority of the nation's Strategic Petroleum Reserve (Baumann, 1988). Pipelines are the primary means of transporting natural gas, crude oil, petroleum products, and sulphur within the region and to the rest of the nation. This chapter describes the means for transporting hydrocarbons via pipelines (≥ 4-inch diameter) from the production field described in **Chapter 6** to points of refining and distribution.

A substantial portion of the pipeline system infrastructure must, by necessity, traverse the coastal wetlands. The required construction techniques combine marine and terrestrial practices and are among the more expensive techniques because of the logistics involved in both construction of the line and restoration of habitat. Some of the more recent projects have approached or exceeded $1 million per mile in total costs (True, 1987). This chapter discusses the state-of-the-art knowledge concerning standard pipeline construction techniques in wetlands, impacts on Gulf Coast wetlands, and methods to avoid, minimize, and restore wetland habitats. With respect to costs, we have

included such data where reported or provided by operators so that others may attempt their own analyses to evaluate some benefits versus costs when deemed appropriate.

7.1.1. History

At the start of World War II the pipeline infrastructure within the coastal wetlands of Louisiana was limited to 300 miles of line, primarily for oil (LGS, 1941). By 1947 the system had grown slightly to 460 miles in length (LGS, 1947) as new onshore fields were discovered and developed in the coastal zone. The Truman Proclamation of 1947, in which the U.S. claimed rights to resources of the seabed subsurface of the continental shelf, was the catalyst for offshore development. By 1953 the total length of the system had grown to 1,570 miles within the coastal zone (LGS, 1953) and included the first lines originating in the offshore region beyond the territorial sea limit. From that period to 1979, the number and total length of lines grew tremendously as the Louisiana coastal zone and federal Outer Continental Shelf (OCS) hydrocarbon and sulfur resources were developed. Virtually all of the estimated 12,000 miles of pipelines in the Louisiana coastal zone (LGS, 1983) were constructed prior to 1980. Since that time pipeline construction has decreased markedly, especially onshore. Most of the lessened activity has been limited to feeder lines in the OCS (Slitor and Wiese, 1988; True, 1988). It is widely regarded that existing infrastructure is largely sufficient for future resource development. Thus, even with future technological advances to exploit deepwater OCS, extensive use of the onshore component of the existing system is expected, as much of it has been constructed for additional capacity. In addition, as older fields mature, some pipeline capacity will be made available. It is, of course, in industry's interest to make use of existing systems and thereby forego new construction costs. Still, some new major lines should be expected as new fields come on-line and as some pipelines are abandoned because of age, safety or other factors.

Technological advances in construction techniques since the early 1970s have made a major contribution in reducing impacts of pipelines on wetlands. Before 1970, canals had to be dredged wide enough and deep enough through the marsh to accommodate large work barges. However, by the early 1970s, the technology existed to construct and push-pull a pipeline through much narrower ditches. Although the large work barges are still used as work platforms and pipe carriers, they no longer go through the marsh (Section 7.1.2) except in unusual circumstances. The smaller push ditches through the marsh were made possible by the innovation of marsh buggy mounted draglines and backhoes **(Figures 7.1 and 7.2)**.

Other advances that have contributed to reducing direct impacts from pipeline construction include: advances in mitigating marsh buggy tracks; greater use of helicopters in right-of-way surveying (as opposed to using marsh buggies); general advances in construction productivity that reduce the time the canal spoil is exposed to the air (Section 7.3); and, closer coordination with permit agencies to optimize pipeline routing while reducing impacts.

7.1.2. Pipeline Construction Techniques

Pipeline construction through the coastal wetlands requires a combination of equipment for marine and terrestrial environments, as well as some specialized equipment. The primary method used today to lay the pipe is the push-pull method.

The types of equipment required vary with the types of habitats the pipelines traverse. The pipeline right-of-way is surveyed using a combination of helicopters, boats, marsh buggies, and terrestrial equipment and, in some instances, aerial photography. In the marsh, helicopters are being used more frequently as they have become more cost-effective and, at the same time, they have little or no environmental impact.

In general, it is less expensive for operators to establish a work yard to store pipe, flotation buoys, and other supplies, as well as the equipment, on a terrestrial site that can support heavy loads and is accessible by roads. Approximately 2 acres of land adjacent to the right-of-way are necessary for a work yard (University of Texas and Pipeline Contractors, 1980). The alternative is to provide storage and work space on barges. In many cases, both barges and dry land sites are used as staging areas. Barge operation is generally more expensive as barges have to be leased, some dredging of preexisting canals or natural waterways may be required to get the barge on location, crews must be transported by boat or helicopter, and pipe must be barged to the work area. On the other hand, barges have the advantage of being transportable, and a considerable amount of pipe can be carried on a single barge. This latter aspect can result in cost savings over a dry land operation, especially when dealing with large diameter pipe, where trucks may only be able to transport as little as a single section of pipe per trip.

The push ditch is dredged through the marsh usually with a dragline or backhoe mounted on a

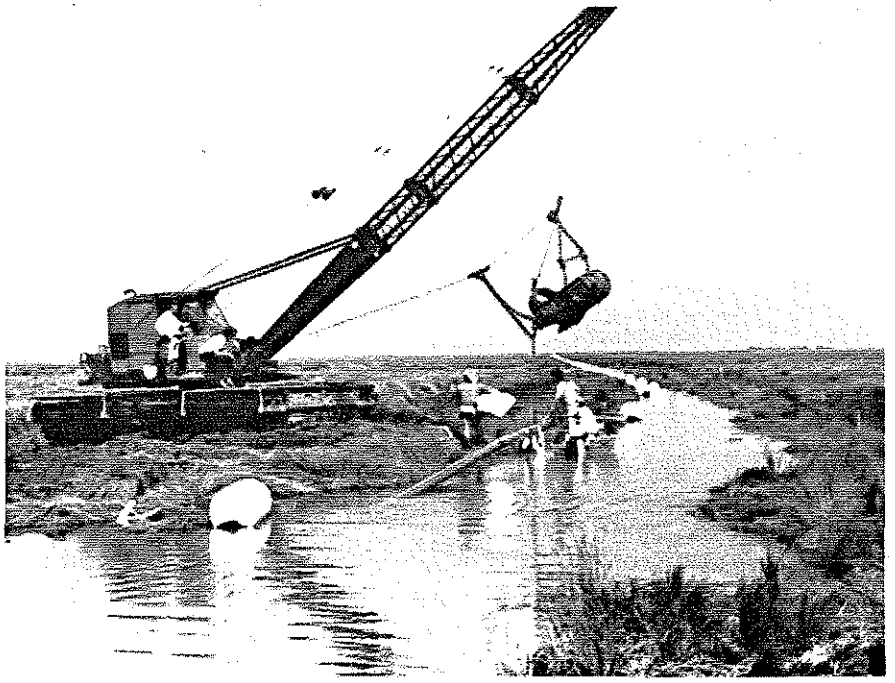


Figure 7.1. Dragline mounted on wide-track marsh buggy. (Photography courtesy of United Gas Pipe Line Company.)

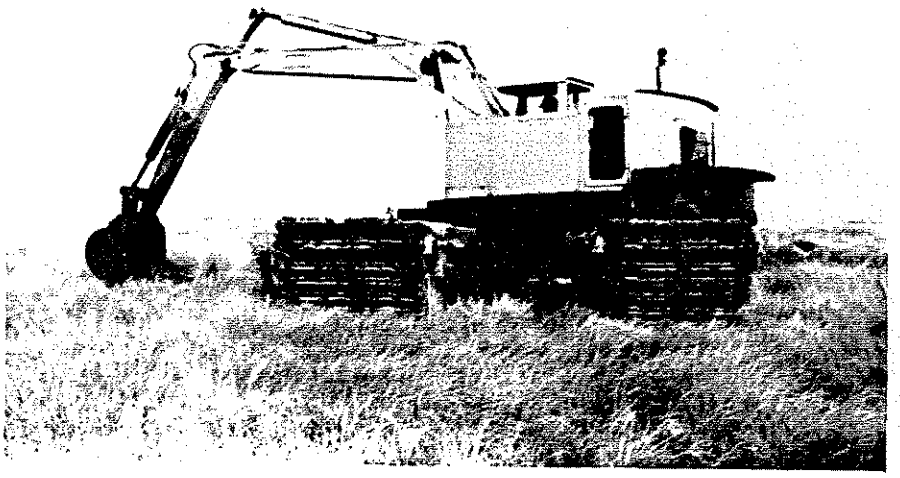


Figure 7.2. Backhoe dredge mounted on wide-track marsh buggy. (Photography courtesy of United Gas Pipe Line Company.)

marsh buggy (**Figures 7.1 and 7.2**). The resulting ditch (**Figure 7.3**) is narrower (8 to 10 feet) and shallower (4 to 6 feet) than the older method of dredging a flotation canal (40 to 50 feet wide and 6 to 8 feet deep) for the pipeline (McGinnis et al., 1972). The push ditch advancement substantially reduces the amount of dredging, the operator's costs, and the short- and long-term direct impacts on the marsh (Section 7.2).

miles (University of Texas and Pipeline Contractors, 1980). Most pushes are for much shorter distances because other lines are encountered and crossings must occur that require different equipment. The flotation devices are then removed and the ditch is backfilled. The slip is also frequently backfilled and a dam (bulkhead) may be constructed along (**Figure 7.6**) or set back from the shoreline (Section 7.1.4).

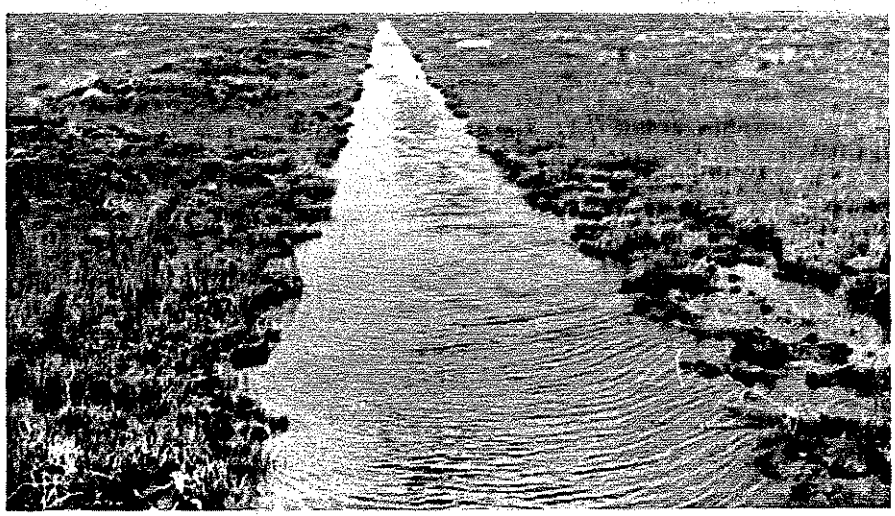


Figure 7.3. Typical push ditch canal prior to backfilling. (Photography courtesy of United Gas Pipe Line Company.)

The work barge is towed to sites along the right-of-way. A short slip (**Chapter 3**) is dredged into the bank of the marsh to help keep the barge stationary. Once sited in the slip, the barge may be partially flooded to rest on the bottom and spuds project from the barge to the bottom to help stabilize the barge's position (University of Texas and Pipeline Contractors, 1980). If the pipeline is to cross the waterway, a second slip is dredged on the opposite bank to enable the barge to relocate and push pipe in the opposite direction (**Figure 7.4**).

The pipe is treated with a protective corrosion control coating either in the field or just before barge loading. The pipe is welded, inspected, and coated on the work barge. Flotation devices are placed on the pipe and the pipe is then pushed or pushed and pulled through the ditch (**Figure 7.5**). Theoretically, pipe can be pushed for 10 to 15 miles; however, the longest reported push is for 7

A larger work area is required in cases where existing pipelines are crossed in the marsh. Cradles to raise and align pipes are required (**Figure 7.7**), and suction or jet dredges (**Figure 7.8**), rather than backhoe or draglines, are frequently needed to make crossings under other pipelines. A minimum vertical separation distance between the two crossing pipelines is normally specified.

In forested wetlands, the right-of-way needs to be cleared by cutting before the laying of pipe. The Louisiana Department of Transportation requires that the right-of-way be maintained free of trees because of the potential damaging impact of tree roots on the pipeline and also to provide access for maintenance, inspection, and emergency repairs.

A backhoe or dragline cannot be used to lay pipe across lakes, bays, and other relatively large water bodies greater than 2 to 3 feet in depth. Large lay barges are used (**Figure 7.9**), and the pipe is laid

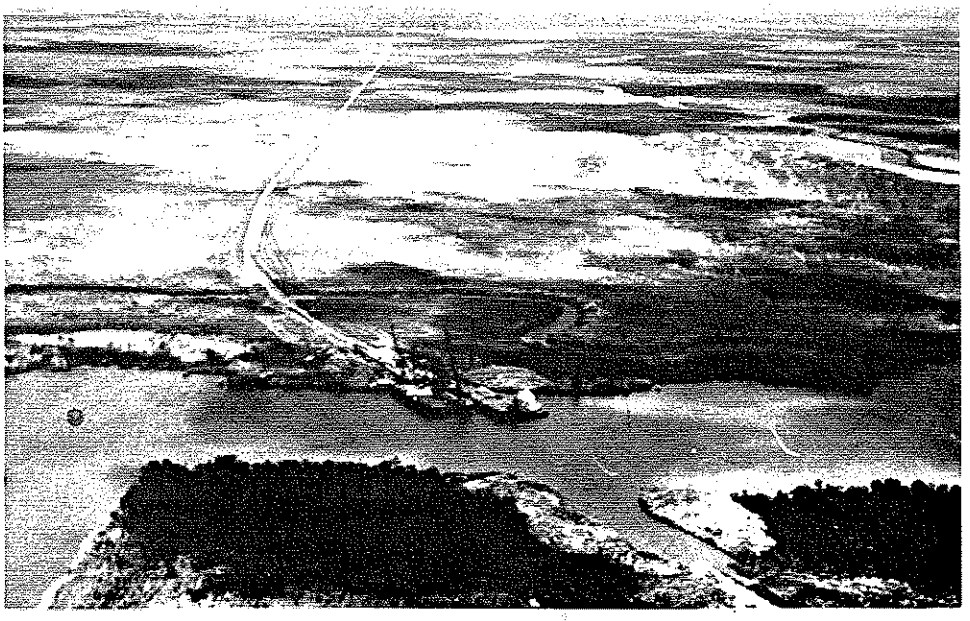


Figure 7.4. Pipeline crossing a waterway, with two slips on either side of the waterway. (Photography courtesy of Tennessee Gas Pipeline.)

joint by joint (typically in 40-foot lengths). Welding and coating is conducted on the lay barge, and the pipe is launched off the rear end of the barge. The dredging is normally conducted by a separate dredge ahead of the lay barge. A second dredge can be located toward the rear of the barge to backfill the line or the front end dredge, after completing its passage across the water body, returns to the rear to backfill. Alternatively, a pipeline may be "jetted in" to a waterbottom by a jet barge that excavates a ditch using a high pressure stream of water. The ditch is allowed to backfill naturally through sloughing of the ditch walls and sediment from the turbid water.

Major river crossings, such as the Atchafalaya or Mississippi Rivers, require a custom-designed approach. Each crossing represents a different set of engineering problems dependent upon the width, depth, strength of current, and other factors associated with the waterway (Taylor, 1957). Several case studies are reported in Taylor (1957). A common current practice is to directionally drill the pipeline across the river (Hair, 1989).

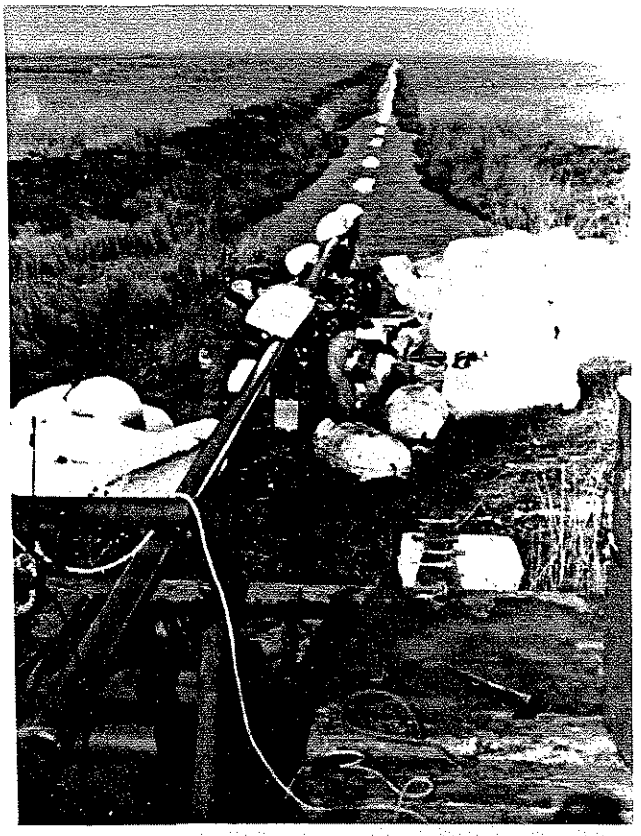


Figure 7.5. Push method of pipe installation. Note flotation devices. (Photography courtesy of United Gas Pipe Line Company.)

7.1.3. Right-of-Way Restoration Techniques

7.1.3.1. Marsh Habitat. A pipeline right-of-way through marsh is restored usually by backfilling. In some special or experimental cases,

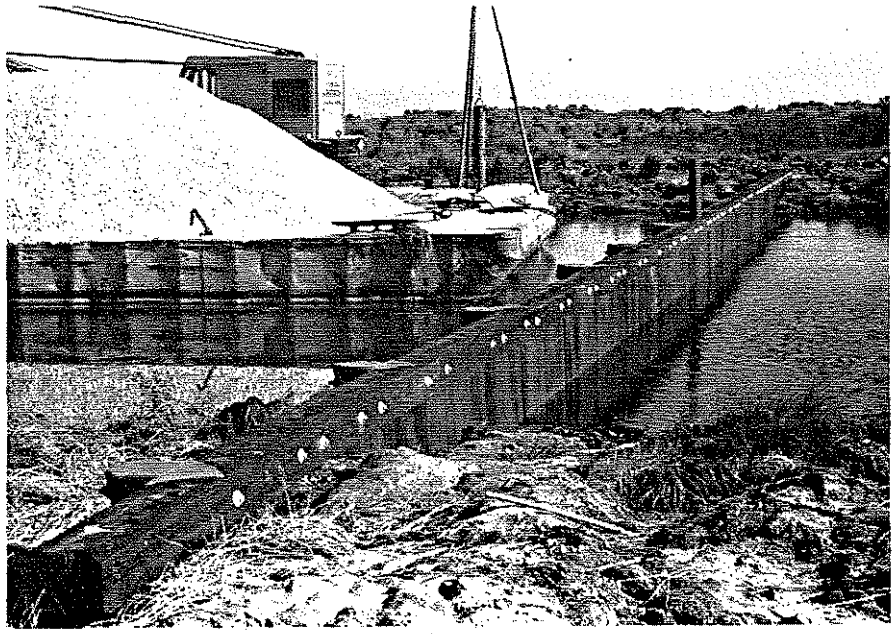


Figure 7.6. Bulkhead dam near shoreline intersection. Note shell on barge that will be placed as a cap over the bulkhead. (Photography courtesy of United Gas Pipeline Company.)

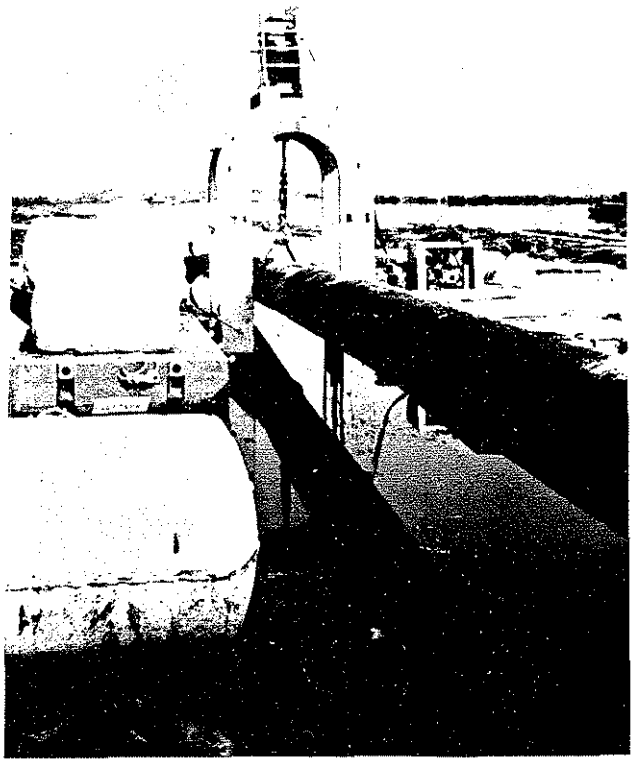


Figure 7.7. Pipeline lifted by a cradle so that a new pipeline can be laid under it. (Photography courtesy of Tennessee Gas Pipeline.)

double ditching and/or vegetative plantings are used.

Backfilling. Backfilling is now the common and usually required practice for minimizing damage from pipelines. In the older flotation canals, where pipe was laid joint by joint, the canals were frequently left open. It is, of course, expensive to backfill. The older flotation canals, with their large cross sectional area in relation to the current push-in method, generated considerably more spoil and, thus, more expense in both dredging and backfilling. In Louisiana and the upper Texas coasts, a typical backfilled pipeline canal results in a 75 percent reduction in direct impacts to the marsh, as opposed to an unbackfilled canal (Baumann and Turner, in press). Because backfilling has such considerable potential for reducing direct impacts, some attention has been given to refining and experimenting with different methods of backfilling.

The current common practice for backfilling push ditches is to backfill with a dragline mounted on a wide-track marsh buggy. The care with which the dredge operator scoops the spoil from the marsh back into the ditch is considered an important factor (**Figure 7.10**). The Gulf Coast marshes occupy a very narrow elevation range, even in relation to other coastal marsh areas of the U.S. and world (Baumann, 1980). This is largely because

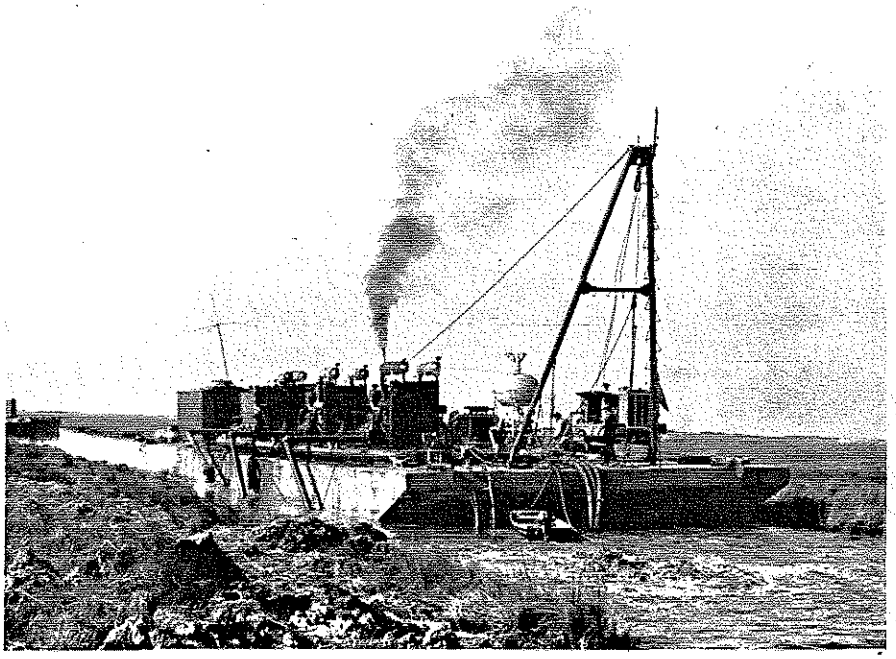


Figure 7.8. Jet dredge, which pushes material away from existing intersecting pipeline. Note compressed airhoses at front of barge. (Photography courtesy of United Gas Pipe Line Company.)

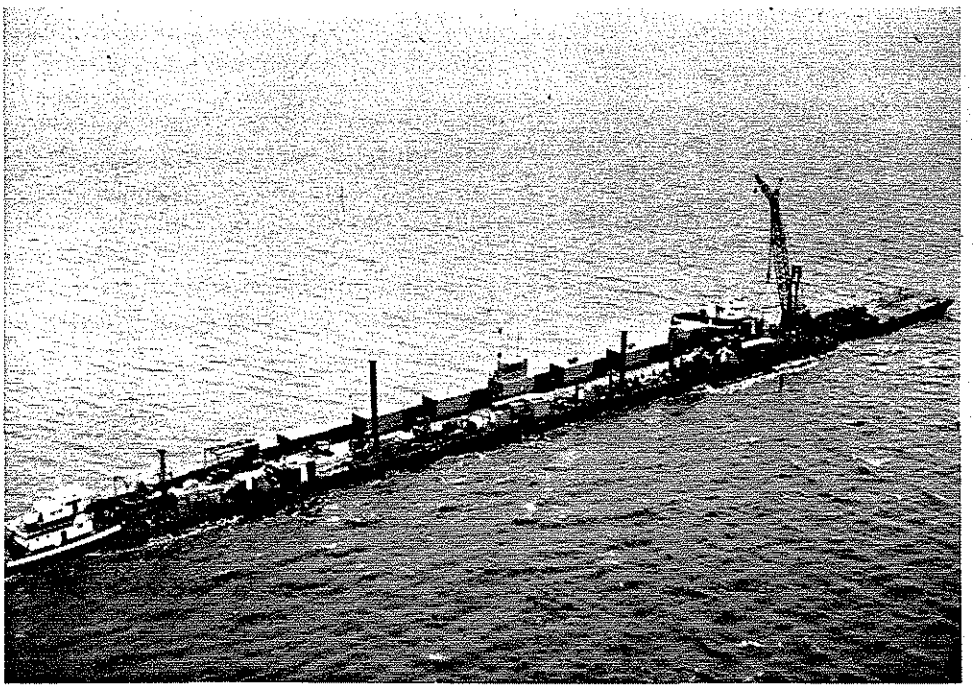


Figure 7.9. Lay barges being pushed across a waterway. (Photography courtesy of Tennesse Gas Pipeline.)

Figure 7.10. Example of a properly backfilled and restored pipeline right-of-way. Note limestone in foreground which helps prevent shoreline erosion. (Photography courtesy of Tennessee Gas Pipeline.)

the tidal range is so small. Thus, if the dragline operator digs just a few inches below marsh grade in scooping the spoil, the scooped area may never again support emergent vegetation. Similarly, in placing the spoil back into the ditch, care must be taken to properly grade the backfill. Krone et al. (1987) believe this latter aspect can be more important in ultimate recovery than the actual construction technique used. As Krone et al. (1987) point out, the success of the restoration can hinge on properly educated equipment operators.

Double Ditching. Double ditching is a common excavation method used in terrestrial environments. The top 6 to 12 inches of topsoil and vegetation matter is removed and placed on one side of the ditch, and the material excavated below that level is placed on the other side. In backfilling, the process is reversed. It has been suggested, and some implementation has occurred, that the double ditch method be used in the wetlands. This method adds about $1 to $1.50 per linear foot of excavation to the total costs (Woodson Construction, Lafayette, LA., Dec. 1988, *personal communication*). For comparative purposes, the average cost for excavating a pipe ditch with a backhoe type dredge through the marsh is $3 to $4.50 per linear foot. The range in price depends on the diameter of the pipe. For a swamp forest, an additional $3 to $4 per linear foot must be added for tree removal costs. Thus, double ditching is a significant additional cost to the excavation component of pipeline construction.

Of greater relevance to maintaining habitat integrity is whether double ditching provides any benefits to wetland environments. The edaphic conditions encountered in the wetlands are different in just about every aspect from dry-land soils. An obvious difference is the lack of a topsoil in the marsh. In two reported uses of double ditching in the marsh, Chabreck (1979a) had inconclusive results in comparing double ditch to single ditch spoil backfill in some Texas and Louisiana marshes. In southeastern Louisiana, Krone et al. (1987) found no statistical differences in marsh recovery between the two methods. Krone et al. (1987) were hesitant to use the statistical findings in a conclusive manner as other environmental differences between the double ditch and single ditch areas may have affected statistical results.

In summary, the knowledge concerning double ditching in Gulf Coast wetlands is:

(1) The scientific and practical consensus is that double ditching is not as beneficial in wetland soils as in dry land soils because of inherent differences in the development of their respective soils;

(2) Experimental results in the field have produced inconclusive results regarding recovery differences, probably because it is extremely difficult to isolate environmental conditions in the field and

to have bona fide controls to validate statistical comparisons; and,

(3) double ditching is substantially more expensive than current excavation practices.

Plantings. Planting, planting and fertilizing, transplanting, and seeding are additional methods that have been employed to enhance and accelerate right-of-way restoration along the Gulf Coast. For emergent marsh vegetation, planting in or transplanting into the right-of-way accelerates marsh recovery for a growing season (Chabreck, 1979a). Recovery differences between natural and planted areas diminish over time and become insignificant after approximately three-year periods (Chabreck, 1979a; Hinchman and George; 1987; Krone et al., 1987).

To our knowledge, planting or transplanting has only been conducted in a few isolated cases, experimentally, on very short segments of individual pipelines. The costs for planting are extremely high with operators paying in excess of $100,000 per acre planted. This cost estimate, however, includes longer-term monitoring studies and the development costs associated with establishing methodologies for planting or transplanting. Clearly, costs will decrease if planting becomes a more regular occurrence; however, it remains a very labor-intensive effort and the benefits of enhancing recovery are short-lived.

While we have no knowledge of massive plantings, there are specific habitat areas where planting is increasingly being requested. These so-called sensitive areas include the foredunes along coastal barriers and seagrass beds.

7.1.3.2. Beach Habitat. The beach, inclusive of foredunes, serves a very important wetland system function as the barrier absorbs much of the impact from storm wave and surge energies. It thus protects the landward habitats from the more erosive storm energies. The vegetative cover on dunes is widely considered to be of critical importance to help bind sediments and maintain dune integrity. Odegard et al. (1984), followed by Hinchman and George (1987), working along the Gulf Coast of South Texas, planted and fertilized the foredunes of a disturbed pipeline crossing after rebuilding the foredune back to its predisturbed elevations. Monitoring was conducted for more than 1 year and again after a 5-year post construction period. Despite the plantings and fertilization there was significantly less cover on the right-of-way foredunes than on the control foredunes just after the start of the next growing season. Later, during the same growing season, a major hurricane directly impacted the area and virtually destroyed the windward portion of the foredunes at both sites. Sampling conducted four years later indicated no significant difference in the percentage of cover between the two sites; curiously, both sites had significantly greater coverage than their respective pre-hurricane condition. Working on a low-level barrier in Louisiana, Mendelssohn and Hester (1988) found that natural revegetation density of foredunes was equal to planted foredunes within 6 to 12 months. It is clear, however, that vegetated dunes withstand storm energies better than non-vegetated dunes as has been proved time and again along developed barriers. Thus, if a storm occurs soon after a dune is denuded, we would expect the dune to have a lessened ability to dissipate energies and the landward marsh may be more severely affected by erosional processes. Thus, the prudent action is to require planting of the foredune area. Finally, the Louisiana coastline is generally sand deficient and lacks natural barriers along many sections of its coast. Therefore, the exact onshore siting location is important for recommendations on coastline restoration. A method that can be used in some instances to avoid disturbance of the beach habitat is directional drilling.

7.1.3.3. Seagrass Beds. Seagrass beds are another sensitive habitat. Most of the work on seagrass restoration was initiated in Florida and has been transferred to Texas and other areas. The restoration success, other than natural, can be generally characterized as mixed and expensive. Part of the problem has been developing successful transplanting, laboratory growth and seed collection techniques of the several species involved. Discussion of some of these problems and progress being made are included in Fonseca et al. (1982, 1985) and Holtz (1986). In the attempts of the 1970s and early 1980s in Florida, costs per acre ranged from $64,000 to $439,000. These figures represent total planting costs but the success of plantings was very modest and the cost per area of permanent recovery was correspondingly higher. For example, the cost of restoring 36 acres in Biscayne Bay in 1982 was $781,425; however, only 6 acres were successfully restored ($130,237 per restored acre). In Texas, a verbal bid to a pipeline operator in 1985 estimated costs at $15,000 to $20,000 per acre, with up to 5 years for total recovery with no guarantee (per operator written correspondence to these authors dated November 11, 1988). By 1986, techniques in Florida had improved and Holtz (1986) estimated restoration could be conducted for $3,760 to $8,000 per acre, still a very sizable cost factor. More importantly,

we do not know if the effort produces any better or faster recovery than natural recovery. The authors are unaware of any published field data on natural recovery rates after pipeline construction. Aerial photographs of the Texas coast show areas where disturbance effects appear to have remained for many years; however, there are many examples that do not show any difference in the seagrass beds within the pipeline right-of-way versus nearby areas.

7.1.4. Dams (Bulkheads)

The general functions of dams are to retard public access into the right-of-way (for safety reasons) and into private property, retard erosion of the landward shoreline, and provide barriers to saltwater intrusion and other water control functions. The latter two aspects are particularly important for the older open canals that have not been backfilled. Dams are a commonplace structure along the pipeline routes through the coastal wetlands. The dams and other similar structures, such as fixed crest weirs, are quite variable in construction **(Figures 7.6 and 7.10)** and design. They are most frequently encountered at or near land-waterbody boundaries along the pipeline route. There are hundreds and perhaps a few thousand of such structures in the Louisiana coastal zone. They are fairly expensive to construct, they frequently require extensive maintenance, and it is not uncommon for them to undergo complete reconstruction and relocation. Many of the larger operators have several employees whose jobs are devoted to reconnaissance of these structures and maintenance scheduling.

Despite this considerable infrastructure investment, there are no true standards for exact implacement or what type of structure to build under a particular set of conditions. In discussions with operators as to why there appears to be such a chaotic mix of structures, it is clear that the operator's decision on what to build where is largely influenced by the individual landowner's preference within a fairly broad set of regulatory guidelines for dams along pipeline routes. In general, few of the structures appear to be very efficient in the long-term (>10 years). Natural shoreline erosion results in some structures being located several hundred feet out from the shoreline in as little time as a decade. Washouts along the sides of the dam are commonplace and result from both natural causes (water level differences on either side of the dam causing pressure build-up and washout of unconsolidated sediments) and man-made causes (vandalism or hunters and fishermen wanting access to wetlands).

Because erosion is so commonplace and many structures become non-functional within the span of just a few years, there has been a recent tendency to recommend that the structures be placed some distance landward from the current shoreline. In some cases, however, the most important function of the structure is short-term, and the landowner wants the structure placed at the current shoreline. For example, a slip that is backfilled along a well-travelled waterway will be subjected to the erosive potential of boat wakes to a greater extent than the nearby vegetated shoreline that contains a root system to help retard erosion. A major function of the structure is to provide erosion protection for the first few years until the backfilled area revegetates and develops a root system.

7.1.5. Ancillary Facilities

There are a number of ancillary facilities that are required along the pipeline system. These include small areas for compressor and pumping stations and larger areas for processing, fractionation plants, and refineries. These facilities range in size from less than a small standard urban lot to many acres for some of the larger plants that include condensate strippers, dewatering devices, and hydrocarbon storage areas. Most of the larger plants service multiple lines; thus, the construction of new pipelines may not require new plants.

A number of factors influence facilities siting. Distance is one factor, and many of these facilities (especially for natural gas liquids) are located very near the coast. Dry land sites easily accessible by road are preferred, and, in some cases, wetland areas are filled or leveed and drained to provide the necessary siting areas. The total impact on wetlands for these facility sitings in relation to the total wetland loss problem is extremely small. For example, Baumann and Turner (in press), in looking at the direct impacts of OCS pipelines on wetland loss, found that ancillary facilities represented only 6 percent of the total direct wetland loss attributable to the pipelines, which, in turn, accounted for less than 5 percent of the total wetland loss in coastal Louisiana.

A major environmental concern associated with the larger facilities is the disposal of production and processing related wastes. Separation of liquids from offshore production is frequently conducted by onshore facilities via pipeline transport. In some cases, brine disposal is permitted to be directly discharged into surface waters. The issues

concerning waste disposal practices are currently very much in debate in Louisiana and are undergoing review **(Chapter 6)**.

7.2. IMPACTS on WETLAND VALUES and FUNCTIONS

In the previous discussions we have described the construction process and have included some of the types of wetland impacts that result. In this section, we will examine what those total impacts are and what factors affect the degree of impact. Impacts and degree of restoration vary both spatially and temporally. Understanding these variations is important in planning and projecting future pipeline construction.

7.2.1. Direct Impacts

The primary direct impacts of push-pull pipeline construction are the direct conversion of marsh to open water and the loss of forested wetland habitat **(Table 7.1)**. However, the degree of impact is much less than that for a drilling site access canal **(Chapter 3)** because the pipeline canal is narrower and is backfilled. In fact, restoration of marsh habitat by backfilling may approach 100 percent in some wetland regions of Louisiana. The ecological impacts associated with habitat alteration **(Table 7.1)** are similar to but usually less severe than those for an access canal.

The total direct impact on marsh habitat of any given pipeline depends upon a large number of factors. Baumann and Turner (in press) have shown that age of pipeline (when constructed), pipeline diameter, geologic region of construction, construction method (backfill vs. non-backfill) and habitat type all have a statistically significant relationship with the degree of direct impact on a per unit length of pipeline basis.

Direct impacts from OCS pipelines accounted for over 4 percent of the total wetland loss that occurred in coastal Louisiana from 1955 to 1978. If we assume that all pipelines in the Louisiana coastal zone have proportionately the same degree of direct impacts per unit length as OCS pipelines, then direct impacts from all pipelines would account for about 10 percent of the wetland loss from 1955 to 1978.

Direct impacts from OCS pipelines averaged 9.9 acre per mile through wetland habitats excluding open bay and lake areas (Baumann and Turner, in press). Pipelines constructed after 1972 have had less impact, and the preceding average includes the older flotation canals. Backfilled canals averaged 75 percent less direct impact than the open flotation canals (Baumann and Turner, in press). Thus, the 9.9 acres per mile is a high value in relation to a pipeline constructed today.

The geologic region in which the pipeline is constructed is an important factor. Direct impacts in the Chenier Plain (from Galveston, Texas to Freshwater Bayou in Vermilion Parish, Louisiana) are significantly less than in the Mississippi Deltaic Plain. The Chenier Plain is inherently more stable, geologically, than the Deltaic Plain, and recovery of the marsh from backfilling is more successful. For backfilled pipeline canals crossing a typical habitat mix, we can expect an average direct impact of 2.7 acres per mile in the Chenier Plain and 4.2 acres per mile in the Deltaic Plain (Baumann and Turner, in press).

The diameter of the pipe is a significant factor affecting direct impacts. Larger diameters result in greater impacts, the relationship is non-linear, and the effects are statistically less important than other factors in accounting for variability (Baumann and Turner, in press). These results are not surprising as larger equipment is required to lay large diameter pipe.

Among the wetland habitat types, there are differences in expected direct impacts in backfilled pipeline canals. Forested wetlands are more adversely affected because there is an intentional effort to prevent the forest from recovering in the pipeline corridor for pipeline safety reasons. Among marsh habitats, salt marsh is impacted less than less saline habitats. It is unclear why, but it is suspected that because salt marsh soils contain a higher inorganic component there is greater potential for successful recovery. Stated another way, because fresher marsh soils contain a high organic content there is more potential for oxidation of the soil during the period when the soil is exposed to the air (as spoil). As oxidation occurs, there is correspondingly less material to use for backfill. Consequently, right-of-way may not be returned to pre-excavation elevations, and plant recovery potential will be diminished.

Pipeline age is also positively related to the degree of direct impact because older lines used the flotation method. Separating out the backfilled pipelines, Baumann and Turner (in press) found that age was not a factor in the Chenier Plain but was in the Deltaic Plain. Thus, in the Chenier Plain, a properly filled pipeline is not expected to have any additional impacts through time. In the Deltaic Plain, however, backfilled canals may experience some additional consolidation of the backfilled sediments through time resulting in elevations too low to support emergent vegetation along some sections of the line.

Table 7.1. Observable and hypothetical cause-effect relationships between pipeline construction and habitat alteration for push-in pipelines.

	Surveying	Construction Impact Excavation/ Construction	Backfilling/ Restoration
ACUTE ENVIRONMENTAL CONSEQUENCES (short-term)			
Habitat Alteration – Physical Impact			
Direct Conversion to Open Water		√	
Increase in Turbidity (local)		√	√
Loss of Forested Wetland		√	
Noise, Commotion during Construction	√	√	√
Habitat Alteration – Ecological Impact			
Increased Susceptibility to Storm Damage		√	√
Immediate Loss of Marsh Shallow Water Habitat		√	
Immediate Gain of Open Water Ponds		√	√
Disruption of Natural Surface Drainage		√	
Release of Nutrients and Toxins		√	√
Soil Oxidation		√	√
Change in Plant Species Composition, Diversity, Percent Cover	√	√	√
Impact on Biota			
Nesting Disturbance	√	√	√
New and Different Habitat		√	√
Disturbance of Fish Spawning and Feeding		√	√
Positive/Negative Impact on Plant Growth		√	√
Destruction/Disturbance of Benthos		√	√
CHRONIC ENVIRONMENTAL CONSEQUENCES (long-term)			
Habitat Alteration – Altered Physical Process			
Surface Hydrology (drainage patterns, water quality, sediment, and nutrient flow patterns)		√	√
Habitat Alteration – Physical Impact			
Bank Erosion		√	√
Compacted Marsh Surface	√	√	√
Direct Habitat Conversion		√	√
Habitat Alteration – Ecological Impact			
Forest Succession		√	√
Change in Plant Species Composition, Diversity, Percent Cover		√	√
Shoreline Bank Stability			√

7.2.2. Indirect Impacts

There is consensus among the scientific community that canals, in general, result in indirect impacts that affect wetland loss (**Chapter 3**). In theory, the spoil banks retard water exchange, inorganics and organics between the marsh and natural drainage ways and the canals themselves alter the natural hydrology, and the eventual synergistic impact can be the loss of emergent vegetation (**Table 7.1**). Field experimentation to monitor and quantify these theoretical effects have had little success, largely because there are so many operative factors in the natural environment that it has been extremely difficult to isolate the effects of canals and spoil banks (Cahoon et al., 1987).

Many studies have been conducted with statistical comparisons between canal densities and wetland loss rates over varying geographic scales (Chapters 19-22, Turner and Cahoon, 1987). These efforts almost universally conclude that statistical relationships exist between canal densities and wetland loss rates, but the cause and effect relationships remain unclear, and the results are highly

variable. This field of inquiry is, at present, a highly debated scientific issue that has been catalyzed by considerable public interest.

Older, open flotation canals are of concern from the perspectives of scientific inquiry and management implications. The modern backfilled pipeline canal is of much less concern and, in fact, these have been omitted from the above statistical analyses of canal densities. Thus, from the perspective of reviewing permits for future construction, the debate is not currently of major concern, unless a non-backfilled canal is being proposed.

7.3. MANAGING IMPACTS through the REGULATORY PROCESS

The development of the push-pull method, along with the development of smaller dredging equipment, has resulted in a cost savings to industry and a 75 percent reduction in direct impacts to wetland habitats. Because the spoil banks are removed and the ditches are filled using the push-in method, indirect impacts on wetland habitat loss associated with the old flotation canals should also be reduced or eliminated. The current construction standards should continue and efforts should be directed at improving and refining the basic construction process.

Knowledge regarding pipeline installation and wetland impacts has markedly grown over the past decade, but a number of gaps remain. For example, we have discussed the problems and questions relating to the use of dams (Section 7.1.4), but we have omitted discussion of impacts on habitats, such as benthic communities. Approximately 40 percent of the length of a typical pipeline will be in bay-lake bottom environments. The assumption is that the bay bottoms recover to normal conditions over some time period. We have yet (despite considerable efforts) to document as cause and effect, implied indirect land loss relationships with human activities, such as canalization.

There are few construction techniques or mitigation procedures that are universally successful in avoiding, minimizing, and restoring impacts. The wetland systems affected are diverse and the impacts are highly variable. Clearly, some techniques have a better history of success than others over a wide range of habitats, but each pipeline has its own set of problems. The relative state of scientific knowledge is by no means sufficient to provide "cookbook" solutions for each set of circumstances. Many unanticipated problems and changes occur during construction and after initial permits are issued. For example, routing changes may occur because of safety considerations, and there are cases where this occurs at the expense of the wetlands. The ultimate impacts of these deviations are often affected by the practical and technical knowledge of the regulatory agencies' field personnel and how they assess the deviations. Also, the actual field implementation for avoiding, minimizing, and restoring impacts may depend on those same field personnel. This is extremely difficult to document in a quantitative manner; however, the perception among many in the scientific community, regulatory agencies and the operating private sector is that the development of good professional working relationships among these staff members can make very substantial differences in impacts and costs.

7.3.1. Avoiding Impacts to Surface Features

7.3.1.1. Route Selection: Upland. A large-scale planning aspect is to route pipelines in a manner that minimizes the area of wetlands traversed. This includes maximizing the use of topographically higher lands, such as natural levees, cheniers and Pleistocene outliers. This could lower construction costs as less expensive dry land construction techniques can be used over longer segments of the system. These positive attributes notwithstanding, upland pipeline routes also present some disadvantages. The dry land areas already contain a large number of pipelines in many areas. In addition, these areas tend to be populated and contain water lines, consumer gas lines and electric lines. Space and safety factors may prohibit pipelines from many of these areas. In the case of natural gas lines, regulations require reductions in maximum allowable operating pressures through populated areas. This can result in engineering design problems for the system as a whole. Finally, these populated areas have many landowners, and right-of-way acquisition is frequently a problem. In order to avoid impacts to wetlands, pipelines should be routed through uplands if possible, but this requires weighing many variables. In addition, the laying of pipelines in the coastal wetlands of this region is frequently unavoidable as the oil and gas reservoirs are often located beneath the wetlands.

7.3.2. Minimizing Impacts to Surface Features

7.3.2.1. Route Selection: Wetland. Route planning should include at least a cursory review of some historic aerial photographs of the route. There is good historic photographic coverage of at least the Louisiana and Texas Gulf Coasts. These pho-

tos have been found to be valuable in identifying wetland areas that are prone to deterioration and may be particularly sensitive to construction impacts (Krone et al., 1987).

7.3.2.2. Pipeline Corridors. There are two aspects of the corridor approach that have been offered as favorable attributes. First, by limiting pipelines to a few corridors, the impact area is limited to only a few areas of the coastal wetlands. This is a somewhat idealistic approach in that most of the infrastructure has already been built, and it is too late to use this approach for most of the Louisiana and Texas coasts. It may be a valid approach for other areas that are presently undeveloped or minimally developed (e.g., Alabama or the western Florida coast). Second, there is a belief that the total of direct impacts of two or more pipelines in a corridor is less than that of the same pipelines constructed in random locations. For open flotation pipeline canals this was found to be true by Baumann and Turner (in press), but there was no statistically significant difference in direct impacts between random single lines versus corridor approach for backfilled pipelines.

In as much as we strongly recommend backfilling, the corridor approach provides no additional environmental advantage. There are, however, disadvantages. The corridor may be far from the best route in terms of distance (cost) and avoidance of wetland habitats. In addition, the construction of one pipeline alongside one or more additional pipelines can present safety problems. When it comes to safety, prudence is the rule, and wider rights-of-way that result in greater potential damage may be required as a safety margin against the disturbance of pre-existing pipelines.

7.3.2.3. Equipment Usage. Agreements reached during the planning process to reduce, avoid and minimize impacts must be monitored during the construction process. For example, permanent damage by marsh buggy tracks has been cited by several researchers (**Chapter 2**). This problem may be avoided or reduced by having vehicles travel within rather than alongside the construction zone (e.g., vehicles could travel on top of spoil rather than on the undisturbed marsh adjacent to the spoil). This is not always practical, but the vehicle operators need to be educated about impact avoidance. Similarly, dredge and dragline operators need to be aware of how to properly place and grade fill material. This can make a substantial difference in wetland habitat recovery.

7.3.2.4. Construction Techniques. There have been several experiments conducted to enhance the natural wetland recovery process. Double ditching is a common and beneficial practice in upland environments and has been transferred on an experimental basis to the wetlands. There is no evidence that double ditching enhances wetland habitat recovery over either the short- or long-term. Proper grading of the fill is regarded as a more critical factor. In fact, it is possible for double ditching to reduce recovery potential. In double ditching, spoil is placed on both sides of the ditch. When backfilling, the dragline operator must scoop from both sides, and, thus, there is twice the potential to scoop too much or not enough in comparison to placing all the spoil on one side of the ditch.

7.3.2.5. Pipeline Diameter. There is a positive, non-linear relationship between pipeline diameter and direct impacts. This factor is of less importance than others discussed (Section 7.2.1); therefore, as a general strategy, it is better to install larger diameter pipelines to allow for future expansion of product flow rather than a repetitive smaller diameter installation (i.e., reduce the number of lines rather than the size of individual lines) (Baumann and Turner, in press). This strategy is quite compatible with operator economics, and the chosen diameter is based on the best available information regarding future production volumes. This strategy, however, cannot always be followed for interstate pipelines. The Federal Energy Regulatory Commission (FERC) may not allow building a larger diameter pipeline to avoid building future pipelines. The cost of the pipeline is included in the rate base. A larger pipeline will cost more; therefore, the rate base will be higher in the short term. The FERC wants to minimize rates and will not allow the building of any facilities (or larger diameter-higher cost pipelines) in excess of those required to supply current needs.

7.3.3. Restoring Impacts to Surface Features

7.3.3.1. Plantings. Planting, transplanting, seeding, and fertilizing has been shown to accelerate emergent wetland recovery but at great expense. Natural recovery rates equal induced recovery rates within one to three growing seasons. The suggested benefits versus economic costs appear to be very marginal. However, in cases where rapid recovery may be of critical importance, the benefits versus costs may be more reasonable. For example, while natural recovery rates for dune vegetation are equivalent to control sites in one to

three years, it may be considered important to have vegetation restored before the next tropical storm season, thus justifying a modest planting or seeding effort in the foredune area.

Seagrass. There have been several attempts to artificially induce seagrass bed recovery through transplanting, planting, and seeding. Although recovery results are not impressive, improved techniques could reduce costs. The authors are unaware of any scientific studies that clearly document any difference in natural recovery versus induced recovery for seagrass beds. Many scientists believe that artificial transplantation is a viable alternative to conservation (avoidance of seagrass beds in project design), and more efforts should be devoted to technique refinement and cost reduction (Fonseca et al., 1982).

7.3.4. Suggestions for Implementing Management Techniques

Proactive cooperative efforts need to be encouraged among operation planning and environmental personnel and the regulatory and academic sectors during the project planning stage. Krone et al. (1987) have pointed out that there is considerable potential to minimize impacts through route planning (e.g., avoid crossing water bodies with irregular shorelines because these areas are in the process of erosion that spreads to the right-of-way).

In summary, some general procedures for permit review for pipeline installation are as follows:

- Establish working relationships with operators and regulatory field personnel.
- Review general route plan as early in the process as possible, preferably prior to official permit review. Use historic aerial photography to initially ascertain if any particularly sensitive habitats or cultural resources will be potentially impacted.
- Review shoreline crossings. Are any areas particularly prone to erosion included?
- Are non-wetland areas available for right-of-way? What potential pipeline safety problems would accrue by use of non-wetland areas? Are there any system pressure maintenance problems associated with use of non-wetland habitats (populated areas)? Are there any right-of-way acquisition problems in non-wetland habitats that could result in unusually long project delays?
- What is the diameter of the pipeline? What types of equipment will be required for construction?
- How many existing pipelines will be crossed and where? How many staging areas will occur in the wetlands? Can the number or size of staging areas be reduced?
- What is the projected method of backfilling? How long an interval will occur between excavation and backfill? Can this time element be reduced especially in fresher marsh areas (oxidation problems)? Are there any sections of pipeline proposed that will not be backfilled? If yes, why? What assurances are there that dredge and dragline operators will take care in backfilling? Note: operators want to maintain good corporate relations and will impress upon their contractors the importance of proper backfilling.
- How will shorelines be restored? Are dams anticipated? Will they be set back from the shoreline or placed at the shoreline? What is the landowner's preference and why with respect to location and material of construction?
- To what extent will marsh buggies be used in surveying, excavating and backfilling, and as general service vehicles? Can they operate within the working and spoil zone areas and avoid the outer boundaries of the right-of-way?
- Are there any innovative experimental approaches proposed? Will the experimental design provide useful data to the review process? Require a copy of reported results for use in future permits.
- Depend on practical knowledge and experience of regulatory and management field personnel for recommendations, field implementation and modifications.

SPILL CONTROL AND CLEANUP

by
Donald R. Cahoon

8.1 INTRODUCTION

This chapter presents an overview of habitat protection and cleanup procedures for spills of toxic materials that result from petroleum operations in coastal wetlands and the environmental impacts associated with these procedures. Although numerous types of substances may be spilled during petroleum production **(Table 6.1)**, this chapter focuses almost exclusively on petroleum hydrocarbons (i.e., oil) because oil has the potential to severely affect large tracts of coastal wetland/shallow water habitats. The purpose for presenting this information is to allow the permit analyst to make an informed decision about the environmental consequences of current habitat protection and cleanup techniques when confronted with a spill emergency. Emergency response procedures (e.g., who to contact when a spill occurs and bureaucratic responsibilities of the oil company during and after spill cleanup) are not discussed in detail as these requirements are fully outlined in the Region 6 Oil and Hazardous Substances Pollution Contingency Plan (USEPA, 1986). Protection and cleanup techniques developed for spills in marshlands and associated waterways (e.g., bayous, canals, and ponds) are described with particular emphasis on Louisiana and northern Gulf of Mexico coastal wetlands. Response techniques for offshore spills are discussed only indirectly and not in great detail.

For more detailed discussions of spill control and cleanup procedures in both inshore and offshore environments, the reader is referred to several manuals prepared for the U. S. Environmental Protection Agency (Maiero et al., 1978; Foget et al., 1979a and b; and Byroade et al., 1981).

8.1.1. Petroleum Spills

A spill is defined as the accidental (i.e., unintentional) leakage or discharge of petroleum products or production by-products (e.g., brine) into the environment. There are two immediate concerns for petroleum spills in coastal environments: the toxicity of the material spilled and the potential for the substance to spread by currents and tides. In this chapter, we present a brief discussion of the toxic effects of petroleum, followed by a review of the common procedures for controlling the spread and cleanup of petroleum spills. The environmental impacts of spill control and cleanup procedures are evaluated in detail.

The majority of our knowledge about oil spills comes from analyses of spills in the marine environment (e.g., shipwrecks and offshore blow-outs) and their impacts on nearby shorelines and fringing salt marsh and mangrove communities. However, coastal Louisiana is not only vulnerable to oil spills in the marine environment from extensive offshore drilling and production operations but also to spills in wetlands and their intricate network of waterways from extensive petroleum operations in all wetland types (e.g., saline, brackish, intermediate, and fresh marshes, and swamps). Because of the close proximity of petroleum operations to wetlands in Louisiana, the potential impact to those environments is more immediate for more wetland habitats in that state than in any other region of the U. S. coast, with the possible exception of Alaska. Therefore, spill control and cleanup procedures for use in the wetland environs (e.g., canals, bayous, and small open water bodies) described in **Chapters 1, 3 and 4** are emphasized, while response techniques for offshore spills are discussed only indirectly. Also, we describe, to the extent the literature permits, potential impacts to wetland habitats other than salt marshes and mangroves.

8.1.1.1. Sources. On a worldwide basis, approximately 39 percent of the petroleum hydrocarbons entering the marine environment are derived directly from oil and gas production and transportation (National Research Council, 1985). Greater than 45 percent originates from other shipping, industrial, municipal, and urban activities and river runoff (National Research Council, 1985). The majority of petroleum entering Outer Continental Shelf (OCS) waters in the northern Gulf of Mexico comes from onshore activities. River runoff accounts for 78 percent of the annual petroleum input, while accidental spillage from oil and gas related facilities (including production) contributes less than 0.01 percent (less than 50 barrels) (MMS, 1983). However, the low percentage contribution for offhore oil and gas related activities is a minimum estimate of the number and volume of spills in wetland environments because not all wetland spills reach OCS waters. Also, regulation and surveillance in onshore environments is more difficult and more infrequent than in offshore areas. If the amount of oil spilled offshore during production operations (about 12,000 barrels per year) (MMS, 1983) is any indication of the amount spilled during the same operations in onshore areas, onshore spills still make up a small percentage of the total contribution but represent a significant impact to local environments just the same.

In the coastal environment of Louisiana, petroleum hydrocarbons can enter the wetlands from several different sources. The most common sources for petroleum operations in wetlands are at the point of production and storage **(Chapter 6)** and the well-head **(Chapter 5).** Other sources include spills during transportation operations (i.e., pipelines—**Chapter 7**) or from sources external to the wetlands (e.g., spills offshore or in major rivers and tributaries).

8.1.1.2. Substances. Petroleum is composed of toxic compounds that can have serious adverse effects on local environments, often persisting, in some cases unaltered, for decades. The term petroleum defines a broad spectrum of compounds (i.e., oils). Knowledge of the physical and chemical properties of a spilled oil is essential to evaluating its potential environmental impact and to selecting appropriate protection and cleanup measures (Maiero et al., 1978). An oil classification based on field-observable properties has been developed to aid in diagnosing a spill and determining response procedures **(Table 8.1).** Four types of oils are described: light volatile, heavy sticky, waxy, and nonfluid (Maiero et al., 1978). It should be noted that a spilled oil can change behavior and, therefore, classification if the temperature changes or the oil becomes weathered.

Light Volatile Oils. These are fuel oils and light crude oils that are highly toxic, flammable (i.e., dangerous to handle), spread rapidly, evapo-

Table 8.1. Oil classification, diagnostic properties, and control/cleanup potential (from Maiero et al., 1978).

Class	Designation	Typical Oil Spills	Diagnostic Properties	Response Properties
A	Light Oils	Distillate fuel and light crude oils (all types)	Highly fluid, usually transparent or opaque, strong odor, rapid spreading, can be rinsed from plant sample by simple agitation	May be flammable, high evaporative loss of toxic when fresh, tend to form unstable emulsions, may penetrate substrates, respond well to most control techniques
B	Heavy Sticky Oils	Residual fuel oils; medium to heavy asphaltic and mixed base crudes	Typically opaque brown or black sticky or tarry, viscous, cannot be rinsed from plant sample by agitation	High viscosity, hard to remove from surfaces tend to from stable emulstons, high S. G. and potential for sinking after weathering, low substrate penetration, low toxicity-biological effects due primarily to smothering, will interfere with many types of recovery equipment
C	Waxy Oils	Medium to heavy paraffin base crudes	Moderate to high viscosity, waxy feel	Generally removable from surfaces, soil penetration variable, toxicity variable–may be high in fresh oils, decreased tendency to form stable emulsion
D	Nonfluid oils (at ambient temperature)	Residual and heavy	Tarry or waxy lumps oils (all types)	Nonspreading, cannot be recovered with most equipment, cannot be pumped without heating or slurrying, relatively nontoxic, may melt and flow when stranded in sun

rate quickly, may penetrate substrates, and usually are easily removed by flushing. They are designated Class A oils **(Table 8.1).**

Heavy Sticky Oils. These are residual fuel oils and heavier crude oils that are less toxic than Class A, not easily flushed, less likely to penetrate substrates, but capable of smothering benthic organisms and plants and adhering to birds and wildlife. They often interfere with cleanup equipment. They are designated Class B oils **(Table 8.1).**

Waxy Oils. These are medium to heavy paraffin-based oils that have a waxy feel. They adhere to vegetation, but these viscous oils are moderately removable by flushing. Their toxicity varies with the percentage of volatile components, and their tendency to penetrate substrates increases as temperatures rise. They are designated Class C oils **(Table 8.1).**

Nonfluid Oils. These are residual and heavy crude oils and weathered oils that are solid or nonfluid at spill temperatures. They are essentially nontoxic when solid. They may melt and flow if heated by the sun. They are designated Class D oils **(Table 8.1).**

8.1.2. Impacts of Petroleum Hydrocarbons on Estuarine Biota

There is an enormous body of literature on the impacts of petroleum spills on estuarine and marine flora and fauna (National Research Council, 1985; Getter et al., 1984; Vandermeulen, 1982; Breuel, 1981). The two key properties of oil that most influence its impact are toxicity and viscosity. The higher the concentration of low-boiling compounds, unsaturated compounds, and aromatics, the more toxic the oil (Baker, 1970). Class A oils are the most toxic and therefore have a severe

short-term impact. However, they dissipate readily and leave relatively little residue. Heavy viscous oils (Class B) also have a severe short-term impact because large volumes of the oil are retained (i.e., stick to surfaces); however, they cause mortality not through toxicity but through smothering. Also, heavy viscous oils are more persistent than Class A oils and therefore exert a long-term impact, as well as resulting in a slower recovery rate (Getter et al., 1984).

8.1.2.1. Impacts on Vegetation and Fauna. Severe ecological damage to the ecosystem is probable from any spill confined in shallow, nearshore or wetland environments. Vegetation is killed both by smothering and the toxic effects of the oil. Smothering reduces transpiration, respiration, and photosynthesis. Absorption of toxic oil fractions may poison the plant by disrupting cell membranes and cellular organelles (Getter et al., 1984). Benthic organisms, and intertidal invertebrates are susceptible to lethal and sublethal toxic effects of oil and to smothering by heavy oils. Fish can be directly affected by ingesting oil or oiled prey, through uptake of dissolved petroleum compounds through the gills, effects on eggs and larvae, and changes to its habitat (National Research Council, 1985). Birds die when coated with oil because the oil clogs the fine structure of the feathers that provide water repellancy and heat insulation. Consequently, the birds absorb water and drown. Birds also ingest oil when preening themselves and suffer toxic side effects. In addition to all these specific effects on estuarine species, spilled oil effects population structure and the overall health of the ecosystem (National Research Council, 1985).

A detailed explanation of the physiologically toxic effects of oil on the numerous sensitive estuarine species is beyond the scope of this manual. The reader is referred to the reviews cited above for an introduction to the extensive literature on field and laboratory research into this subject.

8.1.2.2. Factors Affecting Impacts Although the type of oil spilled is a primary factor in determining a spill's impact, the toxic and smothering effects of spilled petroleum can be modified directly by environmental factors, some of the more important being oil dosage and impact area, meteorological conditions, season, marsh physiography and substrate, and species sensitivity. These factors determine whether a spill causes severe, long-term damage or comparatively little or no damage to wetland environments.

Oil Dosage and Impact Area. For a given volume and type of oil, damage is greater if the spill occurs in a small, confined area from which the oil cannot escape than in a relatively open area of the coast (National Research Council, 1985). Spills in confined areas result in nearly uniform oiling of the entire area with considerable damage to flora and fauna. The wetland environments described in **Chapter 1** must be considered confined areas in terms of an oil spill because they are so extensive (up to 30 to 40 miles from beach to upland). The small tidal amplitude and meandering nature of the waterways in Louisiana's extensive wetlands restricts the flushing action of the water when compared with areas along the shore. A spill in a drilling site access canal in wetlands 10 to 30 miles inland from the shoreline will not likely ever be flushed into the Gulf of Mexico.

Low level chronic doses of petroleum hydrocarbons have a different impact on biota than sudden accidental releases of large volumes of oil. Accidental spills eventually dissipate because of physical/chemical processes and biological degradation (National Research Council, 1985). However, chronic releases of hydrocarbons are a continual stress to which the ecosystem must adjust and adapt.

Meteorological Conditions. Severe weather, such as storms, can have either a beneficial or detrimental influence on the environmental effects of a spill. Increased wave action and wind speed can accelerate evaporation of lower molecular weight and volatile (i.e., toxic) compounds. On the other hand, the storm can drive the oil up into the marsh where, if it is a Class B oil, it may cause severe damage. Also, storms can resuspend oiled sediments into the water column and spread them over a wider area.

Season. Season is important because of the types and life stages of biota that might be present at the spill site. If a spill occurs during waterfowl migratory or nesting periods, bird populations are highly vulnerable to contamination. If a spill is coincident with fish spawning, hatching, and larval developmental stages, higher than normal mortality rates are likely to occur. Damage to marsh habitats can add to the severe effects on fish and bird populations.

Impacts to marsh vegetation are highly dependent on season. During the winter, many plant species have little live above-ground tissue exposed to a spill, but new shoots and germinating seedlings present during the spring and summer are especially susceptible to the toxic effects of oil.

Flowering and seed production can be reduced if a spill occurs just before or during flowering (Getter et al., 1984). This has a long-term impact for populations of annual plant species.

Physical environmental conditions that influence the severity of the spill often change on a seasonal basis. Climatological and meteorological conditions change throughout the year as do water circulation patterns and other hydrologic processes. All of these factors influence the spread of a spill.

Marsh Physiography and Substrate. Size of the marsh, slope of the substrate, and sediment characteristics influence the amount of damage from a spill. Narrow fringing marshes may be completely covered by a spill, while extensive marshes may not be completely covered even by a massive spill. In the latter case, damage is concentrated along the sides of creeks and drainage channels (Getter et al., 1984). The extent of movement of the oil into the marsh depends on the volume of the spill, the slope of the substrate, the density of the vegetation, and local flooding patterns. Areas away from creeks often are protected by the tall and dense vegetation along the creeks, which traps a large portion of the oil. Unaffected areas are important sources of propagules for revegetating damaged areas.

Sediment characteristics of particle size and drainage patterns affect oil retention. Sandy soils are more freely drained and more easily penetrated by oils than fine-grained, water-logged muds. If oil accumulates in anaerobic soils, weathering is reduced or stops. Such oil may remain unchanged in the sediment for a long period of time and consequently reduce or prevent plant growth (Getter et al., 1984).

Species Sensitivity. The amount of damage to biota caused by an oil spill depends in large part on the sensitivity of the affected species to the oil. It seems that most important coastal species of plants (e.g., *Spartina*) and animals (e.g., birds) are susceptible to oil spills in at least a minor way. The sensitivity varies widely and is strongly influenced by the type and persistence of the oil. However, some species of plants (Baker, 1971) and invertebrates (Dicks and Hartley, 1982) are resistant to even high dosages or repeated dosages of oil. Resistant plants are often perennial species with large root systems that permit regrowth of aerial parts (Getter et al., 1984).

The sensitivity of a species also is influenced by its geographic location. If a species is growing at the limits of its geographical range that is in a less than optimal physical setting, existing environmental stresses may predispose the species to damage from oil that it otherwise would not suffer. The black mangrove is an example of a species in coastal Louisiana that is living at the northern limit of its geographical range. This species' slower growth rate and smaller stature in Louisiana probably predisposes it to more severe damage from spilled oil.

8.1.3. Emergency Response Procedures

Emergency response procedures for reporting an oil spill are outlined in the U. S. EPA and U. S. Coast Guard Region 6 Oil and Hazardous Substances Pollution Contingency Plan. If a spill occurs in Louisiana, call the Louisiana Department of Environmental Quality (504-342-6363 during duty hours and 504-342-1234 after hours), the U. S. Coast Guard Regional Response Center (8th Coast Guard District, New Orleans : 504-589-6296 during duty hours and 504-589-6225, 24-hours; or FTS 682-6296), or the U.S. Coast Guard National Response Center (1-800-424-8802, 24-hours toll free). Rules and regulations for oil spill reporting and response are fully described in this document.

8.1.4. Protection Measures

The first and most immediate concern with any oil spill is to protect the environment, which means controlling the spill by preventing it from spreading. Until the spill is under control, protective action takes precedent over concerns about cleaning up the spilled oil. This does not mean that cleanup is unimportant. Cleanup is essential to minimize impacts at affected areas, but every effort should be made to control the spill first in order to limit the extent of its effect before substantial effort is expended to clean it up.

A wide array of technological innovations and techniques have been developed for controlling spilled oil in coastal environments (Schulze, 1985). Few of these techniques are specifically designed for use in marshlands but most can be adapted to this environment (Maiero et al., 1978). Those techniques suitable for use in wetland environments are described below. The information presented in this section is summarized in large part from a procedural manual prepared for the U. S. Environmental Protection Agency by D. J. Maiero et al. (1978). The reader should refer to Maiero et al. (1978, Appendix B) for detailed implementation instructions for the techniques discussed below. Engineering specifications and designs for protection devices are summarized in Schulze

(1985).

There are eight basic protective devices or techniques that can be used effectively in marsh habitats: (1) existing control features; (2) skirt and fence booms; (3) sorbent booms; (4) improvised booms; (5) earth and rigid barriers; (6) permeable barriers; (7) sorbents; and, (8) wildlife deterrents. The use of chemical agents (e.g., chemical dispersants used for offshore spills) in wetland environs is not recommended because of their potential toxic effects on marsh biota.

8.1.4.1. Existing Control Features. Water levels and flows in Louisiana marshes are often controlled by man through the use of water control structures, such as variable-crest weirs, flap-gated culverts, and siphons. The spread of an oil spill can be limited by closing water control structures in the immediate vicinity of the spill. The impacts from reduced tidal circulation need to be weighed against the potential impact of the spilled oil when determining a schedule for closing and reopening the structures. In general, closure of the structures for a few days should have little impact on the marsh while, at the same time, keeping out potentially very damaging oil.

8.1.4.2. Skirt and Fence Booms. A boom is a floating barrier placed in the path of a spill to control its spread. Although there is a wide variety of booms available, most have some common characteristics. Booms have a flexible or solid barrier (curtain or skirt) extending vertically into the water to inhibit oil from flowing under the boom **(Figure 8.1).** Some also have a barrier (i.e., fence) extending vertically above the boom to control the splash of water and oil over the boom **(Figure 8.1).**

The effectiveness of a boom in controlling an oil spill is influenced by current speed, possible stranding at low tide, current reversals, and vessel traffic wakes. Most booms fail in currents exceeding 1.5 knots (Maiero et al., 1978) and may fail at lower rates. Angling the boom to the direction of the flow can improve boom effectiveness. Booms are most effective when free-floating. In shallow-water tidal marsh areas, booms may become stranded at low tide. When resting on the bottom, skirt booms usually leak around the sides and fence booms fall over. Therefore, shallow booms (skirts ≤ 12 inches) are most useful in marshes.

From a logistical standpoint, the two factors most limiting the use of a boom at a spill site in the marshes of Louisiana are availability and ease of handling. Large booms are very heavy and difficult to manipulate, often requiring mechanical transport and much manpower. In general, small, shallow booms are most effective in marshes. **Figure 8.2** shows a small boom surrounding a production platform in a canal from which a brine storage tank has collapsed. The boom was assembled at the platform and then deployed. The small boom is adequate to control the spill because only a small amount of oil was mixed with the brine (approximately 2 barrels) and water movement is restricted in the canal network in the marsh interior. Proper deployment methods for booms are described in Maiero et al. (1978, Appendix B).

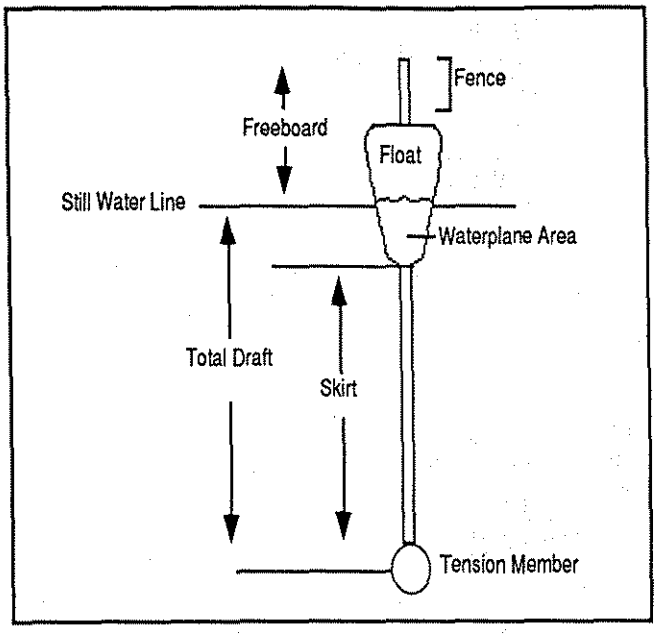


Figure 8.1. Schematic of a typical boom (adapted from Schulze, 1985).

All booms must be used in conjunction with an oil recovery system (e.g., skimmers, vacuum systems, sorbents) to be effective. These are described in Section 8.1.5., Cleanup Measures.

8.1.4.3. Sorbent Booms. Sorbent booms are made of loose sorbent materials encased in a mesh sleeve with no skirt or fence. Sorbent booms ride high in the water because of their low density and are effective only in calm waters. They collect oil through absorption and are thus well-suited for light oils. They should not be used for diverting flows or blocking channels. Their best application is probably to contain existing shoreline contamination by recovering oil as it comes out of the marsh.

8.1.4.4. Improvised Booms. Improvised booms are generally constructed at the spill site from any floating material. The type of material used determines the manpower needed to deploy it and its effectiveness. In general, improvised booms,

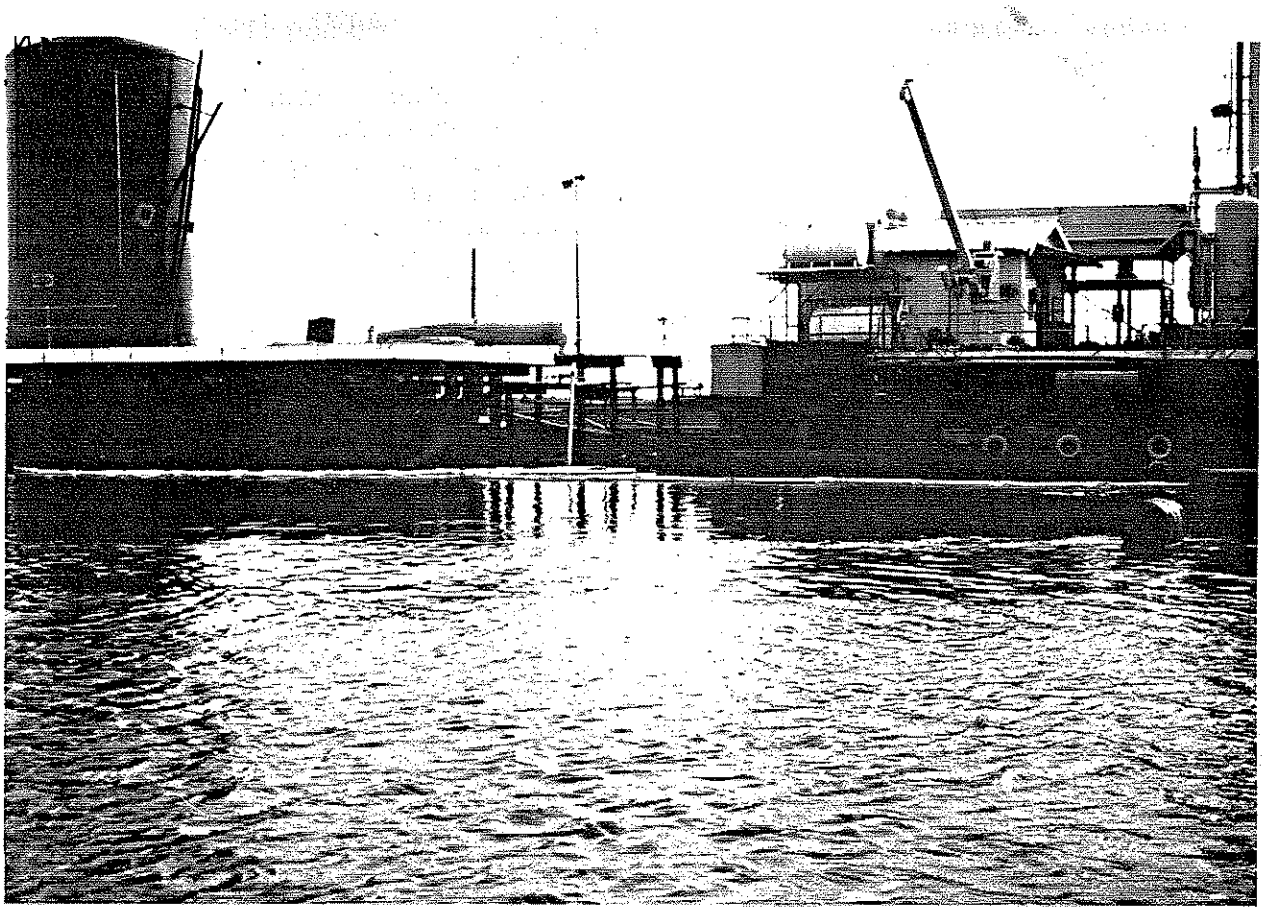


Figure 8.2. Small flotation boom deployment at production platform to contain minor spill caused by collapse of brine storage tank. (Photography by D. Cahoon.)

like skirt and fence booms, are ineffective in winds, waves, and currents. There are several types of improvised booms: (1) wooden (e.g., railroad ties); (2) pipe (e.g., watertight plastic or aluminum pipe); (3) fire hose; (4) rubber tire; (5) float (e.g., cork or synthetic floats); and, (6) U. S. Navy boom (55-gallon drums strapped to marine plywood).

8.1.4.5. Earth and Rigid Barriers. The movement of oil through narrow channels into the marsh interior can be prevented through the construction of earth and rigid barriers across the waterways. Tidal height must be considered during construction. The barriers should not be constructed across deep channels or high flow areas and must be removed as soon as they are no longer needed. Earthen plugs, logs, and sandbags are typical rigid barriers that are relatively easy to construct.

8.1.4.6. Permeable Barriers. In areas where water flows should not be interrupted but oil should not be allowed to enter, the use of permeable barriers should be considered. Permeable barriers consist of building two parallel fences across the waterway and filling the space between the fences with sorbent material. The sorbent material is allowed to float on the water surface. It must be replaced at regular intervals. The major advantage of this type of protection is that it allows water exchange but limits oil movement and can be designed for use in streams with one-way and two-way (i.e., tidal) flows. Disadvantages are that the sorbent material must be changed and that they cannot be used in areas with heavy boat traffic.

8.1.4.7. Sorbents. Sorbent materials can be used to protect marshes by either being deployed ahead of the spill to form a barrier or applied directly on the spill to immobilize it. There are two general forms of sorbents—granular and rolls. Both can be applied to the edge of a marsh as a barrier to absorb and stop the migration of the oil into the marsh. They should be used in low-flow, low-energy environments and only granular sorbents should be applied directly to a spill. Because of the

difficulty in recovering granular sorbents, biodegradable granular sorbents should be used whenever possible.

8.1.4.8. Wildlife Deterrents. When a spill occurs in the vicinity of a large concentration of waterfowl or wildlife, action can be taken to keep the animals away from the spill. Wildlife deterrents are classified as two types—loud noise or animal distress and predator call. Loud noises (fire crackers, shotgun blasts, or automated noise makers) scare wildlife away from the site. Tape recordings of animal distress calls or predator calls will also cause wildlife to flee the area. The effectiveness of these techniques is limited in severe weather and high winds. Numerous noise or call devices should be deployed so that the sounds overlap and thus cover a contiguous area.

8.1.5. Cleanup Measures

If the oil spill reaches and contaminates the marsh, cleanup procedures are required to ameliorate the impacts of the oil. However, because cleanup procedures take place immediately on or in the marsh, the potential for damage caused by cleanup procedures is high. Consequently, a no action alternative (i.e., allow natural cleansing to occur) must be considered. If natural cleansing is not deemed feasible, cleanup operations should begin as soon as possible.

Cleanup techniques can be divided into three general categories: (1) removal and collection of oil; (2) handling of contaminated materials; and, (3) bird cleaning (Maiero et al., 1978). The success of any cleanup procedure depends on adhering to three basic principles: (1) the marsh is fragile, therefore restrict physical actions to only those that are absolutely essential; (2) physical conditions in a marsh may change rapidly and unpredictably, therefore monitor cleanup procedures closely and adjust equipment accordingly; and, (3) many cleanup techniques require removal of oil or oiled materials at regular intervals, therefore regular maintenance and monitoring of equipment is essential (Maiero et al., 1978). The reader should refer to Maiero et al. (1978, Appendix C) and Schulze (1985) for detailed implementation instructions for the techniques discussed below.

8.1.5.1. Natural Cleaning. The two most important factors determining the feasibility of natural cleaning are the mobility and type of oil. Natural cleaning is most feasible for oils of low mobility and low toxicity spilled in areas with a low degree of contamination and high tidal and current energies. Natural cleaning also is best suited for highly weathered oils. This technique should not be employed in areas with high waterfowl concentrations or in marsh areas that have been previously damaged. The use of microbes to degrade the oil should be considered when using natural cleaning. The acceptability of natural cleaning is determined in part by the efficiency of active cleanup measures, particularly in lightly contaminated areas.

8.1.5.2. Removal and Collection of Oil. Numerous technological innovations have been developed to remove spilled oil from the surface of the water or the marsh once it has been controlled or collected. Oil can be removed from the marsh surface in some instances by low-pressure flushing, while many techniques exist for removing oil from the water's surface (e.g., sorbents, skimmers, and vacuum systems).

Low-pressure Water Flushing. A flood of water sprayed under low pressure across the marsh from hoses and portable pumps can be used to loosen oil from the marsh substrate and the vegetation and to float it out of the marsh. Flushing should be carried out from the highest elevation towards the lower, from upstream to downstream, and can be performed from land or a boat. Water should not be sprayed directly and forcefully at the substrate to avoid soil erosion. Flushing works best with lighter oils.

Once the oil is flushed out of the marsh, it should be herded toward collection points. Booms may be necessary to do this. Organic debris washed out of the marsh with the oil should be removed manually (e.g., with dip nets, seines, and rakes) to prevent clogging the collection devices. Protection measures should be considered to prevent recontamination of flushed areas.

Sorbents (formed products). Oil on the surface of water can be readily removed by use of commercial sorbent materials produced in a variety of shapes (e.g., pads, blankets, rolls, sweeps, pillows, booms, and snares). The use of sorbents on the marsh surface is limited because oil/sorbent contact is difficult to achieve. In general, sorbents should not be used if other options exist because they require more manpower, more disposal operations, and recovery can severely disrupt and damage the marsh surface. Of all the sorbent forms, pads, snares (oleophilic strands - "spaghetti"), and rolls are the most suited for marshes. Nevertheless, the use of pads and rolls in wetlands is limited because they can only be used in areas devoid of vegetation. Moreover, their use requires consider-

able surface activity during application and recovery, and they are difficult to handle when oiled. Therefore, their use in marshes should be limited to situations where no better options exist.

Snares are often used to fill sorbent booms and permeable barriers. Sorbent pads are very suitable for removing oil from water. Pads were used to remove the oil in the spill depicted in **Figure 8.1.** The pads were thrown onto the spill by hand from the storage platform and later removed by hand from a boat.

Sorbents (loose). Two advantages of loose sorbent materials for removing oil are that they can penetrate around plant stems and they respond to changes in water level. They can be applied by hand or mechanically and removed by flushing and recovered by vacuum systems or nets. Along shorelines they can be recovered by conveyor systems or aquatic weed cutters. They should not be raked and foot traffic should be kept to a minimum to avoid damaging the marsh substrate. Whenever possible, biodegradable sorbent granules (e.g., bark) should be used because total recovery of granular sorbents is not possible. Granular sorbents are impractical in areas with high tidal energy or water flow.

Absorbent Skimmers. Once oil has been contained in a confined area, it can be removed from the water by devices made from oleophilic materials. Examples of such devices are the disc, rotating drum, conveyor-belt, and endless rope skimmer. The oil that adheres to the oleophilic surfaces is squeezed into a holding tank or scraped off by a blade or squeegee. All but disc skimmers recover little water and are unlikely to be fouled by debris.

The endless rope skimmer consists of an oleophilic rope, floating pulleys, a wringer, collection bin, and power source (**Figure 8.3**). The rope is deployed into the spill and is continually pulled through the wringer and collection system. It can be easily adapted to whatever configuration necessary to fit the geometry of the site. The disc, rotating drum, and conveyor-belt skimmers pass oleophilic discs or belts through the oil. They are best used in a stationary deployment in conjunction with booms. Performance with debris is poor for disc skimmers and fair for belt skimmers.

Weir Skimmers. Weir skimmers float on the water and separate oil from the water by gravity (**Figure 8.4**). They must be used in conjunction with directing and concentrating systems. Their use in marshes is limited because of susceptibility to fouling by debris and necessity to float in order to function. The advantage of weir skimmers is their small size and ease of deployment. They are best-suited for areas with high concentrations of oil, adequate water depth for operation, access to large-scale removal/collection equipment, and little or no debris.

Vacuum Systems. Oil can be removed from confined areas by using vacuum suction skimmers (**Figure 8.5**). Floating skimmers on a hose connected to a septic tank pumping truck can remove large quantities of oil from a confined space. Pump suction draws the oil to the skimmer and the oil is separated from the water by gravity. Skimmers are simple to operate, have shallow draft, and can be used in nearly any location. However, suction skimmers are easily clogged by debris and are effective only in calm waters.

8.1.5.3. <u>Handling of Contaminated Materials</u>. The impact of oil on a marsh ecosystem may be minimized by the removal of oiled marsh vegetation and soil. The three main techniques for handling contaminated materials are cutting, burning, and soil removal.

Cutting. Removal of oiled vegetation can be accomplished by hand cutting or mechanical cut-

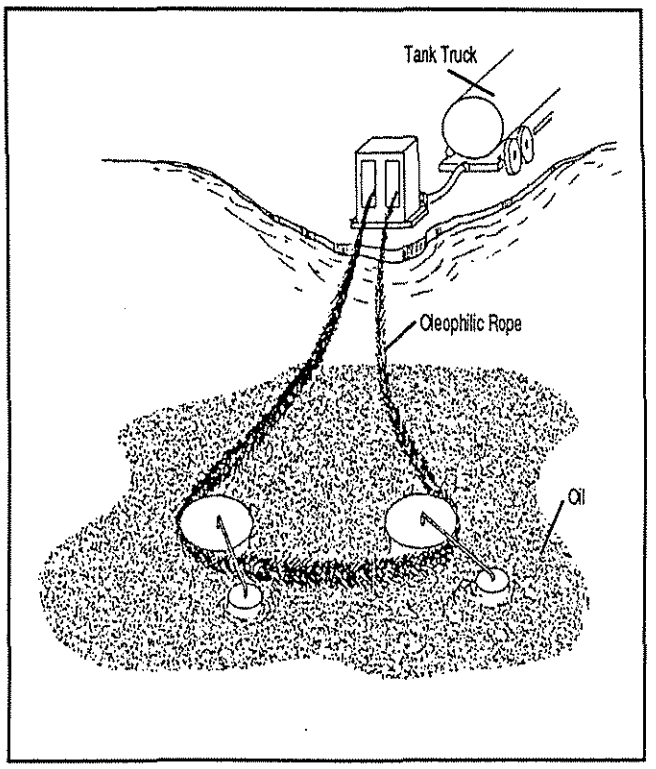


Figure 8.3. Rope mop skimmer and vacuum pump assembly (adapted from Schulze, 1985).

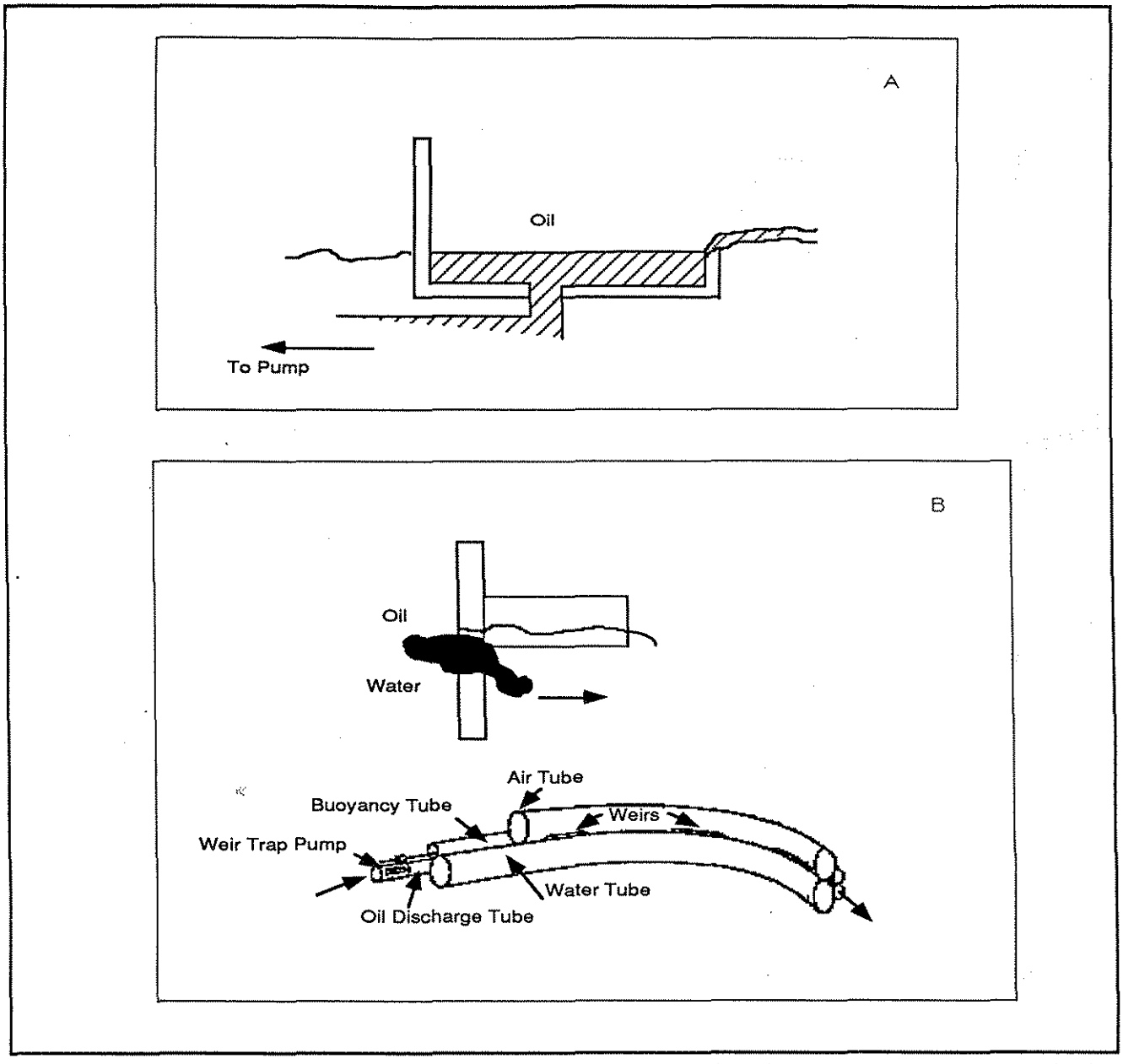


Figure 8.4. A. Weir skimmer attached to vacuum pump (adapted from Schulze, 1985). B. Boom skimmer-combination of pressurized chamber boom and weir skimmers (adapted from Schulze, 1985).

ting. A boom system should be deployed at every cutting operation to contain the possible spread of oil and debris. All cutting operations should start at the upstream end and work downstream. Factors to be considered when choosing a cutting method include the extent of contamination, marsh trafficability, tidal variation, shoreline slope, and water depth.

Hand cutting is labor intensive and requires large crews to cut and handle the debris. Hand-held cutting devices are used at low tide, starting at the low tide mark and working inland. Hand-cut debris should not be stockpiled at the site but removed to a disposal area by the best means possible (e.g., boat, land vehicle or helicopter). The advantage of hand-cutting is that all areas of the marsh can be accessed if necessary. The major disadvantage is the damage done to the marsh substrate by extensive foot traffic.

Commercially available aquatic weed harvesting machines cut, pick up, and temporarily store oiled debris. Because these machines float, they do not impact the marsh substrate. However, they are limited to use in shoreline marshes because they cannot be used much beyond the high tide mark. If the load bearing capacity of the soil is high, it may be possible to use agricultural harvesting equipment to collect and remove the oiled debris.

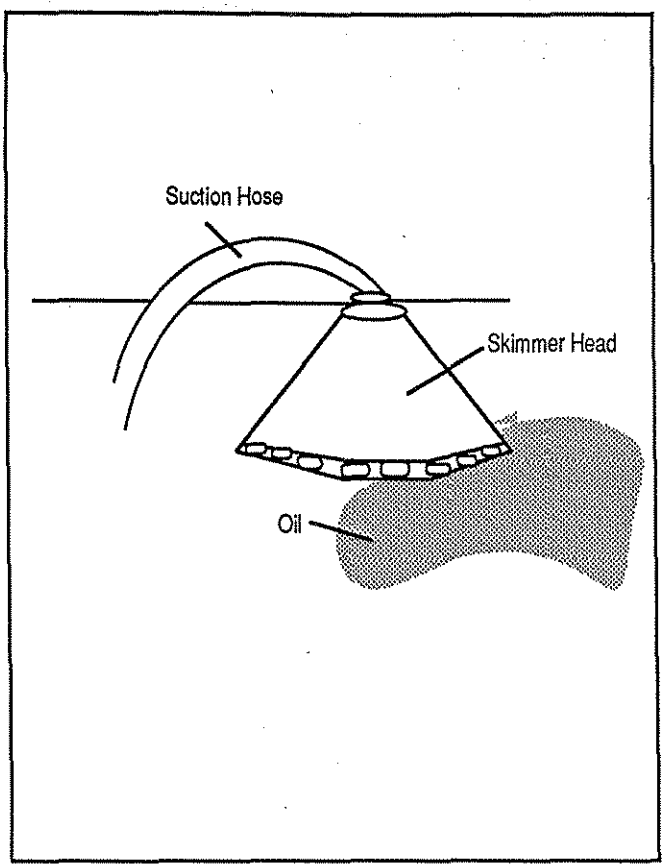


Figure 8.5. Weir skimmer attached to vacuum pump (adapted from Schulze, 1985).

However, damage to the marsh substrate is likely to be high with this type of equipment.

Burning. It is possible to remove some oil from the marsh surface without disturbing the surface by burning. Not all oils will support combustion; therefore, a test burn should be conducted to determine the feasibility of this handling technique. Disadvantages of this technique are that fires are often difficult to control, burning permits have to be obtained from the US EPA, and state/local wildlife and air pollution agencies, and risks to personnel are high. Burning of the marsh is a routine practice by local trappers in south Louisiana during fall and winter months. Burning during the growing season (i.e., spring and summer) is difficult because of high water levels and predominance of green tissues. Therefore, summer burns are not advisable. A local "burn expert" (i.e., trapper or land manager) should be consulted before designing or beginning any burning operations.

Soil Removal. Physical removal through digging or dredging operations is the only treatment for contaminated soil, and there is no standard procedure for soil removal. However, soil removal operations should be limited to the smallest area possible because of the severe environmental damage that can occur. If at all possible, manual methods (i.e., shovels) should be used instead of dredging equipment (e.g., dragline) to minimize damage to the marsh. Any area from which the substrate has been removed will have to be restored. At a minimum, this requires restoring the original marsh surface elevation.

8.1.5.4. Bird Cleaning. If a substantial number of birds become oiled, a local bird-cleaning center should be established in the vicinity of the cleanup operation. Bird-cleaning operations should be supervised by professional veterinarians and wildlife management personnel. Surveys of contaminated areas should be conducted at regular intervals to detect oiled birds, even after the area has been cleaned because birds can become oiled if recontamination occurs.

8.2 IMPACTS on WETLAND VALUES and FUNCTIONS

8.2.1. Impacts Associated with Protection Measures

When weighed against the potential impacts of spilled oil, the impacts of oil spill protection measures on marsh ecosystems are minimal. Protection measures take place for the most part in open water or tidal channels and, therefore, have little direct effect on marsh biota and marsh ecosystems in general. Most impacts are short-term and will cease when the protection activity ceases. The impacts of protection measures on marshes are summarized in **Table 8.2.** The use of booms has virtually no impact on the marsh. However, foot and vehicular traffic in the marsh during construction of booms and rigid barriers or deployment of sorbents and wildlife deterrents can be damaging to the marsh substrate and vegetation. Barriers can interrupt tidal cycles and hence alter normal marsh processes. Construction of earthen barriers from local marsh material converts the habitat to open water. Nonbiodegradable remnants of sorbent materials can cause injury to marsh animals. Wildlife deterrents can disrupt nesting activities of waterfowl and shore birds.

8.2.2. Impacts Associated with Cleanup Measures

Cleanup measures, by definition, occur on the marsh surface and, therefore, have the potential to directly affect the marsh. Some cleanup tech-

Table 8.2. Observable and hypothetical cause-effect relationships of protection techniques.

	Technique					
	Existing Water Control Structures	Booms	Rigid Barriers	Permeable Barriers	Sorbents	Wildlife Deterrents
ACUTE ENVIRONMENTAL CONSEQUENCES						
Habitat Alterations-Physical Impacts						
Interruption of Tidal Cycle	√		√			
Direct Conversion of Marsh to Open Water			√			
Trampling of Vegetation		√	√		√	
Habitat Alterations-Ecological Impacts						
Immediate Loss of Marsh Habitat			√			
Temporary Interruption Aquatic Organism Migration and Flux of Matter	√		√			
Impact on Biota						
Injury to Birds and Wildlife					√	
Disrupting Avifauna Nesting						√
CHRONIC ENVIRONMENTAL CONSEQUENCES						
Habitat Alterations-Ecological Impacts						
Loss of Marsh Habitat			√			
Impacts on Biota						
Injury to Birds and Wildlife					√	

Table 8.3. Observable and hypothetical cause-effect relationships of cleanup techniques.

	Technique					
	Flushing	Sorbents	Traffic	Cutting	Burning	Soil Removal
ACUTE ENVIRONMENTAL CONSEQUENCES						
Habitat Alterations-Physical Impacts						
Potential Disruption of Substrate	√		√			√
Removal of Vegetation						
Stems-Leaves				√	√	√
Roots-Rhizomes						√
Habitat Alterations-Ecological Impacts						
Immediate Loss of Marsh Habitat						√
Decrease in Biological Production			√			√
Impacts on Biota						
Destruction of Vegetation and Benthic Organisms						√
Disruption of Plant Habitat			√			√
Potential Negative Impact on Plant Growth			√			√
Potential Injury to Wildlife		√				
CHRONIC ENVIRONMENTAL CONSEQUENCES						
Habitat Alterations-Physical Impacts						
Loss of Marsh Habitat						√
Impacts on Biota						
Injury to Birds and Wildlife		√				

niques, such as skimmers, do not impact the marsh although there may be occasional foot traffic associated with their use. On the other hand, some cleanup techniques (e.g., soil removal) can cause severe damage to the marsh. The potential impacts of cleanup operations on marsh systems are summarized in **Table 8.3.** Traffic is included as a separate category because of its damage potential even though traffic damage is generally considered a secondary impact of many of the cleanup measures described in this manual. Impacts associated with the following cleanup measures are discussed below: traffic, flushing, sorbents, cutting, and soil removal.

8.2.2.1. Traffic. Damage caused by foot and vehicular traffic can be greater than the damage caused by oil contamination. Disruption of the marsh substrate with concomitant destruction of plant root and rhizome systems may require long recovery periods, particularly if oil becomes mixed with the upper sediment layers. Once oil is mixed into the substrate, root systems and organisms not previously exposed are contaminated, the rate of oil degradation through weathering is likely to decrease, and cleanup becomes more complicated (Maiero et al., 1978). Except for boat operated skimmer systems and burning, most cleanup operations involve at least some foot traffic (e.g., flushing, sorbents, cutting) and some require heavy equipment (e.g., soil removal, and some sorbents and cutting operations). Heavy traffic may accelerate erosion of the marsh surface. Foot and vehicular traffic should be avoided whenever possible, especially in oiled substrates and should be considered only when other alternatives have been rejected.

8.2.2.2. Flushing. Flushing causes little damage to the marsh when performed properly except for associated foot traffic. If flushing is directed at the substrate instead of the vegetation, or if high pressure flushing is used, soil erosion may result.

8.2.2.3. Sorbents. The use of sorbent pads and snares requires a large group of personnel and can result in heavy foot traffic. If personnel are not properly trained, oil may be further mixed with the substrate during recovery of the sorbent material. Also, recovery of all the sorbent material is a problem. Formed sorbents often are encased in a plastic mesh. If all of the sorbent material is not recovered, this plastic mesh can ensnare birds and other wildlife. Unoiled granular sorbent material is also a potential wildlife hazard if not recovered. Oiled sorbent material not recovered may result in recontamination of the area from the oil contained within them. Unrecovered sorbent material can smother large areas of the marsh, thus decreasing overall productivity of the marsh system. For this reason, biodegradable sorbent materials should be used whenever possible.

8.2.2.4. Cutting. Cutting requires the physical destruction of plant tissues and usually entails a great deal of foot traffic. In a *Spartina* marsh, plants should not be cut if they are not completely oiled because air will still be able to diffuse from the stem down to the roots. Cutting in this situation exposes the internal portions of the plant to damage from the oil. On the other hand, if the plants are completely oiled, it is necessary to cut the plants to allow air diffusion. There is a risk of internal contamination of the plant but the plant will die anyway if it is not cut. *Spartina* and other grass-dominated marshes are tolerant of cutting. Mangroves should never be cut.

8.2.2.5. Soil Removal. Removal of the marsh substrate eliminates plant and benthic organism habitats and should be avoided if at all possible. This technique leads to direct marsh loss. However, in substrates heavily saturated with toxic oil and with little chance of natural cleaning, it may be the only option available. The potential for oil-related damage must be great to consider this cleanup technique.

8.3 MANAGING IMPACTS through the REGULATORY PROCESS

There are no special regulatory techniques for managing the impacts described above through the 404 permitting process because the occurrence and location of oil spills are not planned. All protection and cleanup operations must abide by applicable federal, state, and local regulations. Because a spill cannot be predicted, the only steps a permit analyst can take in reviewing a 404 application for a petroleum operation in wetlands is to insure that the applicant will use the highest quality equipment and personnel available for the operation and abide by all applicable rules and regulations concerning the control and cleanup of a spill.

DRILLING SITE AND ACCESS ROUTE CLOSURE

by
Donald R. Cahoon, R. Eugene Turner, and
Joseph C. Holmes, Jr.

9.1. INTRODUCTION

Once the decision is made to cease production and close-in the well, closure of the drilling site and access route begins. When a well is abandoned, every step should be taken to restore any impacted wetland values or functions to as near pre–project conditions as possible. This is in keeping with the regulatory mandate of the Clean Water Act (see **Chapter 1**). Fulfilling this mandate may not be easy, as restoration depends in large part on the age of the impact. If a well is a non-producer (i.e., a dry hole), restoration takes place within a few weeks of site access and preparation. In this situation, the potential for restoring both pre–project hydrologic conditions and lost habitat is greater than in wells that have produced for 10 to 20 years or more. Restoring hydrologic regimes at old well sites is generally easier than restoring lost marsh habitat. Historically, restoration efforts at old well sites have concentrated on re-establishing natural hydrologic functions, while off-site compensation (often called mitigation) is sought for what is irretrievably lost marsh habitat.

This chapter presents an overview of the methods used for on-site restoration of hydrology and marsh habitat altered by canals and road dump/ring levees. [A discussion of the methods and policies for off-site compensation of unavoidable wetland impacts is beyond the scope of this handbook. The reader should consult the wetland habitat creation literature for an explanation of this issue.]

9.2. ON-SITE RESTORATION of IMPACTED WETLAND VALUES and FUNCTIONS upon ABANDONMENT of WELL – CANAL/KEYHOLE

In theory, re-creating marsh habitat from spoil bank and canal habitats is the best form of restoration because not only is the marsh acreage regained but normal hydrologic functions are restored. In practice, however, the success rate of this restoration method varies widely depending on soil type, age of canal, technology, and time since restoration. If conversion to marsh habitat is not suitable or possible, management efforts should focus on restoring hydrologic functions.

The same procedures are used to restore a keyhole and a canal route because of the similarity of construction. Therefore, the restoration techniques described in this section apply equally to the drill site and the access route. Upon abandonment of the drill site, the wellhead with its protector may be left in place. However, it may be necessary to cut the wellhead off at the mudline if it is a hazard to navigation or if the canal is to be backfilled. Any shell pad existing at the site can be left in place. It will provide additional fill if the site is backfilled or hard-substrate habitat if the well is only plugged. All pits constructed in the spoil bank adjacent to the keyhole should be closed in accordance with federal and state regulations concerning oil field wastes and water quality.

9.2.1. Restoring Spoil Bank and Canal Habitat to Marsh

Filling canals back in, or "backfilling", is carried out on-site for canal/spoil bank restoration after well abandonment. Backfilling is performed by a barge-mounted bucket dredge or dragline using the previously deposited spoil banks to fill the existing canal. The spoil banks are regraded to as near marsh elevation as possible, and the fill is placed uniformly over the bottom of the canal (**Figure 9.1**). Aerial views of backfilled canals are presented in **Figure 9.2**. Removing spoil banks and filling in canals are the most direct means to restore the detrimental effects of canal access as described in Section 3.2.2.

The intended benefits of backfilling are (1) re–establishment of marsh vegetation in the canal and on the regraded spoil bank; (2) restoration of marsh soils on the regraded spoil bank; (3) restoration of natural hydrologic conditions, including re-establishing the original drainage patterns; and (4) restoration of fish and wildlife habitat. The following discussion on backfilling is based on four published studies on backfilling in Louisiana: Neill and Turner, 1987a; Turner et al., 1986; Swenson and Turner (1987); Neill and Turner (1987b). These studies examined, to various degrees, all of the estimated 35 backfilled sites in Louisiana. The objections to backfilling are (1) it costs money to backfill (similar to dredging costs because a dredge is used); (2) there may not be enough spoil material to immediately fill the canal; and, (3) spoil banks, which are removed during backfilling, may be part of a planned water management or upland wildlife habitat program.

9.2.1.1. Typical Backfilled Canal. Backfilled canals vary in size, age, and success of restoration as measured by depth and marsh re–establishment. The general characteristics of an average backfilled canal are: (1) a high percent of spoil returned to the canal; (2) an age of less than 10 years; (3) incomplete restoration of canal depth; and, (4) incomplete but developing vegetative recovery (**Table 9.1**). The median canal depth after backfilling is 3.6 feet. The median estimate (percent) for re–establishing marsh on the old

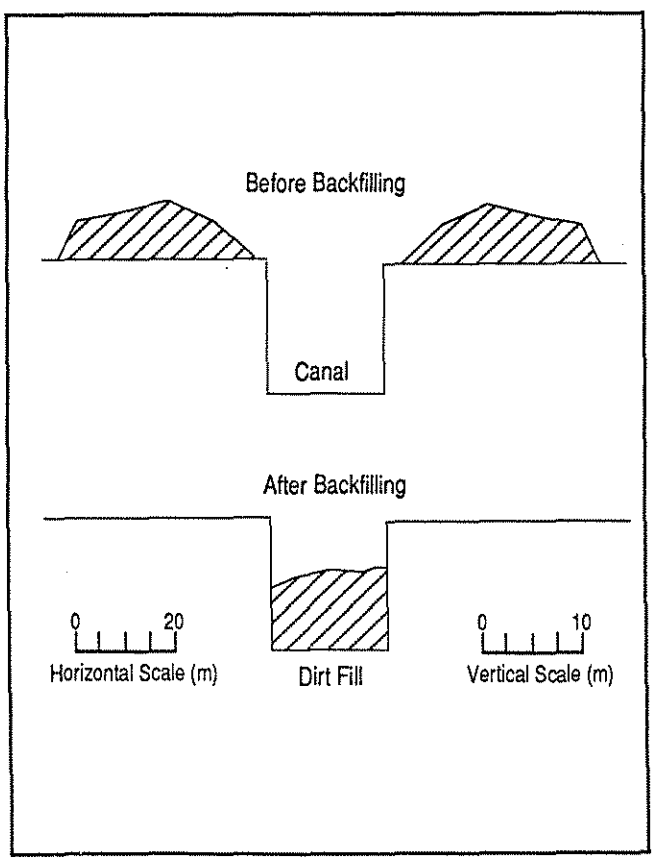


Figure 9.1. Schematic representation of a typical oil and gas drilling site canal before and after backfilling.

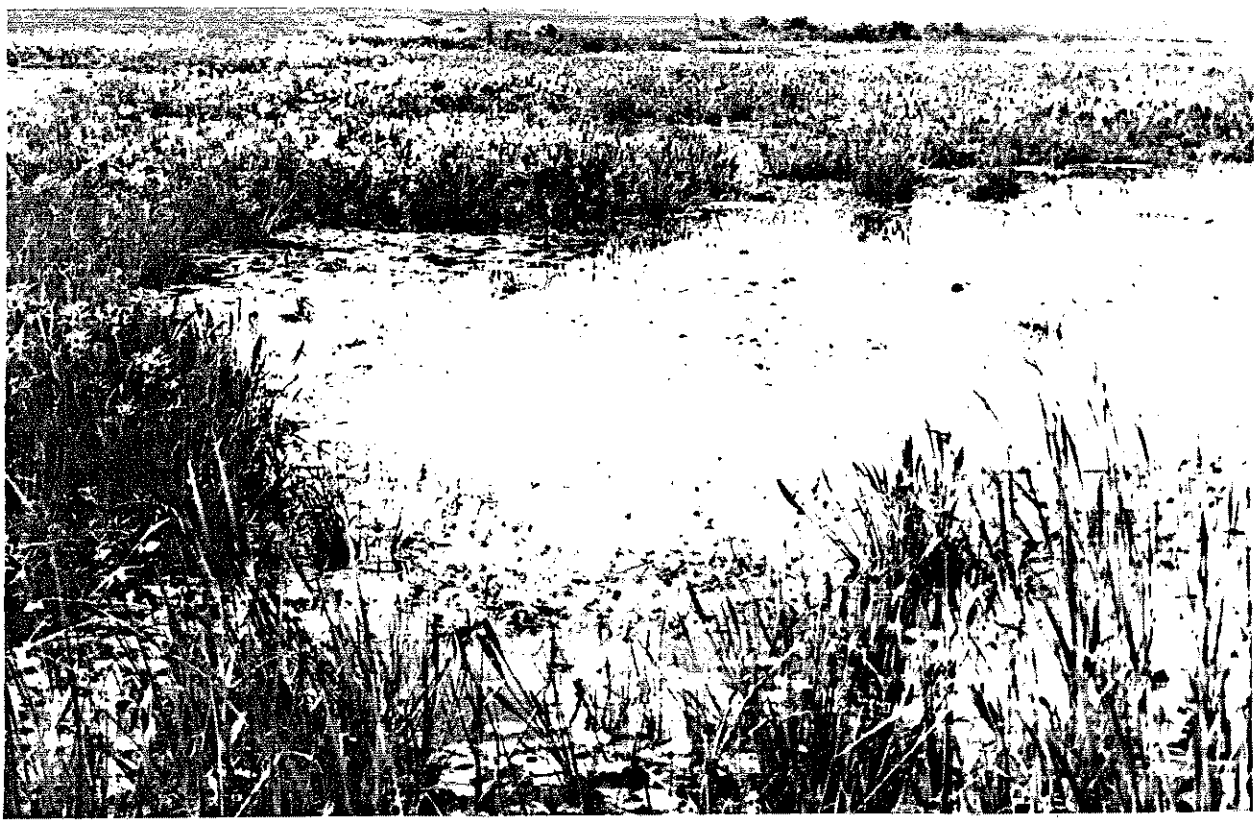


Figure 9.2. Examples of backfilled canals in south Louisiana. A. No emergent marsh is yet established (+2 years) in the Buckskin Bayou backfilled canal despite the use of most of the available spoil material as fill. B. Marsh re-establishment and creation of shallow open water habitat at the Mallard Bay West canal bear a physical resemblance to natural marsh ponds and have a high habitat value for fish and wildlife. (Photography by R. E. Turner.)

Table 9.1. Characteristics of a typical backfilled canal.

Characteristic	Median	Maximum	Minimum	N
Length (m)	400.0	1859.0	120.0	33
Canal area (ha)	1.3	3.6	0.6	33
Spoil area (ha)	3.0	8.2	1.0	33
Percent spoil returned	94.0	100.0	45.0	31
Years between dredging and backfilling	2.1	40.1	0.0	31
Depth (m)	1.1	1.8	0.1	26
Percent marsh cover in canal	0.7	40.1	0.0	26
Percent marsh cover on spoil	51.6	98.5	0.0	31
Percent spoil cover on spoil	22.2	92.8	0.0	31
Percent open water cover on spoil	21.4	100.0	0.1	31

canal site is 11 percent; marsh on the original spoil bank is 52 percent; and open water on the regraded spoil bank is 21 percent.

Soils. Compared to neighboring marshes, the average backfilled spoil bank soils have a soil bulk density of 41 percent, an organic matter content of 23 percent, a water content of 51 percent, and vegetation cover at regraded spoil bank sites of 46 percent. Recovery of vegetation in backfilled canals averages only 5 percent (**Table 9.2**). Site–to–site differences occur and are generally explained on the basis of spoil bank micro-relief. Elevation differences within a site are largely determined by dredge operator skills. Marsh soils dry when deposited on spoil banks, and oxidation of organic matter leaves soil predominantly composed of mineral material. Lowering spoil bank elevation by regrading probably accounts for an observed increase in the water content of the soil. To achieve a water content similar to that of the soil in natural marsh would probably require increasing both organic matter content and the water-holding characteristics of the inorganic matter. Recovery of soil organic matter also depends on re–establishing vegetation, depositing organic matter and incorporating organic matter into the soil structure. The time needed for complete recovery of marsh soil organic matter is not known but is apparently longer than five years.

Table 9.2. Restoration of depth, vegetation, and soil properties at backfilled canals. The confidence interval ( ) is two standard errors of the mean, corrected for sampling a finite population. "N" is the number of backfilled canals sampled.

Characteristic	Percent Restored		N
Depth	59	(4)	26
Percent cover of marsh in canal	5	(1)	31
Percent cover of marsh on spoil banks	46	(2)	31
Soil water content on spoil banks	51	(10)	18
Soil organic matter content on spoil banks	23	(9)	18

Vegetation. Backfilling does not rapidly generate marsh vegetation in canals because it does not immediately fill canals to the elevation of the natural marsh surface. Consequently, the backfilled substrate remains too waterlogged for any emergent vegetation to establish or survive. Once the canal fills to an adequate depth by natural sedimentation processes, revegetation of an area may quickly occur. Canal revegetation with emergent plants is statistically related to canal depth after backfilling. The threshold depth for emergent plant regrowth appears to be about two to three feet. Canals deeper than three feet experience no marsh re-vegetation. However, not all backfilled canals less than two feet deep experience significant amounts of marsh re-vegetation. The lack of re-vegetation in the canal is attributed to the short time for recovery (less than 10 years) and to spoil dewatering and oxidation (which reduces the volume of the dredge spoil) between dredging and backfilling. Only 6 out of 35 locations had more than 10 percent of the canal revegetated with marsh species. The partial filling of the canal itself, however, does promote the growth of submerged grass species, such as widgeongrass, *Ruppia maritima*, in the shallow parts of a backfilled canal. The growth of submergent species is encouraged by installing a plug (**Table 9.3**).

Marsh revegetation of spoil banks is more successful than in the canal. More than 50 percent of the area of the backfilled spoil bank was revegetated in 17 of 31 canals. In general, 49 percent of the spoil was covered by vegetation when compared with an average of 6 percent in the canal. The

primary factor determining marsh re-vegetation of a spoil bank is its elevation after backfilling. Spoil banks with elevations too high or too low for normal growth of marsh species are not quickly recolonized. Generally, the optimum elevation for rapid recolonization is within 6 inches above or below mean sea level.

Table 9.3. The influence of plugs on the presence of aquatic vegetation.

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

The presence of a spoil bank has an indirect effect on the streamside marsh adjacent to the unfilled canal **(see Section 3.2.2)**. Increased waterlogging in the streamside marsh at unfilled canal sites may result in higher soil sulfide levels, insufficient root oxygen and decreased nitrogen metabolism. Soil waterlogging may result from the weight of the spoil bank causing the streamside marsh to subside and/or the relatively stagnant waters and poor circulation in deep unfilled canals. Removing the spoil bank from the berm zone at the backfilled canal may help reduce the intensity of soil waterlogging in the streamside marsh and prevent the deterioration of this zone.

A significant factor influencing backfilling success is the skill of the dredge operator. Operator skills vary widely, but spoil banks can be completely removed to the original marsh level. Revegetation success also depends on canal location. Backfilled canals in the Chenier Plain in western Louisiana have higher revegetation rates than those in the Mississippi River Deltaic Plain. The reasons for this difference are discussed in Section 9.2.1.2.

Benthos. Backfilling a dead-end drilling site access canal creates benthic habitat. The density of benthic organisms in a backfilled canal does not differ greatly from that of a natural bayou. In contrast, the mean annual abundance of macrofauna and meiofauna in an unfilled canal may be only one-half and one-sixth, respectively, than a natural waterway or backfilled canal. Diversity measures indicate that an unfilled canal is a highly disturbed habitat.

There may be extremely high sulfide levels in the bottom sediment of an unfilled canal, possibly caused by highly reduced conditions and the accumulation of toxic sulfide in the bottom sediments. Even partial backfilling creates a productive, shallow water benthic habitat that provides postlarval and juvenile estuarine-dependent organisms food and shelter, provided they have access to it.

Fish. Backfilling canals improves fish and shrimp habitat through the increased wetland habitat and number of benthic prey organisms, the expanded area of shallow zones, and the restoration of natural hydrologic patterns. Increased wetland vegetation resulting from backfilling supports fisheries by providing refugia for fish and shrimp to escape from predators and increased detrital production (i.e., food). The shallower depth of backfilled canals also increases the "edge effect" (i.e., increased productivity at the marsh/water interface) that presumably results from increased hiding spaces from predators. Where spoil banks are removed after backfilling, fish and shrimp have access to wetlands via routes that were previously inaccessible.

Water Quality. There is very little data on water quality in backfilled canals. However, the shallower depth of a backfilled canal probably results in fewer instances of anoxic conditions because of improved vertical mixing in the water column. Evidence supporting this conclusion is the increased benthic biomass in canals after backfillling.

9.2.1.2. Factors Affecting Backfilling Success. Backfilled canal depth is significantly shallower in intermediate marshes than in brackish or fresh marshes. Insufficient data on canals in salt marshes makes it difficult to compare them with other marsh types. Also, the great variation of vegetation prevents any prediction of backfilling success on the basis of marsh type. The average percent of restored marsh in the canal is low in intermediate marshes and high in fresh and salt marshes. The average percent of re–established marsh on the regraded spoil banks is high in intermediate marshes and low in fresh and salt marshes.

How well backfilling works in different marsh types depends, in part, on how success is measured. Intermediate marshes are high in the total amount of marsh restored on the spoil banks but low on the amount of marsh restored in the canal and in the amount of canal backfilled. Fresh marsh canals are shallow, have high marsh restoration in the canal, but low marsh restoration on the regraded spoil banks. Brackish and salt marshes tend to fall into the middle, having fairly shallow depths and

moderate amounts of marsh in the canal and on the backfilled spoil banks. It should be noted, however, that restoration of water depth and marsh elevation need not be 100 percent successful in order to improve the quality of fish and wildlife habitat in the canal. See sections on Fish above and Backfilled Canals as Habitat for Fish and Wildlife below for further details.

Hydrologic Unit. Coastal Louisiana is composed of two depositionary environments: the eastern Mississippi River Deltaic Plain, formed by direct deposition of river-borne sediments; and the western Chenier Plain, formed by deposition of reworked deltaic sediments. The Chenier Plain sediments typically contain more mineral material and have lower rates of compaction and land subsidence. Backfilling success does not differ between hydrologic units within the Deltaic Plain (Barataria, Terrebonne, and Vermilion Parish), but the average backfilled canal water depth in all deltaic hydrologic units is significantly greater than in the Chenier Plain.

The average marsh revegetation in the canal is greater in the Chenier Plain than in the most successful Deltaic Plain hydrologic unit. One possible reason for the success of backfilling in the Chenier Plain is a difference in operator performance. The amount of spoil returned to the canal in the Chenier Plain is high. The area of re–graded spoil banks remaining covered by spoil vegetation is lower in the Chenier Plain than in deltaic hydrologic units. Superior backfilling success in the Chenier Plain most likely is the result of higher marsh elevations, lower subsidence rates, and decreased erosion.

Time Between Dredging and Backfilling. When dredged spoil is deposited on the marsh in spoil banks, it dries, and the organic matter in the spoil oxidizes, mostly within the first year of dredging (Monte, 1978; Okey, 1918; Turner and Neill, 1984). Spoil shrinkage has been cited as a reason why backfilling would never be successful (Matthews, 1983). Although soils do shrink, it is apparent that significant amounts of spoil remain for backfilling.

Canal Size. Canal size (length, volume dredged, or area disturbed) exhibits no clear relationship to any measure of backfilling success.

Soil Organic Matter Content. Soil organic matter content is inversely related to canal depth. Canals in marshes with highly organic soils showed poor backfilling success. Organic matter content is not related to the amount of marsh or open water on the spoil banks after backfilling. The percent of marsh soil organic matter varies widely among sites with no clear trends between hydrologic units. Thus, soil organic matter cannot account for the more successful backfilling in canals in the Chenier Plain. Soil organic matter content generally decreases from fresh to salt marsh.

Plugging the Canal. The status of the plug (present, absent, or deteriorated) at the mouth of backfilled canals is not related to backfilled canal depth (Neill and Turner, 1987a). Plugged and semi-plugged canals are, however, more likely to support a denser cover of emergent vegetation in the canal than unplugged canals (**Table 9.3**). The need for a plug is often cited by landowners and permitting agencies as necessary to prevent spoil material from washing out of the canal after backfilling and to reduce erosion. Although plugs may help contain spoil material in the canal and reduce erosion, plugs do not appear to have any effect on backfilled canal depth. Plugs slightly increase the amount of marsh in the canal, perhaps by reducing erosive water movement.

The amount of marsh on regraded spoil banks is higher for plugged and semi-plugged canals than for unplugged canals. Plugged canals have a greater amount of open water on the spoil banks than semi-plugged or unplugged canals. It may be that by creating an impediment to drainage, plugs result in higher water levels and more open water on backfilled spoil banks.

Plugs greatly increase the likelihood of establishing floating or submerged aquatic vegetation in a backfilled canal (**Table 9.3**). Aquatic vegetation has been observed in 12 out of 13 plugged backfilled canals. More than half (8 of 14) of the unplugged canals examined had no aquatic vegetation. All plugged canals with vegetation contained large amounts of vegetation of several species. These results agree with the higher frequency of submerged aquatic vegetation in shallow ponds, lakes, and bayous behind weirs (Chabreck and Hoffpauir, 1962; Chabreck, 1968; Larrick and Chabreck, 1976).

Dredge Operator Performance. Dredge operator skill is an important factor influencing how well the objectives of backfilling are met. Regrading spoil banks to the elevation of the surrounding marsh is crucial for marsh re–establishment. A skillful dredge operator can remove spoil banks very close to marsh level, provide a maximum amount of spoil for canal fill, keep gouge scars and open water areas on the old spoil bank to a minimum, and increase marsh

cover. If the dredge operator fails to return most of the spoil bank to the canal, spoil vegetation will remain and reduce the re–establishment of marsh. If the spoil bank is dug too deeply, the re-graded spoil bank remains unvegetated mud or open water. There are not enough cases of high quality dredging to clearly demonstrate that the goal of leveling spoil banks to marsh elevation can be achieved using current bucket dredge techniques.

The amount of re–established marsh on the regraded spoil banks is significantly related to the percentage of spoil material returned to the canal. The more spoil material returned, the lower the spoil bank elevation and the greater the cover of marsh re-established. When too much spoil is returned, dredge gouge scars and areas of open water form. Elevation appears to be the key to plant re–establishment, as has been shown for planting programs (Kadlec and Wentz, 1974).

Factors encouraging backfilling success. Table 9.4 is a summary of the various major factors affecting the success of backfilling. In general,

(1) restoration of marsh and shallow aquatic habitat is more effective in the Chenier Plain than in the Deltaic Plain;

(2) creation of shallow aquatic habitat is more effective if backfilling is performed in marshes with low soil organic matter content;

(3) backfilling is at least somewhat effective in all marsh types and for all sizes of canals;

(4) backfilling success will be greater if the canals are less than 5 years old or greater than 20 years old;

(5) canals should be monitored during backfilling to insure optimal dredge operator performance.

Backfilled Canals as Habitat for Fish and Wildlife. The increased elevation of a spoil bank results in decreased soil moisture and salinity, which, in turn, allows invasion by terrestrial plant species and elimination of marsh species. Al-

Table 9.4. Factors encouraging backfilled canal restoration for seven marsh components. The percent recovery (after less than 10 years) is the estimated return of the component to the original conditions. Positive factors are those which are positively related to higher recovery (N = sample site number; NA = not applicable). (Adapted from Turner et al., 1986).

Component	Average % Recovery	Factors Encouraging Recovery To Date
Soils (N = 18)		
Organic matter	23	Time; revegetation
Water content	51	Time; revegetation
Bulk Density	18	Time, revegetation
Vegetation (N = 31)		
Marsh in Canal	5	Depths less than 2-3 feet
Marsh on Spoil Bank	46	Operator skill; % spoil removed; lack of gouge marks; elevation (+/- 0.5 ft MSL); in Chenier rather than Deltaic Plain
Submerged and Floating Aquatics	NA	Plugs in canals
Hydrology	NA	Spoil Bank removal
Depth (N = 26)	59	Spoil removal; longer time between dredging and backfilling if older than 1 year; in Chenier rather than Deltaic Plain; operator skill; mineral soils; good sediment supply; isolation from boat traffic
Bird Habitat	NA	Shallow depths; aquatic vegetation
Fish Habitat	NA	No plugs; vegetation
Sedimentation	NA	Belowground and overland water movement; lack of spoil banks

though the terrestrial plants on the spoil banks provide habitat for birds and mammals, it is at the expense of the marsh vegetation that provides habitat and food for animals and produces food (detritus) for benthos, finfish and crustaceans.

Even though re-vegetation within a canal does not usually occur before 10 years, backfilling is quite successful in reducing the depths of the canals and forming high quality shallow water habitat. Therefore, it is important to note that vegetative restoration need not be complete for backfilling to provide effective benthic habitat creation and fish use. For example, backfilling 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, 1987a). Backfilled canals resemble 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).

Backfilling often results in the inadvertent creation of shallow open water areas on the old spoil banks where the dredge scraped the spoil too deeply. While this prevents reestablishment of emergent marsh vegetation, the shallow aquatic areas created may serve as valuable habitat in their own respect.

Backfilled canals also have the potential to be high quality habitat for waterfowl. There is considerable evidence that waterfowl use these areas for resting sites, feeding or both. Species of aquatic vegetation known to be eaten by waterfowl have been observed in backfilled canals, including widgeongrass (Ruppia maritima), 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 20 inches deep, a depth that can be used by dabbling ducks for feeding (Chabreck, 1979b; Fredrickson and Drobney, 1979).

Plugging canals encourages the growth of submerged aquatic vegetation, but restricts the access of migratory estuarine fishes (Neill and Turner, 1987b). An alternative strategy for managing backfilled canals for fish and wildlife is to plug canals to promote the growth of aquatic vegetation in fresh marshes or in preferred waterfowl areas, but to leave canals in brackish and saline marshes open or semi-plugged to allow access by juvenile migratory fishes.

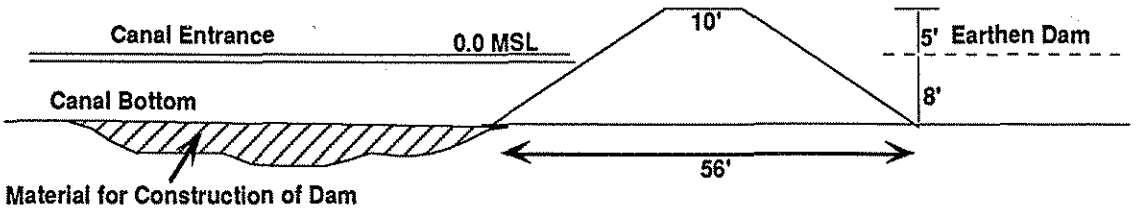
9.2.2. Restoring Alterations to Hydrology and Sediment Distribution

If restoring marsh habitat by backfilling the canal or removing the spoil banks is not feasible, every effort should be made to restore the hydrologic regime (**see Section 3.2.2.2** for a review) to as near pre-project conditions as possible. This requires hydrologically isolating the 8-foot deep canal from natural waterways to eliminate saltwater intrusion and captured water flow. It also requires minimizing barriers to surface water flow across the marsh and opening any small tidal streams that were blocked by spoil placement in order to restore normal inundation (i.e., flooding) patterns and tidal exchange. These management techniques can be very effective in restoring hydrology at the site to near pre-project conditions, especially if used in combination.

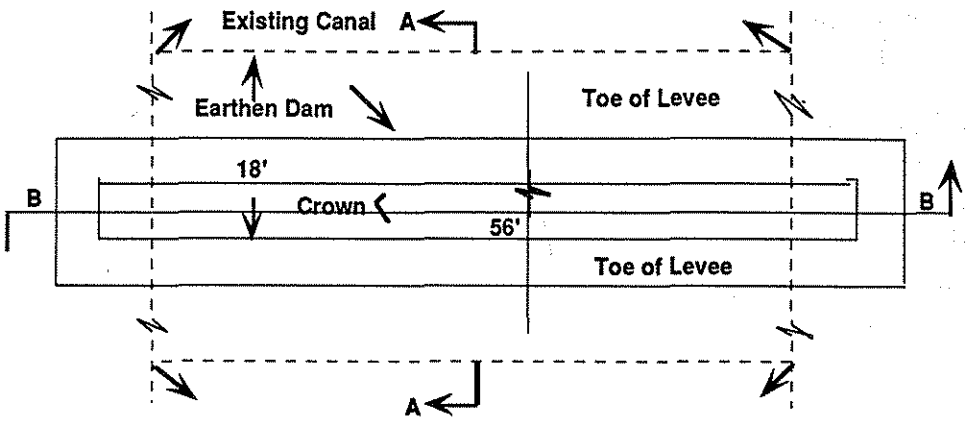
9.2.2.1. <u>Plug Canal with Earthen Dam</u>. The standard method for isolating an access canal from adjoining waterways is to construct an earthen plug at the mouth of the canal (**Figure 9.3**). This dam is constructed from earth dredged from the bottom of the canal or the spoil bank (**Figure 9.4**) and is usually capped with shell or a similar erosion–retardant material. It is set back from the adjoining waterway to minimize erosion from waves and water currents (**Figure 9.5**). The success rate of plug construction depends on the quality of the fill material, the suitability of plug design to local hydrologic conditions, and the skill of the dredge operator. Plugs often wash out very shortly after construction in situations where one or more of these factors is lacking.

Plug construction requires the mobilization of a dredge and/or shell barge to the site and the purchase of shell or limestone. The cost to the company varies depending on the distance equipment must travel and the time and volume of material used for construction. In any case, this method of restoration can add substantially to the total cost of site abandonment.

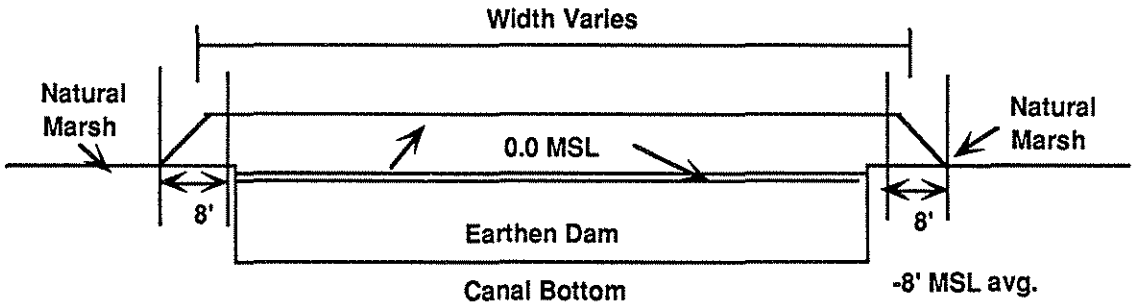
The source of fill material can become an environmental concern if the bottom sediments are not suitable and the supply of spoil material is insufficient. The dredge operator may have no choice but to use marsh material for fill; this, however, is counter-productive to the purpose of marsh restoration. This especially may be a problem for canals dredged with spray technology



PROFILE A-A



PLAN



PROFILE B-B

Figure 9.3. Illustrations of a typical plug design used in closing a drilling site access canal, showing plan and cross-section views of the plug, canal, and borrow area.

Figure 9.4. Earthen plug installed at mouth of canal. Note vegetation debris from spoil bank. (Photography by D. Clark.)

(Cahoon and Cowan, 1988). The use of marsh material for fill can be avoided if the quality of fill material is identified prior to plug construction and, consequently, fill material is hauled to the site. This adds to the cost of restoration because an upland source of fill must be located, the fill purchased, and then loaded onto a barge and shipped to the site.

Because plugs hydrologically isolate canals from adjoining waterways, they may exacerbate hydrologic problems in highly impacted (e.g., leveed) areas. For example, they may restrict migration of estuarine fishes and crustaceans to the canal and adjacent marsh. Therefore, in such situations, installation of a plug should be reviewed on a case-by-case basis. One alternative to the standard plug described above is to construct a culvert in the plug to allow ingress and egress of migratory aquatic species. This restoration measure does not require any new technology, but it does entail more expense than ordinary plug construction because of increased labor and material costs.

9.2.2.2. Construct Gaps in the Spoil Bank. If the spoil bank is continuous and not backfilled into the canal, the next best method for restoring spoil bank impacts on local hydrology is to construct gaps in the spoil bank. To restore surface water flow patterns, 50-foot gaps should be dredged every 500 feet in the spoil bank, the same as for the discontinuous spoil disposal method illustrated in **Figures 3.9 and 3.10**. This requires mobilization and demobilization of a bucket or dragline dredge and, therefore, represents a sizable expense for the company. If local hydrologic conditions are such that the potential for erosion of the canal banks or saltwater intrusion is high, gapping of the spoil banks should not be done unless the canal is first plugged.

Gapping probably will not be needed for canals dredged by high pressure spray disposal technology because of the thinness of the spoil deposit. However, further research is needed to verify this assumption.

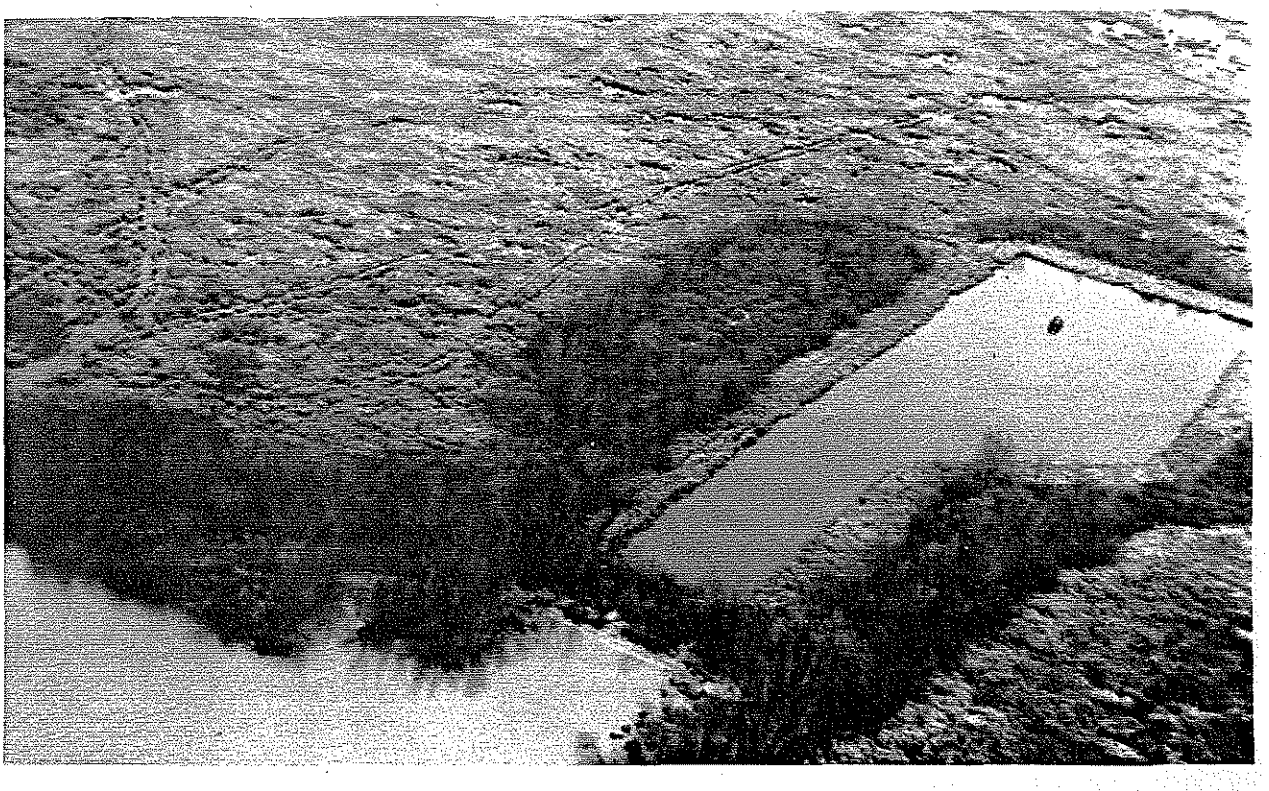


Figure 9.5. Aerial view of plugged canal/slip, showing the relationship between the canal, slip, berm, spoil bank, and plug. Note that the spoil banks and plug are vegetated with trees and shrubs. (Photography by P. Keney.)

9.2.2.3. Open Blocked Waterways. Restoration of local hydrologic conditions can be quickly enhanced by opening all waterways blocked during spoil deposition. This can be easily achieved by existing dredging technology. Again, this method requires the mobilization and demobilization of a bucket or dragline dredge, but, if it is performed in conjunction with plugging or gapping operations, the additional expense is low. The necessity of opening any waterways can be avoided if the canal is dredged by high pressure spray technology.

9.2.2.4. Combinations of the Above. The most effective means of restoring chronic hydrologic impacts is to use the above techniques in combination. Backfilling canals is more effective at meeting certain objectives if a plug is also constructed, while restoring hydrologic functions at a non-backfilled canal is most complete when the canal is plugged, the spoil bank gapped, and all blocked waterways opened (**Figure 9.6**) Also, the cost of each operation is less when they are performed in conjunction with one another.

9.2.2.5. Suggestions for Implementing Management Techniques. As indicated in **Table 3.3**, measures required to restore the impacted habitat to pre-project status quo should be identified during permit review before the project is implemented. This means the objectives of the restoration need to be clearly defined. For instance, when backfilling is considered, the soil type, geologic setting, and vegetation type must be evaluated along with the final habitat objective (i.e., waterfowl, fish, or marsh). However, this is often very difficult or impossible to do before the project is implemented because no one knows how long the well will produce or what the environmental setting will be years from now. For example, the quality of fill material for backfilling or plug construction may change considerably over the years, especially spoil bank material.

To this end, it is often useful to put two sets of restoration conditions on a permit: one aimed at current environmental conditions in case the well is a dry-hole and the other tempered by the fact that the well may produce for many years. Because backfilling is more effective in young canals, it

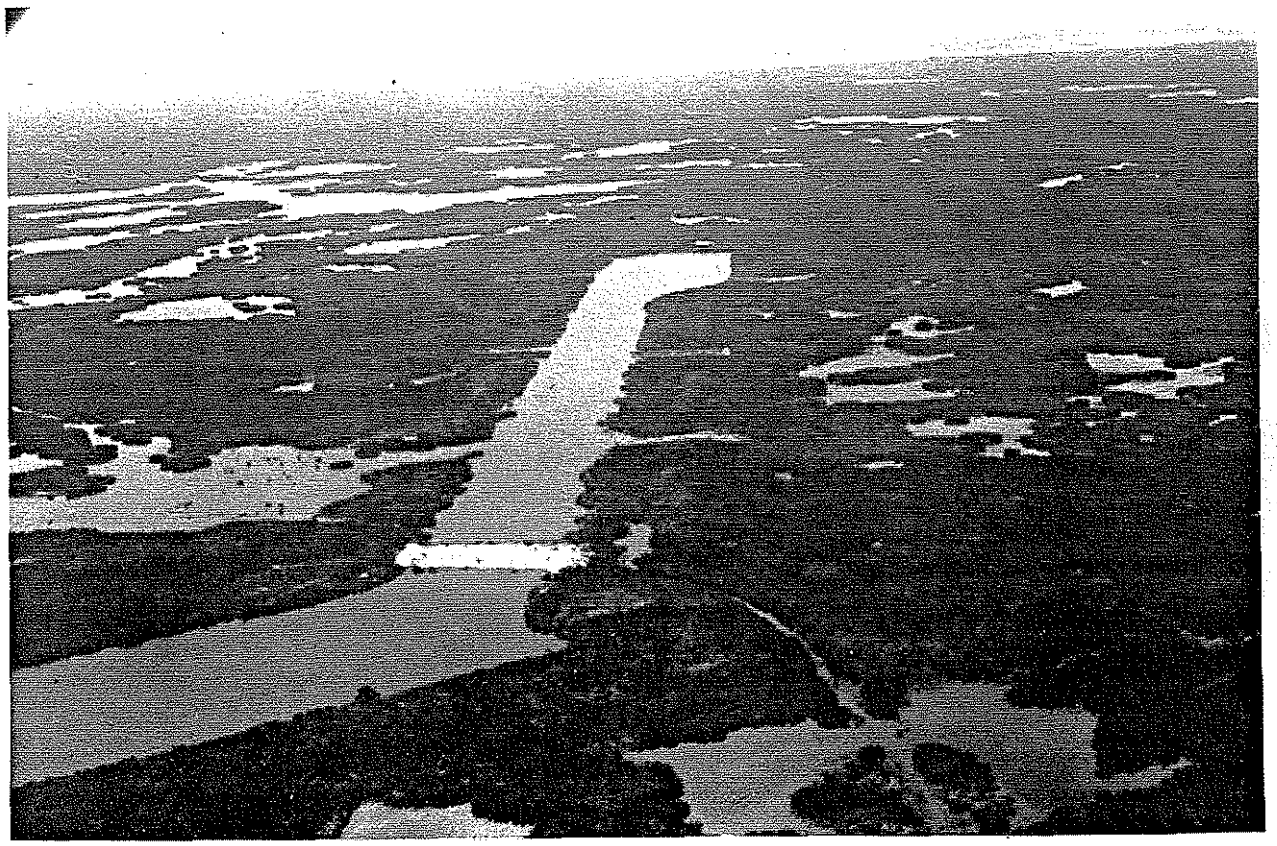


Figure 9.6. Aerial view of a plugged canal/slip with gaps dredged every 500 feet in the spoil bank. Note that the plug is off-set from the mouth of the canal and has been capped with shell to retard erosion. (Photography by P. Keney.)

would always be appropriate to recommend this restoration method for any dry-hole situation. Conversely, it is prudent to recommend that fill material for plug construction be hauled in for any well that produces for more than several years in a canal with soft-soupy substrates. In general, restoration measures should be matched to the local environmental setting, or predicted environmental setting, as closely as possible. To be effective in any way, they also must be incorporated into the permit that authorizes site access.

9.3. ON–SITE RESTORATION of IMPACTED WETLAND VALUES and FUNCTIONS upon ABANDONMENT of WELL - ROAD DUMP/RING LEVEE

When a drilling site is abandoned, either as a dry hole or after the productive life of a well, action must be taken to return the access route and drill site to pre-project conditions. This section discusses the steps necessary to achieve a reduction in chronic impacts at the locale.

9.3.1. Restoration of Habitat

All practical actions should be taken to return a land–based drilling site to as near pre-project habitat conditions as possible. Such restoration may occur only months after the initial activity at the site if exploratory drilling results in a dry hole, or it may occur years after construction if the well has produced. Restoration in either case should strive toward the same result: removing all foreign materials, regrading all earthen construction, and returning the material to the borrow pits.

9.3.1.1. <u>Regrade Drill Site to as near Pre-Project Conditions as Possible</u>. Material excavated to form the ring levee, drill pad, and any pit levees should be regraded to as near original elevations as possible and the fill placed back into the borrow pits (**Figure 9.7**). Oxidation and compaction probably will reduce the volume of material to an insufficient amount to fill the pit. Compaction of the marsh surface within the ring levee lowers the surface elevation. Aerial photographs of board

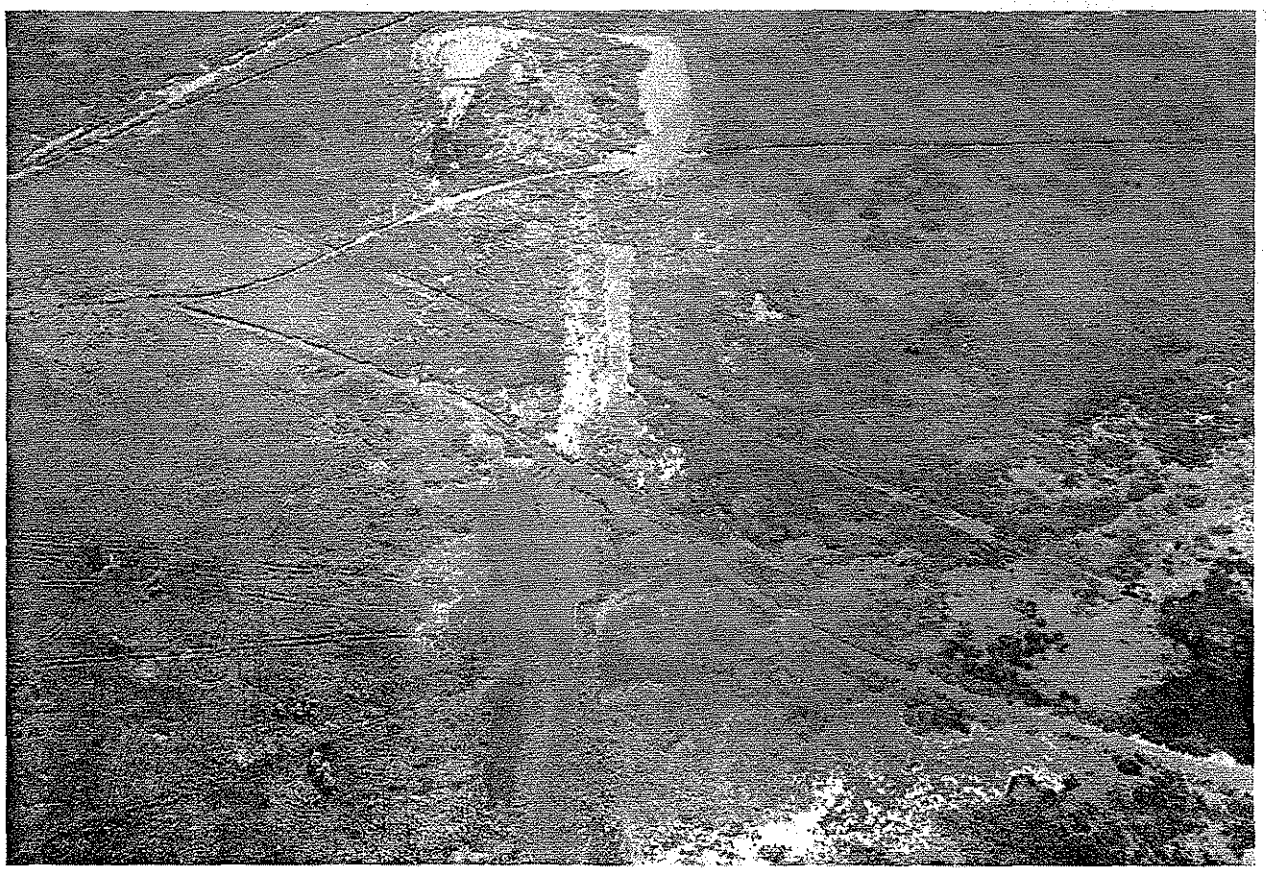


Figure 9.7. Aerial view of restored road dump and ring levee in coastal fresh marsh. (Photography by T. Michot.)

road sites reveal numerous rectangular ponds in wetlands indicating that regrading the existing structures was not sufficient to restore elevations to a level where marsh species could recolonize. A time limit for completion of restoration should be included in all permits issued for ring levee drill sites.

9.3.1.2. Removal of Drill Pad Material. If the exploratory drilling results in a dry hole and abandonment of the well, the site must be restored to as near pre-project condition as practical. Such restoration includes removal of all boards which have formed the drilling pad. All plastic sheeting or filter cloth must be removed, including any pit liners. Any muds or fluids present in the mud or reserve pits must be removed (see Section 9.3.2.3 Pit Closure). The pad must be regraded to as near marsh level as possible. In forested wetlands, the regraded drill site should be planted with one-year-old tree seedlings, spaced 20 feet apart. Bald cypress should be planted in swamp environments, and water oak or nuttal oak in bottomland hardwood habitats. It may be necessary to place predator guards (e.g., wire cages) around the seedlings to protect them from nutria grazing. In marsh habitat, plantings most likely will not be needed because natural vegetative recolonization will occur rapidly.

9.3.1.3. Removal of Road Surface. The steps involved and the success rate of road restoration depend on whether the well was a producer or a dry-hole.

Dry-Hole – Temporary Access Road. Upon abandonment of an exploratory drilling site, all boards should be removed. Filter cloth, plastic sheeting, and all other foreign material are transported from the access route.

Producing Well – Permanent Access Road. If the road dump/board road has been in use for many years as an access route to a producing well, the surfaces of the route and drill site likely have been made permanent, i.e., the boards have been covered with shell or limestone. Over a period of years several layers of

on the route as maintenance. Often a field will have been developed and the access route may serve other locations. Consequently, such a route normally is not restored.

Restoration of a permanent road is difficult. Removal of the shell or limestone and boards may not be practical because the narrow width of the road dump/board road prohibits movement of draglines, bull dozers, and dump trucks. Also, the shell or limestone has usually been worn into small particles and the underlying boards may or may not be intact.

Landowners often want to maintain access routes onto their land or preserve the upland habitat site created by the elevated linear feature. Such a site provides a haven for upland wildlife species not normally found in the marsh and are regarded by some landowners as a beneficial environment not previously present in the wetland. To restrict access to the wetlands, the route may have any or all of the culverts or bridges removed or a 10- to 20-foot gap in the elevated route dredged at its beginning or take-off site. Such actions create linear "islands" which are rapidly colonized by upland shrub/scrub species.

9.3.1.4. Removal of Road Dump (linear feature). After removing the boards and other foreign materials, the excavated material that forms the road dump is regraded and deposited in the borrow pits from which the material was excavated. Usually, oxidation and compaction of the excavated material results in insufficient volume to completely refill the borrow pits. Shallow water ponds are often created in the borrow pit sites and often along the road dump route. **Figure 9.7** shows a restored board road and ring levee site. Access to this fresh marsh site required a 2,807 foot road dump route. A 30-foot bridge was needed to cross a stream. This unsuccessful well location was accessed, drilled and abandoned, and restored within eight months. Note that the ring levee and road dump have been regraded and water flow restored to as near pre-project conditions as possible in the impacted waterways.

Permit conditions should specify that degrading the road dump and restoring the site must be completed within a specified time after abandonment. If the activity was performed in accordance with the NOD-13 General Permit, the site must be regraded as agreed. If the site was constructed in accordance with a regular USACE permit, the access route will have to be restored according to the specific conditions of the permit.

9.3.2. Restoration of Surface Hydrology and Maintenance of Water Quality

The regrading of the road dump and ring levee back into the borrow pits promotes re-establishment of the pre-project surface hydrology. Removal of culverts and restoration of re–routed streams also promote the return to former conditions. Proper disposal of drilling muds, cuttings, and other pit wastes is necessary to maintain water quality.

9.3.2.1. Open Blocked Streams. Culverts placed in the road dump at any natural water courses are removed to re-establish natural flows. Streams which had been re-routed during construction are returned to the original location, and the dredged artificial channel is filled with previously excavated material.

9.3.3. Suggestions for Implementing Management Techniques

As in the case of canal restoration, measures required to restore the impacted habitat to pre-project status quo should be identified during permit review before the project is implemented and incorporated into the construction permit. The objective should always be to completely restore all impacted wetland values and functions.

CONVERSION TABLE

Metric to U.S. Customary

Multiply	By	To Obtain
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
kilometers (km)	0.6214	miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	2205.0	pounds
metric tons	1.102	short tons
kilocalories (kcal)	3.968	British thermal units
Celsius degrees	1.8 (C°) + 32	Fahrenheit degrees

U.S. Customary to Metric

inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft^2)	0.0929	square meters
acres	0.4047	hectares
square miles (mi^2)	2.590	square kilometers
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28.35	grams
pounds (lb)	0.4536	kilograms
short tons (ton)	0.9072	metric tons
British thermal units (BTU)	0.2520	kilocalories
Fahrenheit degrees	0.5556 (F° - 32)	Celsius degrees

GLOSSARY

The following glossary identifies technical terms used in the handbook. Definitions are based primarily upon terms in: *Environmental Impact Statement Glossary, A Reference Source for EIS Writers, Reviewers, and Citizens*, 1979; *Dictionary of Environmental Terms*, 1976; *A Dictionary of Ecology, Evolution, and Systematics*, 1982; *Wetlands Thesaurus, A Vocabulary of Coastal Wetlands Research*, 1983; *Topics and Terms in Environmental Problems*, 1977; *The Illustrated Petroleum Reference Dictionary*, 1982; *Protection, Cleanup and Restoration of Salt Marshes Endangerd by Oil Spills—A Procedural Manual, 1978; and Glossary of Geology*, 1980. Italicized synonyms and related key words follow each definition where applicable.

Accretion - the upward growth of a sedimentary deposit, e.g., settling of sediment from suspension in a stream subject to overflow.

sedimentation, deposition, delta, vertical accretion

Acute effect - caused by the action and occurring at the same time and place as the action; effects include ecological (effects on natural resources and on components, structures, and functions of affected ecosystems), economic, social, and health impacts.

short-term or immediate impacts

Aerobic - living or active in the presence of free oxygen; a process taking place in the presence of oxygen.

aeration, oxygen, wetland chemistry

Aggradation - the building up of the earth's surface by deposition, specifically the upbuilding performed by a stream in order to establish or maintain uniformity of grade or slope.

upgrading

Air-cushioned vehicle (hovercraft) - a vehicle employing the hovercraft principle of down-thrusting airstream support, developed to transport equipment and supplies. The air cushion protects the surface from being cut by wheels or treads of conventional vehicles.

hovercraft

Alluvium - a general term for clay, silt, sand, gravel, or similiar unconsolidated detrital material deposited during comparatively recent geologic time by a stream or other body of running water as a sorted or semi-sorted sediment in the bed of a stream or on its floodplain or delta, or as a cone or fan at the base of a mountain slope, especially deposited during time of flood.

deposition, sediment, soil, sedimentation, floodplain, river, gravel, sand, silt, clay, stream, terrace, geological deposits, delta

Anaerobic - living or active in the absence of free oxygen; a process taking place in the absence of oxygen; an oxygen-independent type of respiration.

soils, wetland chemistry, anoxic

Annulus - the space between the drillstring and the walls of the wellbore.

Aquatic - living in or near water; used of organisms adapted for a partially or completely submerged life.

marine, riverine

Aquatic weed cutter - specially designed mechanical device used to cut aquatic vegetation.

Aquifer - an underground water reservoir.

Aromatic - organic compounds containing any of a series of benzene ring compounds. They are unsaturated organic ring compounds with low boiling points and are generally toxic to aquatic life.

toxic compound

Artificial levee - an artificial embankment, usually of random earth fill, built along the banks of a water-course or an arm of the sea and designed to protect land from inundation or confine streamflow to its channel; spoil material placed along a dredged canal.

spoil bank, control structure, dike, flood wall, revetment, shore protection

Artificial life - a means of supplying energy to a reservoir in an attempt to recover oil and gas.

Backfill - the process of refilling an excavation; to replace the earth dug from a ditch.

mitigation, dredging, canal

Bailer - a unit in cable tool drilling, a bailer is a tool that was lowered to the bottom of the hole to remove cuttings and fluid from the hole.

Barge-mounted dragline - a revolving shovel mounted to a barge; the shovel carries a bucket attached only by cables and digs by pulling the bucket toward itself.

dredging, oil and gas exploration, dredge

Barrel - a unit of measure equal to 42 U.S. gallons.

Bayou - a creek or secondary water course that is tributary to another body of water, especially a sluggish or stagnant stream that follows a winding course through alluvial lowlands, coastal swamps, or river deltas; an effluent branch, especially sluggish or stagnant, of a main river, e.g., a distributary flowing through a delta, also the distributary channel that carries floodwater or affords a passage for tidal water through swamps or marshes; the term is variously applied to many local features in the lower Mississippi River Basin and in the Gulf Coast region of the United States, especially Louisiana.

marshes, creeks, deltas, swamps, wetlands

Benthic - bottom dwelling organisms. Aquatic organisms that live in or on waterbottoms, usually not mobile.

sessile

Bearing strength - resistance of soil to pressure. This is an important consideration in accessing wetland areas where spills have occurred.

soil, trafficability

Berm - the area between a canal bank and the edge of the spoil bank; a slightly elevated area along man-made and natural waterways and beaches having an abrupt fall and formed by deposition of materials by wave action.

beaches, canals, embankments, spoil banks

Blowout - when high pressure formation fluids force the mud and/or the drillstring out of the wellbore.

Blowout preventors - safety valves attached to the wellhead, used to shut-in a well or control the well flow in an emergency situation.

Board road - wooden planks placed on the surface of the marsh or road dump to allow access of vehicles and equipment to wetland areas.

Boom - a linear floating device used to contain oil spills in aquatic environments.

skirt, fence, sorbent

Borrow ditch (pit) - A ditch dug along a roadway or canal to furnish fill for another location.

Brackish - a term used to describe water which contains some salt in solution, but less than is contained in sea water; brackish waters are usually regarded as those containing between 500 and 30,000 parts per million (ppm) sodium chloride.

marsh, salt marsh, tidal marsh, estuary, saltwater intrusion, wetlands

Bucket dredge - an open container attached to the movable arms of a wheeled or tracked vehicle to spread solid waste and cover material and to excavate soil.

dredge, spoil, clam shell

Build-angle - the rate at which a turn in a directional well is increased. This term is expressed in degrees of build (increase per one hundred feet).

Bulk density - the mass of dry soil per unit bulk volume including the air space; the bulk volume is determined before drying to constant weight at 105 degrees centigrade.

soil, sediments

Canal - an artificial watercourse of relatively uniform dimensions, cut through an inland area, and designed for navigation, drainage, or irrigation by connecting two or more bodies of water; a long narrow channel or arm of the sea connecting two larger stretches of water, usually extending far inland and approximately uniform in width.

waterway, navigation, transportation, channel, intracoastal waterway, locks

Canal widening - enlargement of the boundaries of water courses through erosion.

channel, erosion

Carbonate rocks - geologic formation formed from compounds that contain the carbonate ion, e.g., limestone.

Casing - pipe used to protect shallower formations from contamination and to prevent the borehole from collapsing. This pipe is usually cemented into place.

Channel- a natural or artificial watercourse of perceptible extent, with a definite bed and banks to confine and conduct continuously or periodically flowing water.

waterway, canal

Chenier Plain - a classical coastal strandplain. Also a marginal deltaic plain; the term chenier refers to the higher elevation stranded beach deposits and its origin is from the French for the live oaks that commonly grow on the elevated areas.

Chronic effect - caused by the action, but may occur later in time or be longer lasting; chronic effects may include growth-inducing effects and other effects related to induced changes in the pattern of land use, population density or growth rate, and related effects on air and water and other natural systems, including ecosystems.

long-term impact

Clamshell bucket - a hinged, jaw-like digging implement suspended at the end of a cable running down from the boom of an excavating machine; a dragline bucket.

drilling, oil and gas exploration, bucket dredge

Closed-loop system - a series of solids control equipment used to clean the drilling mud of cuttings and other contaminants. The result is a solid sludge and clean water that can be discharged.

Coastal zone - ocean waters and adjacent lands that exert a measurable influence on the uses of the sea and its ecology.

wetlands, marshes, estuaries, beaches, shores, deltas

Compaction - reduction in bulk volume or thickness of, or the pore space within, a body of fine-grained sediments in response to the increasing weight of overlying material that is continually being deposited or to the pressures resulting from earth movements within the crust; it is expressed as a decrease in porosity brought about by a tighter packing of sediment particles; the process whereby fine-grained sediment is converted to consolidated rock (such as clay lithified to a shale).

consolidation

Control structure - a structure (such as a weir) constructed across a stream or other water body to stop, raise, divert, or measure the flow of water.

weir, revetment, diversion, flood control, floodwall, dike, levee, sea wall, impoundment, embankment, jetty, dam, diversion structure

Core - a sample of the formation from a known depth.

Coupling - denoting a condition of linkage between ecological systems through the exchange of information in the form of water, inorganic and organic matter, and biota.

linkage

Cuttings - pieces of the formation that have broken up by the action of the drill bit.

formation

Dam - a barrier constructed usually at or near a shoreline along the pipeline to protect the right-of-way from erosion and to prevent hydrologic alterations.

Dehydration - the process of removing water molecules from natural gas production.

Delta - the low, nearly flat alluvial tract of land deposited at or near the mouth of a river, commonly forming a triangular or fan-shaped plain of considerable area enclosed and crossed by many distributaries of the main river, perhaps extending beyond the general trend of the coast, and resulting from the accumulation in a wider body of water of sediment supplied by a river in such quantities that it is not removed by tides.

accretion, alluvium, deposition, floodplains, sedimentation

Delta lobe - rounded areas of sedimentation which are formed when a river course shifts its locus of deposition. The Mississippi River deltaic plain represents the coalescence of seven major lobes that were built at various times and in various positions during the last 5000 years.

accretion, alluvium, deposition, floodplain, sedimentation

Dessicant - in solid or liquid form, this agent removes moisture from a gas.

Development well - wells drilled in an area already proven to be productive.

Diapir - a dome or anticlinal fold in which the overlying rocks have been ruptured by the squeezing out of plastic core material. Diapirs in sedimentary strata usually contain cores of salt or shale; igneous intrusions may also show diapiric structure.

diapirism, piercement dome

Differential sticking - side-wall sticking of the drillstring caused by changing bottomhole conditions.

directional drilling

Dike - an artificial wall, embankment, ridge, or mound, usually of earth or rock fill, built around a relatively flat, low-lying area to protect it from flooding; a levee.

embankment, ridge, levee, control structure, dam, groin, revetment, impoundment, sea wall, flood protection, intrusion

Directional drilling - a process of directing the wellbore along some trajectory to a planned target zone.

Double-ditch - dredging technique in which the top 6 to 12 inches of overburden is placed on one side of the trench and the remaining excavated material is placed on the other side.

Drainage - the manner in which the waters of an area pass or flow off by surface streams or subsurface conduits; the processes of surface discharge of water from an area by streamflow and sheet flow, and the removal of excess water from soil by downward flow; also the natural and artificial means for effecting this discharge or removal.

discharge, flood control, flow, runoff, surface waters, water management, watersheds

Dredge - a large floating machine for scooping up or excavating earth material at the bottom of a body of water, raising it to the top, and discharging it on a bank through a floating pipeline, by conveyors, or into a scow for removal to a distant point (e.g., a "hydraulic dredge" using a centrifugal pump to draw mud or saturated sand from river channels).

excavation, spoil

Dredged material - any material excavated or dredged from the navigable waters of the United States.

spoil

Dredging - to remove earth from the bottom of waterbodies using a scooping machine.

canalization, channelization, channels, excavation, waterways

Drill bit - a tool placed at the bottom of a drillstring used to break the formations into pieces that can be transported to the surface.

Drill collar - heavy tubulars added to the drillstring to provide additional weight on the drill bit and strength to the drillstring.

Drilling barge - see submersible barge platform.

Drilling site access canals - open channels constructed to efficiently transport people and equipment to and from drilling locations.

petroleum engineering, exploration, permits, oil wells, dredge

Drill pad - the area within the ring levee where well drilling takes place. The drill pad is usually constructed by placing boards on dredged material; the drill pad may also be supported by 60 foot pilings driven into the marsh below the drill site.

Drill pipe - thick-walled pipe used to transmit torque to the bit and provides an avenue for the drilling mud to reach the bit.

Drillstring - consists of drill pipe, drill collars, and the drill bit.

Drop-angle - the rate at which a turn in a directional well is decreased to bring the well back to vertical. This term is expressed in degrees of drop (decrease) per one hundred feet.

Ebb tide - that period of tide between a high water and the succeeding low water; falling tide.

current

Edaphic - relating to, or determined by, conditions of the soil.

Edge effect - more robust plant production along the natural levees of marsh streams and bayous compared to inland marsh areas due to increased aeration and nutrient supply.

streamside effect

Emergent vegetation - a plant having most of the aboveground vegetative parts above water.

autotrophs, primary production

Emulsion - the suspension of small droplets of water in oil.

Endless rope - a continuous rope-like oil sorbent device that is pulled across the surface of the water to pick up oil.

Enhanced oil recovery (EOR) - methods used to change characteristics of the reservoir fluid in an effort to increase recovery of oil and gas.

Erosion - the general process or group of processes whereby the materials of the earth's crust are loosened, dissolved, or worn away, and simultaneously moved from one place to another by natural agencies (e.g., weathering, transportation); specifically, the mechanical destruction of the land and the removal of material (such as soil) by running water, waves and currents, moving ice, or wind; erosion may be intensified by land-alteration processes.

scouring, levees, degradation, weathering, soils, crevasses, rainfall

Estuary - any semi-enclosed coastal body of water which has a free connection with the open sea; it is thus strongly affected by tidal action, and within it sea water is mixed (and usually measurably diluted) with fresh water from land drainage.

tidal entrances, tidal marshes, wetlands

Eustatic sea level rise - see relative sea level rise.

Feeder line - smaller pipelines that collect the hydrocarbons from individual fields and transport to the trunk line.

Flare stack - this piece of equipment is used to burn or release any undesirable natural gas.

Flood - a rising body of water (as in stream, lake, or sea) that overwashes its natural or artificial confines and covers land not normally under water.

inundate, hydrology, storm, overland flow, floodplain, discharge, rainfall, surface water

Flood tide - an incoming tide; a tide at its greatest height.

current

Floodwater storage capacity - the capacity of an area to store water that has overflowed its confines.

hydrology, watersheds, water level, floodplain

Flotation canal - an older method of pipeline construction wherein a canal was dredged to allow passage of work barges.

Flushing - use of a water stream to make spilled oil flow to a desired location or recovery device.

Formation - a layer of deposited sedimentary material of like geological origin and age.

Gap - Large (50 foot) openings placed in spoil banks on either side of canals for purposes of restoring local surface water flow patterns after abandonment of oil and gas wells.

mitigation, spoil

Geophysical survey - the use of one or more geophysical techniques in geophysical exploration, such as earth currents, gravity, heat flow, radioactivity, and seismic activity.

geophysical exploration

Horizontal drilling - recent technology using downhole motors and steering systems to drill in a horizontal direction.

Hydrology - the science dealing with the occurence, circulation, distribution, and properties of the waters of the earth and their reaction with the environment.

water, drainage, hydraulics, runoff, rainfall, flow, water resources, water supply, discharge, precipitation, surface water, groundwater, floods, evaporation, transpiration

Impoundment - an enclosed parcel of land/water in which some degree of water level control is possible and that is hydrologically isolated from the surrounding ecosystem, either naturally or by artificial leveeing.

containment, control structures, weir, dam, dike, pond, reservoir

Inorganic - pertaining to or composed of chemical compounds that do not contain carbon as the principal element (excepting carbonates, cyanides, and cyanates), i.e., matter other than plant or animal.

Inundation - flooding, by the rise and spread of water, of a land surface that isn't normally submerged; in wetlands, twice daily tidal flooding.

flooding, overflow

Isostatic sea level rise - see relative sea level rise.

isostatic depression

Jet-Spray - a swinging ladder hydraulic dredge used to suck up marsh substrate, grind it up, and spray it as a thin layer over the marsh; Jet-Spray is a registered trademark.

water vac, dredge disposal, dredging

Keyhole - the canal terminus; the keyhole is wider than the canal to accommodate the drilling barge and auxiliary service vessels side by side.

drilling, canal, oil and gas exploration

Keyway - a 7 ft by 16 ft timber protective structure constructed around the wellhead.

drilling, oil and gas exploration, platform

Lay barge - a movable floating platform upon which pipe is welded, coated and put in place; a work barge.

Levee - an embankment which confines water, especially one built along the banks of a river to prevent inundation of lowlands by floodwater; levees may be natural (the result of stream deposition) or artificial (constructed by man).

embankment, floodwall, control structure, shore protection, revetment, dike, spoil bank

Liner - a string of casing hung from the bottom of the last casing string.

Logging - lowering sophisticated measuring instruments into the wellbore and recording data on the formations present in the well.

Loss of circulation - the loss of wellbore fluids to the formation.

Marsh - an ecosystem of more or less continuously waterlogged soil dominated by emersed herbaceous plants but without a surface accumulation of peat.

wetlands, backswamps, swamps, bayous, freshwater marshes, salt marshes, brackish marshes, intermediate marshes, streamside marshes, inland marshes

Marsh buggy - a vehicle with tank-like treads revolving around pontoons used for transporting equipment in wetlands and capable of travelling on marsh and water alike.

Marsh development - the complex interaction of hydrological, geological, and biological processes (water, sediment, and vegetation) resulting in saturated soils held in place by emergent vegetation; distinct from unvegetated mudflats and dry, vegetated soils.

wetlands, bayous, freshwater marshes, salt marshes, brackish marshes, intermediate marshes, streamside marshes, inland marshes, grasses, Spartina

Mineral soils - a soil that is composed mainly of mineral matter but which also has some organic matter.

geological deposits, geochemistry, soils, geology, sediment

Miscible - a characteristic of fluids that will mix with each other, unlike oil and water.

Mitigation - includes 1) avoiding the impact altogether by not taking a certain action or parts of an action, 2) minimizing the impact by limiting the degree of magnitude of the action and its implementation, 3) rectifying the impact by repairing, rehabilitating, or restoring the impacted environment, 4) reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action, and 5) compensating for the impact by replacing or providing substitute resources or environments.

alleviation, moderation, environmental impact, restoration

Natural levee - an embankment of sediment (area of increased elevation) bordering one or both sides of a channel, produced by deposition of sediment during overwash flooding events.

embankment, streamside, ridge

Nutrient - elements essential to growth and development of living things; carbon, oxygen, potassium, and phosphorous, etc., available in dissolved or particulate, organic and inorganic forms.

food, productivity, nutrition, protein, organic, inorganic

Nutrient cycling - the cyclic transformation of nutrients from inorganic to organic forms by the processes of biotic production, decomposition, and remineralization.

nutrients, productivity, food chains, budgets

Oleophilic - a material that has affinity for oil.

Open water - any body of water that is free of emergent vegetation.

shallow water habitat

Organic - pertaining to or composed of chemical compounds based on carbon chains or rings and also containing hydrogen with or without oxygen, nitrogen, or other elements.

Organic flux - the movement of particulate organic matter into and out of a marsh.

organic matter, detritus, export, import

Organic matter - matter pertaining to or derived from living organisms.

organic materials, detritus

Organic matter accumulation - accumulation and build up of matter pertaining to or derived from living organisms, or to compounds containing carbon as an essential component.

organic materials, detritus, accretion, peat

Oyster reef - an organic reef or bank composed mostly of oyster shells attached upon one another in growth position; living examples tend to occur in estuarine waters.

Parallel slip - a short waterway dredged parallel to an existing waterway to accommodate a drilling barge and auxiliary service vessels without hindering navigation.

keyhole, access canal

Peat - an unconsolidated deposit of semicarbonized plant remains of persistently high water content (at least 75%) in a water-saturated environment, such as a bog or fen; carbon content is about 60% and oxygen content is about 30%; structures of vegetable matter can be seen.

bog, fen, swamp, marsh, fossil fuels, hydrocarbons, organic materials, soils

Piling - long, slender structural foundation elements, usually made of timber, steel, or reinforced or prestressed concrete, that are driven or jetted into the ground or cast in place in a borehole. Piling is used to support vertical or lateral loads, to form a wall to exclude water or soft material or resist their pressure, or to compact surrounding ground.

Pipe dope - a viscous lead-based compound used to lubricate and prevent corrosion of pipe threads during drillstring assembly.

Pipeline - a line of pipes for conveying gas, oil, and petroleum products.

Pipeline corridor - a right-of-way dedicated to contain two or more pipelines.

Pipeline pumping station - a small facility which pumps production fluids to maintain adequate pressure for flow to a distribution system.

Pit - a reserve area excavated to a depth of 3 feet below the marsh surface. The pit is used to store drilling fluids, waste, and other products associated with oil and gas excavation.

Pleistocene outliers - topographically higher areas surrounded by wetlands that are common in the Chenier Plain; the areas are of late Pleistocene age, fluvial deposition.

Plug -the process of filling a well's borehole with cement or other impervious material to prevent the flow of water, gas, or oil from one strata to another when a well is abandoned; to screw a metal plug into a pipeline to shut off drainage or to divert the stream of oil to a connecting line; to stop the flow of oil or gas.

or, an earthen dam constructed at the mouth of a canal in order to hydrologically isolate the canal from the adjoining waterway.

Pontoon sled - a metal platform supported by pontoons which is used for carrying seismic equipment. A pontoon sled is towed through the wetlands by a marsh buggy.

Primary production - the total amount of organic matter newly formed by photosynthesis.

food chain, nutrients, trophic levels, biomass, nutrient cycle, autotrophic

Primary recovery - oil and gas production that occurs by the reservoir's own energy, namely pressure and temperature.

Production casing - casing set through the producing zones of the well and cemented into place.

Production facilities - a combination of equipment used to process oil and natural gas to pipeline specifications. Also called processing or production processing facilities.

Prop-washing - to clear a channel through shallow water by forcefully pushing bottom sediments aside with the hull of a boat or churning up bottom sediments with the propeller.

wheelwashing

Push-ditch - a method of pipeline placement where a trench is excavated and the pipe is pushed into the trench from a staging area.

push-pull

Redox potential - abbreviation for oxidation-reduction potential, a measure of the electron pressure or availability in a solution expressed as electric potential in millivolts (mv); aerated soil with free dissolved oxygen has an electric potential in the range of +400 to +700, while saturated, anaerobic wetland soils range from +400 to -400 in electric potential.

electric potential, EH, oxidation-reduction, soil chemistry

Reflection seismography - a procedure in seismic prospecting based on the measurement of the travel times of waves which, originating from an artificially produced disturbance, have been reflected back to detectors from subsurface boundaries; used primarily for oil and gas exploration.

seismic surveying

Regrade - to return dredged material used to construct road dump and ring levee to slope existing prior to dredging; restoration of marsh surface to original grade.

Relative sea level rise - a rise in the level of the sea relative to that of the land caused by eustatic sea level rise (worldwide rise in sea level resulting in part from melting of continental ice caps) and isostatic sea level rise (local rise in sea level caused by isostatic depression in the form of subsidence).

subsidence, downwarping, tectonics, consolidation, compaction

Reserve pit - an exavation connected to the working mud pits of a drilling well to hold excess or reserve drilling mud; a standby pit containing already mixed drilling mud for use in an emergency when extra mud is needed.

Reservoir - a permeable formation holding an accumulation of hydrocarbons bounded by impermeable barriers to form a trap.

Reservoir stimulation - techniques used to increase the production rate of a well.

Right-of-way - legally acquired right of passage over another's property.

Ring levee - a circular, elevated strip of land which serves to contain any potential pollution within the area of drilling.

mitigation

Rip rap - material (stones, blocks of concrete, rock, etc.) placed on a stream bank and bed for protection from currents or wave action.

Road dump - Dredged material "dumped" to create a linear surface raised above the surrounding wetlands. Boards are then placed on top of the road dump to produce a road capable of supporting drilling equipment. The crown is usually 20 feet wide, and the base varies in width depending on the organic and water content of the dredged material.

board road

Rod pumping system - a surface pumping unit that uses suction to bring reservoir fluids to the surface.

Rotary drill rig - a general term for the derrick, power supply, draw works, and other surface equipment necessary to drill a borehole, such as in drilling an oil well.

rig

Salinity - the relative concentration of salts, usually sodium chloride, in a given water; it is usually expressed in terms of the number of parts per thousand of chlorine.

salt marsh, saltwater, brackish, seawater, saltwater intrusion, brines, soils, water quality

Salt dome - a deformed geologic structure caused by the central rise of a core or plug of salt from considerable depth. In strata deformed by the rise of a plug, important accumulations of petroleum are trapped.

Saltwater intrusion - displacement of fresh surface or ground water by the advance of saltwater due to its greater density, usually in coastal or estuarine areas; the saltwater moves in a wedge-shaped mass along the water bottom in stratified estuaries.

salinity, salt marsh, interfaces, tidal marshes, brackish marshes, brines, salt wedge

Seagrass - a marine monocotyledonous angiosperm.

Secondary recovery - producing reservoir fluids by providing additional energy to the reservoir.

Sedimentation - deposition of waterborne sediments due to a decrease in velocity and a concomitant reduction in the size and amount of sediment which can be carried.

deposition, accretion, progradation, mineral soil, bedload, alluvium, floodplains, sediment transport, silt

Seismic exploration - applied seismology; geophysical information on subsurface rock formations gathered by means of a seismograph; the investigation of underground strata by recording and analyzing shock waves artificially produced and reflected from subsurface bodies of rock.

seismology, seismographic survey, reflection seismography

Sessile - permanently fixed; immobile.

Shale barge - a barge used in wetland drilling operations to catch all cuttings and fluids.

Sheet flow - an overland flow or downslope movement of water taking the form of a thin, continuous film over relatively smooth soil or rock surfaces and not concentrated into channels larger than rills.

overland flow, runoff, surface water, rainfall

Shell midden - a mound-like accumulation of bivalve shells normally found on the site of ancient settlements.

Shell cap - an erosion-retardant shell covering placed over earthen plugs which are constructed to close the mouth of a canal upon abandonment of oil and gas wells.

Shell pad - a foundation pad for a drilling barge or production platform constructed by depositing shell (or limestone) on the water bottom.

Shooting a well - exploding a charge downhole in an attempt to stimulate fluid flow.

Shot hole - a small-diameter hole, usually drilled with a portable, truck-mounted or pontoon-mounted drill, for planting explosive charges in seismic operations.

seismic surveying

Shot line - the straight path along which seismic shot holes are drilled and packed with explosive. When explosives detonate, the sound waves are recorded and plotted.

seismic surveying

Skimmer - a mechanical device that removes an oil film from the water surface.

Sorbent - oleophilic material used to absorb oil from water or marsh surfaces.

Species composition - the number of species in a community.

species diversity

Spoil - dirt or rock that has been removed from its original location, destroying the composition of the soil in the process, as with dredging; soil excavated from a canal, ditch, basin, or other site.

disposal, dredging, excavation, fill, soils, waste disposal, dredged material

Spoil bank - a bank, mound, or other accumulation composed of spoil, e.g., an embankment of waste earth material dredged from a channel and dumped along it.

artificial levee, disposal, dredging, excavation, fill, soils, waste disposal

Spudding - the beginning of drilling a hole, the first hole drilled to set the conductor pipe is called the spud hole.

Storm surge - an abnormal sudden rise of sea level along an open coast during a storm, caused primarily by onshore wind stresses, or less frequently by atmospheric pressure reduction, resulting in water piled up against the coast; it is most severe when accompanied by a high tide.

storms, waves, hurricanes, surges, winds, tides

Streamside levee - a ridge of alluvium at the side of a stream where suspended load carried by flooding water has been dumped.

edge effect

Submergence - a rise of the water level in relation to the land, so that areas formerly dry land become inundated; it results either from a sinking of the land or from a rise in water level.

floods, subsidence

Submersible barge platform - a type of drilling rig mounted on a barge-like vessel used in shallow coastal waters; when on location, the vessel's hull is submerged by flooding its compartments leaving the derrick and its equipment well above the water line.

drilling, oil and gas exploration, drill rig

Subsidence - the sudden sinking or gradual downward settling of the earth's surface with little or no horizontal motion; the movement is not restricted in rate, area, or magnitude involved; subsidence may be caused by natural geologic processes (compaction, solution, thawing, etc.) or by human activity (e.g., pumping of oil or groundwater).

landslide, foundation, sinkhole, land subsidence, bottom subsidence

Substrate - basic surface on which a material is attached.

base, foundation, substructure, soil

Subsurface geology - the study of the structure, thickness, facies, correlation, etc., of rock formations beneath land or seafloor surfaces.

Swamp - a low, wet area covered by trees or high bushes, as distinguished from marsh (reed-, sedge-, or grass-covered).

wetlands, backswamps, cypress

Tarballs - lumps of oil, weathered to a high density, semi-solid state.

Terrestrial - pertaining to, or living habitually on, the land or ground surface.

earth, land

Tertiary recovery - see enhanced oil recovery.

Tidal amplitude - the range of fluctuation between low and high tide, usually expressed as an average in feet above mean sea level (msl).

tidal range

Tidal creek - a relatively small stream or bayou in the marsh whose waters fluctuate with the tidal cycle.

tidal inlet, bayou, stream

Tidal flooding - the twice-daily inundation of the marsh caused by the alternate rise and fall of the surface of the ocean which is due to the gravitational attraction of the moon and sun, also called astronomical tide; inundation of the marsh surface caused by wind or other meteorological events, also called wind-driven tides or meteorological tides.

tides, astronomical tides, meteorological tides, wind-driven tides, inundation

Tidal salt marsh - a low-elevation, coastal area formed of mud and the root mat of halophytic plants, traversed by interlaced channels and tidal sloughs and regularly inundated during high tides.

wetland, marsh, brackish marsh, salt marsh, tidal flats, estuary, Spartina

Tide - the rhythmic alternate rise and fall of the surface (or water level) of the ocean, and of bodies of water connected with the ocean, such as estuaries or gulfs, occurring twice daily over most of the earth, and resulting from gravitational attraction of the moon (and in lesser degree, the sun) acting unequally on different parts of the rotating earth.

wave, current, hydrography, shores, saltwater intrustion, sea level, currents, storm surge, surge, ocean, tidal inlet, tidal marsh, tidal flat

Toxin - a poisonous substance generally of plant or animal origin.

waste, contaminant, hazardous waste, effluent, water pollution, chemical waste

Trafficability - see bearing strength.

Viscosity - flowability; a function of oil type and temperature.

Water table - the upper limit of that part of the ground which is saturated with water.

aquifers, drainage, hydrology, groundwater, water supply

Weir - a small dam in a stream designed to raise the water level or to divert its flow through a desired channel; a notch in a levee, dam, embankment, or other barrier across a stream, through which the flow of water is regulated.

water control structure, dam, impoundments, flood control

Well completion - a combination of valves attached to the production casing allowing the production of fluids from the well.

Wellhead - a combination of valves attached to the production casing allowing the production of fluids from the well.

Wetland - those areas that are inundated by surface or groundwater with a frequency sufficient to support, and under normal circumstances does or would support, a prevalence of vegetative or aquatic life that requires saturated soil conditions for growth and reproduction.

marsh, swamp, estuary, tidal marsh, coastal zone, backswamp, fen, bog

Wildcat well - a well drilled in an unproved area, far from a producing well; an exploratory well; a well drilled out where the wild cats prowl and "the hoot owls mate with the chickens."

Wooden mat - removable wooden structures used to store heavy materials in wetland areas, or to support work done by heavy equipment.

Workover - all operations used to increase well production or correct problems with the well.

REFERENCES CITED

Adkins, G. and P. Bowman. A study of the fauna in dredged canals of coastal Louisiana. New Orleans, Louisiana: Louisiana Wildlife and Fisheries Commission; 1976.

Baker, J. M. The effects of oils on plants. Environmental Pollution 1:27-44; 1970.

_____. Seasonal effects of oil pollution on salt marsh vegetation. Oikos 22:106-110; 1971.

Barrett, B. Water measurements of coastal Louisiana. Baton Rouge, Louisiana: Louisiana Wildlife and Fisheries Commission; 1970.

Bates, R. L. and J. A. Jackson, editors. Glossary of geology. Falls Church, Virginia: American Geological Institute; 1980.

Baumann, R. H. Mechanisms of maintaining marsh elevation in a subsiding environment. Baton Rouge, Louisiana: Louisiana State University; 1980. 91 p. Masters Thesis.

_____. A Louisiana energy overview. Appendix A Policy Recommendations, Governor's Commission on a Louisiana Energy Policy, 1988.

Baumann, R. H. and R. E. Turner. Direct impacts of outer continental shelf activities on wetland loss in the central Gulf of Mexico. Environmental Geology and Water Sciences. [1988]. In press.

Boesch, D. F., D. Levin, D. Nummedal, and K. Bowles. Subsidence in coastal Louisiana: causes, rates, and effects on wetlands. Washington, D.C.: U.S. Fish and Wildlife Service, Division of Biological Services, National Coastal Ecosystems Team; FWS/OBS 83-26; 1983.

Berger, W. D.and K. E. Anderson.. Gas handling and field processing plant operations training, vol. 3. Tulsa, Oklahoma: PennWell Publishing Company; 1980.

Bookhout, C. G., R. Monroe, R. Forward, and J. D. Costlow Jr. Effects of soluble fractions of drilling fluids and hexavalent chromium on the development of the crabs, *Rhithropanopeus harrisii* and *Callinectes sapidus*., project summary report to the Environmental Protection Agency. Gulf Breeze, Florida: Environmental Research Laboratory; 1982.

Bourgoyne, A. T., M. E. Chenevert, K. K. Milheim, and F. S. Young Jr. Applied drilling engineering: SPE textbook series, vol. 2. Richardson, Texas: Society of Petroleum Engineers; 1986.

Bozeman, E. L. and J. M. Dean. The abundance of estuarine larval and juvenile fish in a South Carolina creek. Estuaries 3:89-97; 1980.

Breuel, A., editor. Oil spill cleanup and protection techniques for shorelines and marshlands. Park Ridge, New Jersey: Noyes Data Corporation; 1981.

Byrne, P., M. Borengasser, G. Drew, R. Muller, B. L. Smith, Jr., and C. Wax. Barataria Basin: hydrologic and climatologic processes. Baton Rouge, Louisiana: Louisiana State University, Center for Wetland Resources, Coastal Zone Management Series; 1976.

Byroade, J. D., A. M. Twedell, and J. P. LeBoff. Handbook for oil spill protection and cleanup priorities. Prepared for the U. S. Environmental Protection Agency by Versar, Inc., Springfield, VA: EPA Contract No. 68-03-2648; 1981.

Cahoon, D. R. and J. H. Cowan, Jr. Environmental impacts and regulatory policy implications of spray disposal of dredged material in Louisiana wetlands. Coastal Management 16:341-362; 1988.

Cahoon, D. R., R. D. DeLaune, R. M. Knaus, and others. Marsh accretion, mineral sediment deposition and organic matter accumulation along man-made canals and natural waterways: summary of three dating techniques. Turner, R. E. and D. R. Cahoon, eds. Causes of wetland loss in the coastal central Gulf of Mexico, vol. II, technical narrative final report. New Orleans, Louisiana : Minerals Management Service, Contract No. 14-12-0001-30252, OCS Study/MMS 87-0120; 1987; 299-30.

Chabreck, R. H. Weirs, plugs, and artificial potholes for the management of wildlife in coastal marshes. Newsom, J. D., ed. Proceedings of the Marsh and Estuary Management Symposium. Baton Rouge, Louisiana: Division of Continuing Education, Louisiana State University; 1968; 178-192.

_____. Revegetation program for pipeline construction areas in certain Texas and Louisiana Wetlands. Final Report to Transcontinental Gas Pipe Line Corp., September 1979a, 28 pp.

_____. Winter habitat of dabbling ducks—physical, chemical and biological aspects. Bookhout, T. A., ed. Waterfowl and wetlands—an integrated review. The Wildlife Society; 1979b; 133-142.

Chabreck, R. H. and C. M. Hoffpauir. The use of weirs in coastal marsh management in Louisiana. Proceedings, Southeast Game and Fish Commission 16:103-112; 1962.

Collins, A. G. Geochemistry of oil field waters. Elsevier Scientific Publishing Company. New York; 1975.

Craig, N. J., R. E. Turner, and J. W. Day, Jr. Land loss in coastal Louisiana (U.S.A.). Environmental Management 3:133-144; 1979.

Davis, D. W. Changes in marsh environments through canalization. Time-stressed coastal environments: assessment and future action, proceedings of the second annual conference. New Orleans, Louisiana : The Coastal Society; 1976; 232-240.

Deal, T. Jet-spray, water-weeder, and water-vac: new economically superior, ecologically advantageous methods for shallow and/or narrow waterway maintenance dredging and dredged material disposal. Unpublished manuscript prepared for the Aztec Development Company; n. d.

Delaune, R. D., C. M. Reddy, and W. H. Patrick, Jr. Accumulation of plant nutrients and heavy metals through sedimentation processes and accretion in a Louisiana salt marsh. Estuaries 4:328-334; 1981.

Delaune, R. D., C. J. Smith, and W. H. Patrick, Jr. Land loss in coastal Louisiana: effect of sea level rise and marsh accretion. Final report to the Board of Regents Research and Development Program. Baton Rouge, Louisiana: Louisiana State University, Laboratory for Wetland Soils and Sediments, Center for Wetland Resources; 1986.

Detro, R. A. Impact of the marsh buggy on the wetlands. Time-stressed coastal environments: assessment and future action, proceedings of the second annual conference. New Orleans, Louisiana: The Coastal Society; 1977; 223-231.

_____. Transportation in a difficult terrain: the development of the marsh buggy. GeoScience and Man 19:93-99; 1978.

Dicks, B. and J. P. Hartley. The effects of repeated small oil spillages and chronic discharges. Philosophical Transactions, Royal Society of London B 297: 285-307; 1982.

EIA. Natural Gas Annual, 1987. Washington, DC: U.S. Dept. of Energy, Energy Information Agency, EIA-031(87-/1); October 1988.

Eiceman, G. A., B. Davani, and J. Ingram. Depth profiles for hydrocarbon and polycylic aromatic hydrocarbons in soil beneath disposal pit from natural gas production. Environmental Science and Technology 20(5):508-14; 1986.

Fisk, H. N. and E. McFarlan, Jr. Late Quarternary deltaic deposits of the Mississippi River, crust of the earth. Geological Society of America Special Papers 62: 279-302; 1955.

Flude, J. W. Exploring in marsh and water areas of Louisiana and Texas Gulf Coast. Oil and Gas Journal 34:142-144; 1936.

Foget, C., E. Schrier, M. Cramer, and R. Castle. Manual of practice for protection and cleanup of shorelines: Volume I, Decision Guide. Prepared by Woodward-Clyde Consultants, San Francisco, California: U. S. Environmental Protection Agency, EPA 600/7-79-187a; 1979a.

Foget, C., E. Schrier, M. Cramer, and R. Castle. Manual of practice for protection and cleanup of shorelines: Volume II, Implementation Guide. Prepared by Woodward-Clyde Consultants, San Francisco, California: U. S. Environmental Protection Agency, EPA 600/7-79-187b; 1979b.

Fonseca, M. S., W. J. Kenworthy, R. M. Cheap, C. A. Currin, and G. W. Thayer. A low-cost transplanting technique for shoalgrass (*Halodule wrightii*) and manatee grass (*Syringodium filiforme*), Instruction Report EL-84-1. Vicksburg, Mississippi: U.S. Army Engineer Waterways Experiment Station (WES); 1985.

Fonseca, M. S., W. J. Kenworthy, and R. C. Phillips. A cost-evaluation technique for restoration of seagrass and other plant communities. Environmental Conservation 9(3):237-241; 1982.

Franks, K. A. and P. F. Lambert. Early Louisiana and Arkansas Oil: A Photographic History, 1901-1946. College Station, Texas: Texas A & M University Press; 1982.

Frazier, D. E. Recent deltaic deposits of the Mississippi River, their development and chronology. Gulf Coast Association Geological Societies Transactions 17: 287-315; 1967.

Fredrickson, L. H. and R. D. Drobney. Habitat utilization by postbreeding waterfowl. Bookhout, T. A., ed. Waterfowl and Wetlands—An Integrated Review. The Wildlife Society; 1979; 119-131.

Gagliano, S. M., P. Culley, D. W. Earle, Jr., P. King, C. Latiolais, P. Light, A. Rowland, R. Shlemon, and J. L. Van Beek. Environmental atlas and multiuse management plan for south-central Louisiana. Baton Rouge, Louisiana: Louisiana State University, Center for Wetland Resources; Rept. No. 18, Vol. 1; 1973.

Gagliano, S. M., K. J. Meyer-Arendt, and K. M. Wicker. Land loss in the Mississippi River deltaic plain. Gulf Coast Association of Geological Societies Transactions XXXI; 1981; 295-300.

Gerding, M. Fundamentals of petroleum. Austin, Texas: Petroleum Extension Services, University of Texas; 1981.

Getter, C. D., G. Cintron, B. Dicks, R. Lewis III, and E. D. Seneca. The recovery and restoration of salt marshes and mangroves following an oil spill. Cairns, J., Jr. and Buikema, A., Jr., eds. Restoration of Habitats Impacted by Oil Spills. Boston: Butterworth Publishers; 1984; 65-113.

Gilpin, A. Dictionary of Environmental Terms. St. Lucia, Queensland: University of Queensland Press; 1976.

Gleason, M. L., D. A. Elimer, N. C. Pien, and J. S. Fisher. Effects of stem density upon sediment retention by salt marsh cord grass; *Spartina alterniflora*, Loisel. Estuaries 2:271-273; 1979.

Gosselink, J. G. The ecology of delta marshes of coastal Louisiana: a community profile. Slidell, Louisiana: U.S. Fish and Wildlife Service, Division of Biological Services, National Coastal Ecosystems Team; FWS/OBS 84-09; 1984.

Gosselink, J. G., C. L. Cordes, and J. W. Parsons. An ecological characterization study of the Chenier Plain coastal ecosystem of Louisiana and Texas, volume 1, narrative report. Slidell, Louisiana: U.S. Fish and Wildlife Sevice, Division of Biological Services, National Coastal Ecosystems Team; FWS/OBS 78-9; 1979.

Gosselink, J. G., and R. E. Turner. The role of hydrology in freshwater wetland ecosystems. Good, R. E., Whigham, D. F., and Simpson, R. L., eds. Freshwater wetlands, ecological processes and management potential. New York: Academic Press; 1978; 63-78.

Hall, D., P. Adamus, F. Dunham, J. Jacob, A. Korgi, V. Lambou, and E. Smith. Results of a workshop concerning impacts of various activities on the functions of bottomland hardwoods. Washington, DC: Office Of Federal Activities, U. S. Environmental Protection Agency, National Ecology Center, Fish And Wildlife Service, U. S. Department of Interior, Interagency Agreement No. 14-16-0009-84-1879; 1987; 59-74.

Hair, J. D. River crossing technology. Pipeline and Gas Journal 216(1):29-35; 1989.

Herbert, W. F. and H. E. Anderson. Proper design of drilling foundation offers problem to coast operators. Oil and Gas Journal 34:28,32,40,44; 1936.

Hinchman, R. R. and J. F. George. Documentation of successful reclamation of a gas pipeline right-of-way in a gulf Coast barrier island ecosystem, topical report. Chicago, Illinois: April 1980-April 1986, Gas Research Institute, Environmental and Safety Research Department; 1987.

Hinds, A. A., D. M. Donovan, J. L. Lowell, and A. Liao. Treatment reclamation and disposal options for drilling muds and cuttings. Proceedings of IADC/SPE Drilling Conference, Dallas, Texas: February 10-12. IADC/SPE Paper No. 14798; 1986; 617-21.

Holum, J. R. Topics and terms in environmental problems. New York, New York: John Wiley and Sons; 1977.

Holtz, S. Tropical seagrass restoration. Restoration and Management Notes 4(1):5-11; 1986.

Horst, J. 1982 fisheries landings. Louisiana Cooperative Extension Services 7(7): 2-7; 1983.

Howden, N., J. Henderson, R. Hill, D. Fontenot, and N. Giannico. Wetlands thesaurus, a vocabulary of coastal wetlands research. Baton Rouge, Louisiana: Louisiana State University, Center for Wetland Resources; 1983.

IPAA. Report of the IPAA Cost Study Committee. Washington, DC: Independent Petroleum Association of America, unpublished data; 1987.

Johnson, W. B., and J. G. Gosselink. Wetland loss directly associated with canal dredging in the Louisiana coastal zone. Boesch, D. F., ed. Proceedings of the conference on coastal erosion and wetland modification in Louisiana: causes, consequences, and options. Washington, D. C.: U.S. Fish and Wildlife Service, Biological Services Program; 1982: 60-72.

Johnston, J. E., III and J. D. Rives, III. Geologic review: a successful procedure for the minimization of the impact of oil and gas explortion and production on Louisiana wetlands. Magoon, O. T., Converse, H., Miner, D., Clark, D., and Tobin, L. T., eds. Proceedings of the fourth symposium on coastal and ocean management. Baltimore, Maryland: Coastal Zone '85; 1985: 2520-2529.

Kadlec, R. H. Wetlands for tertiary treatment. Greeson, P. E., Clark, J. R., and Clark, J. E., eds. Wetland functions and values: the state of our understanding. Minneapolis, Minnesota: American Water Resources Association; 1979; 490-504.

Kadlec, J. A. and W. A. Wentz. State-of-the-art survey and evaluation of marsh plant re-establishment techniques: induced and natural, Vols. 1 and 2. Vicksburg, Mississippi: U.S. Army Engineers Waterways Experiment Station, Contract Report D-74-9; 1974.

Keller, C. E., J. A. Spendelow, and R. D. Greer. Atlas of wading bird and seabird nesting colonies in coastal Louisiana, Mississippi, and Alabama. Washington, D C: U.S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-84/13; 1983.

Kennedy, J. L. Fundamentals of drilling, technology and economics. Tulsa, Oklahoma: PennWell Publishing Company; 1983.

Krone, M., W. Grip, I. A. Mendelssohn, J. Hill, and F. Monteferrante. Aerial monitoring of marsh regeneration along a single- and double ditched pipeline. Fourth Symposium on Environmental Concerns in Rights-of-Way Management, Proceedings. Indianapolis, Indiana: October 25-28, 1987.

Lamp, The. The swamp shooters. Standard Oil Company of New Jersey; 1948.

Landy, M., ed. Environmental impact statement glossary, a reference source for EIS writers, reviewers, and citizens. New York, New York: Plenum Press; 1979.

Larrick, W. D., Jr. and R. H. Chabreck. Effects of weirs on aquatic vegetation along the Louisiana coast. Proceedings Annual Conference Southeast Association Fish and Wildlife Agencies 30:581-589; 1976.

Larson, J. S. Wetland value assessment, state of the art. Gopal, B., Turner, R. E., Wetzel, R. G., and Whigham. D., eds. Wetlands: ecology and management. New Delhi, India: National Institute of Ecology and International Scientific Publications; 1982; 417-424.

Lincoln, R. J., G. A. Boxshall, and P. F. Clark. A dictionary of ecology, evolution, and systematics. New York, New York: Cambridge University Press; 1982.

Lindstedt, D. S. Effects of long term oil-recovery operations on macrobenthic communities near marsh-estuarine creek banks. Baton Rouge, Louisiana: Louisiana State University; 1978. 67 p. Thesis.

Lindstedt, D. and L. Nunn. Petroleum development in Louisiana's coastal zone. Magoon, O. T., Converse, H., Miner, D., Clark, D., and Tobin, L. T., eds. Proceedings of the fourth symposium on coastal and ocean management. Baltimore, Maryland: Coastal Zone '85; 1985:1410-1416.

Louisiana Department of Environmental Quality. Existing oil and gas production facilities, produced water discharges. Baton Rouge, Louisiana: Department of Environmental Quality, Office of Water Resources; 1987.

Louisiana Department of Natural Resources. Average length of canals by year, 1980-1985. Baton Rouge, Louisiana: Department of Natural Resources, Coastal Management Division, unpublished data; n. d.

_____. Amendment to Statewide Order 29-B. Baton Rouge, Louisiana: Department of Natural Resources, Office of Conservation. 1986.

LGS. Oil and gas maps of Louisiana. Baton Rouge, Louisiana: Louisiana Geologic Survey, Louisiana Department of Natural Resources; 1941.

_____. Oil and gas maps of Louisiana. Baton Rouge, Louisiana: Louisiana Geologic Survey, Louisiana Department of Natural Resources; 1947.

_____. Oil and gas maps of Louisiana. Baton Rouge, Louisiana: Louisiana Geologic Survey, Louisiana Department of Natural Resources; 1953.

_____. Baton Rouge, Louisiana: Louisiana Geologic Survey, Louisiana Department of Natural Resources; 1983.

Louisiana State Planning Office. Louisiana, state of the state 1978: an economic and social report to the governor. Baton Rouge, Louisiana: Office of the Governor; 1979.

_____. Louisiana trends. Baton Rouge, Louisiana: Office of the Governor, 1983.

Maiero, D. J., R. W. Castle, and O. L. Crain. Protection, cleanup and restoration of salt marshes endangered by oil spills—a procedural manual. Prepared by URS Company, San Mateo, California: U. S. Environmental Protection Agency, EPA 600/7-78-220; 1978.

Maruggi, V. and S. D. Hartl. Statistical abstract of Louisiana. New Orleans, Louisiana: University of New Orleans, Division of Business and Economic Research, and the Louisiana State Planning Office; 1981.

Matthews, D. Checking up on Louisiana's wetlands. Exxon USA 22:12-15, 1983.

May, N. L., Jr. The effects of oil-recovery operations on the biology and ecology of killifishes in a Louisiana salt marsh. Baton Rouge, Louisiana: Louisiana State University; 1977. 80 p. Thesis.

McGhee, E., and C. Hoot. Mighty dredgers, little known work horses of coastal drilling, producing, pipelining, now 25 years old. Oil and Gas Journal 4: 150-153; 1963.

McGinnis, J. T., R. A. Ewing, C. A. Willingham, S. E. Rogers, D. H. Douglass, and D. L. Morrison. Environmental aspects of gas pipeline operations in the Louisiana coastal marshes, final report to the offshore pipeline committee. Columbus, Ohio: Battelle Laboratories; 1972.

Mendelssohn, I. A., K. L. McKee, and W. H. Patrick, Jr. Oxygen deficiency in *Spartina alterniflora* roots: metabolic adaptation to anoxia. Science 214: 439-441; 1981.

Mendelssohn, I.A. and M. W. Hester. Texaco USA coastal vegetation project, Timbalier Island, final report. Prepared for Texaco USA, New Orleans Operations Division. Baton Rouge, Louisiana: Laboratory for Wetland Soils and Sediments, Center for Wetland Resources, Louisiana State University, May 1988.

Meo, M., J. W. Day, Jr., and T. B. Ford. Overland flow in the Louisiana coastal zone, the potential for land treatment of wastewater on diked dredge spoil disposal sites in south Louisiana. Baton Rouge, Louisiana: Louisiana State University, Center for Wetland Resources; 1975.

Meyer, J., Jr. The story of the Gulf Coast. New York, New York: J. Meyer, Jr. and Co., Inc.; 1934.

Mitsch, W. J., and J. G. Gosselink. Wetlands. New York: Van Nostrand Reinhold Company; 1986.

MMS. Final regional environmental impact statement, Gulf of Mexico. New Orleans, Louisiana: Minerals Management Service, Department of the Interior, Gulf of Mexico OCS Region; 1983.

Monte, J. A. The impact of petroleum dredging on Louisiana's coastal landscape: a plant biogeographical analysis and resource assessment of spoil bank habitats in the Bayou Lafourche area. Baton Rouge, Louisiana: Louisiana State University; 1978. 253 p. Thesis.

Moseley, H. R, Jr. Summary of API onshore drilling mud and produced water environmental studies. Proceedings of IADC/SPE Drilling Conference, New Orleans, Louisiana: IADC/SPE Paper No. 11398: 321-25; 1983.

National Research Council. Panel on Assessment of Fates and Effects of Drilling Fluids and Cuttings in the Marine Environment. Drilling discharges in the marine environment. Washington, DC: National Research Council, National Academy Press; 1983.

_____. Oil in the sea: inputs, fates, and effects. Washington, D C: National Academy Press; 1985.

Neidhardt, D. Rig-site system allows water reuse, cuts clean-up costs. Oil and Gas Journal. 83(9):88-90,92,94; 1985.

Neill, C. and R. E. Turner. Comparisons of fish communities in open and plugged backfilled canals in Louisiana coastal marshes. North American Journal of Fish Management 7:57-62; 1987a.

Neill, C. and R. E. Turner. Backfilling canals to mitigate wetland dredging in Louisiana coastal marshes. Environmental Management 11(6):823-836;1987b.

Nichols, L. G. Technical report of the Louisiana Wildlife and Fisheries Commission, Rockefeller Refuge levee study. New Orleans, Louisiana: Louisiana Wildlife and Fisheries Commission, Refuge Division; 1959.

Odegard, G. J., J. F. George, J. A. Sproul, and T. M. Sawyer. Vegetation recovery of a pipeline right-of-way on a Texas coastal barrier island. Proceedings Third Symposium on Environmental Concerns in Rights-of-Way Management, Feb. 15-18, 1982. San Diego, California; 1984.

Odum, E. P. The value of wetlands: a hierarchical approach. Greeson, P. E., Clark, J. R., and Clark, J. E., eds. Wetland functions and values: the state of our understanding. Minneapolis, Minnesota: American Water Resources Association; 1978: 16-25.

Okey, C. W. The subsidence of muck and peat soils in southern Louisiana and Florida. Transactions, American Society of Civil Engineers 82:396-422; 1918.

Osterman, M. C., A. K. Wojtanowicz, and S. D. Field. The development study of a centrifuging technique for oilfield production pit closure. Journal of Energy Resources Technology. 109:191-199; 1987.

Penland, S., K. E. Ramsey, R. A. McBride, J. T. Mestayer, and K. A. Westphal. Relative sea level rise, delta plain development, subsidence, and wetland sedimentation in the Teche and Lafourche delta complexes: Terrebonne Parish, Louisiana. Baton Rouge, Louisiana: Louisiana Geological Survey, Coastal Geological Series Publication No. 1; 1986.

Perry, G. W. Standing crops of fishes of an estuarine area in southwest Louisiana. Proceedings, 30th Annual Southeastern Fish and Wildlife Agencies 1976:(30)71-81; 1976.

Petroleum Extension Service. Fundamentals of petroleum. Austin, Texas: The University of Texas; 1981.

Posgate, J. C. History and development of swamp and marsh drilling operations. Oil and Gas Journal 47: 87; 1949.

Reimold, R. J., J. H. Phillips, and M. A. Hardisky. Sociocultural values of wetlands. Kennedy, V.S., ed. Estuarine perspectives. London: Academic Press; 1980: 79-89.

Samuel, R. Doodle bugs that fly. Times Picayune Magazine. 1949 May 15.

Sasser, C. E. Distribution of vegetation in Louisiana coastal marshes as a response to tidal flooding. Baton Rouge, Louisiana: Louisiana State University; 1977. 46 p. Thesis.

Sather, J. H. and R. D. Smith. An overview of major wetland functions and values. Fort Collins, Colorado: U.S. Department of the Interior, Fish and Wildlife Service; 1984.

Scaife, W. W., R. E. Turner, and R. Constanza. Coastal Louisiana recent land loss and canal impacts. Environmental Management 7(5): 433-442; 1983.

Schulze, R. ed. World catalog of oil spill response products. 1985.

Sikora, W. B. Air cushion vehicles for the transport of drilling rigs, supplies, and oil field exploration operations in the coastal marshes of Louisiana. Baton Rouge, Louisiana: Center for Wetland Resources, Louisiana State University, December 1988.

Sikora, W. B., J. P. Sikora, and R. E. Turner. Marsh buggies, erosion and the air-cushioned alternative. Varnell, R. J., ed. Water quality and wetland management conference proceedings. New Orleans, Louisiana: Coastal Ecology and Fisheries Institute; 1983; 323-336.

Skinner, D.R. Introduction to petroleum production reservoir engineering, drilling, well completions, vol. 1. Houston, Texas: Gulf Publishing Company; 1981.

Slitor, D. L. and J. D. Wise. Gulf of Mexico update: July 1986-April 1988. Outer Continental Shelf Oil and Gas Activities. New Orleans, Louisiana: U.S. Dept. of the Interior, Minerals Management Service, OCS Information Program, MMS 88-0038, 1988.

State Times. Marsh buggy-helicopter make team hard to beat for oil explorations. 1953,April 2.

Steever, E. Z., R. S. Warren, and W. A. Niering. Tidal energy subsidy and standing crop production of *Spartina alterniflora*.. Estuarine and Coastal Marine Science 4: 473-478; 1976.

Suhayda, J.N. Subsidence and sea level. Turner, R. E. and D. R. Cahoon, eds. Causes of wetland loss in the coastal central Gulf of Mexico, vol. II, technical narrative final report. New Orleans, Louisiana : Minerals Management Service, Contract No. 14-12-0001-30252, OCS Study/MMS 87-0120; 1987;187-202.

Swenson, E. M. and R. E. Turner. Spoil banks: effects on a coastal marsh water level regime. Estuarine, Coastal, and Shelf Science 24:599-605; 1987.

Taylor, D. M. River crossing construction methods. Pipeline Engineer, Oil and Gas Pipeline Series; 1957; 50-57.

Taylor, W. E. Restoration of oil well drilling sites. Bozeman, Montana: presented at the 1983 Summer Meeting American Society of Agriculture Engineers, Montana State University, June 26-29. ASAE Paper No. 83-2143; 1983.

True, W. R. Pipeline economics report. Oil and Gas Journal 85(47):33-64; 1987.

_____. Pipelines following exploration in deeper Gulf of Mexico. Oil and Gas Journal 86(27):27-30, 32; 1988.

Turner, R. E., R. Costanza, and W. Scaife. Canals and wetland erosion rates in coastal Louisiana. Boesch, D. F., ed. Proceedings of the conference on coastal erosion and wetland modifications in Louisiana; causes, consequences, and options. Washington, DC: U.S. Fish and Wildlife Service, Office of Biological Services; FWS/OBS 82-59; 1981.

Turner, R. E. Coastal land loss, canals, and canal levee relations in Louisiana. Slidell, Louisiana: U.S. Fish and Wildlife Service; 1985.

_____. Intertidal vegetation and commercial yields of Penaeid shrimp. Transactions of the American Fisheries Society 106(5): 411-415; 1977.

Turner, R. E. and D. R. Cahoon. Causes of wetland loss in the coastal central Gulf of Mexico, vol. II, technical narrative final report. New Orleans, Louisiana : Minerals Management Service, Contract No. 14-12-0001-30252, OCS Study/MMS 87-0120; 1987.

Turner, R. E., I. A. Mendelssohn, K. L. McKee, R. Costanza, C. Neill, J. P. Sikora, W. B. Sikora, and E. Swenson. Backfilling canals in coastal Louisiana. Proceedings, National Wetlands Symposium: Mitigation of Impacts and Losses. New Orleans, Louisiana: Association of State Wetland Managers, Inc. [1986]. In press.

Turner, R. E., K. L. McKee, W. B. Sikora, J. P. Sikora, I. A. Mendelssohn, E. Swenson, E. Neill, S. G. Leibowitz, and F. R. Pedrazzini. The impact and mitigation of manmade canals in coastal Louisiana. Water Science Technology 16: 497-504; 1983.

Turner, R. E. and C. Neill. Revisiting impounded wetlands after 70 years. Varnell, R. J., ed. Water quality and wetland management conference proceedings, August 4-5, 1983. New Orleans, Louisiana: 1984; 309-321.

University of Texas, Austin and Pipe Line Contractors Assoc. A primer of pipeline construction, 2nd edition, seventh impression. Austin, TX: Petroleum Extension Service, 1980.

U. S. Environmental Protection Agency. Guidelines for specification of disposal sites for dredged or fill material. Washinton, DC: Federal Register 45(249):85345; 1980.

_____. Region 6 oil and hazardous substances pollution contingency plan. Dallas, Texas: Region VI; 1986.

_____. Combined Federal Regulations, Part 122, Appendix D. Washington D.C: U.S. Printing Office; 1987a; 105-09.

_____. Interior report: wastes from the exploration, development and production of crude oil, natural gas and geothermal energy. Washington, DC: U. S. Environmental Protection Agency, Office of Solid Waste; 1987b.

U. S. Fish and Wildlife Service. Ecological implications of geopressured-thermal energy development, Texas-Louisiana Region. Washington, DC: FWS/OBS-78/60; 1978.

Vandermeulen, J. H. Some conclusions regarding long-term biological effects of some major oil spills. Philosophical Transactions, Royal Society of London B 297: 335-351; 1982.

Van Poollen, H.K. and Associates, Inc. Enhanced oil recovery. Tulsa, Oklahoma: PennWell Publishing Company; 1980.

Vinzant, L. J. Road dump access to oil/gas drilling locations as an alternative to canal dredging. Presented at National Wetland Symposium: Mitigation of Impacts and Losses. New Orleans, Louisiana: Society for Wetland Managers; October 1986.

Weinstein, M. P. Shallow marsh habitats as primary nurseries for fish and shellfish, Cape Fear River, North Carolina. Fisheries Bulletin 77:339-357; 1979.

Whitehurst, C. A. and W. A. Blanchard. The use of color infrared imagery for the study of marsh buggy tracks. Photogrammetric Engineering and Remote Sensing 42(8):1049-1050; 1977.

Wicker, K. M. Mississippi deltaic plain region ecological characterization: a habitat mapping study. A user's guide to the habitat maps. Washington, D. C.: U.S. Fish and Wildlife Service, Office of Biological Services; FWS/OBS 79-07; 1980.

Wicker, K. M., G. C. Castille, D. J. Davis, S. M. Gagliano, D. W. Roberts, D. S. Sabin, and R. A. Weinstein. St. Bernard parish: a study in wetland management. Baton Rouge, Louisiana: Coastal Environments, Inc.; 1982.

Wiegert, R. G., L. R. Pomeroy, and W. J. Wiebe. Ecology of salt marshes: an introduction. Pomeroy, L. R., and Wiegert, R. G., eds. The ecology of a salt marsh, ecological studies 38. New York: Springer-Verlag; 1981; 3-18.

Williams, N. Drilling for oil in a world to itself. Oil and Gas Journal 28:40-41; 1929.

_____. Gulf Coast transportation problems. Oil and Gas Journal 28:41,139; 1930.

_____. Sweet Lake field in Coastal Louisiana is good example of maritime drilling operations. Oil and Gas Journal 32:15-16; 1934a.

_____. Derrick on specially built barge is the solution of drilling on Louisiana water locations. Oil and Gas Journal 32:40,61; 1934b.

_____. Practicability of drilling unit on barges definitely established in Lake Barre, Louisiana tests. Oil and Gas Journal 33:14-18; 1934c.

_____. Dredging canals for servicing fields in marsh and swamp districts of Louisiana. Oil and Gas Journal 43:95-96; 1944.

INDEX

A

access canals
  dredging of, 25, 26, 29
aerobic, 1, 4
aggradation
  deficit in Louisiana, 9
anaerobic
  conditions, 4
  environment, 4
  processes, 1, 9
  root respiration, 4
  soils, 6
  substrate, 10
aquifer, 6, 9

B

barge-mounted dragline
  dredging access canals, 25
blowout, 65, 66
bucket dredge, 25, 26
  dredging access canals, 25
  loss of wetlands, 8
bulkheads (see dams)

C

canal slip *(see keyhole)*
Clean Water Act, 11, 35, 73 *(see wetland management objectives)*
  Section 404, 23, 35
Coastal Zone Management Act, 35, 73
compaction, 8
consolidation, 8
construction
  backfilling, 92
  double ditching, 94
  environmental impacts, 97, 99
  push-pull method, 88, 99
containerized (closed-loop) mud system, 71

D

dams, 96
delta
  cycle, 8
  lobe
    development, 2
    growth and abandonment, 2, 9
denitrification, 10
dewatering, 30, 40
directional drilling, 35, 36, 37
dredging
  access canal equipment *(see submersible barge platform, barge-mounted dragline, bucket dredge, clamshell bucket)*
drill cuttings, 65
drilling mud, 65, 66
  chemical additives, 66, 69
drilling site access *(see board roads, submersible barge platform)*

E

earthen dam *(see plug)*
ebb tide, 3
edge effect
  relation to hydrology, 6
emergent vegetation, 1, 4, 40
enhanced recovery, 78, 79
eutrophication, 32

enhanced recovery, 78, 79
eutrophication, 32

F

flowline, 76, 83

G

Geologic Review Procedure, 67, 73, 83

H

heater treater, 76
helicopter, 33, 44, 55
herbivory, 1
hovercraft, 21, 33, 55
hydrocarbon production, 76

I

impacts of canal construction, 97, 98
  acute, 34
  chronic, 34, 37
inorganic matter, 3

J

Jet-Spray, 39, 40, 41

K

keyhole, 27, 28, 31, 35, 36, 37
keyway, 29

L

land-water interface, 8

M

marsh buggy, 14, 15, 21, 22
mineral soil, 2
  deposition, 4
Mississippi River Deltaic Plain, 2
mud circulating system, 66

N

National Environmental Policy Act, 35
natural gas, 77, 88
  hydrates, 77
  dehydration, 77
nutrient cycling
  effect of hydrology on, 7
  source-sink nature of, 7
noise
    bird breeding and nesting activities, 66, 69, 71

O

organic matter
  accumulation
    effect on land building/sinking, 8
    effect of oil and gas activity on, 9
  content in upper portion of soils, 25
  flux, 8
    influence of hydrology on, 7
  production
    effect on marsh surface, 7

P

parallel slip, 29, 37
peat
  buildup
    effect on flooding regime, 7
    influence of levees on, 9
  formation, 4
petroleum
  access canals
    dredging, 25
  exploration
    drilling sites, 25
pipeline corridors, 100
pits, 65, 66, 67, 69, 70, 71, 75
  reserve pit, 66, 67, 70
plug, 122, 123, 124, 125, 126
primary production
  influence of hydrology on, 4, 6, 7
  terrestrial process, 1
production facility, 77, 81, 84, 85
  tank battery, 81
progradation
  deltaic plain, 8
prop-washing, 39

R

redox
  changes
    in streamside marsh, 6
  state, 32
regulations
  Clean Water Act, 11, 35, 73
  Coastal Zone Management Act, 35, 73
  Louisiana Statewide Order 29-B, 73, 81

remineralization, 7
reservoir
  gas cap, 76
  solution, 76
  water, 76
restoration
  beach crossings, 95
  plantings, 95, 100, 101
  seagrass beds, 95, 101
ring levee 49, 50, 51, 57, 60, 61, 62, 63, 130
Rivers and Harbors Act of 1898, 23
road dump, 47, 48, 49, 50, 51, 52
rotary drilling, 65, 66
runoff, 69

S

salt water
  discharge, 81
  underground injection, 77, 81
saltwater intrusion, 37
  effect of lowering water table on, 9
  deterioration of Louisiana's salt marshes, 33
sea level rise
  eustatic, 8, 9
  isostatic, 8, 9
  relative, 8, 9
Section 404, 23, 35 *(see* wetland *management objectives)*
  regulations, 3-9
sedimentation
  process, 8
seismic exploration, 13, 14, 15, 16, 17
separator
  separation, 75, 76
shale barge, 66
shale shaker, 66

sheet flow, 30, 36
Spartina alterniflora
in marshes, 6
species composition
influence of hydrology on, 7
influence of substrate on , 6
spills, 104
sources, 104
substances, 104
Spindletop, 66
spoil
bank
alteration of marsh habitat, 29, 30
backfilling, 118, 119, 120, 121, 122, 123
influence on hydrology, 32
disposal techniques, 37, 38, 39, 40
stimulation technique
acid fracture, 76, 82, 83
shooting a well, 76
water/sand fracture, 76
stock tanks, 75, 76
storage/discharge of drill cuttings
environmental effects, 81, 83
fluids, 66, 69, 70
produced waters, 76, 77
submergence
coastal, 8, 9, 32
submersible barge platform
dredging access canals, 26
subsidence, 8, 9, 10
fluid withdrawal, 82
system coupling, 3, 4, 7
extra-basin, 4
intercontinental, 4
intra-basin, 4

T

tidal
amplitude
correlation with plant productivity, 7
creek, 1, 3, 6
flooding, 32
inundation
effect of levees on, 9
salt marsh
structure and function, 1
subsidy effect, 6
turbidity screen, 39

V

vertical accretion
effect of oil and gas activities on, 9
influence of hydrology on, 4, 7
land building/sinking, 8
rates in Louisiana's coastal marshes, 9

W

weir, 30, 37
wellbore, 35
wetland loss, 1-8
characteristics *(see anaerobic environment, emergent vegetation)*
link with canal construction, 25
wetland management
objectives, 11 (see *Clean Water Act, Section 404)*
priorities, 11
wheel-washing *(see prop-washing)*