United States
Environmental Protection
Agency

Environmental Monitoring
Systems Laboratory
P.O. Box 93478
Las Vegas NV 89193-3478

EPA 600/4-90/012
April 1990
Pre-Issue Copy

Research and Development

EPA

# Proximity of Sanitary Landfills to Wetlands and Deepwater Habitats

## An Evaluation and Comparison of 1,153 Sanitary Landfills in 11 states

EPA 600/4-90/012
April 1990

# PROXIMITY OF SANITARY LANDFILLS TO WETLANDS AND DEEPWATER HABITATS

## An Evaluation and Comparison of 1,153 Sanitary Landfills in 11 States

by

Victor W. Lambou
Environmental Monitoring Systems Laboratory
U.S. Environmental Protection Agency
Las Vegas, Nevada 89193-3478

J. Michael Kuperberg, John E. Moerlins, Roy C. Herndon
Center for Biomedical and Toxicological Research and
Hazardous Waste Management
Florida State University
Tallahassee, Florida 32306-4016

and

Robin L. Gebhard
National Wetlands Inventory
U.S. Fish and Wildlife Service
St. Petersburg, Florida 33702

ENVIRONMENTAL MONITORING SYSTEMS LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
LAS VEGAS, NEVADA 89193-3478

## NOTICE

The information in this document has been funded wholly or in part by the U.S. Environmental Protection Agency under Grant No. CR-815138 to the Florida State University. It has been subject to the Agency's peer and administrative review and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

## ABSTRACT

Sanitary landfills can cause considerable harm to sensitive ecosystems if they are not properly located, designed, and managed. The purpose of this report is to evaluate and compare the proximity of 1,153 sanitary landfills in 11 states (Connecticut, Delaware, Florida, Georgia, Louisiana, New Jersey, New York, North Carolina, Pennsylvania, Texas, and Washington) to wetlands and deepwater habitats (i.e., rivers, lakes, streams, bays, etc.). The facilities were identified on U.S. Fish and Wildlife Service's National Wetlands Inventory maps. The nearness or proximity of the sanitary landfills to wetlands and deepwater habitats was determined by drawing three concentric regions around the point representing the location of each landfill. The radii of the concentric regions were: 1/4 mile, 1/2 mile, and 1 mile. Almost all of the sanitary landfills are located in or are close to either wetlands or deepwater habitats. Almost all are close to wetlands while approximately half are close to deepwater habitats. The hydrology of wet environments and possible movement of contaminants from waste-disposal sites located in these environments are discussed. Sanitary landfills have the potential to adversely affect sensitive ecosystems, such as wetlands and deepwater habitats, either through habitat alterations or through the migration of contaminants. Because of this, facilities located in or close to wetlands and/or deepwater habitats need to be properly designed and monitored.

CONTENTS

Abstract.....iii
Figures..... v
Tables..... xi

Introduction..... 1
Conclusions..... 1
Recommendation..... 2
Materials and Methods..... 2
Results..... 6
All States..... 6
Wetlands..... 6
Deepwater Habitats..... 7
Wetlands or Deepwater Habitats..... 7
Differences Among States and Regions..... 8
All Systems..... 8
Wetlands..... 8
Deepwater Habitats..... 9
Wetlands or Deepwater Habitats..... 9
Palustrine System..... 10
Riverine System..... 11
Wetlands..... 11
Deepwater Habitats..... 11
Wetlands or Deepwater Habitats..... 12
Lacustrine System..... 12
Wetlands..... 12
Deepwater Habitats..... 13
Wetlands or Deepwater Habitats..... 13
Estuarine System..... 13
Wetlands..... 13
Deepwater Habitats..... 14
Wetlands or Deepwater Habitats..... 14
Marine System..... 15
Discussion..... 15

Literature Cited..... 22

## FIGURES


Number Page

1 Hypothetical sanitary landfill showing the concentric regions used to determine the nearness or proximity to wetlands and deepwater habitats and the boundary of an 100-acre sanitary landfill..... 26

2 Four regions of Texas delineated for this report..... 27

3 Proximity of 1,153 sanitary landfills in 11 states to wetlands..... 28

4 Distance of 1,153 sanitary landfills in 11 states to closest wetland..... 28

5 Proximity of 1,153 sanitary landfills in 11 states to deepwater habitats..... 29

6 Distance of 1,153 sanitary landfills in 11 states to closest deepwater habitat..... 29

7 Proximity of 1,153 sanitary landfills in 11 states to either wetlands or deepwater habitats..... 30

8 Distance of 1,153 sanitary landfills in 11 states to either the closest wetland or deepwater habitat.. 30

9 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of wetlands by state or region..... 31

10 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of wetlands by state or region..... 31

11 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of wetlands by state or region..... 32

12 Distance of 1,153 sanitary landfills in 11 states to the closest wetland by state or region..... 32

FIGURES (continued)

Number Page

13 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of deepwater habitats by state or region..... 33

14 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of deepwater habitats by state or region..... 33

15 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of deepwater habitats by state or region..... 34

16 Distance of 1,153 sanitary landfills in 11 states to the closest deepwater habitat by state or region..... 34

17 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of either wetlands or deepwater habitats by state or region..... 35

18 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of either wetlands or deepwater habitats by state or region..... 35

19 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of either wetlands or deepwater habitats by state or region... 36

20 Distance of 1,153 sanitary landfills in 11 states to the closest wetland or deepwater habitat by state or region..... 36

21 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of Palustrine wetlands by state or region..... 37

22 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of Palustrine wetlands by state or region..... 37

FIGURES (continued)

Number Page

23 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of Palustrine wetlands by state or region..... 38

24 Distance of 1,153 sanitary landfills in 11 states to the closest Palustrine wetland by state or region ..... 38

25 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of Riverine wetlands by state or region..... 39

26 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of Riverine wetlands by state or region..... 39

27 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of Riverine wetlands by state or region..... 40

28 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of Riverine deepwater habitats by state or region..... 40

29 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of Riverine deepwater habitats by state or region..... 41

30 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of Riverine deepwater habitats by state or region..... 41

31 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of either Riverine wetlands or deepwater habitats by state or region..... 42

32 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of either Riverine wetlands or deepwater habitats by state or region..... 42

FIGURES (continued)

Number Page

33 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of either Riverine wetlands or deepwater habitats by state or region..... 43

34 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of Lacustrine wetlands by state or region..... 43

35 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of Lacustrine wetlands by state or region..... 44

36 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of Lacustrine wetlands by state or region..... 44

37 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of Lacustrine deepwater habitats by state or region.... 45

38 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of Lacustrine deepwater habitats by state or region.... 45

39 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of Lacustrine deepwater habitats by state or region.... 46

40 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of either Lacustrine wetlands or deepwater habitats by state or region..... 46

41 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of either Lacustrine wetlands or deepwater habitats by state or region..... 47

42 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of either Lacustrine wetlands or deepwater habitats by state or region..... 47

FIGURES (continued)

Number Page

43 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of Estuarine wetlands by state or region..... 48

44 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of Estuarine wetlands by state or region..... 48

45 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of Estuarine wetlands by state or region..... 49

46 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of Estuarine deepwater habitats by state or region..... 49

47 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of Estuarine deepwater habitats by state or region..... 50

48 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of Estuarine deepwater habitats by state or region..... 50

49 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of either Estuarine wetlands or deepwater habitats by state or region..... 51

50 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of either Estuarine wetlands or deepwater habitats by state or region..... 51

51 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of either Estuarine wetlands or deepwater habitats by state or region..... 52

52 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of Marine wetlands by state or region..... 52

FIGURES (continued)

Number Page

53 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of Marine wetlands by state or region..... 53

54 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of Marine wetlands by state or region..... 53

55 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of Marine deepwater habitats by state or region..... 54

56 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of Marine deepwater habitats by state or region..... 54

57 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of Marine deepwater habitats by state or region..... 55

58 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of either Marine wetlands or deepwater habitats by state or region..... 55

59 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of either Marine wetlands or deepwater habitats by state or region..... 56

60 Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of either Marine wetlands or deepwater habitats by state or region..... 56

## TABLES

Number Page

1 Definition of wetlands used by the U.S. Fish and Wildlife Service from Cowardin et al. (1979)..... 57

2 Definition of deepwater habitats used by the U.S. Fish and Wildlife Service from Cowardin et al. (1979)..... 59

3 Definition of the five major systems (Marine, Estuarine, Riverine, Lacustrine, and Palustrine) used by the U.S. Fish and Wildlife Service from Cowardin et al. (1979)..... 60

4 Number of sanitary landfills by state, number with NWI maps available, and number classified as to their proximity to wetlands and deepwater habitats.. 65

5 Distance of 1,153 sanitary landfills in 11 states to the closest wetland or deepwater habitat by state..... 66

## INTRODUCTION

Sanitary landfills, as typically defined, are waste-management facilities regulated under Subtitle D of the Resource Conservation and Recovery Act (RCRA). These facilities are commonly referred to as municipal waste landfills and they are primarily used to receive household refuse and nonhazardous commercial waste. However, sanitary landfills also receive other types of Subtitle D waste, such as sewage sludge and industrial wastes. Sanitary landfills typically receive some hazardous waste in the form of household hazardous waste, and hazardous waste from small-quantity generators as defined in 40 CFR Part 261.10 (Definitions). Depending upon the definition of a sanitary landfill used by the individual states, there are between 6,500 and 9,300 of these facilities permitted in the United States (U.S. EPA, 1987).

Sanitary landfills can cause considerable harm to sensitive ecosystems if they are not properly located, designed, and managed. These facilities have the potential to adversely affect sensitive ecosystems, such as wetlands and deepwater habitats, either through habitat alterations or through the migration of contaminants. In order to evaluate the seriousness of this problem, information is needed on the nearness of sanitary landfills to wetlands and surface water bodies. The purpose of this study is to evaluate and compare the proximity of sanitary landfills in 11 states (Connecticut, Delaware, Florida, Georgia, Louisiana, New Jersey, New York, North Carolina, Pennsylvania, Texas, and Washington) to wetlands and deepwater habitats (i.e., rivers, lakes, streams, bays, etc.).

## CONCLUSIONS

1. Almost all sanitary landfills in the study area are located in or are close to either wetlands or deepwater habitats. Almost all are close to wetlands while approximately half are close to deepwater habitats. Almost all facilities in the study area are close to Palustrine wetlands.

2. There are some differences among the states and regions in the study area in the relative proximity of the sanitary landfills to wetlands and deepwater habitats. However, in all states, the vast majority of the facilities are located close to wetlands.

3. There is a propensity for sanitary landfills to be located close to wetlands.

4. A major consideration for determining adverse impacts associated with landfills is whether or not the facility site is hydrologically interconnected, either by surface or subsurface flows, with wetlands, deepwater habitats, and/or habitats with water tables close to the surface. If hydrologically interconnected, contaminants can easily migrate off-site and affect these environments.

5. There are special problems associated with the siting, design, operation, and monitoring of waste-disposal sites located either in or close to wetlands or deepwater habitats.

6. Sanitary landfills have the potential to adversely affect sensitive ecosystems, such as wetlands and deepwater habitats, either through habitat alterations or through the migration of contaminants.

7. Sanitary landfills located in or close to wetlands and/or deepwater habitats need to be properly designed and monitored.

## RECOMMENDATION

It is recommended that special monitoring and design requirements be developed for waste disposal sites located either in or close to wetlands and/or deepwater habitats.

## MATERIALS AND METHODS

The source of data used to determine the locations of the sanitary landfills was the computer data file developed by Development Planning and Research Associates, Inc. (DPRA) for use by the U.S. Environmental Protection Agency's Office of Solid Waste in its RCRA Subtitle D program (DPRA, 1986). The DPRA data file includes information on 7,683 sanitary landfills, and 6,849 of these facilities have latitude and longitude coordinates in degrees, minutes, and seconds specified in the data file. Each set of coordinates defines a point which represents the geographic location of a

sanitary landfill (Figure 1). In addition, the data file contains the names of the landfills and data on the cities and counties in which the landfills reside. Individual states are responsible for permitting sanitary landfills under Subtitle D of RCRA and, since DPRA obtained the information for the data file from state sources, the site location information varies in terms of accuracy and the point chosen to represent the location of each facility.

Four types of errors or omissions were identified in the DPRA data file. These errors and omissions include: missing latitude and longitude, missing state code, wrong state code, and erroneous latitude/longitude. The first two items relate to data that were omitted in the facility record. Facilities that did not have latitude and longitude coordinates were not used in this study while facilities that did not have a state code were assigned an appropriate state code by comparing the latitude and longitude coordinates for the facilities with maps of the various states. The last two items relate to errors in the data file. Facilities with the wrong state code were corrected and included in the study. The last item relates to erroneous latitude and/or longitude records. Where discovered, the erroneous coordinate(s) were corrected, if possible. Errors may still exist in the DPRA data file; however, it is believed that the overall results and conclusions contained in this report will not be significantly affected, since the number of errors is probably small.

Wetlands typically form part of a continuous transition zone between uplands and open water. Therefore, the delineation of the upper and lower boundaries in any wetland definition is somewhat arbitrary. There are a number of definitions of wetlands that have been developed for use in classifying natural environments or for regulatory purposes. While these definitions are not identical, they are very similar. The selection of a specific definition for use in this study was determined by the availability of national wetlands and deepwater habitats geographic data.

The most extensive, consistent source of wetlands and deepwater habitats geographic data is the U.S. Fish and Wildlife Service's National Wetlands Inventory (NWI). The NWI has developed detailed, large-scale maps for a significant portion of the United States. To date, wetland maps have been developed for approximately 40 percent of the contiguous 48 states, 10 percent of Alaska, and all of Hawaii. Large-scale NWI maps typically are either 1:24,000 scale or 1:63,360 scale U.S. Geological Survey quadrangle maps; however, most are 1:24,000 scale. Wetlands and deepwater habitats are delineated on the NWI maps. The

delineation of wetlands and deepwater habitats was developed using remote sensing techniques and field investigations. The NWI maps are developed in accordance with the National Map Accuracy Standard (NMAS) (U.S. GS, 1979). The NWI 1:24,000 scale maps used in this study are accurate, according to the NMAS, to within 40 feet of ground measurements. These maps are particularly useful for plotting the location of sanitary landfills and for determining the proximity of these facilities to wetlands and deepwater habitats.

The NWI maps use the definitions (contained in Tables 1 and 2) and the classification system (contained in Table 3) for wetlands and deepwater habitats developed by the U.S. Fish and Wildlife Service (Cowardin et al., 1979). Wetlands are defined as lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is covered by shallow water. Deepwater habitats are defined as permanently flooded lands lying below the deepwater boundary of wetlands. For more expansive definitions and an explanation of the definitions, as well as the boundary limits, see Tables 1 and 2; for further details see Cowardin et al. (1979). The U.S. Fish and Wildlife Service's classification of wetlands and deepwater habitats is hierarchical in nature proceeding from general to specific (Cowardin et al., 1979). There are 5 systems, 10 subsystems, and 55 classes. In this study only the "system", i.e, the complex of wetlands and deepwater habitats that share the influence of similar hydrologic, geomorphologic, chemical, or biological factors, was used for classification purposes. The definitions, as well as the boundary limits of the five systems, i.e., Marine, Estuarine, Riverine, Lacustrine, and Palustrine, are given in Table 3; for further details see Cowardin et al. (1979). The first four systems, i.e., Marine, Estuarine, Riverine, and Lacustrine, include both wetlands and deepwater habitats whereas the Palustrine System includes only wetlands.

In order to link the location of sanitary landfills in the DPRA data file to the appropriate NWI maps, we used the information on the T-70 computer tape obtained from the U.S. Geological Survey (National Cartographic Information Center, 1987). The NWI large-scale maps were developed using U.S. Geological Survey's quadrangle maps as base maps. The T-70 computer tape contains 67 fields of information including latitude and longitude that can be used for identifying the 1:24,000 scale maps, the map names, and the state codes assigned to the maps. Sanitary landfill location data on the DPRA computer file tape were matched by a computer program against location data on the U.S. Geological Survey T-70 computer tape in order to identify the specific maps that contain sanitary landfills and/or that would be needed

to evaluate the wetlands and deepwater habitats that are within 1 mile of each sanitary landfill. Sanitary landfills that were located on the edge or in the corner of a map required more than one map (i.e., two to four maps) to complete the interpretation. The map names obtained from the computer matching were sorted by state and compared with inventories of available NWI maps.

Each sanitary landfill included in this study was located on NWI large-scale maps using standard cartographic techniques. Nearness or proximity of sanitary landfills to wetlands and deepwater habitats was determined by drawing three concentric regions around the point representing the location of each landfill. The radii of the concentric regions were: 1/4 mile, 1/2 mile, and 1 mile (Figure 1). The occurrence or nonoccurrence of the wetland and deepwater habitat systems in each concentric region was then recorded.

Due to the size and significant variation in environmental settings across Texas, as well as the availability of NWI maps, the state was divided into four regions: Region 1 - Coastal, Region 2 - Northeastern, Region 3 - Panhandle, and Region 4 - Central. Figure 2 identifies the four regions of Texas as delineated for this report.

There are 2,191 sanitary landfills in the DPRA data base for the 11 states (Connecticut, Delaware, Florida, Georgia, Louisiana, New Jersey, New York, North Carolina, Pennsylvania, Texas, and Washington) and we were able to classify 1,153 (or 53 percent) of these facilities as to their proximity to wetlands and deepwater habitats (Table 4). However, if the 463 sanitary landfills in Region 4 (Central) of Texas (where we were not able to classify any of the facilities) and the 124 in the state of North Carolina (where we were able to classify only 5 percent of the facilities) are subtracted from the totals, 72 percent of the facilities were classified as to their proximity to wetlands and deepwater habitats. The percent of sanitary landfills classified for the states or regions other than Region 4 of Texas and North Carolina ranges from 12 for Georgia to 100 percent for Delaware and Regions 1, 2, and 3 of Texas.

In order to make comparisons relative to regional differences in the proximity of sanitary landfills to wetlands and deepwater habitats, the data were subdivided into 13 groups, i.e., 10 states (Connecticut, Delaware, Florida, Georgia, Louisiana, New Jersey, New York, North Carolina, Pennsylvania, and Washington) and the 3 regions of Texas (Regions 1, 2, and 3).

Summaries of the data for each state, data on the individual sanitary landfills, as well as the detailed data used in this evaluation, are given in Lambou et al. (1988a, 1988b, 1988c, 1988d, 1989a, 1989b), Gebhard et al. (1988a, 1988b), Herndon et al. (1988a, 1988b, 1988c, 1988d, 1988e, 1988f), Moerlins et al. (1988a, 1988b, 1988c, 1988d, 1989a, 1989b), and Lambou (1989). All of the above reports for the various states surveyed, except Lambou (1989) for North Carolina, are available as U.S. Environmental Protection Agency, Office of Research and Development, Project Reports. Because of the small proportion of sanitary landfills in North Carolina that could be classified as to their proximity to wetlands and deepwater habitats (6 out of 124 or 5 percent), no formal reports were prepared for this state. However, a listing of the sanitary landfills in the state, as well as a tabulation of the facilities classified, are available from the senior author upon request.

## RESULTS

### ALL STATES

#### Wetlands

Approximately 72 percent of the 1,153 sanitary landfills surveyed in the 11 states are located in or within 1/4 mile of wetlands, while 91 and 98 percent are located in or within 1/2 and 1 mile of wetlands, respectively (Figure 3). Most of the facilities are located either in or are close to Palustrine wetlands (i.e., approximately 69, 89, and 97 percent are located in or within 1/4, 1/2, and 1 mile, respectively of a Palustrine wetland). Next comes riverine wetlands with approximately 4, 9, and 15 percent of the facilities located in or within 1/4, 1/2, and 1 mile of them, respectively. Estuarine and Lacustrine wetlands have very few sanitary landfills located in or close to them. Almost no facilities are located in or close to Marine wetlands.

The distribution of the relative distances of the sanitary landfills to the closest wetlands are given in Figure 4. Only 2 percent of the landfills are located further than a mile from any type of wetland. Approximately 18 percent of the sanitary landfills are 1/4 to 1/2 mile from the closest wetland while approximately 7 percent are within 1/2 to 1 mile.

Deepwater Habitats

Approximately 17 percent of the sanitary landfills are located in or within 1/4 mile of deepwater habitats, while 30 and 48 percent are located in or within 1/2 and 1 mile of deepwater habitats, respectively (Figure 5). Most of the facilities are in the vicinity of Riverine or Lacustrine deepwater habitats. Approximately 11, 21, and 33 percent are located in or within 1/4, 1/2, and 1 mile, respectively, of Riverine deepwater habitats while approximately 5, 10, and 20 percent are located in or within 1/4, 1/2, and 1 mile, respectively, of Lacustrine deepwater habitats. Very few facilities are located in or close to Estuarine deepwater habitats and almost none are located close to Marine deepwater habitats. Approximately 52 percent of the landfills are located further than a mile from any type of deepwater habitat (Figure 6).

Wetlands or Deepwater Habitats

Since most of the sanitary landfills are much closer to wetlands (Figure 3) than deepwater habitats (Figure 5), the distribution of their proximity to either wetland or deepwater habitat systems (Figure 7) reflects much more closely the distribution of their proximity to wetland systems. However, in contrast, there are more facilities closer to Riverine deepwater habitats than to Riverine wetlands.

Approximately 76 percent of the sanitary landfills are located in or within 1/4 mile of either wetlands or deepwater habitats, while 93 and 98 percent are located in or within 1/2 and 1 mile of either wetlands or deepwater habitats, respectively (Figure 7). Most of the facilities are near Palustrine habitats (i.e., Palustrine wetlands since the Palustrine system only includes wetlands). Approximately 69, 89, and 97 percent are located in or within 1/4, 1/2, and 1 mile, respectively, of Palustrine habitats. Riverine habitats have the next highest number of sanitary landfills located in or- close to them (approximately 14, 28, and 44 percent in or within 1/4, 1/2, and 1 mile, respectively). Fewer facilities are located in or close to Lacustrine habitats (6, 11, and 22 percent are located in or within 1/4, 1/2, and 1 mile, respectively). Not many facilities are located in or close to Estuarine habitats and almost none are located in or close to Marine habitats. Approximately 2 percent of the landfills are located further than a mile from either a wetland or deepwater habitat (Figure 8).

## DIFFERENCES AMONG STATES AND REGIONS

### All Systems

Wetlands--

There are some differences among the 10 states and 3 regions in the relative proximity of sanitary landfills to wetlands (Figures 9 through 12). The percent of the facilities located in or within 1/4 mile of wetlands ranges from 45 percent for Washington to 96 percent for Connecticut (Figure 9). More than 75 percent of the sanitary landfills in Connecticut, Florida, Georgia, Louisiana, New Jersey, New York, North Carolina, and Texas Region 2 (Northeastern) are located in or within 1/4 mile.

It is surprising that 83 percent of the sanitary landfills in Texas Region 2 (Northeastern) are located in or within 1/4 mile of wetlands as compared to 64 percent in Texas Region 1 (Coastal) with its large expanse of coastal wetlands (Figure 9). It is also interesting that 51 percent of the facilities are located in or within 1/4 mile of wetlands in Texas Region 3 (Panhandle) which is in the more inland and arid portion of Texas (Figure 2).

There is considerably less variation among the states and regions in the percent of sanitary landfills that are located in or within 1/2 mile of wetlands (Figure 10). In all states and regions, except Washington, more than 75 percent of the facilities are located in or within 1/2 mile and in four states and one region (Connecticut, Delaware, Georgia, New York, and Texas Region 2 (Northeastern) more than 95 percent of the facilities are located in or within 1/2 mile.

Very little variation exists among the states and regions in the percent of sanitary landfills that are located in or within 1 mile of wetlands (Figure 11). In all states and regions more than 90 percent of the facilities are located in or within 1 mile and in five states and two regions (Connecticut, Delaware, Georgia, New Jersey, North Carolina, Texas Region 1 (Coastal), and Texas Region 2 (Northeastern) all of the facilities are located in or within 1 mile.

Most sanitary landfills in all states and regions are located within 1/4 mile of a wetland and very few are further than 1 mile from a wetland (Table 5 and Figure 12). The percent of the facilities further than 1 mile from a wetland ranges from 0 percent for Connecticut, Delaware, Georgia, New Jersey, North Carolina, Texas Region 1 (Coastal), and Texas Region 2 (Northeastern) to 8 percent for Washington.

Deepwater Habitats--

There are differences among the 10 states and 3 regions in the relative proximity of sanitary landfills to deepwater habitats (Figures 13 through 16). The percent of the facilities located in or within 1/4 mile of deepwater habitats ranges from 0 percent for Georgia to 33 percent for Delaware (Figure 13). In five states (Connecticut, Delaware, Louisiana, New Jersey, and New York) more than 20 percent of the facilities are located in or within 1/4 mile of deepwater habitats.

The percent of sanitary landfills located in or within 1/2 mile of deepwater habitats ranges from 4 percent for Texas Region 3 (Panhandle) to 54 percent for Connecticut (Figure 14). States and regions with relatively the most facilities located in or within 1/2 mile of deepwater habitats are Connecticut (54 percent), Louisiana (47 percent), New York (45 percent), Delaware (33 percent), Washington (32 percent), Pennsylvania (31 percent), and Texas Region 1 (Coastal) (31 percent).

The percent of the sanitary landfills located in or within 1 mile of deepwater habitats ranges from 4 percent for Texas Region 3 (Panhandle) to 77 percent for Connecticut (Figure 15). States or regions with relatively the most facilities located in or within 1 mile of deepwater habitats are Connecticut (77 percent), Delaware (67 percent), Louisiana (66 percent), New York (62 percent), and New Jersey (59 percent).

In seven of the 10 states and 3 regions, more than half of the sanitary landfills are located further than 1 mile from a deepwater habitat (Table 5 and Figure 16). These are Texas Region 3 (Panhandle) (96 percent), Georgia (67 percent), North Carolina (67 percent), Pennsylvania (57 percent), Texas Region 2 (Northeastern) (56 percent), Texas Region 1 (Coastal) (54 percent), and Florida (51 percent). Connecticut, with 23 percent, has relatively the fewest facilities further than 1 mile from a deepwater habitat.

Wetlands or Deepwater habitats--

Relative distances of the sanitary landfills to either wetlands or deepwater habitats are given in Figures 17 through 19. Since most facilities are must closer to wetlands than to deepwater habitats, the distribution of their relative proximity to either wetlands or deepwater habitats reflects more closely the distribution of their proximity to wetlands (Figures 9 through 11). The percent of the facilities located in or within 1/4 mile of either wetlands or deepwater habitats ranges from 49 percent for Washington to 99 percent for Connecticut (Figure 17). More than 75 percent of the sanitary landfills in Connecticut,

Florida, Georgia, Louisiana, New Jersey, New York, North Carolina, and Texas Region 2 (Northeastern) are located in or within 1/4 mile of either wetlands or deepwater habitats.

There is considerably less variation among the states and regions in the percent of sanitary landfills that are located in or within 1/2 mile of either wetlands or deepwater habitats (Figure 18) than the percent that are located in or within 1/4 mile. In all states and regions, at least 80 percent of the facilities are in or within 1/2 mile of either wetlands or deepwater habitats, and in four states and one region (Connecticut, Delaware, Georgia, New York, and Texas Region 2 (Northeastern)) more than 95 percent of the facilities are in or within 1/2 mile.

Few differences exist among the states and regions in the percent of sanitary landfills that are located in or within 1 mile of either wetlands or deepwater habitats (Figure 19). In all states and regions, more than 90 percent of the facilities are in or within 1 mile of either wetlands or deepwater habitats, and in five states and two regions (Connecticut, Delaware, Georgia, New Jersey, North Carolina, Texas Region 1 (Coastal), and Texas Region 2 (Northeastern)) all of the facilities are in or within 1 mile.

In all states and regions, most sanitary landfills are located within 1/4 mile of either a wetland or deepwater habitat and relatively very few are located further than 1 mile (Table 5 and Figure 20). The percent of the facilities located further than 1 mile from either a wetland or deepwater habitat ranges from 0 percent for Connecticut, Delaware, Georgia, New Jersey, North Carolina, Texas Region 1 (Coastal), and Texas Region 2 (Northeastern) to 7 percent for Washington.

Palustrine System

There are differences among the 10 states and 3 regions in the relative proximity of sanitary landfills to Palustrine habitats (i.e., to Palustrine wetlands, since the Palustrine system includes only wetlands) (Figures 21 through 24). The percent of the facilities located in or within 1/4 mile of Palustrine habitats ranges from 33 percent for Delaware to 95 percent for Connecticut (Figure 21). More than 75 percent of the facilities in Connecticut, Florida, Georgia, New York, North Carolina, and Texas Region 2 (Northeastern) are located in or within 1/4 mile of a Palustrine habitat.

Considerably less variation exists among the states and regions in the percent of sanitary landfills that are located in or within 1/2 mile of Palustrine habitats (Figure 22). In all states and regions, except Washington, more than 75 percent of the facilities are located in or within 1/2 mile of Palustrine habitats and in three states and one region (Connecticut, Delaware, New York, and Texas Region 2 (Northeastern) more than 95 percent of the facilities are located in or within 1/2 mile.

Very few differences exist among the states and regions in the percent of sanitary landfills that are located in or within 1 mile of Palustrine habitats (Figure 23). In all states and regions, more than 90 percent of the facilities are located in or within 1 mile of Palustrine habitats and in five states and two regions (Connecticut, Delaware, Georgia, New Jersey, North Carolina, Texas Region 1 (Coastal), and Texas Region 2 (Northeastern)), all of the facilities are located in or within 1 mile.

Most sanitary landfills in all states and regions are located within 1/4 mile of a Palustrine habitat and very few are further than 1 mile from a Palustrine habitat (Figure 24). The percent of the facilities further than 1 mile from a Palustrine habitat ranges from 0 percent for Connecticut, Delaware, Georgia, New Jersey, North Carolina, Texas Region 1 (Coastal), and Texas Region 2 (Northeastern) to 9 percent for Washington.

Riverine System

Wetlands--

Some differences exist in the relative proximity of sanitary landfills to Riverine wetlands among the 10 states and 3 regions (Figures 25 through 27). The percent of the facilities in or within 1/4 mile of Riverine wetlands ranges from 0 percent for Connecticut, Delaware, and Louisiana to 17 percent for Georgia and North Carolina (Figure 25). In Connecticut and Delaware none of the facilities are in or within 1/2 mile of Riverine wetlands and the percent ranges up to 25 percent for Georgia (Figure 26). The range for the facilities in or within 1 mile of Riverine wetlands is from 0 percent for Delaware to 42 percent for Georgia (Figure 27).

Deepwater Habitats--

Relative distances of the sanitary landfills to Riverine deepwater habitats in the 10 states and 3 regions are given in Figures 28 through 30. More of the facilities are located close to Riverine deepwater habitats than to Riverine wetlands (Figures 25 through 27). The percent of the facilities located in or within 1/4 mile of Riverine

deepwater habitats ranges from 0 percent for Georgia to 33 percent for Delaware (Figure 28). Texas Region 3 (Panhandle) has 1 percent of its facilities located in or within 1/2 mile of Riverine deepwater habitats and the percent ranges up to 39 percent for Connecticut (Figure 29). The range for the facilities located in or within 1 mile of deepwater habitats is from 1 percent for Texas Region 3 (Panhandle) to 67 percent for Delaware (Figure 30). In three states (Connecticut, Delaware, and Louisiana) more than half of the facilities are located in or within 1 mile of Riverine deepwater habitats.

Wetland or Deepwater Habitats--

Since more of the sanitary landfills are located closer to Riverine deepwater habitats than Riverine wetlands, the distribution of their relative proximity to either Riverine wetlands or deepwater habitats (Figures 31 through 33) follows more closely the distribution of their proximity to Riverine deepwater habitats (Figures 28 through 30). The percent of the facilities located in or within 1/4 mile of either Riverine wetlands or deepwater habitats ranges from 6 percent for Texas Region 3 (Panhandle) to 33 percent for Delaware and North Carolina (Figure 31). Texas Region 3 (Panhandle) has 11 percent of its facilities located in or within 1/2 mile of either Riverine wetlands or deepwater habitats and the percent ranges up to 42 percent for Pennsylvania (Figure 32). The range for the facilities located in or within 1 mile of either Riverine wetlands or deepwater habitats is from 21 percent for Texas Region 3 (Panhandle) to 67 percent for Delaware (Figure 33). In seven states (Connecticut, Delaware, Georgia, Louisiana, North Carolina, Pennsylvania, and Washington) at least half of the facilities are located in or within 1 mile of either Riverine wetlands or deepwater habitats.

<u>Lacustrine System</u>

Wetlands--

In all states and regions relatively very few sanitary landfills are located close to Lacustrine wetlands (Figures 34 through 36). Florida and Texas Region 3 (Panhandle), each with 3 percent, have relatively the most facilities located in or within 1/4 mile of Lacustrine wetlands (Figure 34). Florida, with 6 percent, has the greatest percent of facilities located in or within 1/2 mile of Lacustrine wetlands (Figure 35). Likewise, Florida, with 10 percent, has relatively the most facilities located in or within 1 mile of Lacustrine wetlands (Figure 36).

Deepwater Habitats--

More of the sanitary landfills in the various states and regions are located closer to Lacustrine deepwater habitats (Figures 37 through 39) than to Lacustrine wetlands (Figures 34 through 36). Texas Region 2 (Northeastern), with 10 percent, has relatively the most facilities located in or within 1/4 mile of Lacustrine deepwater habitats (Figure 37). The percent of the facilities located in or within 1/2 mile of Lacustrine deepwater habitats ranges from 0 percent for Delaware and North Carolina to 17 percent for Connecticut (Figure 38). The range of the facilities located in or within 1 mile of Lacustrine deepwater habitats is from 0 percent for Delaware and North Carolina to 30 percent for Connecticut and Texas Region 2 (Northeastern) (Figure 39).

Wetlands or Deepwater Habitats--

Since more of the sanitary landfills are located closer to Lacustrine deepwater habitats than to Lacustrine wetlands, the distribution of their relative proximity to either Lacustrine wetlands or deepwater habitats (Figures 40 through 42) follows more closely the distribution of their proximity to Lacustrine deepwater habitats (Figures 37 through 39). The percent of the facilities located in or within 1/4 mile of either Lacustrine wetlands or deepwater habitats ranges from 0 percent for Delaware, Georgia, and North Carolina to 10 percent for Florida and Texas Region 2 (Northeastern) (Figure 40). Delaware and North Carolina do not have any facilities located in or within 1/2 mile of either Lacustrine wetlands or deepwater habitats and the percent ranges up to 18 percent for Connecticut (Figure 41). The range of the facilities located in or within 1 mile of either Lacustrine wetlands or deepwater habitats is from 0 percent for Delaware and North Carolina to 31 percent for Connecticut (Figure 42).

Estuarine System

Wetlands--

In all states and regions few sanitary landfills are located close to Estuarine wetlands (Figures 43 through 45). Three states and two regions (Georgia, North Carolina, Pennsylvania, Texas Region 2 (Northeastern), and Texas Region 3 (Panhandle) do not have any facilities located in or within 1/4 mile of Estuarine wetlands (Figure 43). Delaware, with 33 percent, has relatively the most facilities located in or within 1/4 mile of Estuarine wetlands. The range of the facilities located in or within 1/2 mile of Estuarine wetlands is similar with Georgia, North Carolina, Pennsylvania, Texas Region 2 (Northeastern), and Texas Region 3 (Panhandle) having 0 percent and Delaware having 33 percent (Figure 44). Again, the percent of the

facilities located in or within 1 mile of Estuarine wetlands is somewhat similar and ranges from 0 percent for North Carolina, Pennsylvania, Texas Region 2 (Northeastern), and Texas Region 3 (Panhandle) to 33 percent for Delaware (Figure 45).

Deepwater Habitats--

Not many sanitary landfills are close to Estuarine deepwater habitats in any of the states and regions (Figures 46 through 48). Five states and two regions (Delaware, Georgia, North Carolina, Pennsylvania, Texas Region 2 (Northeastern), Texas Region 3 (Panhandle), and Washington) do not have any facilities located in or within 1/4 mile of Estuarine deepwater habitats (Figure 46). Louisiana, with 11 percent, has relatively the most facilities located in or within 1/4 mile of Estuarine deepwater habitats. The only other state or region with an appreciable proportion is New Jersey with 10 percent. The range of the percent of the facilities located in or within 1/2 mile of Estuarine wetlands is similar with Georgia, North Carolina, Pennsylvania, Texas Region 2 (Northeastern), and Texas Region 3 (Panhandle) having 0 percent and Delaware having 33 percent (Figure 47). Again, the percent of the facilities located in or within 1 mile of Estuarine deepwater habitats is somewhat similar and ranges from 0 percent for Georgia, North Carolina, Pennsylvania, Texas Region 2 (Northeastern), and Texas Region 3 (Panhandle) to 33 percent for Delaware (Figure 48).

Wetland or Deepwater Habitats--

Few sanitary landfills are close to either Estuarine wetlands or deepwater habitats in any of the states and regions (Figures 49 through 51). Delaware and Louisiana, with 33 and 17 percent, respectively, have relatively the most facilities located in or within 1/4 mile of Estuarine wetlands or deepwater habitats (Figure 49). Georgia, North Carolina, Pennsylvania, Texas Region 2 (Northeastern), and Texas Region 3 (Panhandle) do not have any facilities located in or within 1/4 mile of either Estuarine wetlands or deepwater habitats. The range of the facilities located in or within 1/2 mile of either Estuarine wetlands or deepwater habitats is similar with Georgia, North Carolina, Pennsylvania, Texas Region 2 (Northeastern), and Texas Region 3 (Panhandle) having 0 percent and Delaware having 33 percent (Figure 50). Again, the percent of the facilities located in or within 1 mile of either Estuarine wetlands or deepwater habitats is somewhat similar and ranges from 0 percent for North Carolina, Pennsylvania, Texas Region 2 (Northeastern), and Texas Region 3 (Panhandle) to 33 percent for Delaware (Figure 51).

Marine System

Very few sanitary landfills in any of the states and regions are located close to Marine habitats (Figures 52 through 60). None are located in or within 1/4 mile of either Marine wetlands or deepwater habitats (Figures 52, 55, and 58). New York and Washington, each with 2 percent, are the only states or regions with any facilities located in or within 1/2 mile of either Marine wetlands or deepwater habitats, (Figures 53, 56, and 59). In three states (Louisiana, New Jersey, and New York) 2 percent of the sanitary landfills are located in or within 1 mile of Marine wetlands while Washington has 4 percent (Figure 54). Only two states, i.e., New York with 2 percent and Washington with 4 percent, have facilities located in or within 1 mile of Marine deepwater habitats (Figure 57). In all states and regions, the percent of the facilities located in or within 1 mile of either Marine wetlands or deepwater habitats (Figure 60) is identical to the percent in or within 1 mile of Marine wetlands (Figure 54).

## DISCUSSION

Almost all of the sanitary landfills included in this study are located either in or close to wetlands. Approximately three-fourths (72 percent) of the facilities are located in or within 1/4 mile of wetlands while almost all are in or within 1/2 or 1 mile of wetlands (91 and 98 percent, respectively). Very few (2 percent) are further than a mile from a wetland. Considerably fewer facilities are located either in or close to deepwater habitats. A little more than half of the facilities are further than a mile from a deepwater habitat. Since most of the sanitary landfills are much closer to wetlands than deepwater habitats, the distribution of their relative proximity to either wetlands or deepwater habitats is similar to their distribution to wetlands.

The vast majority of the sanitary landfills that are located either in or close to wetlands are close to Palustrine wetlands while most of the facilities that are close to deepwater habitats are close to either Riverine or Lacustrine deepwater habitats.

There are some differences among the 10 states and 3 regions in the relative proximity of the sanitary landfills to wetlands and deepwater habitats. However, in all states and regions, the vast majority of the facilities are close to wetlands, and, in all states and regions except one (i.e., Washington), most facilities are in or within 1/4 mile of wetlands.

A comparison of the proximity of sanitary landfills to wetlands among the three regions of Texas surveyed is especially interesting. It surprised us to find that 83 percent of the sanitary landfills in Texas Region 2 (Northeastern) are located in or within 1/4 mile of wetlands as compared to 64 percent in Texas Region 1 (Coastal) with its large expanse of coastal wetlands (Figure 9). We also found it intriguing that 51 percent of the facilities are located in or within 1/4 mile of wetlands in Texas Region 3 (Panhandle) which is in the more inland and arid portion of Texas (Figure 2). Undoubtedly, there are other considerations, besides the commonness of wetlands in an area, that determine the proximity of sanitary landfills to wetlands.

All states and regions have considerably fewer sanitary landfills located either in or close to deepwater habitats than wetlands. In seven out of the 10 states and 3 regions more than half of the facilities are located further than a mile from a deepwater habitat. Since most of the sanitary landfills in all states and regions are much closer to wetlands than deepwater habitats, the distribution of their relative proximity to either wetlands or deepwater habitats is similar to their distribution to wetlands.

In all states and regions, most of the sanitary landfills that are located either in or close to wetlands are located close to Palustrine wetlands. Much fewer facilities are located close to Riverine wetlands and even fewer are located close to Lacustrine, Estuarine, and Marine wetlands. In the majority of the states and regions, most facilities that are located either in or close to deepwater habitats are located close to Riverine habitats. Fewer facilities are located close to Estuarine and Lacustrine deepwater habitats and almost none are located close to Marine deepwater habitats.

The data available to us specifies only the point location of the sanitary landfills and, therefore, does not define either their size or boundaries. However, we know from other studies that many sanitary landfills are typically on the order of 100 acres in size. For example, in the state of Florida, approximately 35 percent of the active sanitary landfills are between 50 and 150 acres in size, with an average size of 110 acres (Florida Department of Environmental Regulation, 1987). A landfill that is 100 acres in size and uniformly distributed around a point will have a radius of approximately 1/4 mile and, therefore, will approximate the boundary of the first concentric 1/4-mile radius region (Figure 1). Undoubtedly, most of the landfills located in a 1/4-mile radius region containing either wetlands or deepwater habitats are located in,

adjacent, adjoining, contiguous, abutting, or in very close proximity to wetlands or deepwater habitats. Since landfills vary considerably in size and shape, some of the landfills located in the 1/2-mile radius and 1-mile radius regions containing wetlands or deepwater habitats will probably also be located in wetlands or deepwater habitats.

The exact geographic boundary of the landfill is not the critical consideration for determining adverse impacts associated with these facilities. A major consideration is whether or not the facility site is hydrologically interconnected, either by surface or subsurface flows, with wetlands, deepwater habitats, and/or habitats with water tables close to the surface. If hydrologically interconnected, contaminants can easily migrate off-site to the other environments. Also, the construction and operation of a landfill in or close to sensitive habitats can cause physical alterations to the landscape that may adversely affect these habitats. Beyond the adverse physical alterations to the habitat from the landfill, ingress or egress (i.e., access roads and transportation of waste) to a landfill can cause additional physical alterations to the surrounding landscape.

It is the possible hydrological interconnections of deepwater habitats, wetlands, and adjacent or close by areas with high-water tables that need to be considered in assessing the potential environmental hazards of waste sites located in such environments (Lambou et al., In press; van Beek et al., In press). It was this recognition of the possible hydrological interconnections of these environments, as well as other considerations, including the need to be able to identify environments with high-water tables, that lead to the development of a "Wet Subsurface Environments: Definition and Identification Guide" (Lambou et al., In press; Parker et al., In press; van Beek et al., In press; Moerlins et al., In press). "Wet subsurface environments" were defined as "areas where the soils or substrate are saturated near the surface for some part of the year" and the phrase "where soils or substrate are saturated near the surface" was stated to mean "a vertical depth of 2 meters or less to saturated soils or substrate from the land or substrate surface."

Wet subsurface environments as defined above include deepwater habitats, wetlands, as well as adjacent or close by areas with a high-water table (Lambou et al., In press; Parker et al., In press; van Beek et al., In press; Moerlins et al., In press). It is in these environments that most of the sanitary landfills in the 11 states included in this study are located. Wet subsurface environments are part of a continuum in the landscape. They are numerous in the

Nation's coastal corridors where much of the present populations is and where much of the predicted future population growth will occur (Lambou et al., In press). Associated with these concentrations of population is the problem of disposing of the large amounts of solid and hazardous waste in an environmentally acceptable manner.

Areas with high-water tables, i.e., wet subsurface environments, are common in areas having a positive moisture index, i.e., areas where precipitation is greater than potential evapotranspiration, as well as in areas of low relief where water-table gradients are small (Lambou et al., In press; van Beek et al., In press). Many of these areas are groundwater discharge zones or have underlying zones of low permeability that help maintain the water table close to the surface. Discharge areas commonly constitute 5 to 30 percent of the surface area of a watershed (Freeze and Cherry, 1979).

In areas having a positive moisture index, large quantities of leachate that are high in both organic and inorganic contaminants can be produced by percolation through the waste-disposal site, especially where waste piles are not effectively capped (Griffen et al., 1976; Bartel, 1986). Surface-water sources (Freeze and Cherry, 1979), as well as saturated conditions above the base of a landfill (Bartel, 1986), can lead to the production of significant quantities of leachate from landfills; contaminants may then become subject to transport as part of the ground-water flow system. In the presence of a high-water table, the influx of water through the more porous landfill materials will also provide a driving force for ground-water transport of contaminants beyond the landfill area. In wet subsurface environments this transport is most likely to be dominated by both lateral and upward components and the transport beyond the confines of the waste-disposal area is facilitated by saturated conditions.

Bartel and Barksdale (1985) found in a survey of landfills in northwest Florida that ~40 percent of the landfills had waste buried in the range from less than 5 feet above the water table to below the water table. Twenty-five percent of the landfills had waste submerged below the water table. Based on a nation-wide survey, Moerlins et al. (1989c) estimated that 22 out of 71 (31 percent) Subtitle D municipal-waste-combustion-ash disposal facilities had the waste pile extending below the water table.

The transport of contaminants beyond the waste-disposal site can occur through a number of mechanisms (van Beek et al., In press). These include focussed recharge at the waste-disposal site causing water-table mounding which will provide the driving force for movement of contaminants. Also, the presence of a permeable soil layer will provide for surface spreading similar to that utilized in pit recharge. Regardless of the source of water, the presence of leachates in combination with saturated conditions near the surface in an area surrounding a waste-disposal facility is a major cause of concern. This is due to the fact that the hydraulic conductivity of the substrate (i.e., its ability to transmit water) is generally greatest when saturated.

In areas of low relief, high rainfall, and low water-table gradients, certain factors (e.g., small-scale topographical features, waste-disposal management, soil-profile characteristics, and hydrologic events, such as river-stage fluctuations) are likely to play a major role in determining subsurface flow direction and magnitude (Lambou et al., In press; van Beek et al., In press). The local subsurface hydrology is often complex and difficult to predict.

If waste-disposal sites are not effectively capped, they may act as recharge areas after rainfalls. This can produce moderate mounding of water tables which can affect local flow gradients and lead to radial flow away from landfills (Russell et al., 1987). If the landfills are effectively capped, runoff to peripheral ditches or ponds can create separate ground-water mounds, which may lead to complex local-flow systems. Improved drainage ditches can be effective sinks for ground-water discharge and may often constitute a ground-water, flow-system boundary; however, when surface runoff is high, streams and drainage ditches may act as points of recharge to the ground-water system, leading to some seasonal cycling of water (Russell et al., 1987). Improved drainage ditches can be effective sinks for ground-water flows and can facilitate the movement of contaminants to surface waters.

Focussed recharge may result in water-table highs under topographic lows (Winter, 1984), and substrate permeability contrasts can become the dominant factor in the development of flow systems. It is the local and intermediate systems that are of major concern in wet subsurface environments as the flow patterns in such systems are often complex, making the movement of contaminants difficult to predict. Russell et al. (1987) points out that it is difficult to predict the direction of the movement of contaminants from landfills using regional gradients alone in these low-gradient

environments. Prediction may also be made more difficult by the discharge of mineralized water from deepwater aquifers, naturally or through irrigation, which can mask geochemical surveys intended to detect landfill leachates. Contaminant transport in shallow ground-water may easily escape detection, as monitoring often appears to be focused largely on underlying aquifers at somewhat greater depths.

Because of the possible lateral or upward movement of contaminants at, near, or over the surface in wet subsurface environments, contaminants that escape from disposal areas are more likely to come in contact with surface waters and soils, as well as plants and animals, than in other types of environments. Near surface soils and surface waters are areas of significant biological activity. The lower limit of soils is generally considered to be approximately 2 meters and below this limit the hard rock or earthy materials are virtually devoid of roots, animals, or marks of other biologic activity (USDA SCS, 1975). It is in the soil area of the landscape that many of the biological, chemical, and physical reactions and transformations of contaminants are most likely to occur that are of interest in protecting and monitoring environmental quality.

We believe that, for the most part, the wetlands and deepwater habitats identified in this study as being close to sanitary landfills are not small, isolated, or unimportant habitats. Small wetlands or deepwater habitats typically do not appear on NWI maps, because of the limitations associated with the remote sensing techniques and interpretation procedures used by the NWI. Habitats less than 5 acres in size are typically not included in NWI map products due to these limitations. However, some habitats between 1 and 5 acres in size may occasionally appear on NWI maps. The minimum size of a habitat that will appear on NWI maps depends upon the habitat type (i.e., some types are easier to photo interpret than others), isolation from similar types, areal extent and shape, as well as other attributes.

If the results presented here for 11 states relative to the proximity of sanitary landfills to wetlands and deepwater habitats are somewhat typical of the rest of the country, then, there is a propensity for sanitary landfills to be located either in or close to wetlands. This is supported by the fact that more than half of the sanitary landfills are located in or within 1/4 mile of wetlands in Texas Region 3 (Panhandle), which is in the more inland and arid portion of Texas. This study did not acquire data that would elucidate why facilities are located close to wetlands. However, we speculate that wetlands or areas

close to wetlands are not deliberately sought out as sites for sanitary landfills; but, are often used for this purpose because they have low market values, are undeveloped, and are relatively close to sources of solid waste.

Most of the sanitary landfills included in this study are located in or close to wet subsurface environments. There are special problems associated with the siting, design, operation, and monitoring of waste-disposal sites in these environments. These problems stem from conditions that are common and somewhat unique to wet subsurface environments. Conditions of concern that often occur in these environments include: (1) high-water tables; (2) hydrological interconnections of deepwater habitats, wetlands, and adjacent areas with a high-water table; (3) ground-water discharges; (4) production of large quantities of leachates as a result of water percolating through waste-disposal piles; (5) lateral and upward components of ground-water flows; (6) disposal-site waste piles extending below the water table; (7) complex local hydrology; (8) high hydraulic conductivity of the substrate because of saturated conditions; and (9) increased likelihood of contaminants coming in contact with surface waters, soils, plants, and animals.

We conclude that sanitary landfills have the potential to adversely affect sensitive ecosystems, such as wetlands and deepwater habitats, either through habitat alterations or through the migration of contaminants. Landfills located in or close to these environments need to be properly designed and monitored.

## LITERATURE CITED


Bartel, R. L. 1986. Hydrogeology and contaminant movement at selected solid waste landfills in northwest Florida. Northwest Florida Water Management District, Water Resources Special Report 86-2. 119 pp.

Bartel, R. L. and J. D. Barksdale. 1985. Hydrogeologic assessment of solid waste landfills in northwest Florida. Northwest Florida Water Management District, Water Resources Special Report 85-1. 104 pp.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. FWS/OBS-79/31. 103 pp.

Development Planning and Research Associates, Inc. 1986. U.S. Environmental Protection Agency list of municipal waste landfills. Computer Data File, U.S. Environmental Protection Agency.

Florida Department of Environmental Regulation. 1987. GMS 25 data file. Computer Data File, Florida Department of Environmental Regulation.

Freeze, R. A. and J. A. Cherry. 1979. Groundwater. Prentice-Hall, Inc. 604 pp.

Gebhard, R. L., R. C. Herndon, J. E. Moerlins, and V. W. Lambou. 1988a. Proximity of Delaware sanitary landfills to wetlands and deepwater habitats, statewide results. EPA 600/X-88/279e. 16 pp.

Gebhard, R. L., R. C. Herndon, J. E. Moerlins, and V. W. Lambou. 1988b. Proximity of Delaware sanitary landfills to wetlands and deepwater habitats, data on individual landfills. EPA 600/X-88/279e. 11 pp.

Griffen, R. A., K. Cartwright, N. F. Shimp, et al. 1976. Alteration of pollutants in municipal landfill leachate by clay materials: part I. column leaching and field verification. Illinois State Geol. Surv. Bull. 78.

Herndon, R. C., J. E. Moerlins, V. W. Lambou, and R. L. Gebhard. 1988a. Proximity of Pennsylvania sanitary landfills to wetlands and deepwater habitats, statewide results. EPA 600/X-88/279d. 16 pp.

Herndon, R. C., J. E. Moerlins, V. W. Lambou, and R. L. Gebhard. 1988b. Proximity of Pennsylvania sanitary landfills to wetlands and deepwater habitats, data on individual landfills. EPA 600/X-88/279d. 29 pp.

Herndon, R. C., J. E. Moerlins, V. W. Lambou, and R. L. Gebhard. 1988c. Proximity of Florida sanitary landfills to wetlands and deepwater habitats, statewide results. EPA 600/X-88/118a. v + 16 pp.

Herndon, R. C., J. E. Moerlins, V. W. Lambou, and R. L. Gebhard. 1988d. Proximity of Florida sanitary landfills to wetlands and deepwater habitats, data on individual landfills. EPA 600/X-88/118b. iv + 28 pp.

Herndon, R. C., J. E. Moerlins, V. W. Lambou, and R. L. Gebhard. 1988e. Proximity of New Jersey sanitary landfills to wetlands and deepwater habitats, statewide results. EPA 600/X-88/279b. 16 pp.

Herndon, R. C., J. E. Moerlins, V. W. Lambou, and R. L. Gebhard. 1988f. Proximity of New Jersey sanitary landfills to wetlands and deepwater habitats, data on individual landfills. EPA 600/X-88/279b. 20 pp.

Lambou, V. W. 1989. Proximity of North Carolina sanitary landfills to wetlands and deepwater habitats. Memorandum Report, U.S. Environmental Protection Agency. 29 pp.

Lambou, V. W., R. C. Herndon, J. E. Moerlins, and R. L. Gebhard. 1988a. Proximity of Louisiana sanitary landfills to wetlands and deepwater habitats, statewide results. EPA 600/X-88/145a. v + 16 pp.

Lambou, V. W., R. C. Herndon, J. E. Moerlins, and R. L. Gebhard. 1988b. Proximity of Louisiana sanitary landfills to wetlands and deepwater habitats, data on individual landfills. EPA 600/X-88/145b. iv + 17 pp.

Lambou, V. W., R. C. Herndon, J. E. Moerlins, and R. L. Gebhard. 1988c. Proximity of Connecticut sanitary landfills to wetlands and deepwater habitats, statewide results. EPA 600/X-88/279c. 16 pp.

Lambou, V. W., R. C. Herndon, J. E. Moerlins, and R. L. Gebhard. 1988d. Proximity of Connecticut sanitary landfills to wetlands and deepwater habitats, data on individual landfills. EPA 600/X-88/279c. 22 pp.

Lambou, V. W., R. C. Herndon, J. E. Moerlins, and R. L. Gebhard. 1989a. Proximity of Texas sanitary landfills to wetlands and deepwater habitats, statewide results. EPA 600/X-89/040. 24 pp.

Lambou, V. W., R. C. Herndon, J. E. Moerlins, and R. L. Gebhard. 1989b. Proximity of Texas sanitary landfills to wetlands and deepwater habitats, data on individual landfills. EPA 600/X-89/040. 145 pp.

Lambou, V. W., J. E. Moerlins, W. B. Parker, J. L. van Beek, J. M. Kuperberg, and R. C. Herndon. In press. Wet subsurface environments: definition and identification guide, part I - definition and rationale. EPA-ORD Project Report. (This is an update and revision of EPA/600/x-88/403a.)

Langbein, W. B. and K. T. Iseri. 1960. General introduction and hydrologic definitions manual of hydrology. Part I. General surface-water techniques. U.S. Geol. Surv. Water-Supply Paper 1541-A. 29 pp.

Moerlins, J. E., R. C. Herndon, V. W. Lambou, and R. L. Gebhard. 1988a. Proximity of Georgia sanitary landfills to wetlands and deepwater habitats, statewide results. EPA 600/X-88/279a. 16 pp.

Moerlins, J. E., R. C. Herndon, V. W. Lambou, and R. L. Gebhard. 1988b. Proximity of Georgia sanitary landfills to wetlands and deepwater habitats, data on individual landfills. EPA 600/X-88/279a. 14 pp.

Moerlins, J. E., R. C. Herndon, V. W. Lambou, and R. L. Gebhard. 1988c. Proximity of New York sanitary landfills to wetlands and deepwater habitats, statewide results. EPA 600/X-88/279f. 16 pp.

Moerlins, J. E., R. C. Herndon, V. W. Lambou, and R. L. Gebhard. 1988d. Proximity of New York sanitary landfills to wetlands and deepwater habitats, data on individual landfills. EPA 600/X-88/279f. 26 pp.

Moerlins, J. E., R. C. Herndon, V. W. Lambou, and R. L. Gebhard. 1989a. Proximity of Washington sanitary landfills to wetlands and deepwater habitats, statewide results. EPA 600/X-89//086A. 16 pp.

Moerlins, J. E., R. C. Herndon, V. W. Lambou, and R. L. Gebhard. 1989b. Proximity of Washington sanitary landfills to wetlands and deepwater habitats, data on individual landfills. EPA 600/X-89//086B. 27 pp.

Moerlins, J. E., J. M. Kuperberg, R. C. Herndon, D. W. Teaf, and V. W. Lambou. 1989c. Municipal-waste-combustion-ash disposal, characterization of disposal practices and facilities and review of monitoring data. EPA 600/x-89/258a. 44 pp.

Moerlins, J. E., V. W. Lambou, W. B. Parker, J. L. van Beek, J. M. Kuperberg, and R. C. Herndon. In press. Wet subsurface environments: definition and identification guide, part IV - data synthesis and identification procedures. EPA-ORD Project Report. (This is an update and revision of EPA/600/x-88/403d.)

National Cartographic Information Center. 1987. T-70 computer tape. Computer Data File, National Mapping Division, U.S. Geological Survey.

Parker, W. B., J. E. Moerlins, W. W. Lambou, J. L. van Beek, J. M. Kuperberg, and R. C. Herndon. In press. Wet subsurface environments: definition and identification guide, part II - soils. EPA-ORD Project Report. (This is an update and revision of EPA/600/x-88/403b.)

Russell, G. M., M. Stewart, and A. L. Higer. 1987. Examples of landfill-generated plumes in low-relief areas, southeast Florida. Water Resources Bull. 23(5):863-866.

U.S. Department of Agriculture, Soil Conservation Service. 1975. Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys. United States Department of Agriculture, Soil Conservation Service. Agric. Handb. 436. 754 pp.

U.S. Environmental Protection Agency. 1987. Resource Conservation and Recovery Act Subtitle D report to Congress. Final Draft Report, May 28, 1987.

U.S. Geological Survey. 1979. Maps for America, first edition. U.S. Geological Survey.

van Beek, J. L., V. W. Lambou, J. E. Moerlins, W. B. Parker, R. C. Herndon, and J. M. Kuperberg. In Press. Wet subsurface environments: definition and identification guide, part III - hydrology. EPA-ORD Project Report. (This is an update and revision of EPA/600/x-88/403c.)

Winter, T. C. 1984. Modeling the interrelationship of groundwater and surface water. In J. L. Schnoor (ed.) Modeling of total acid precipitation impacts, Acid Precipitation Series Vol. 9, Butterworth Publishers. P. 89-119.

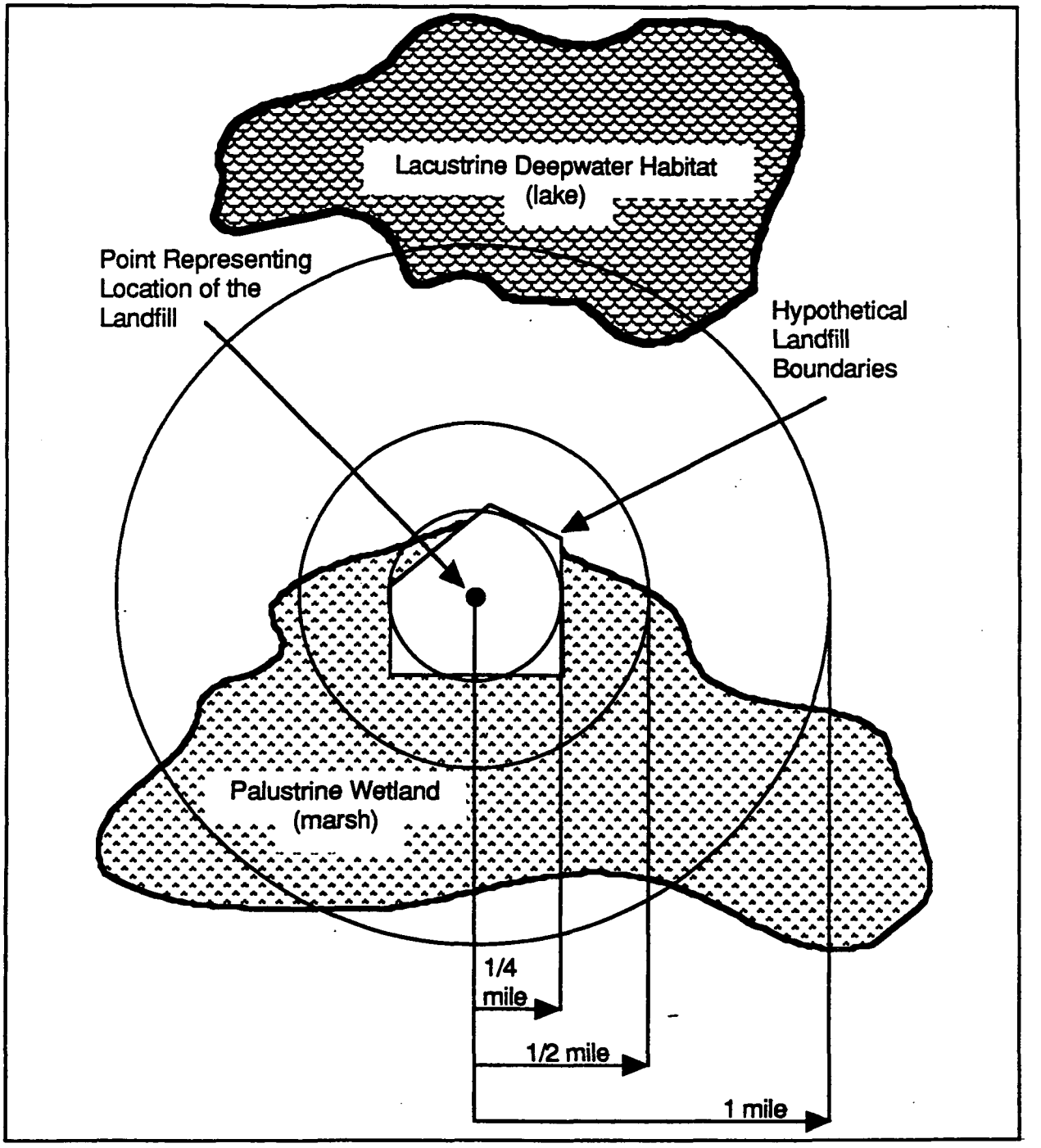


Figure 1. Hypothetical sanitary landfill showing the point (latitude and longitude coordinates) that represents the location of the landfill, the concentric regions used to determine the nearness or proximity of the sanitary landfill to wetlands and deepwater habitats, and the boundary of a 100-acre sanitary landfill distributed approximately evenly around its point location (a 100-acre sanitary landfill uniformly distributed around a point will have a radius of approximately 1/4 mile).

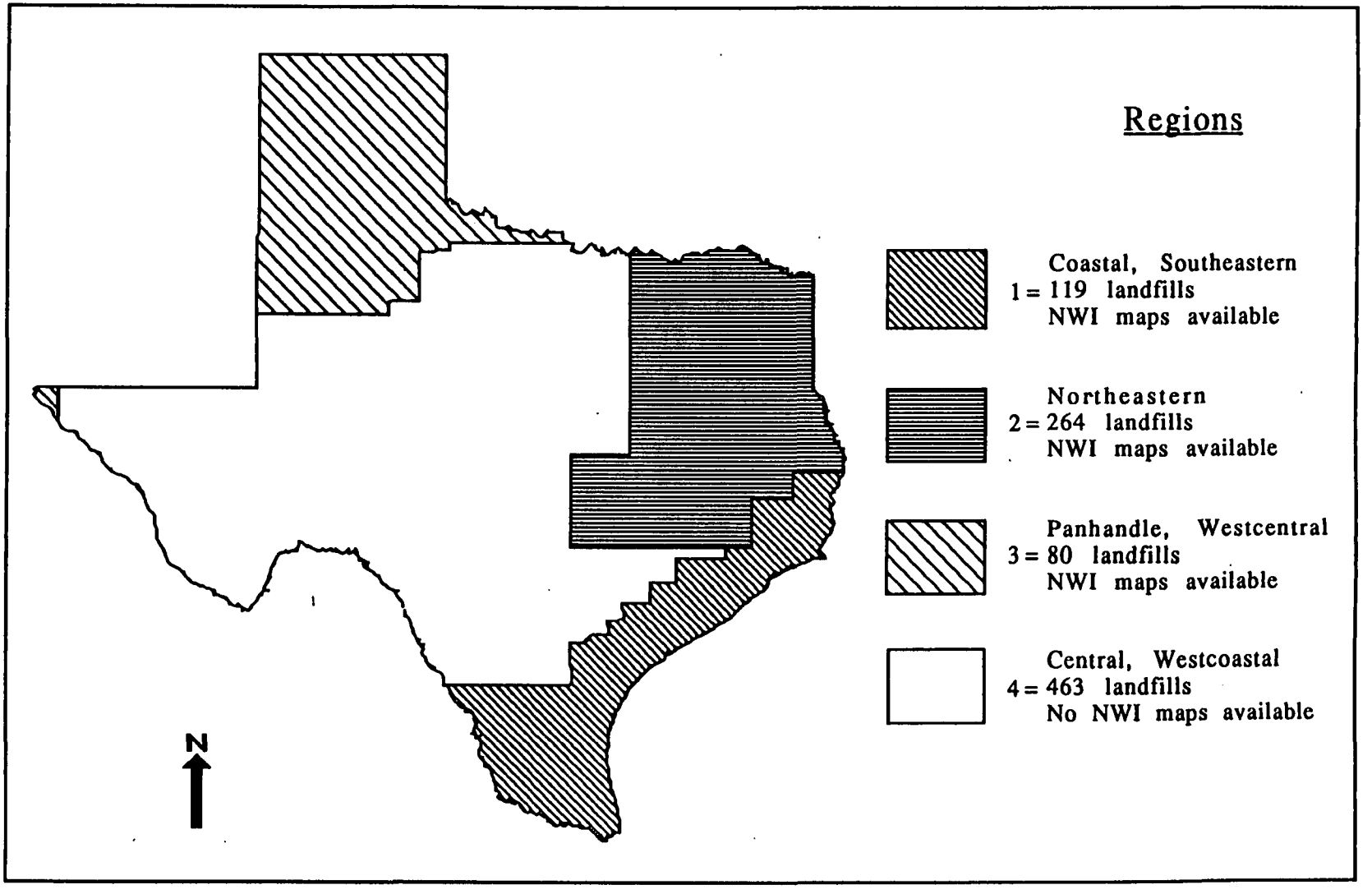


Figure 2. Four regions of Texas delineated for this report.

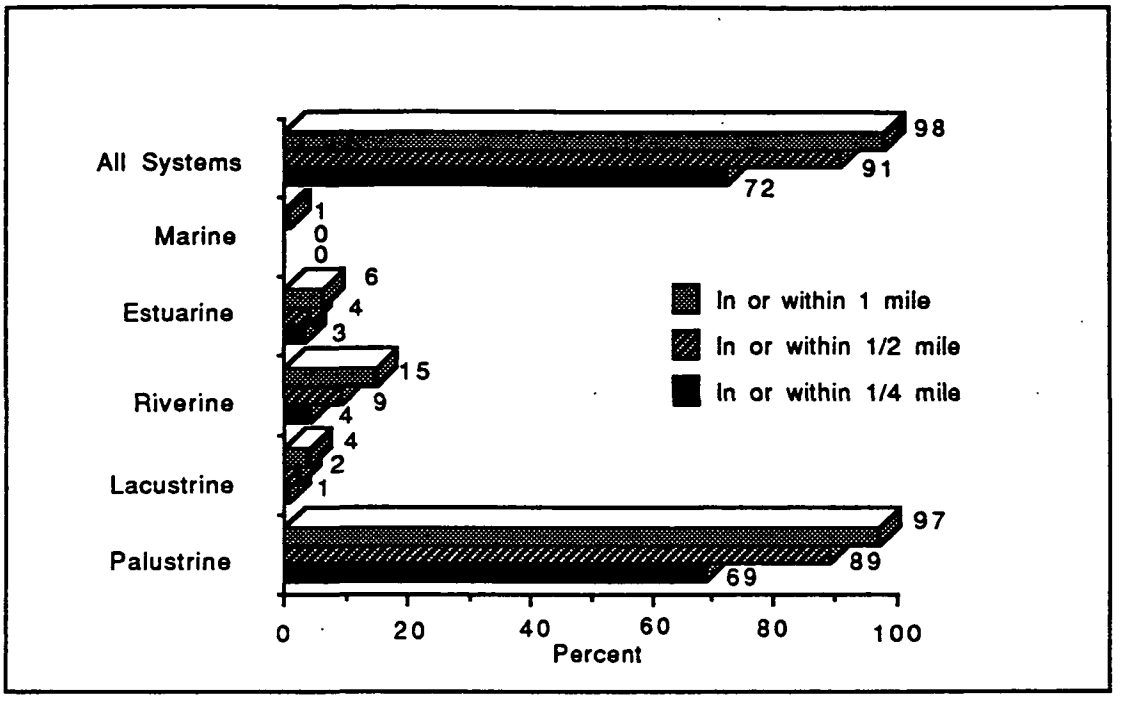


Figure 3. Proximity of 1,153 sanitary landfills in 11 states to wetlands.

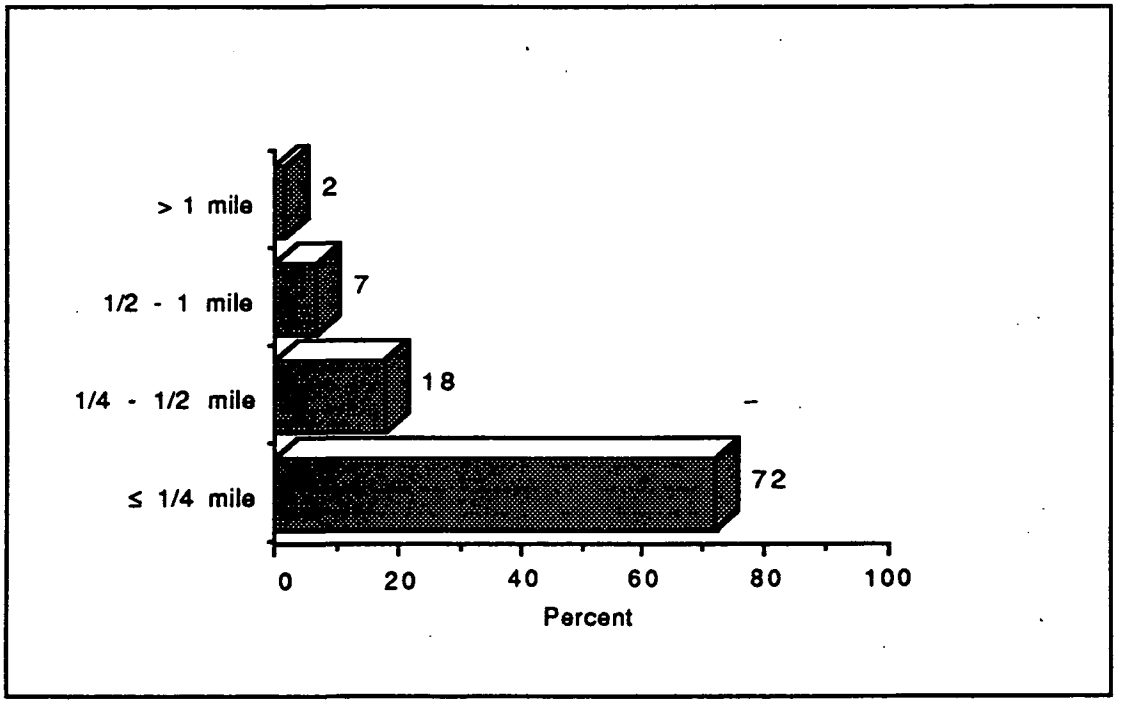


Figure 4. Distance of 1,153 sanitary landfills in 11 states to closest wetland.

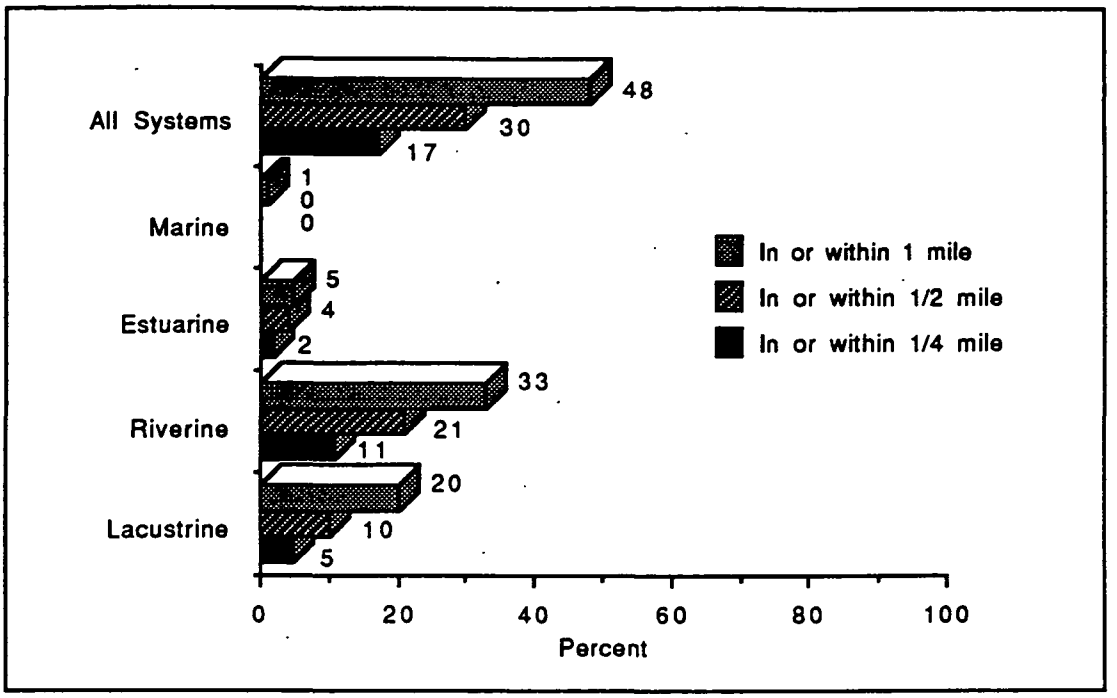


Figure 5. Proximity of 1,153 sanitary landfills in 11 states to deepwater habitats.

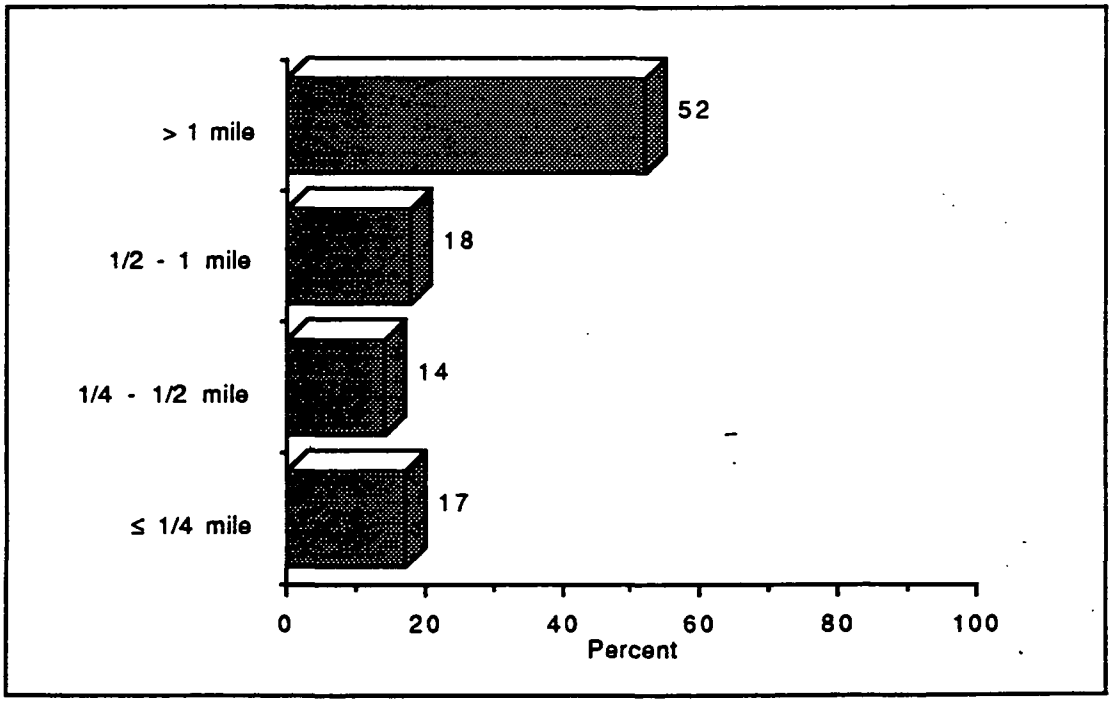


Figure 6. Distance of 1,153 sanitary landfills in 11 states to closest deepwater habitat.

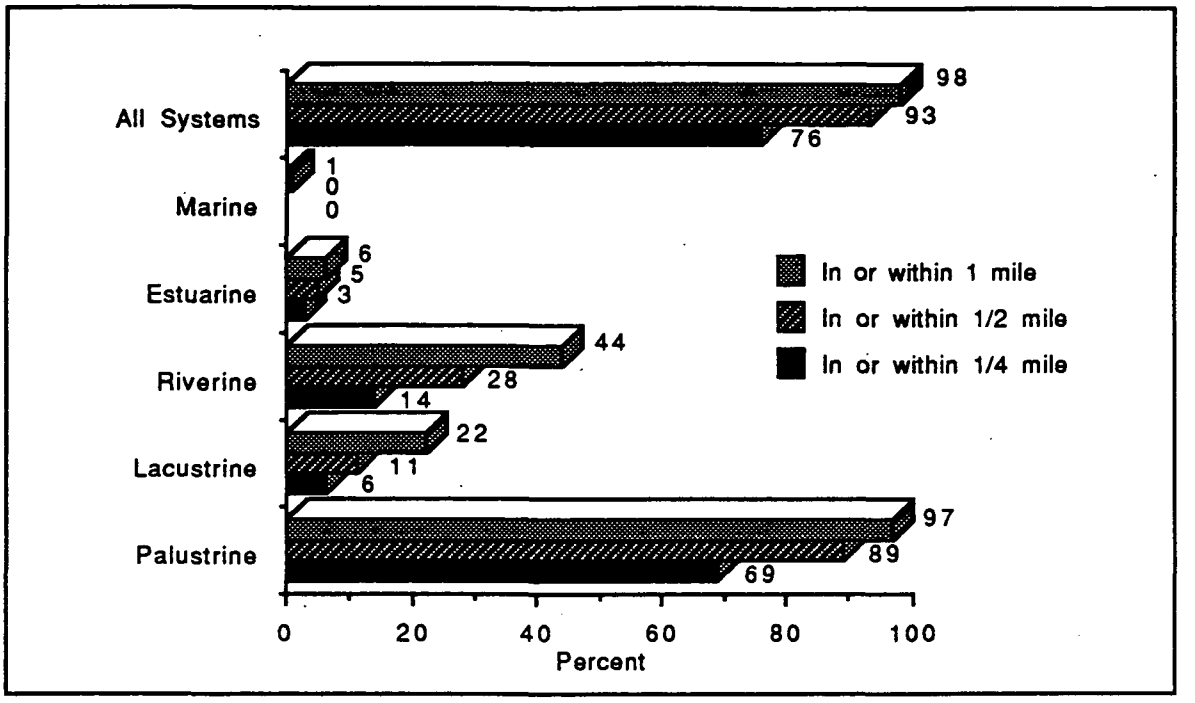


Figure 7. Proximity of 1,153 sanitary landfills in 11 states to either wetlands or deepwater habitats.

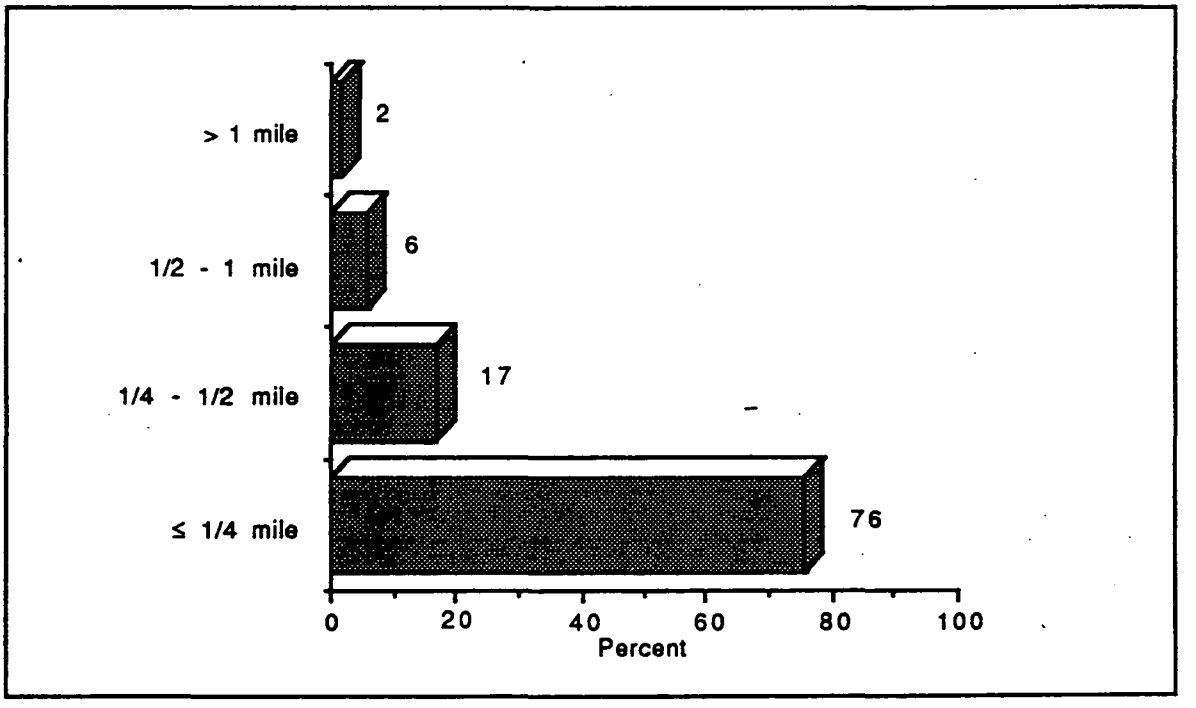


Figure 8. Distance of 1,153 sanitary landfills in 11 states to either the closest wetland or deepwater habitat.

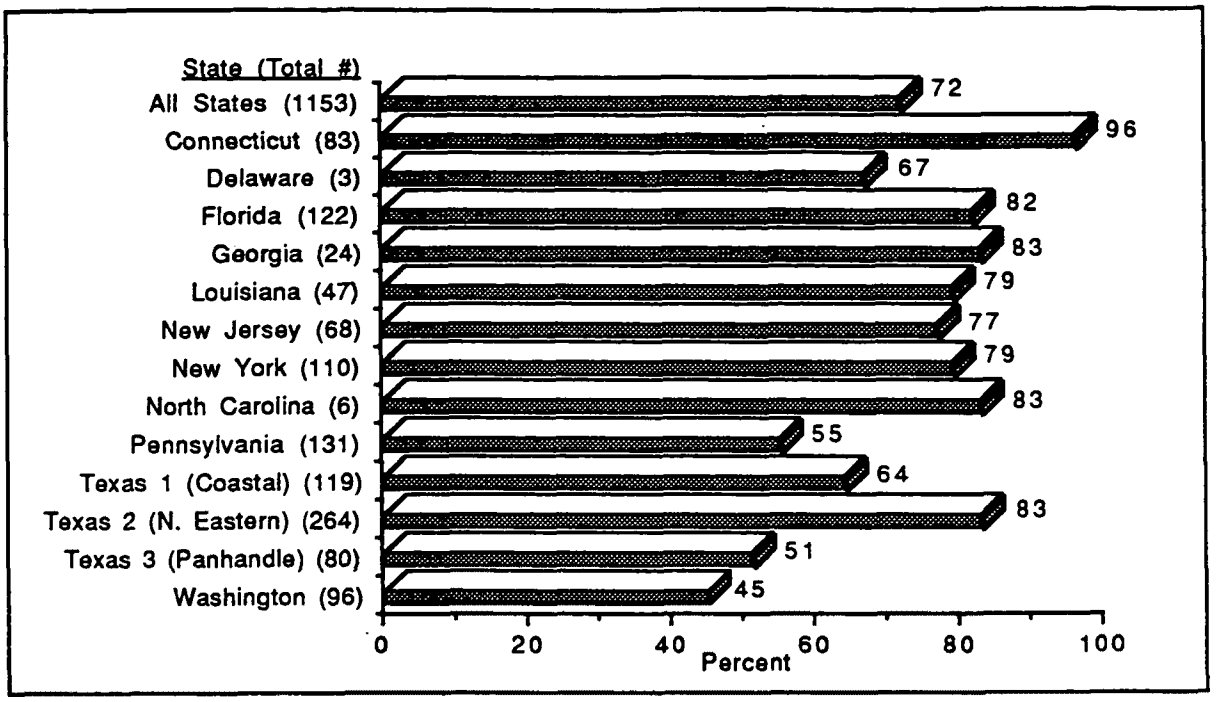


Figure 9. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of wetlands by state or region.

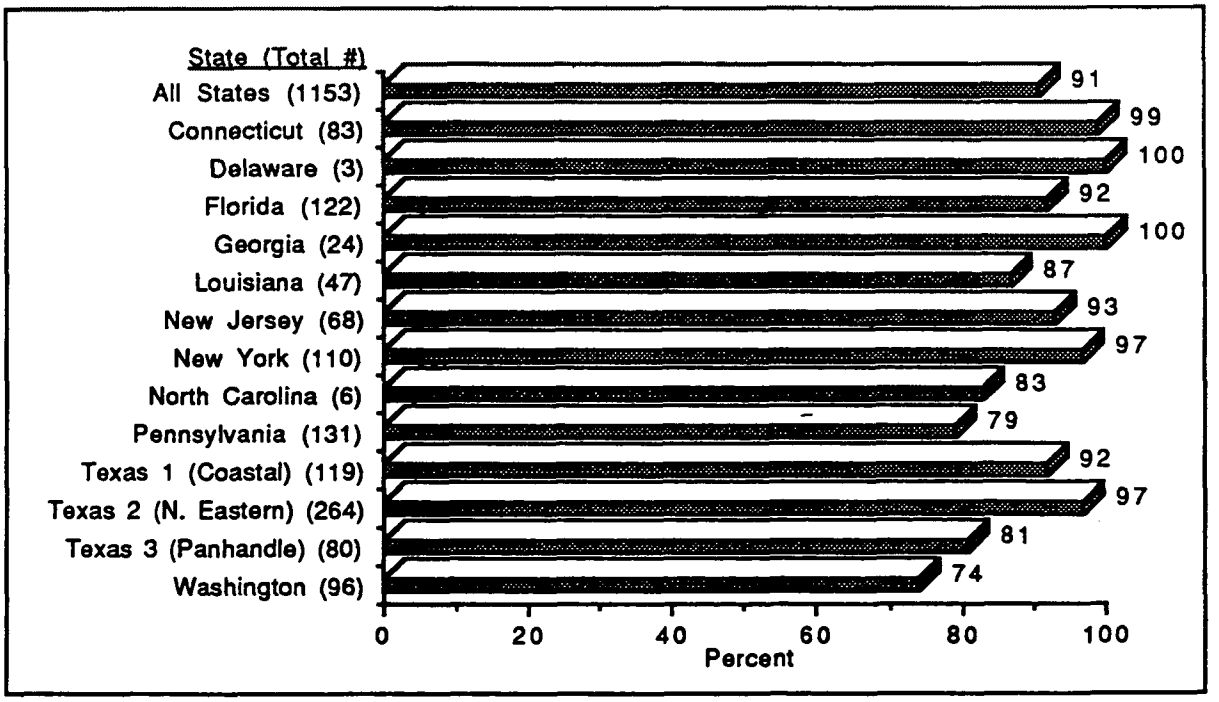


Figure 10. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of wetlands by state or region.

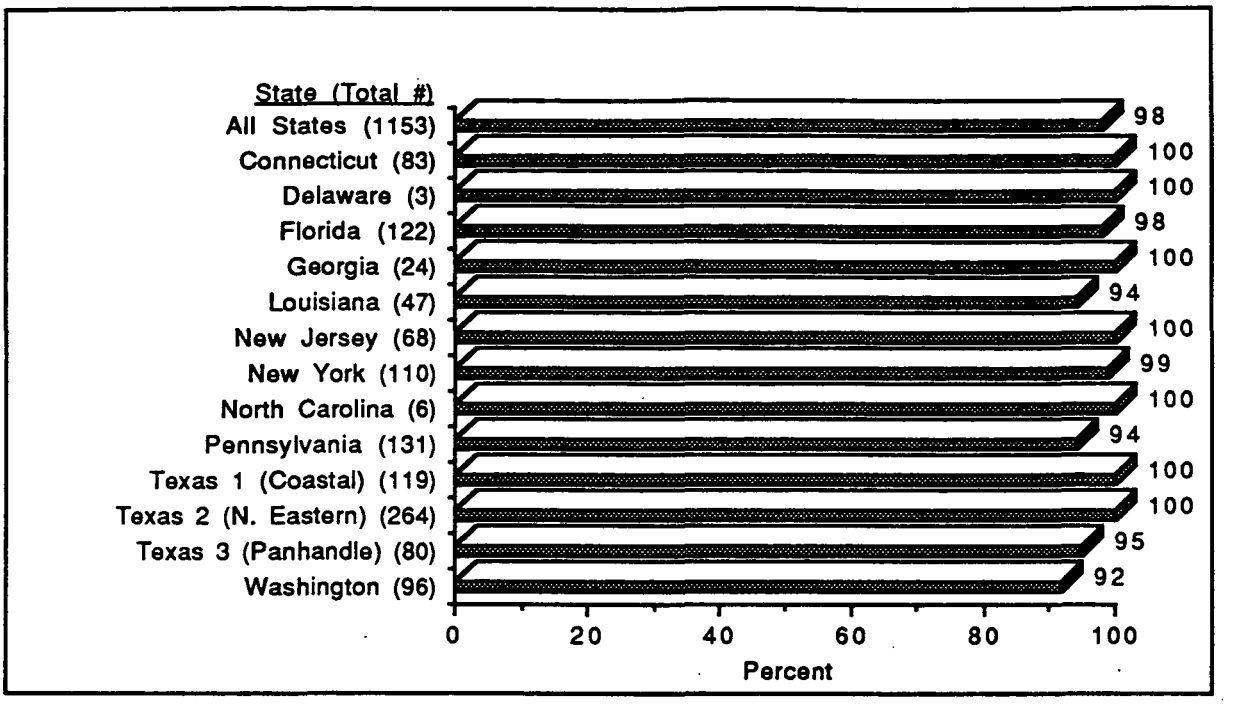


Figure 11. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of wetlands by state or region.

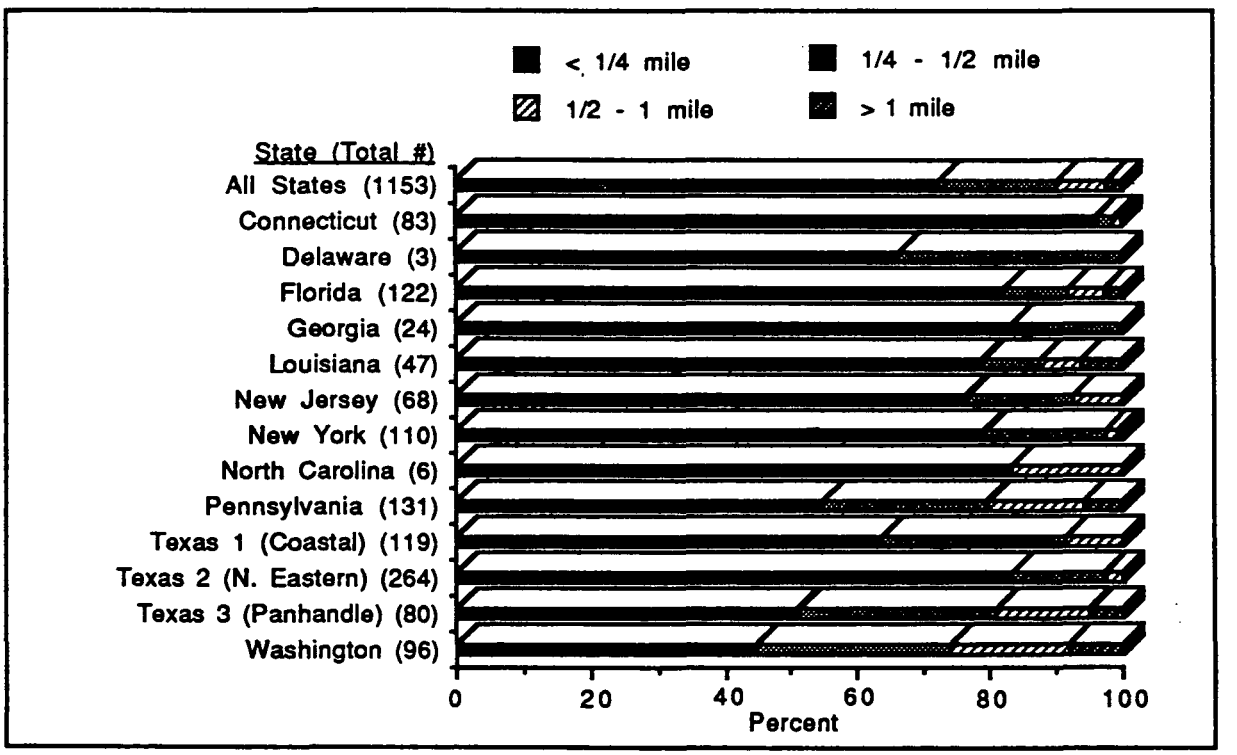


Figure 12. Distance of 1,153 sanitary landfills in 11 states to the closest wetland by state or region.

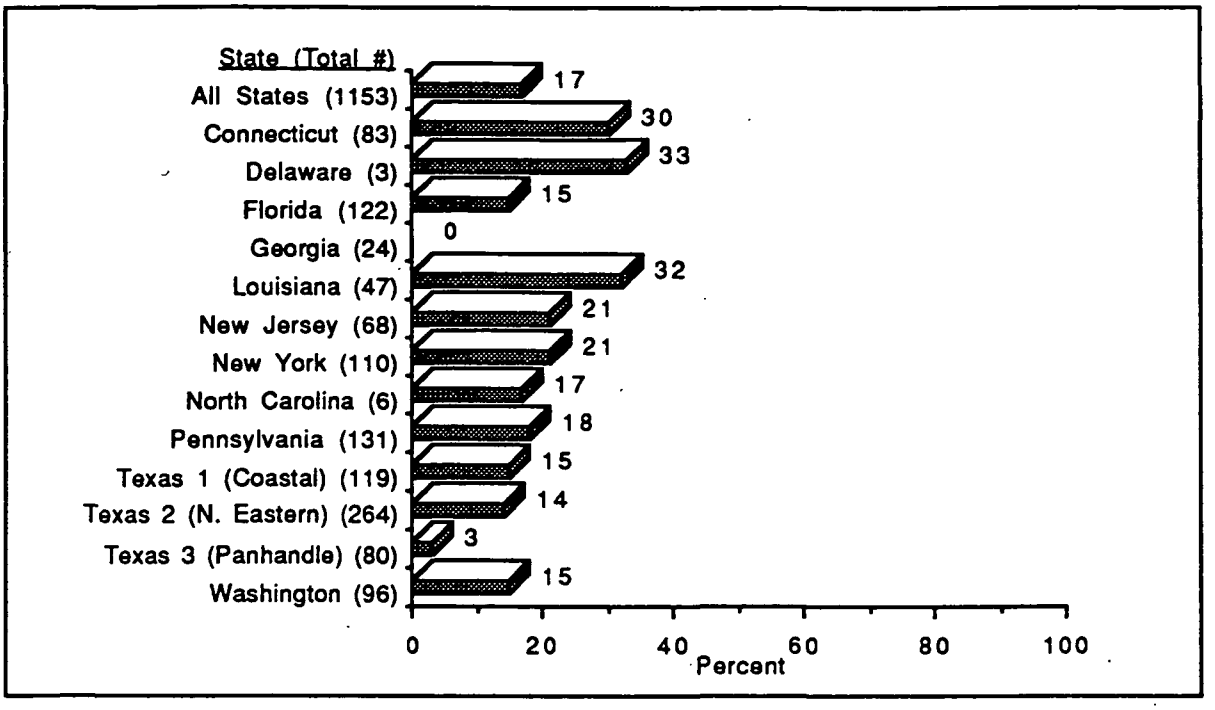


Figure 13. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of deepwater habitats by state or region.

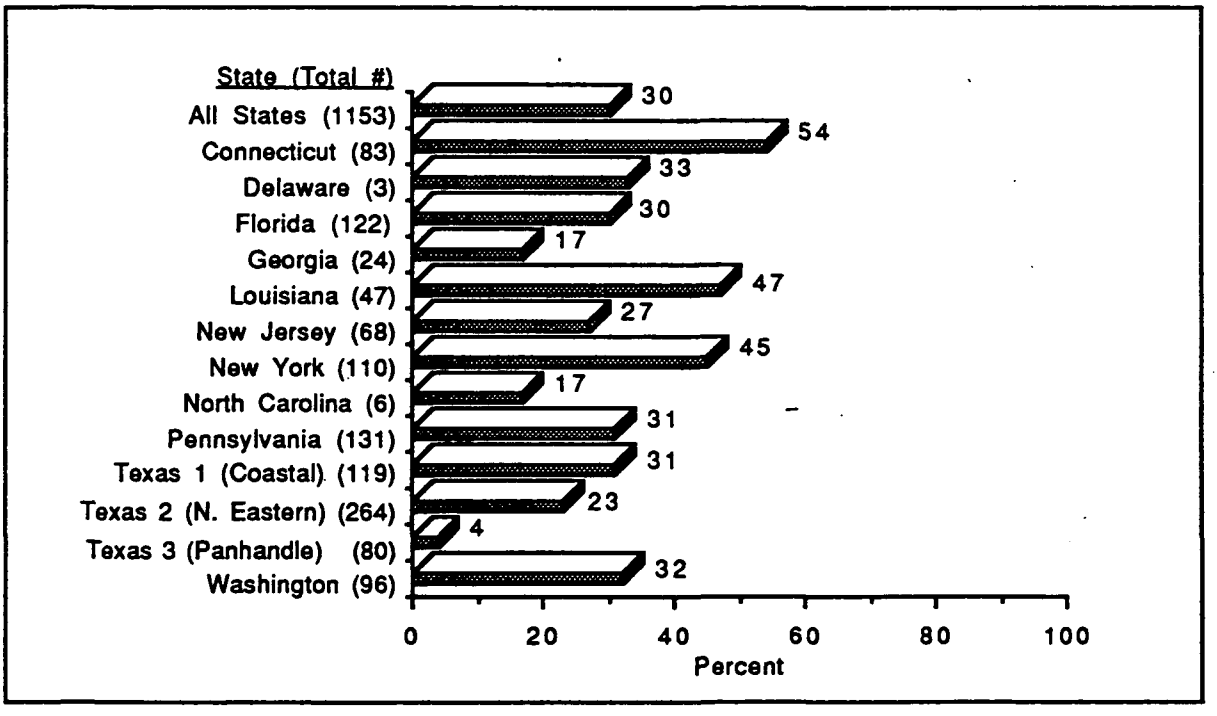


Figure 14. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of deepwater habitats by state or region.

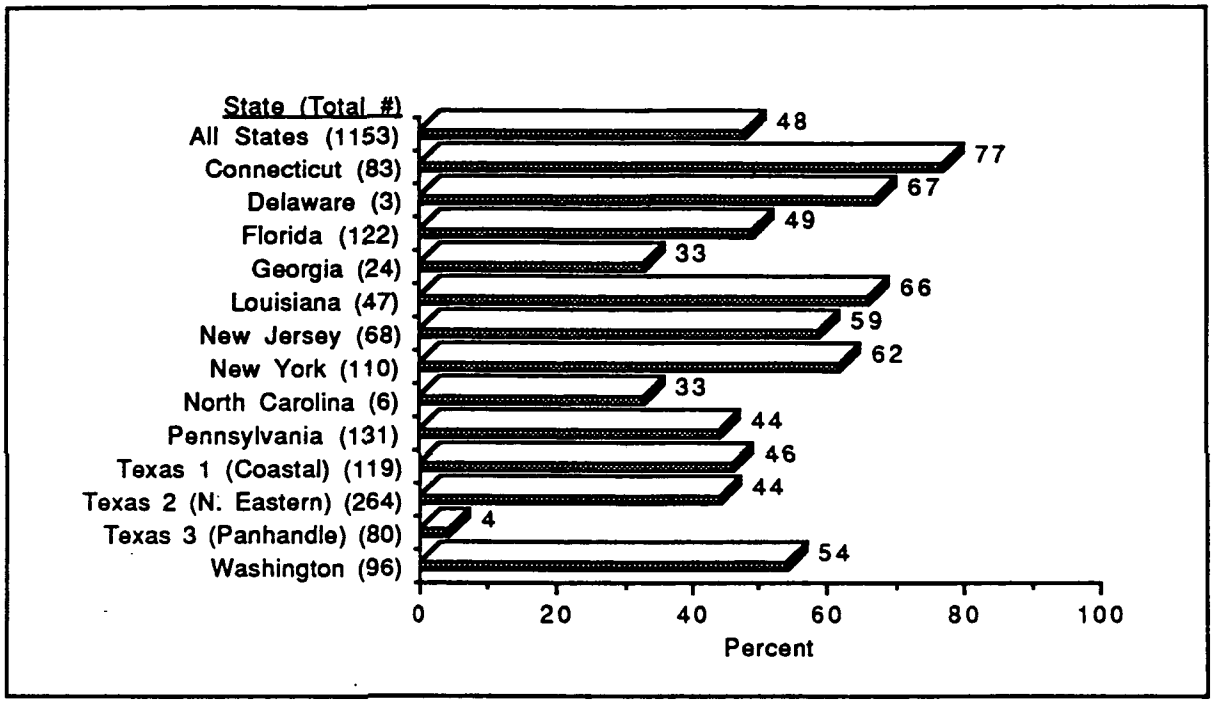


Figure 15. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of deepwater habitats by state or region.

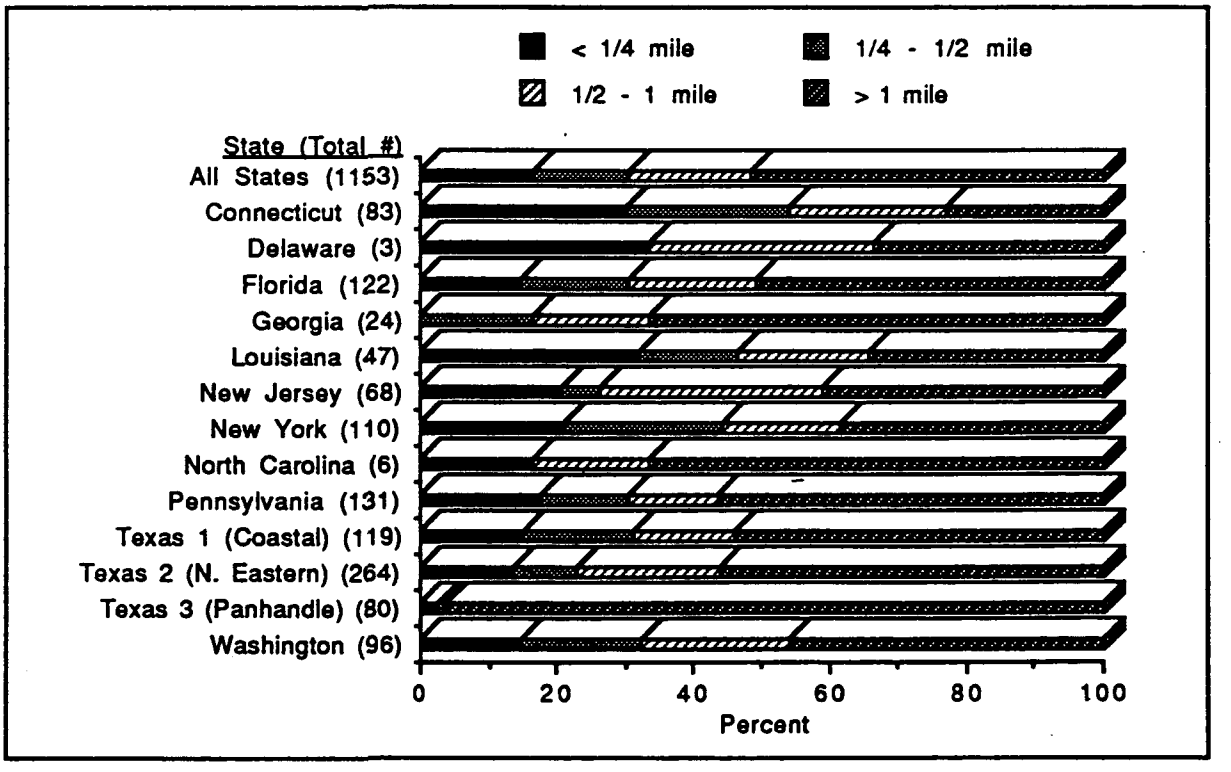


Figure 16. Distance of 1,153 sanitary landfills in 11 states to the closest deepwater habitat by state or region.

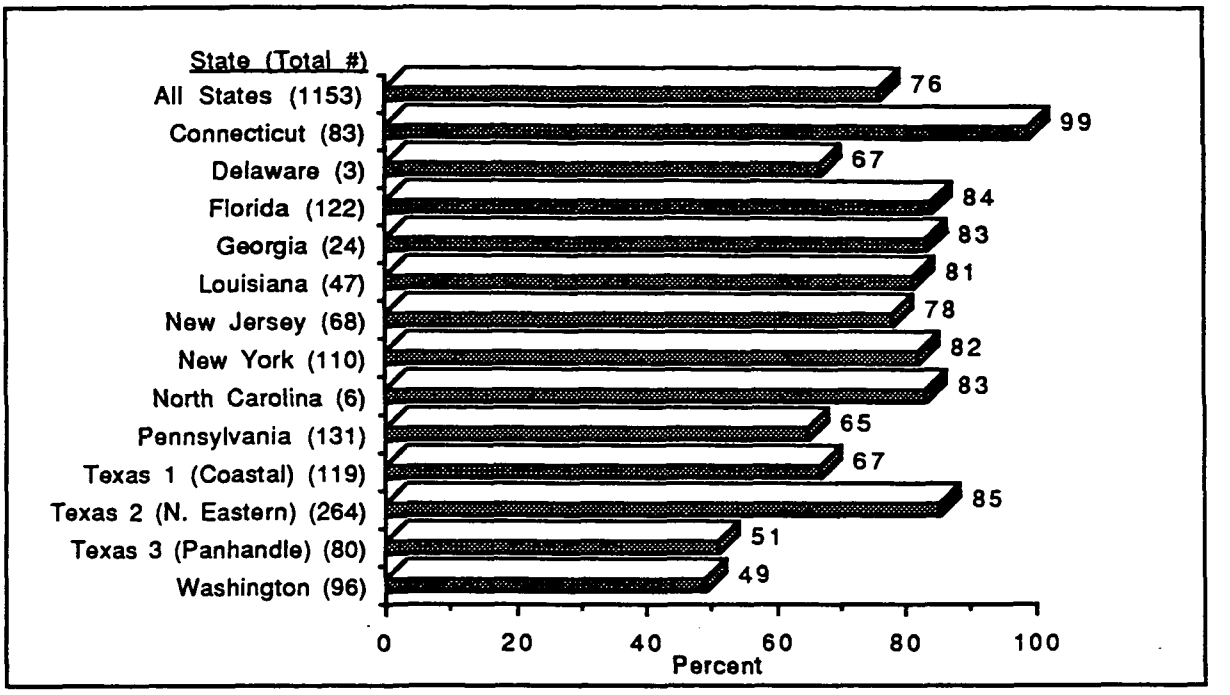


Figure 17. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of either wetlands or deepwater habitats by state or region.

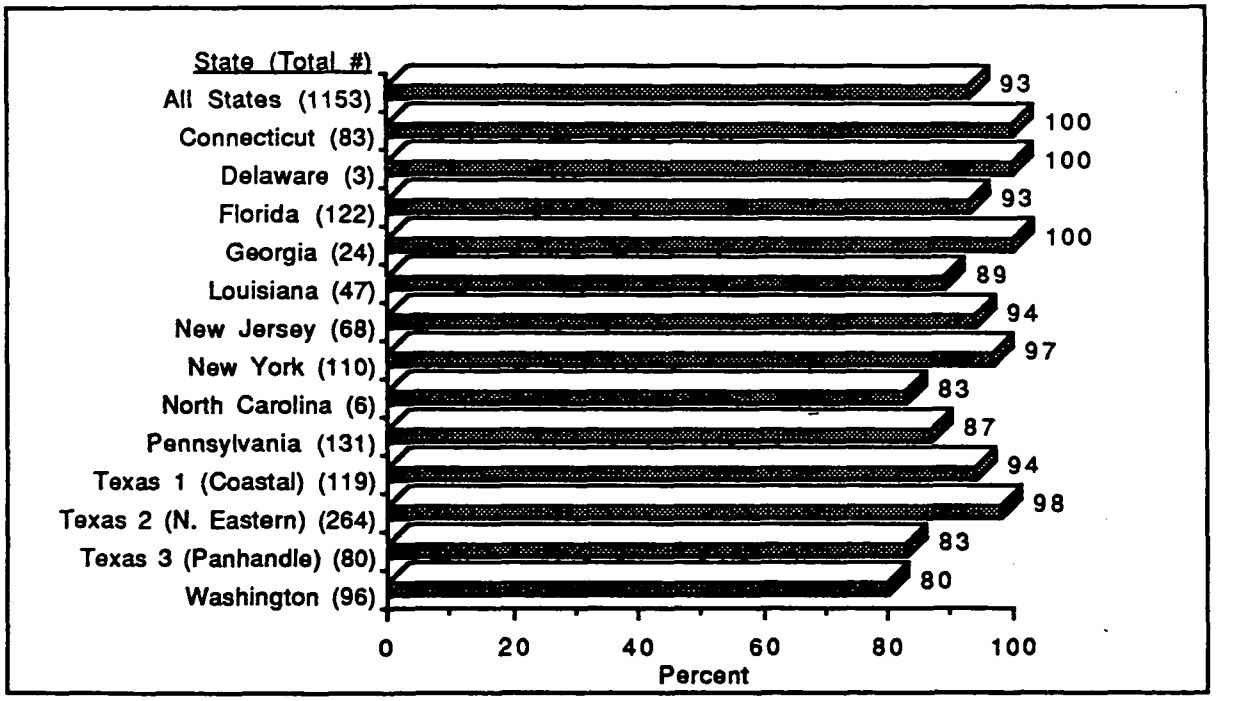


Figure 18. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 of either wetlands or deepwater habitats by state or region.

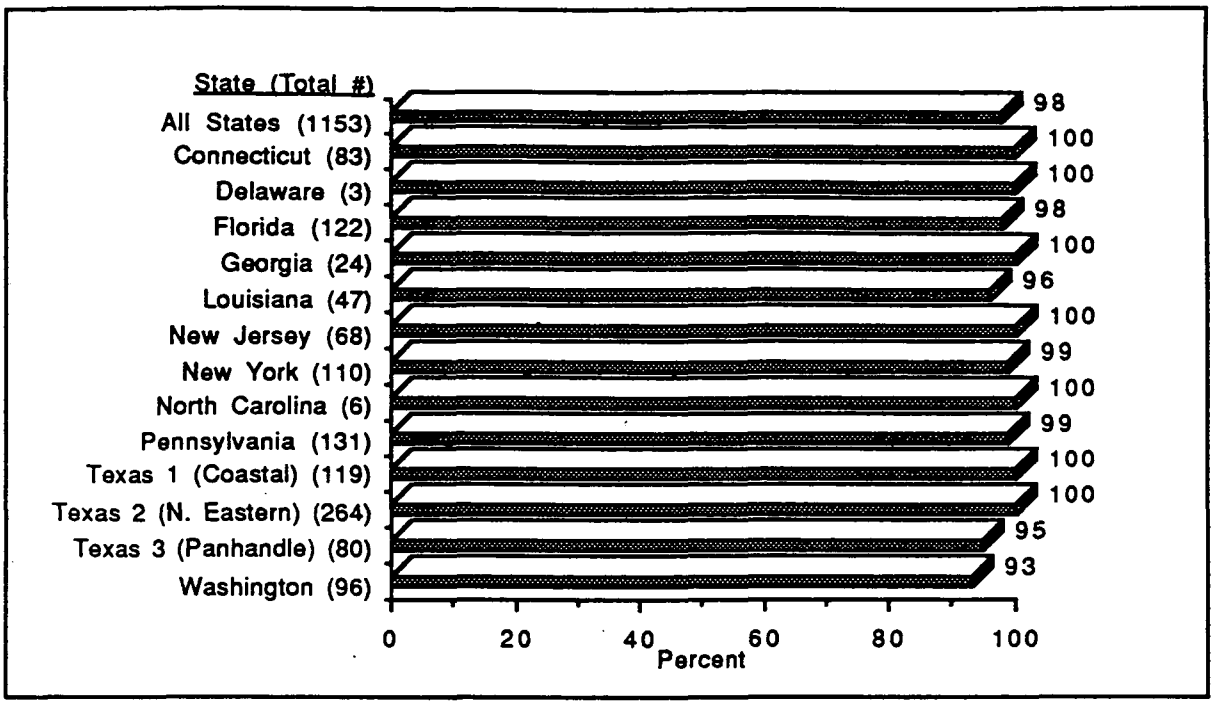


Figure 19. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of either wetlands or deepwater habitats by state or region.

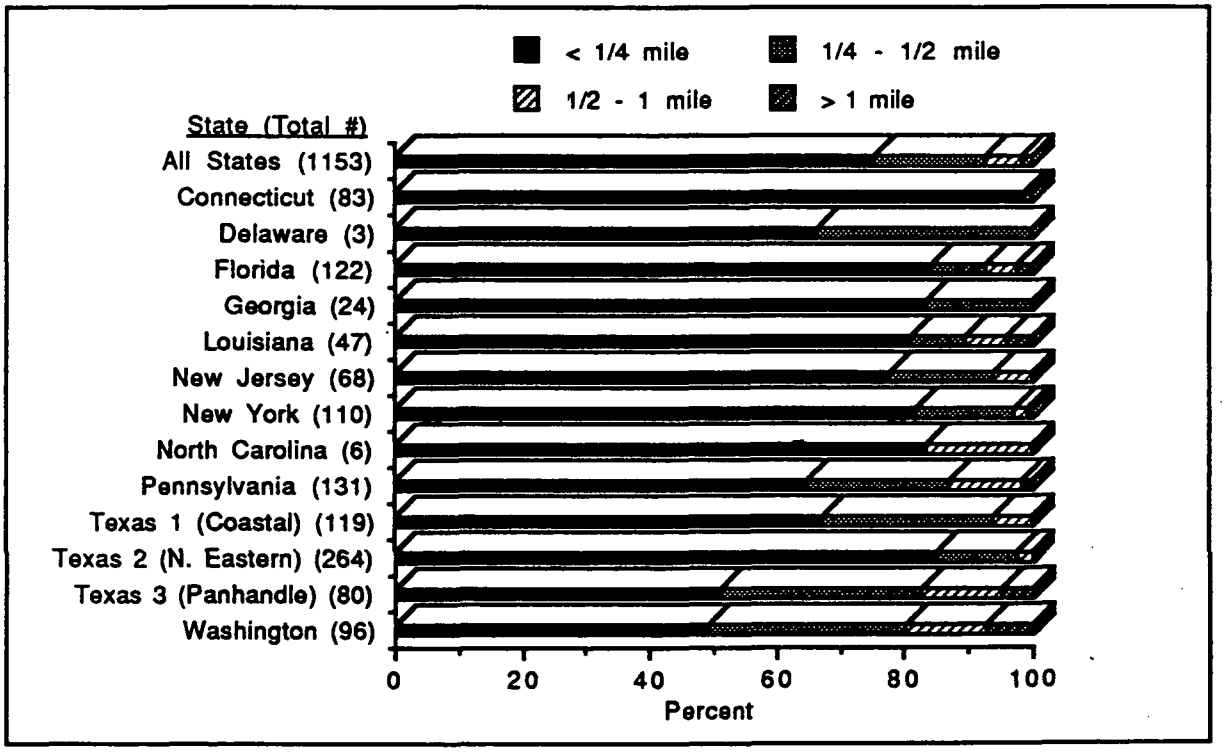


Figure 20. Distance of 1,153 sanitary landfills in 11 states to the closest wetland or deepwater habitat by state or region.

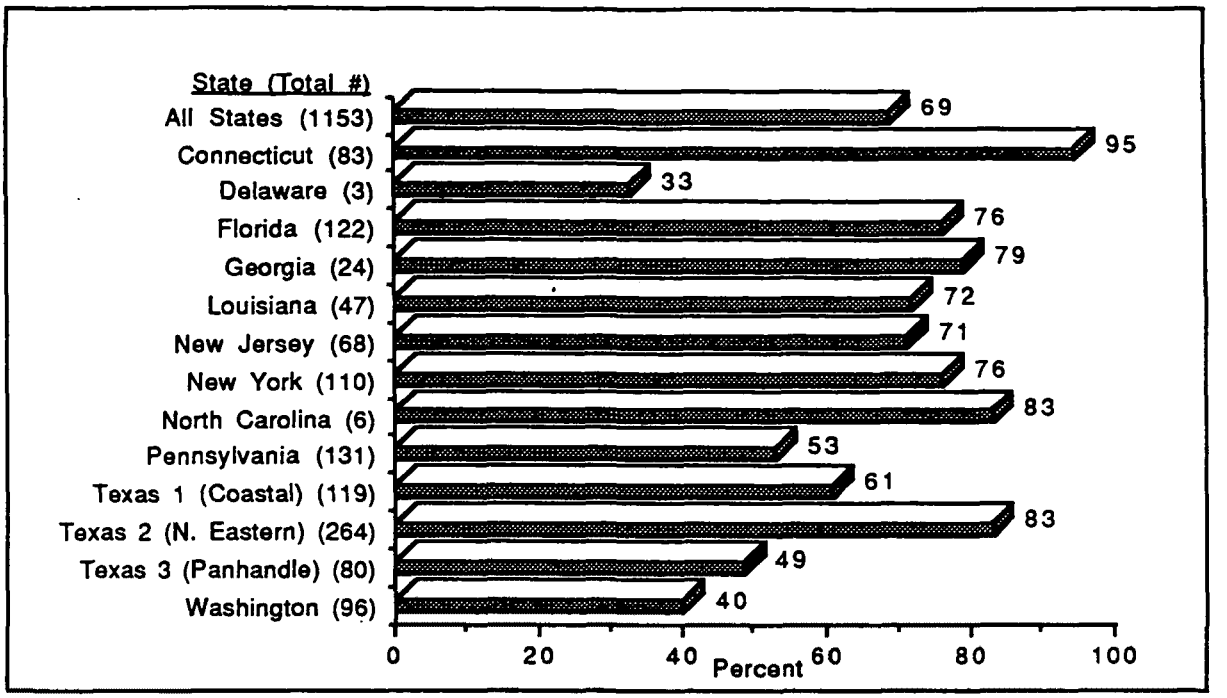


Figure 21. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of Palustrine wetlands by state or region.

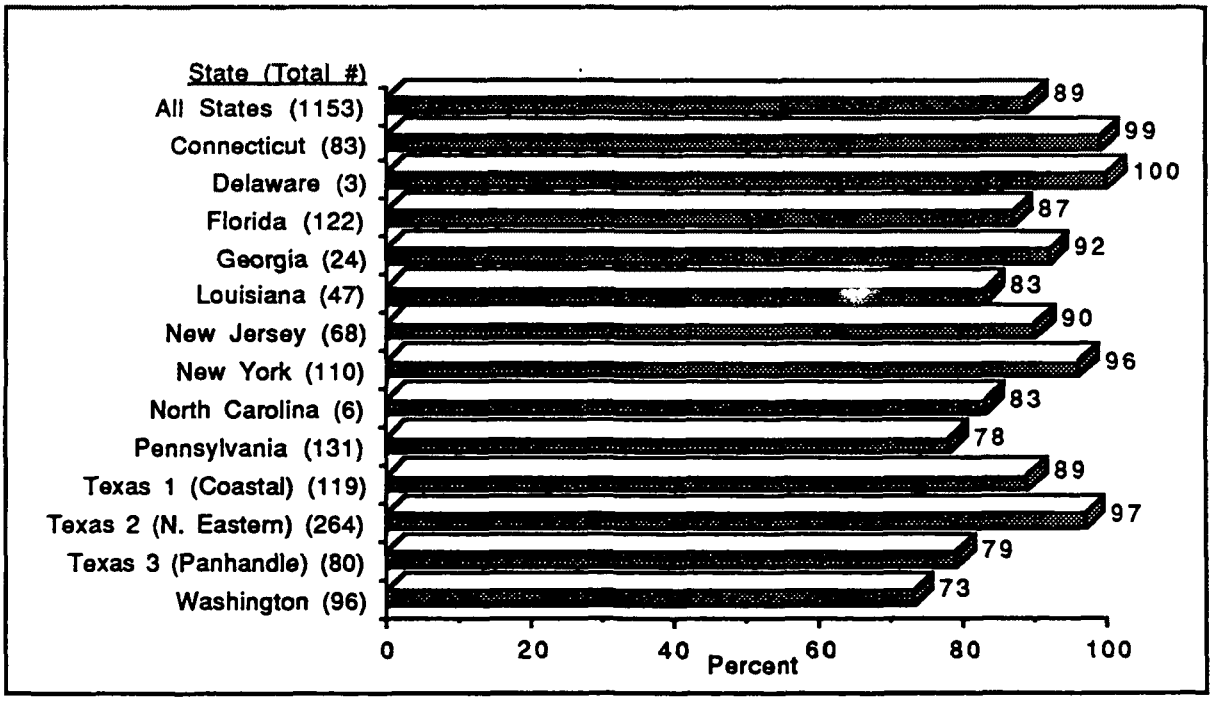


Figure 22. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of Palustrine wetlands by state or region.

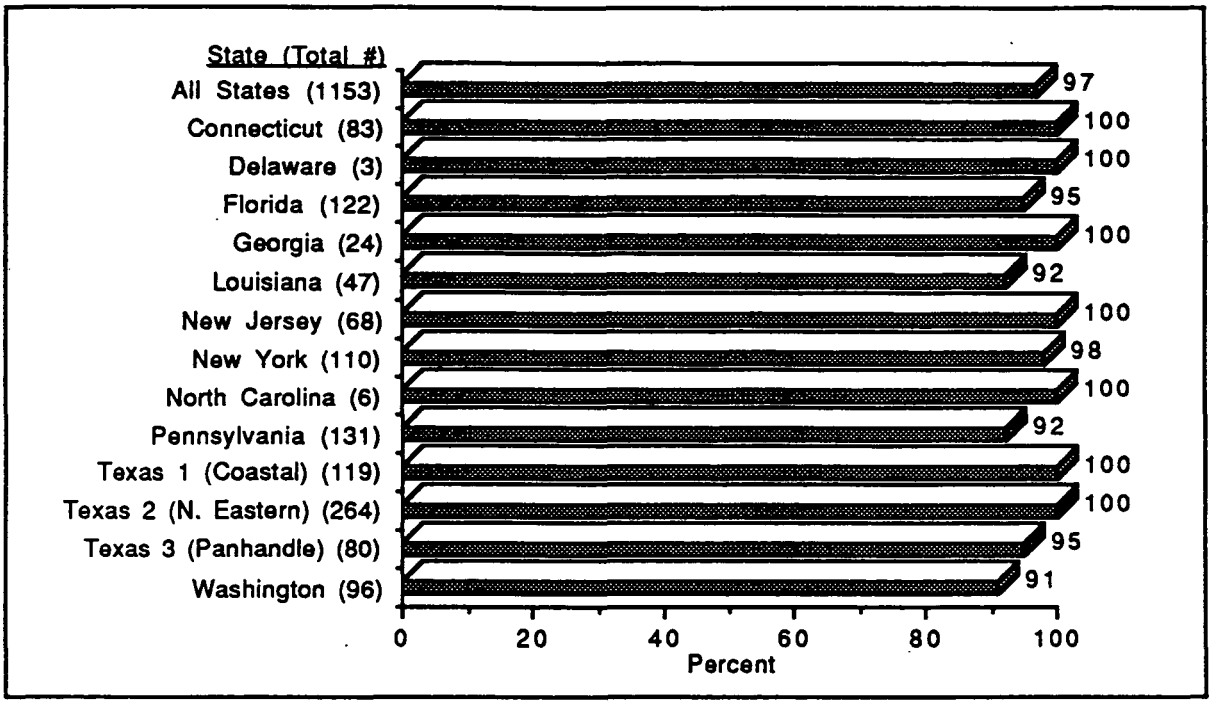


Figure 23. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of Palustrine wetlands by state or region.

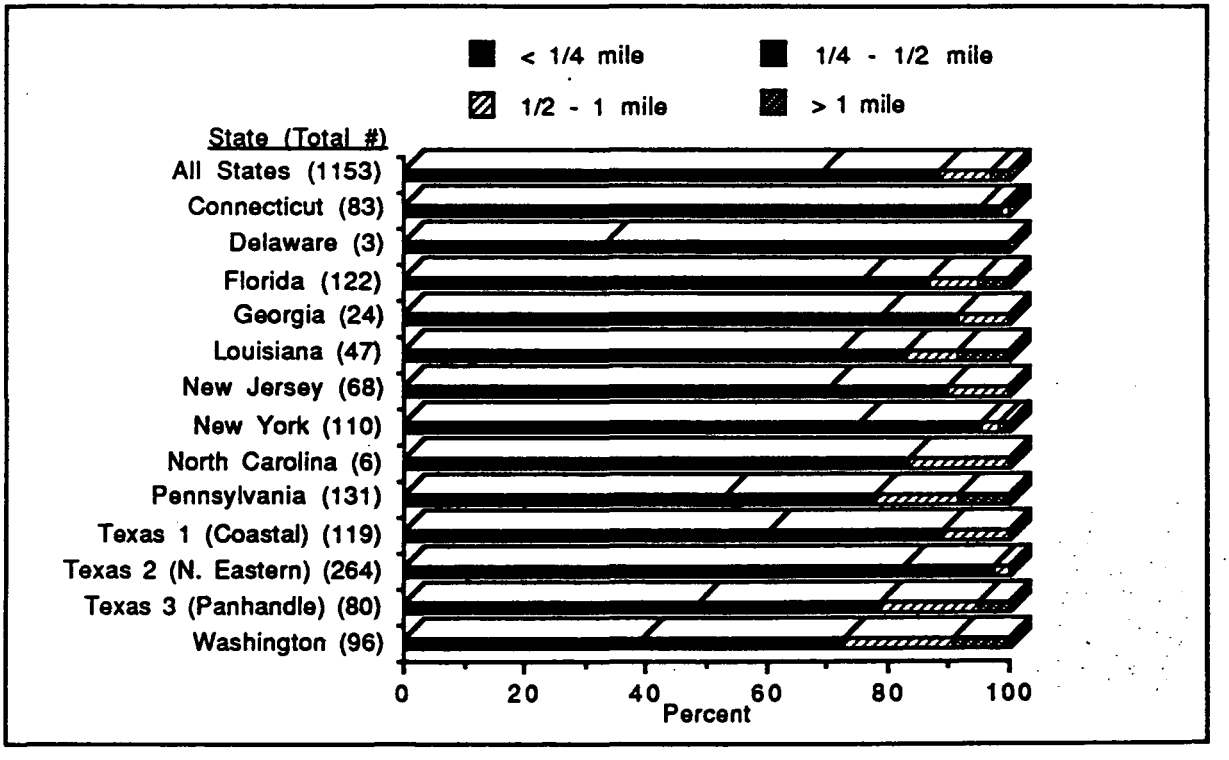


Figure 24. Distance of 1153 sanitary landfills in 11 states to the closest Palustrine wetland by state or region.

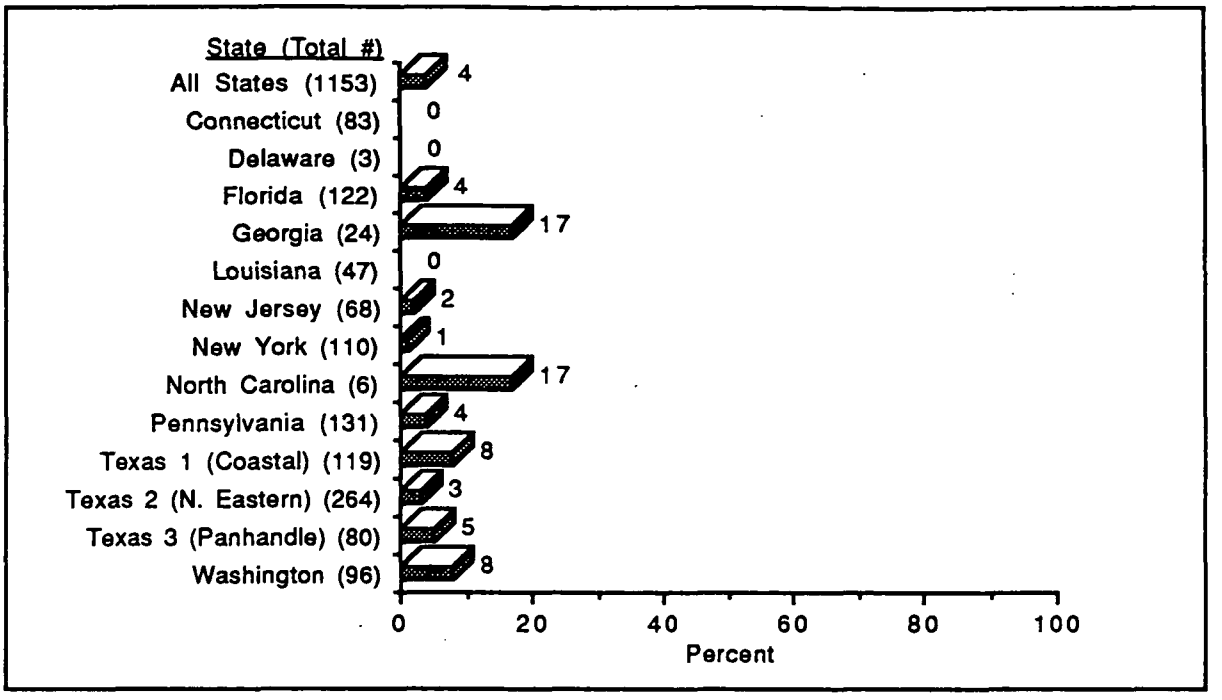


Figure 25. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of Riverine wetlands by state or region.

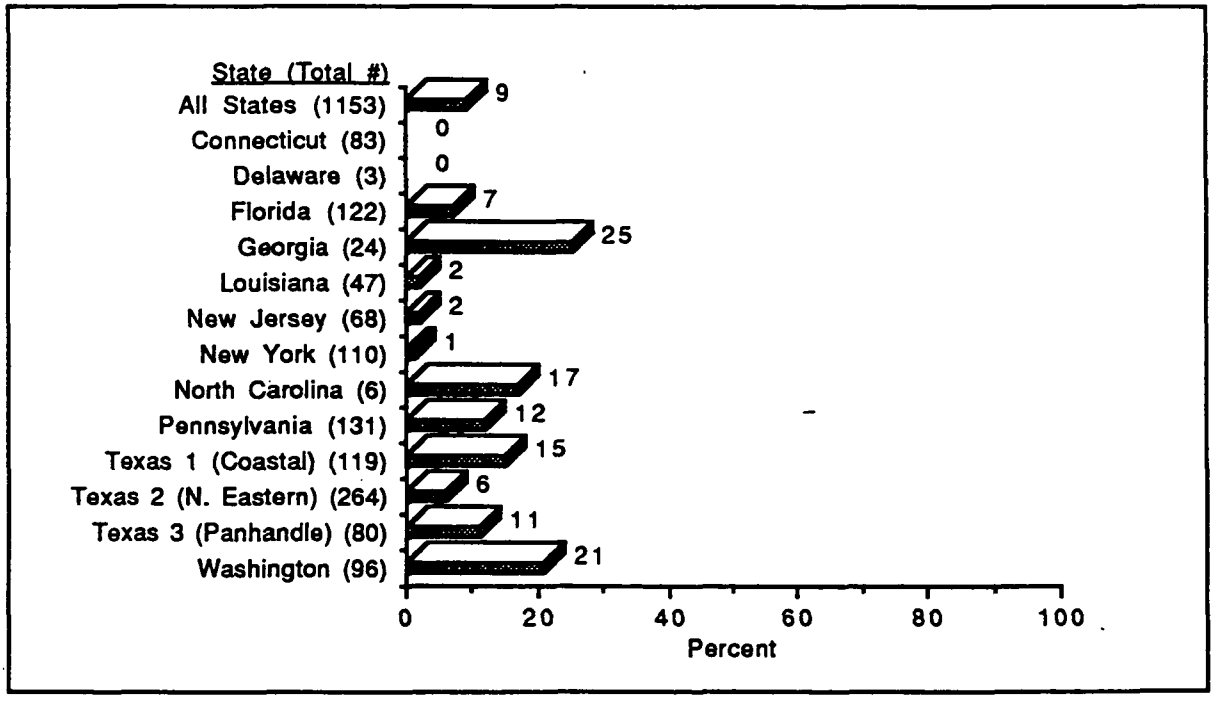


Figure 26. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of Riverine wetlands by state or region.

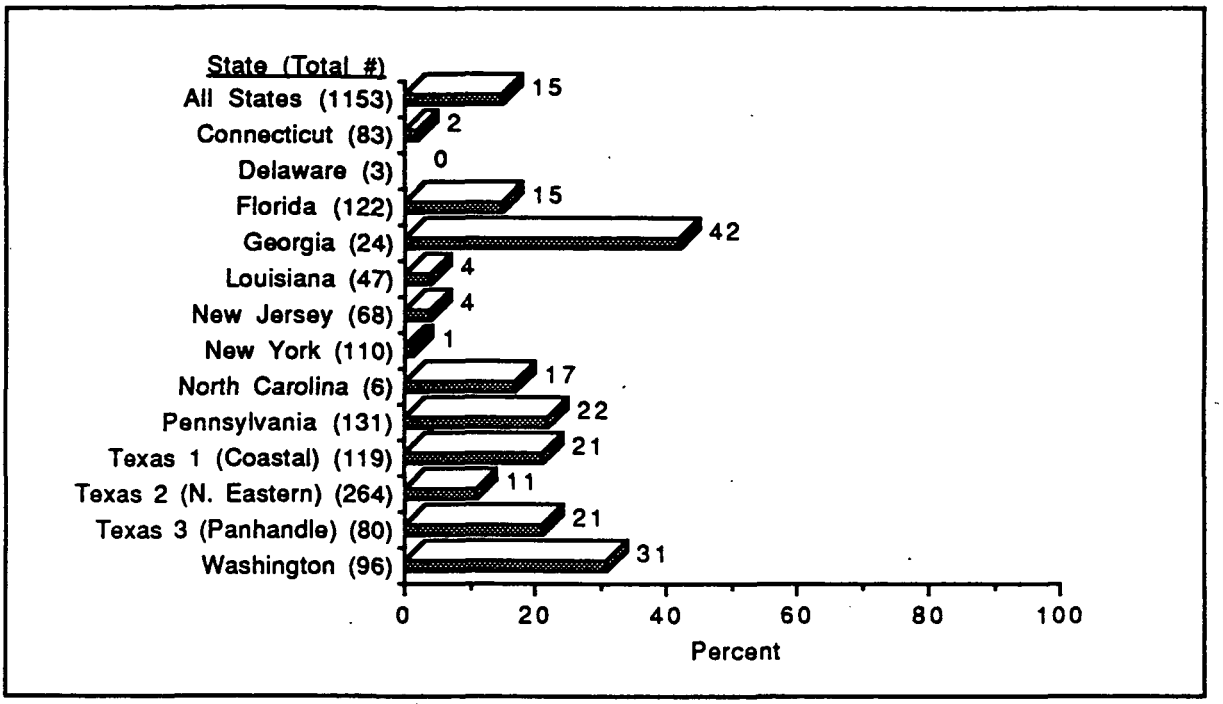


Figure 27.. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of Riverine wetlands by state or region.

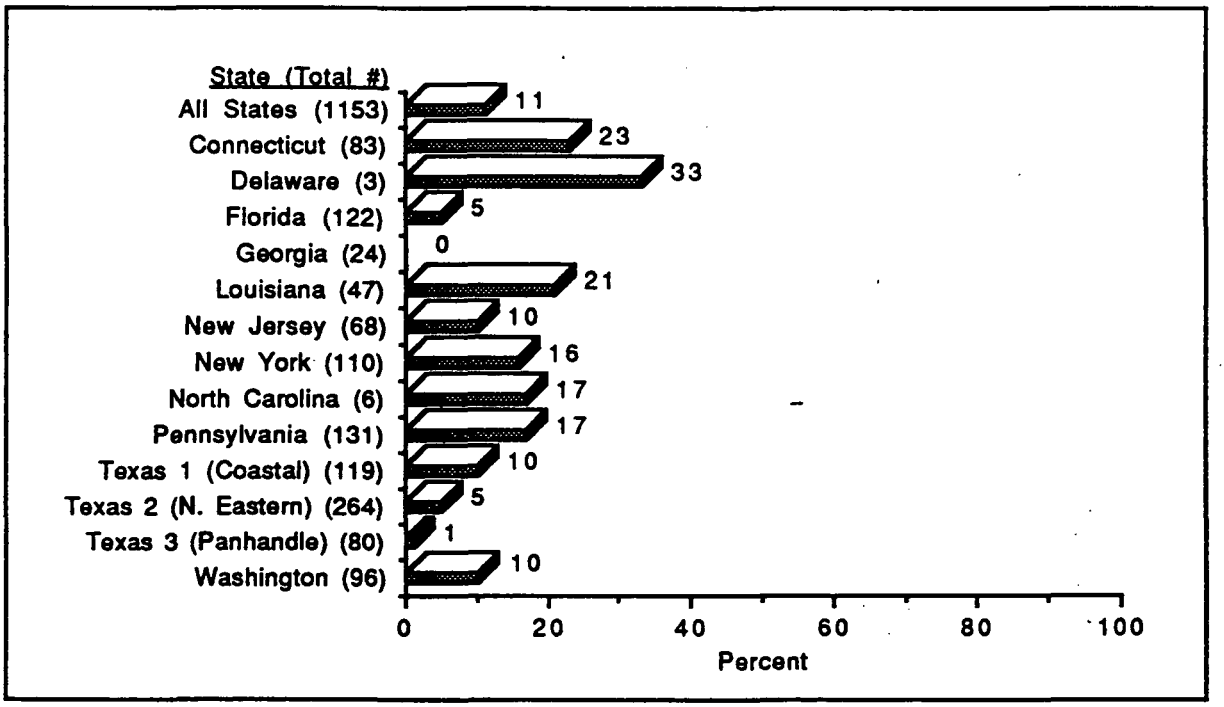


Figure 28. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of Riverine deepwater habitats by state or region.

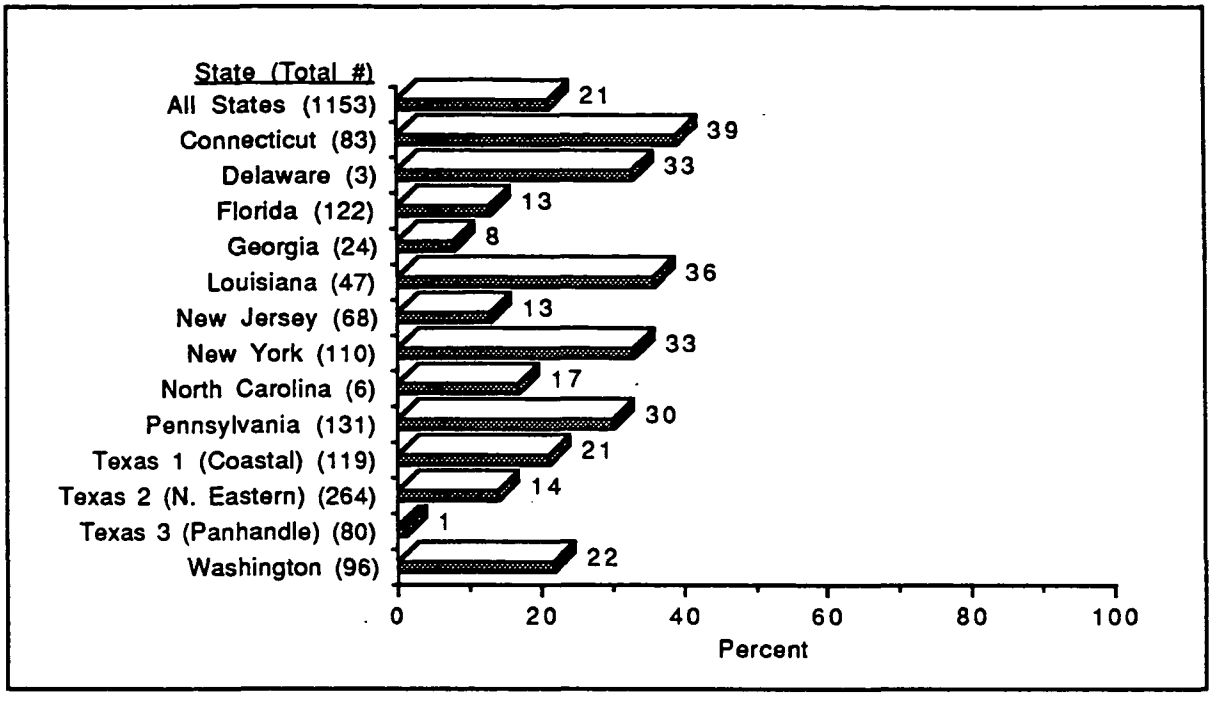


Figure 29. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of Riverine deepwater habitats by state or region.

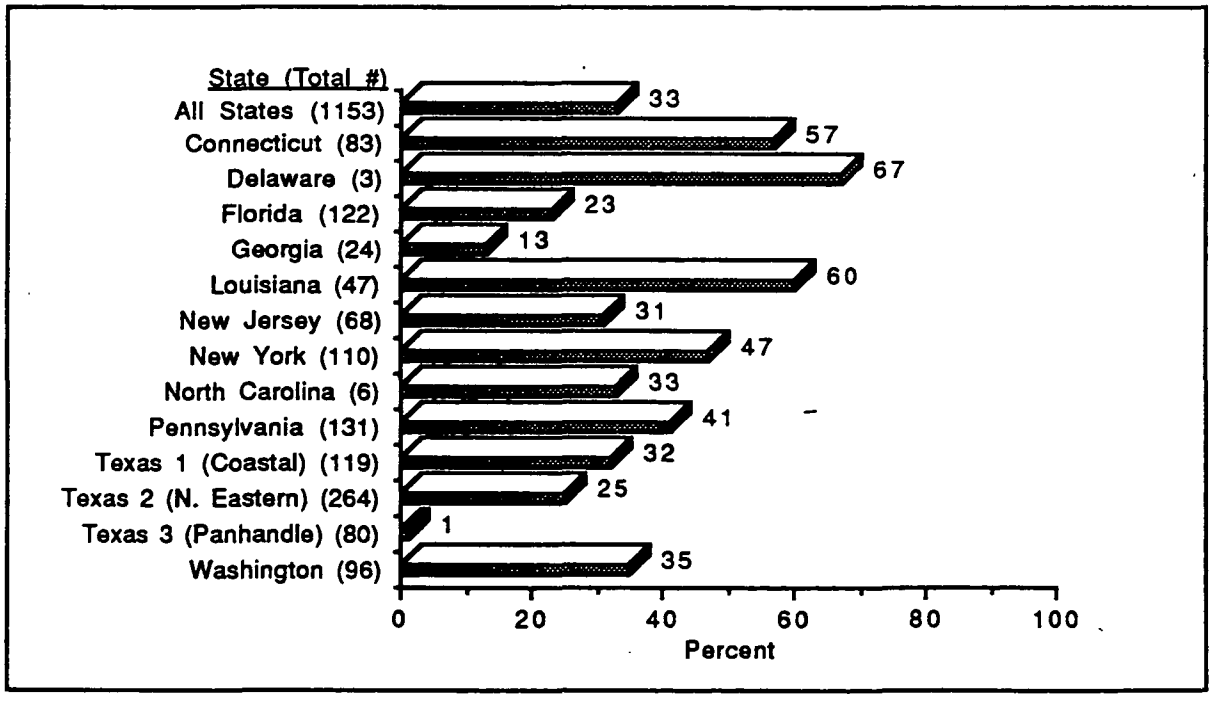


Figure 30. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of Riverine deepwater habitats by state or region.

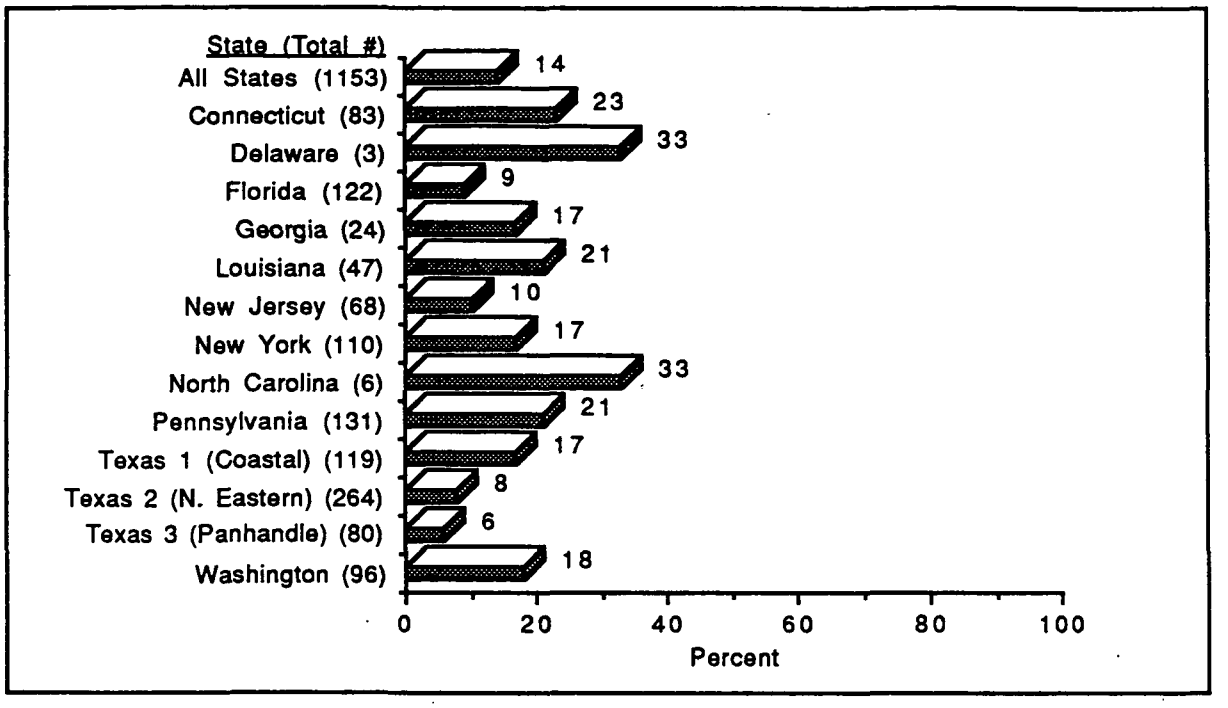


Figure 31. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of either Riverine wetlands or deepwater habitats by state or region.

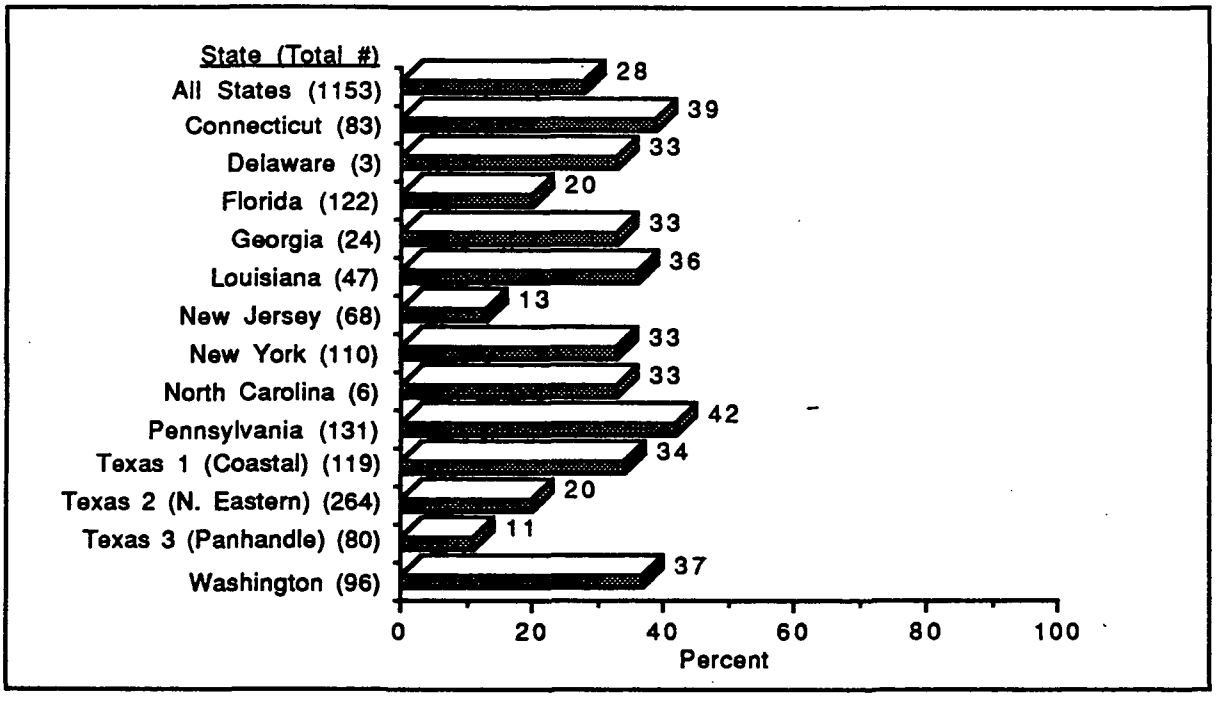


Figure 32. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of either Riverine wetlands or deepwater habitats by state or region.

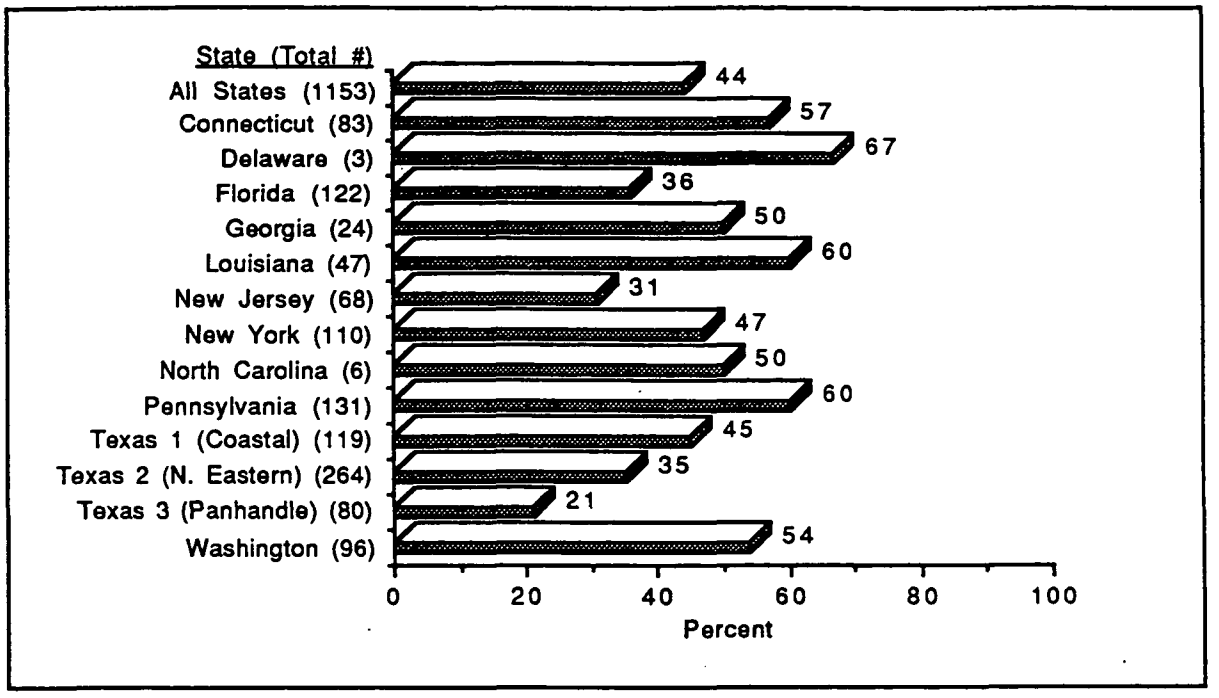


Figure 33. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of either Riverine wetlands or deepwater habitats by state or region.

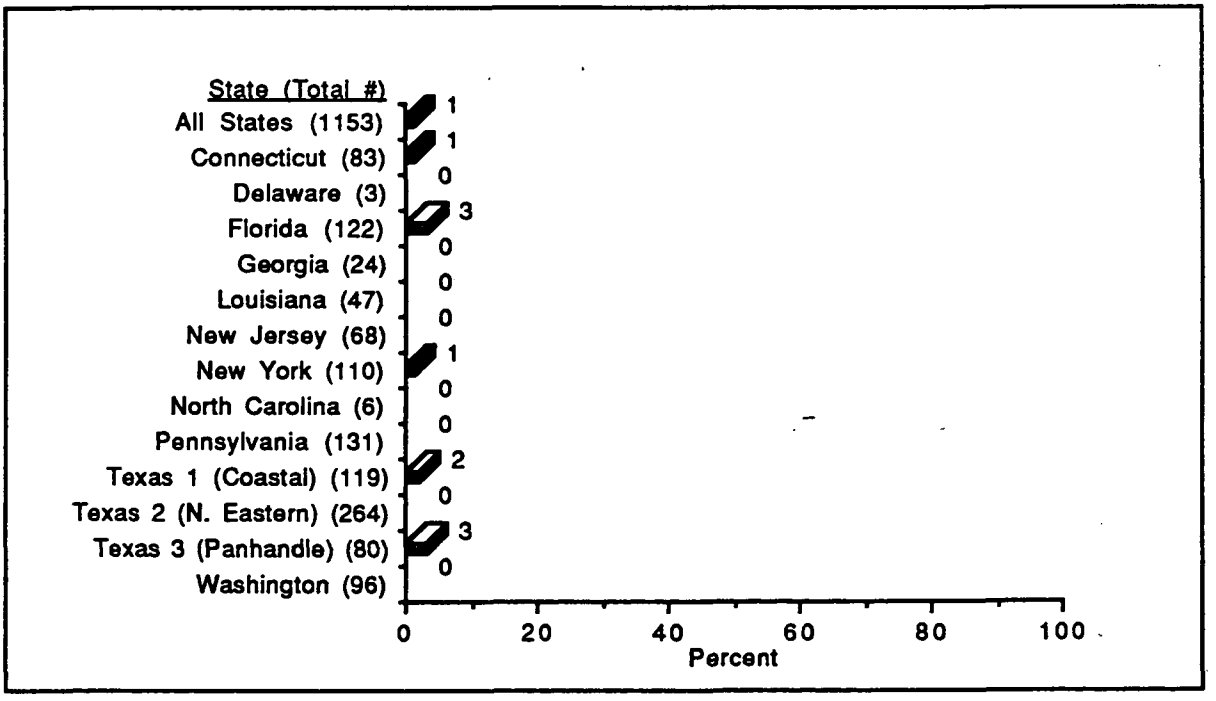


Figure 34. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of Lacustrine wetlands by state or region.

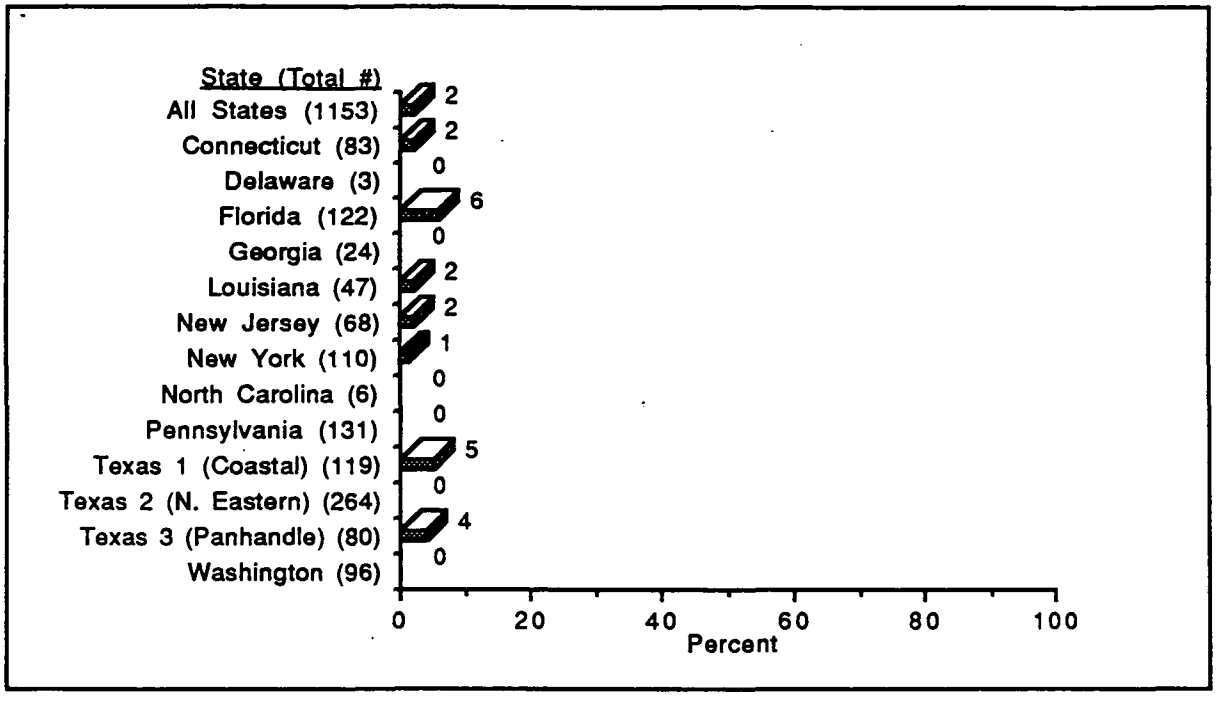


Figure 35. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of Lacustrine wetlands by state or region.

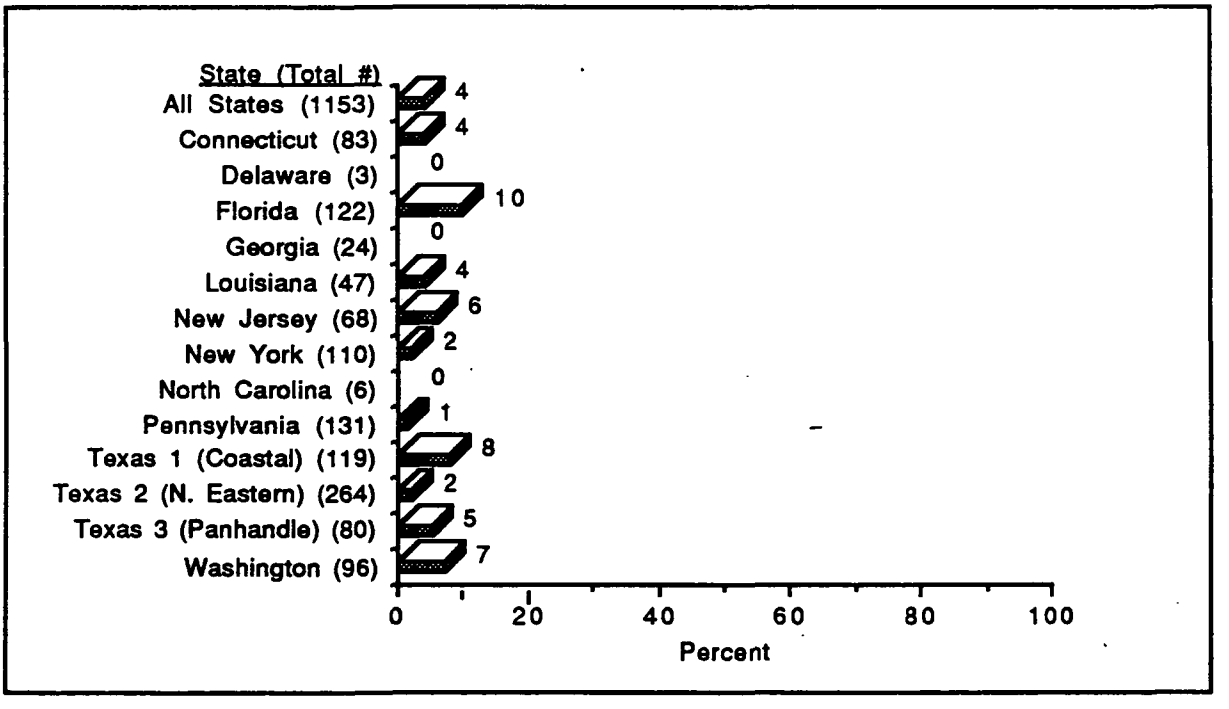


Figure 36. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of Lacustrine wetlands by state or region.

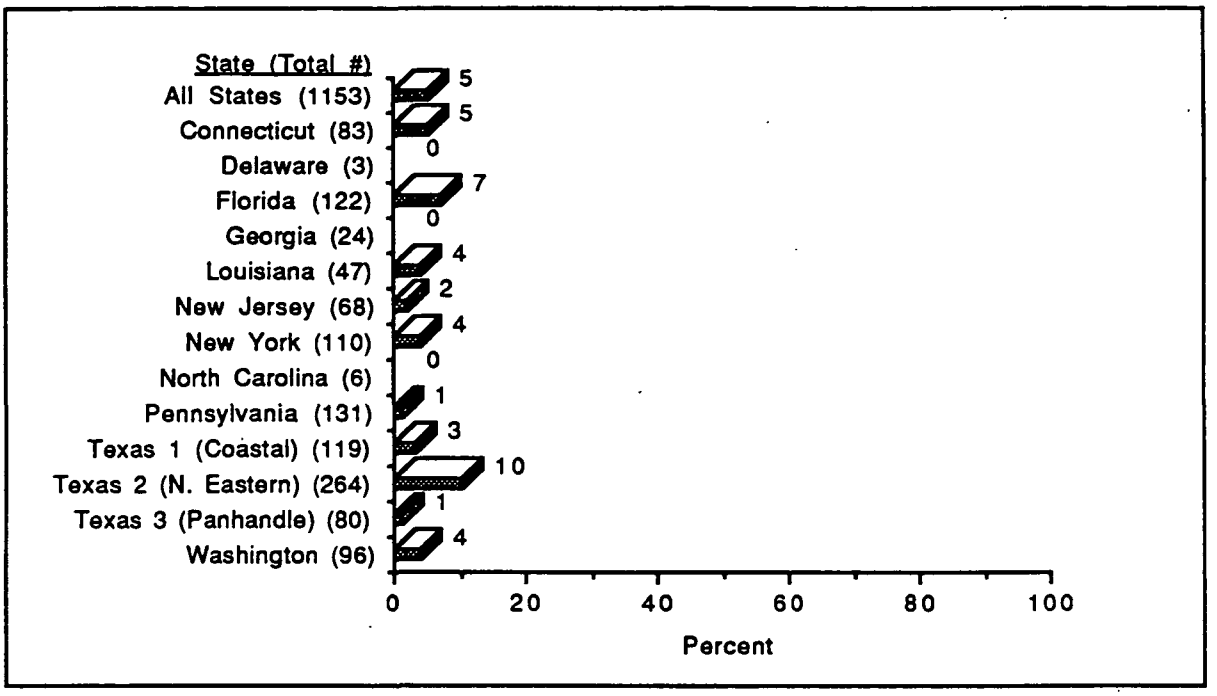


Figure 37. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of Lacustrine deepwater habitats by state or region.

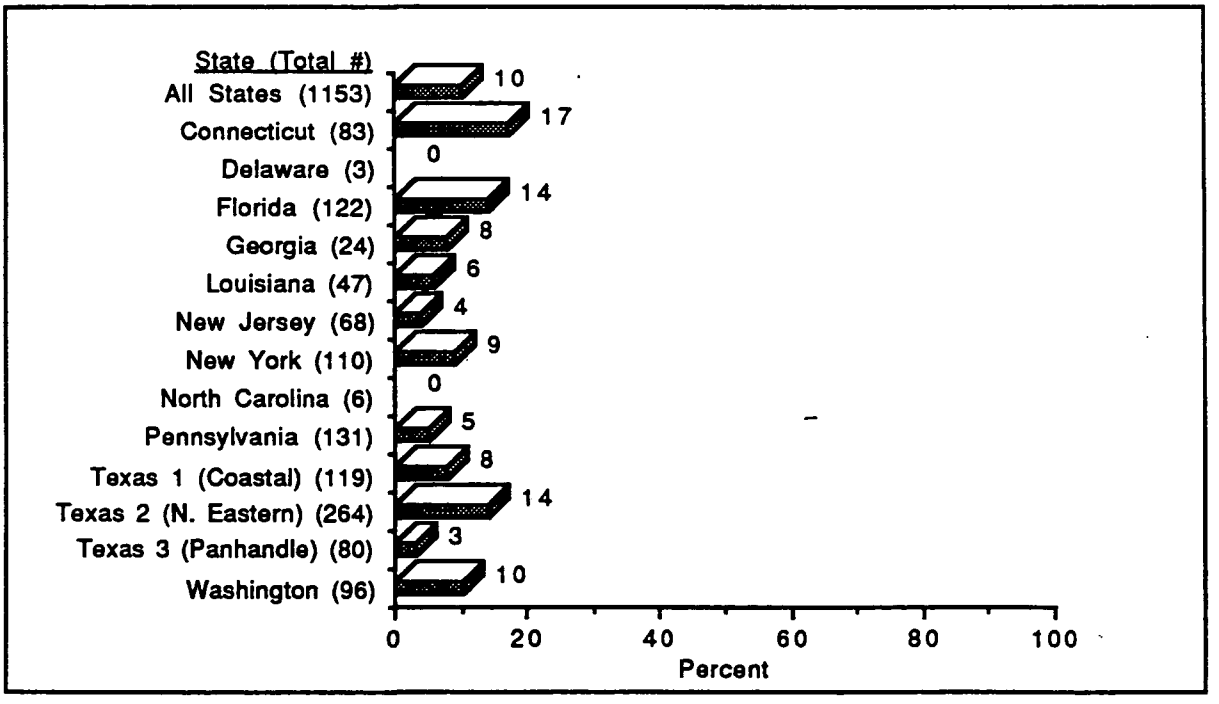


Figure 38. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of Lacustrine deepwater habitats by state or region.

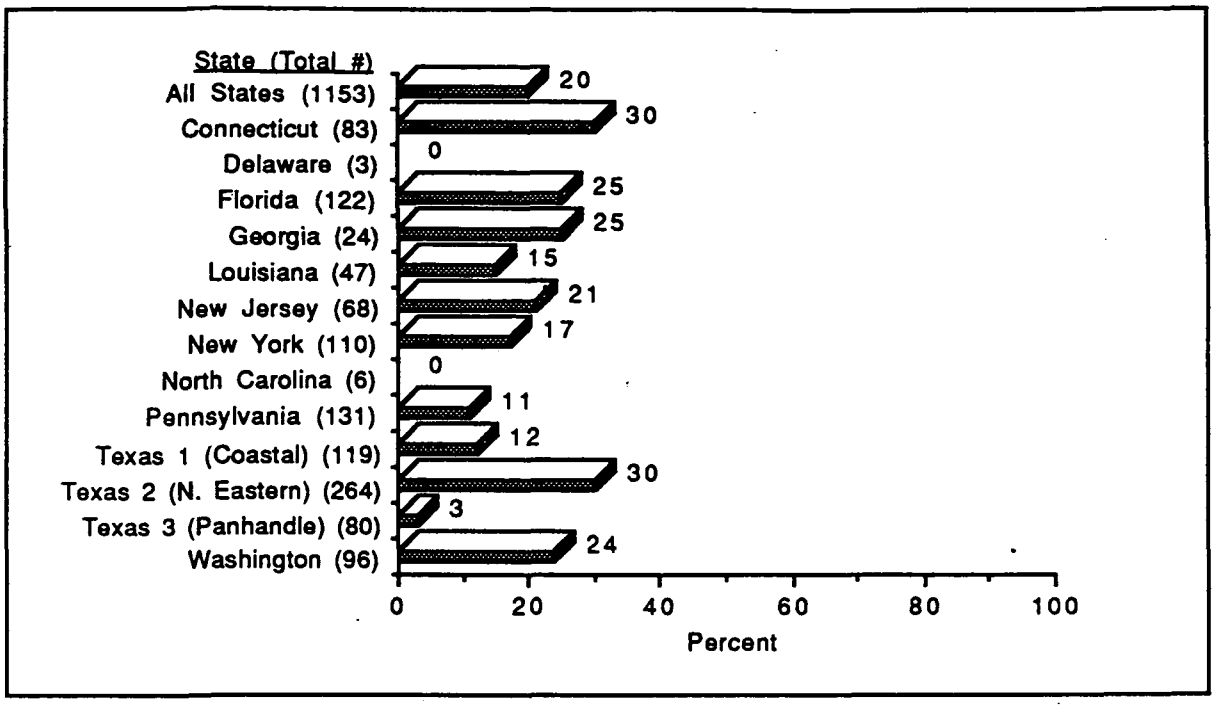


Figure 39. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of Lacustrine deepwater habitats by state or region.

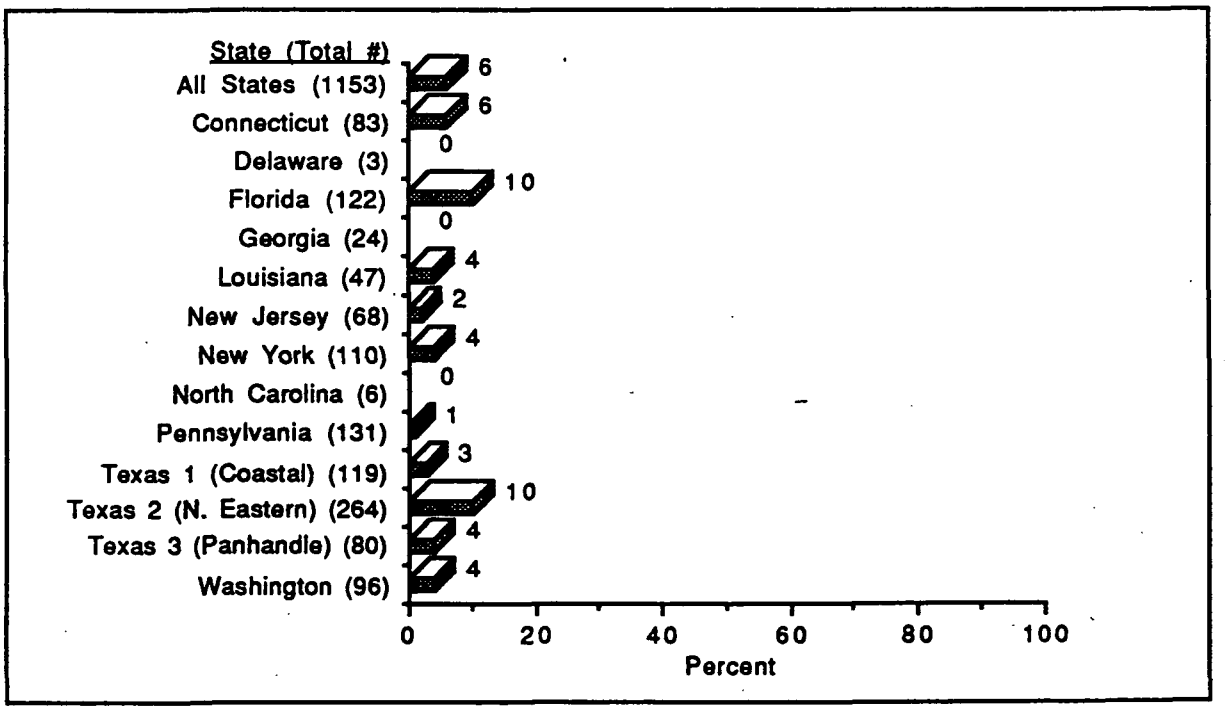


Figure 40. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of either Lacustrine wetlands or deepwater habitats by state or region.

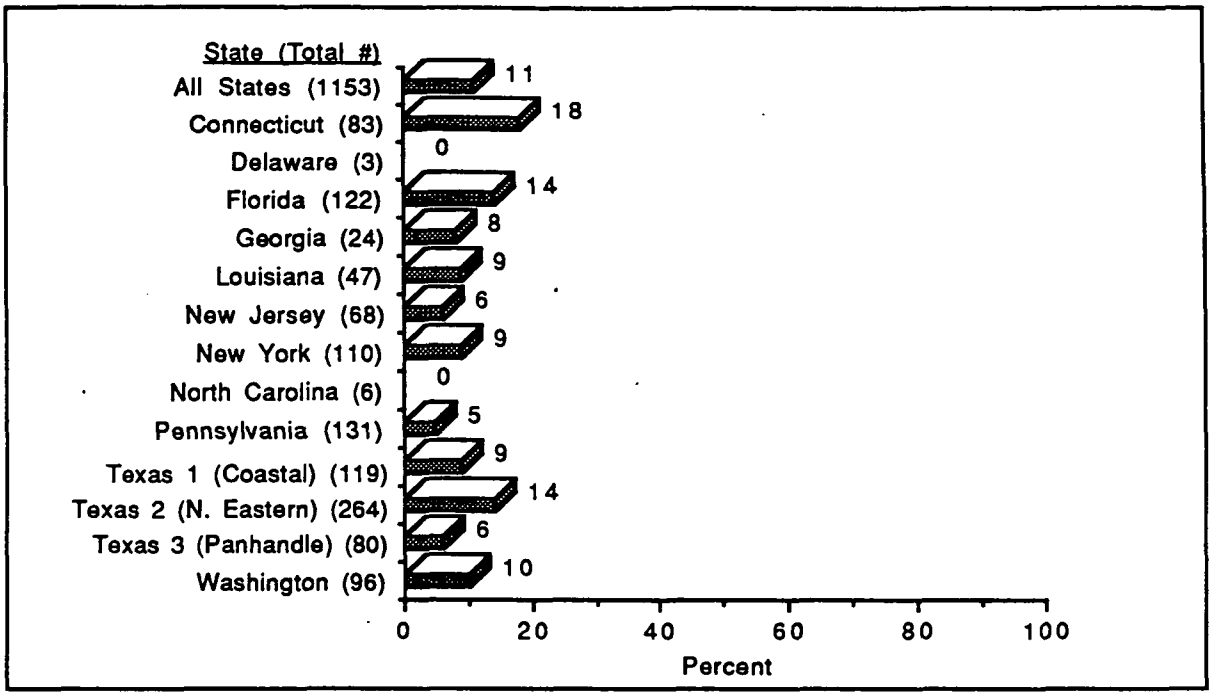


Figure 41. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of either Lacustrine wetlands or deepwater habitats by state or region.

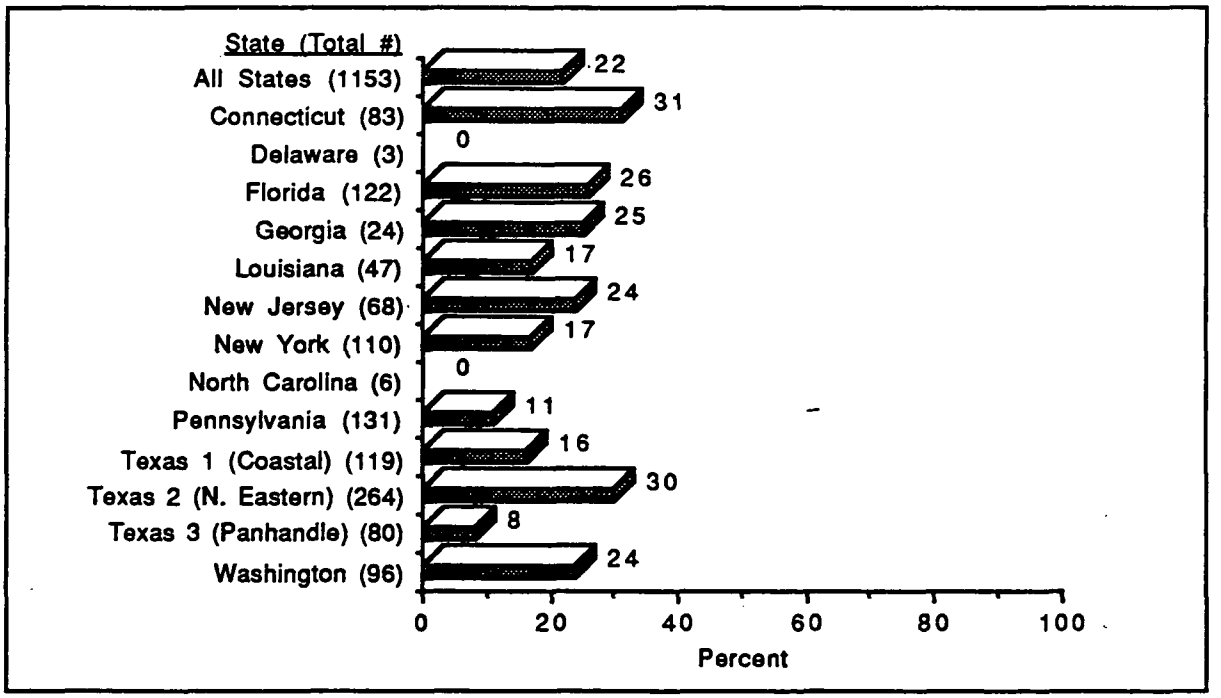


Figure 42. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of either Lacustrine wetlands or deepwater habitats by state or region.

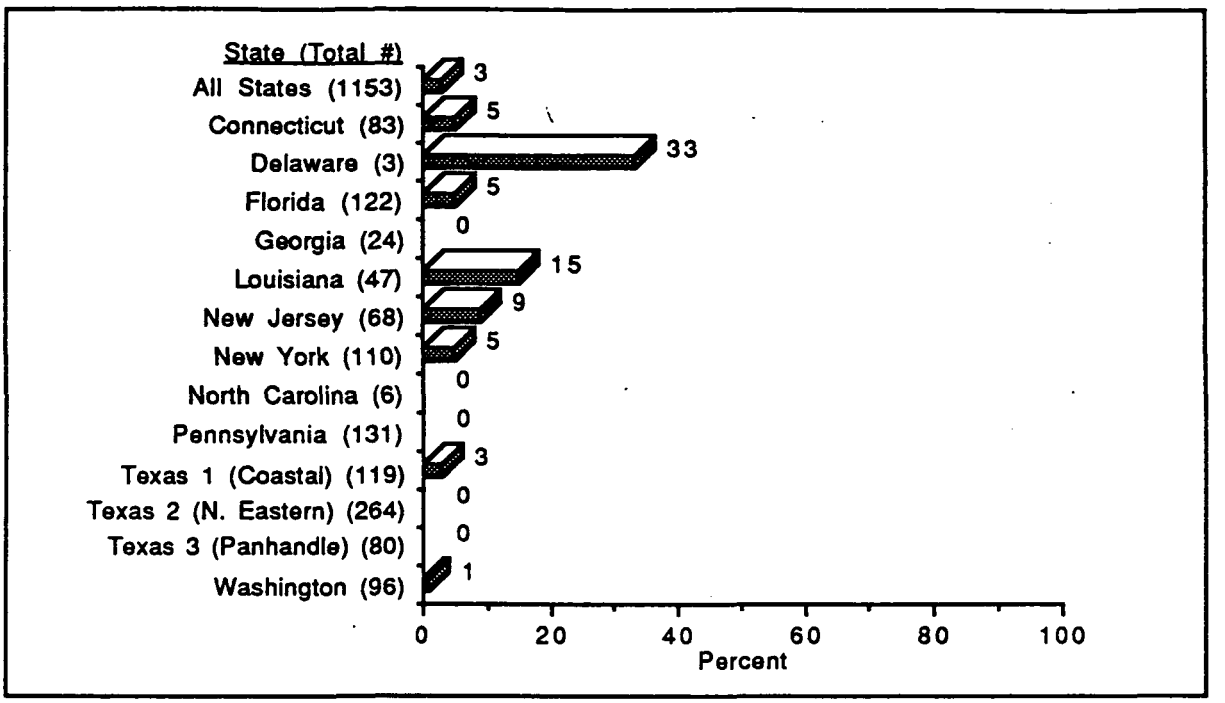


Figure 43. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of Estuarine wetlands by state or region.

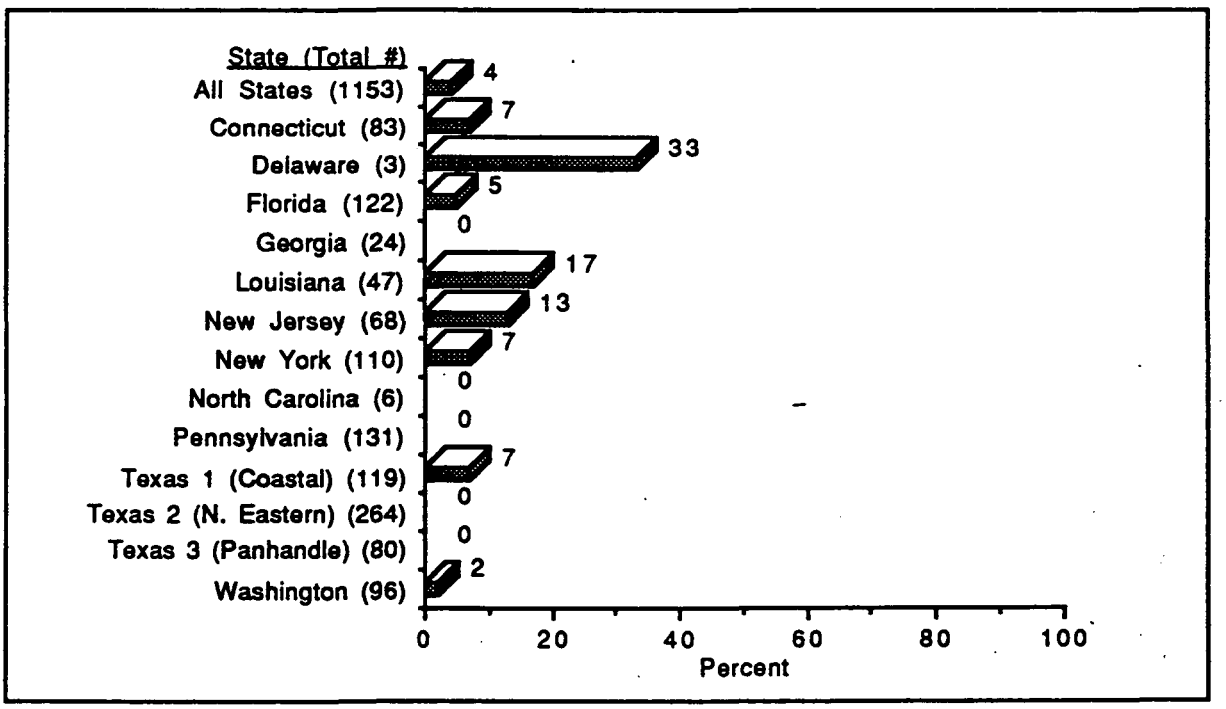


Figure 44. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of Estuarine wetlands by state or region.

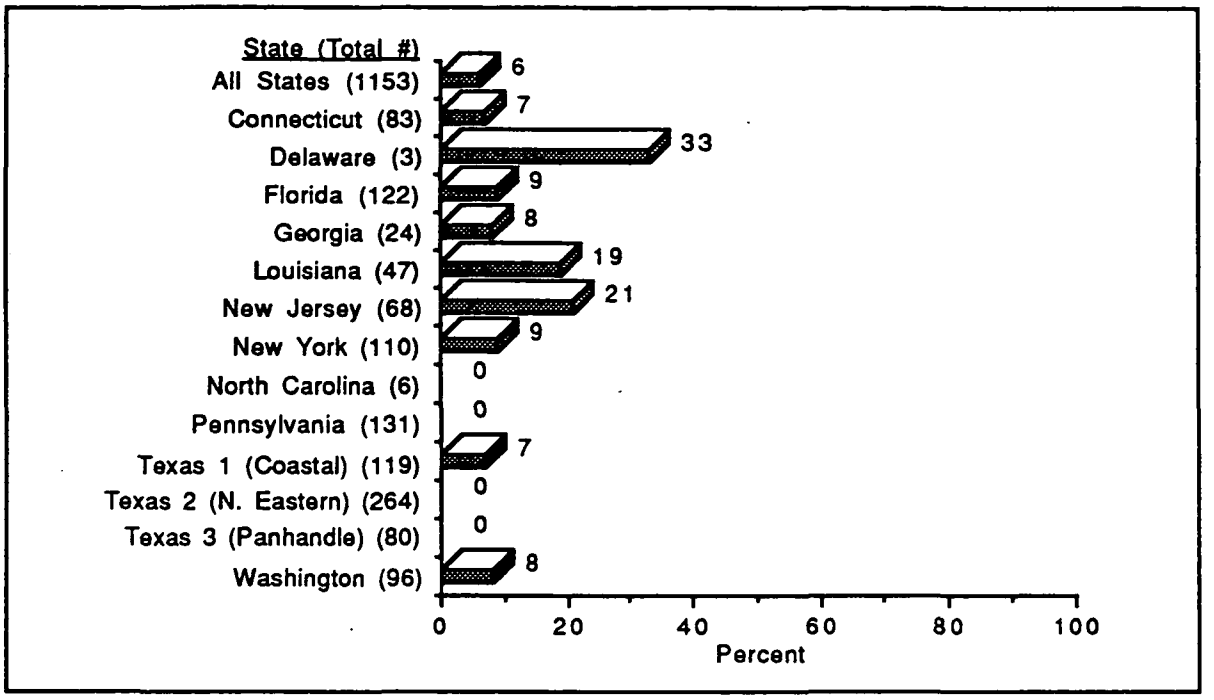


Figure 45. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of Estuarine wetlands by state or region.

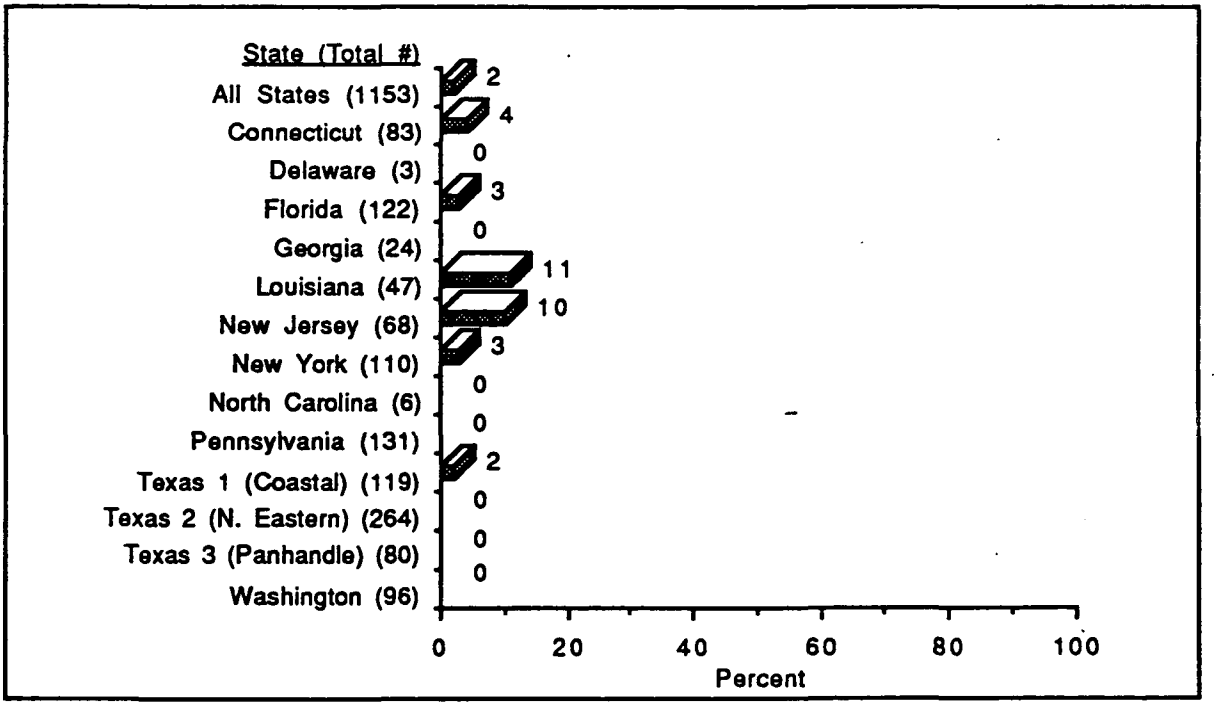


Figure 46. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of Estuarine deepwater habitats by state or region.

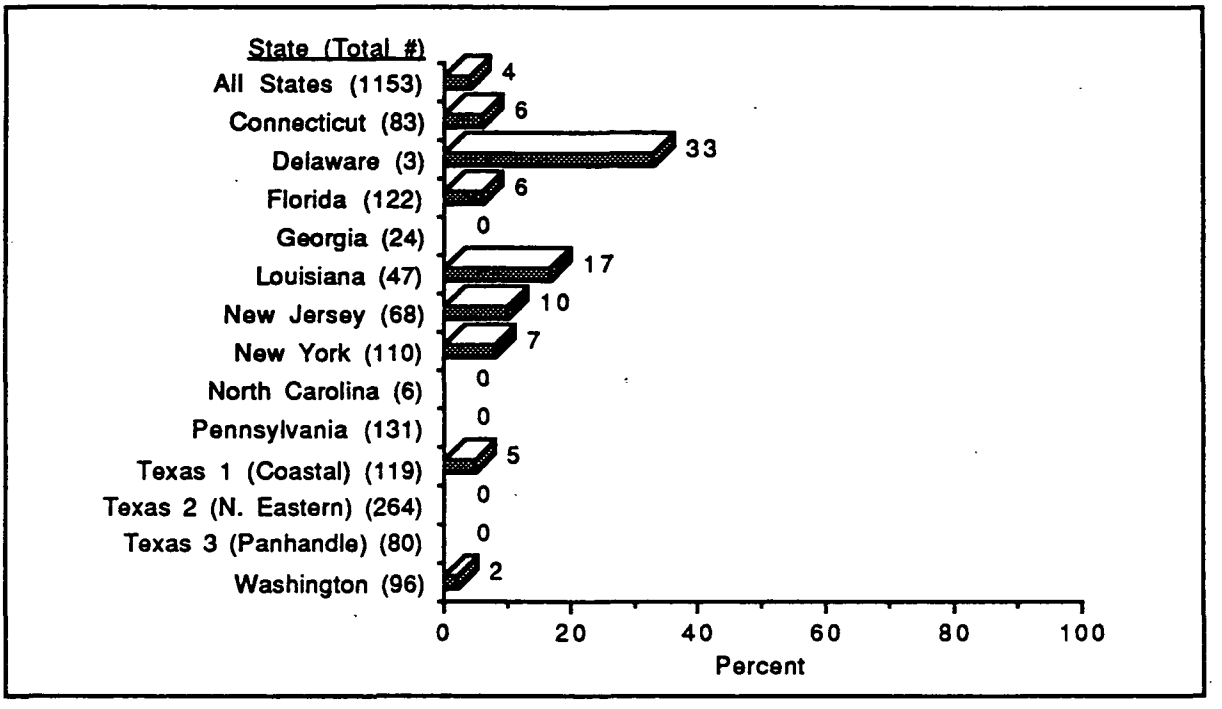


Figure 47. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of Estuarine deepwater habitats by state or region.

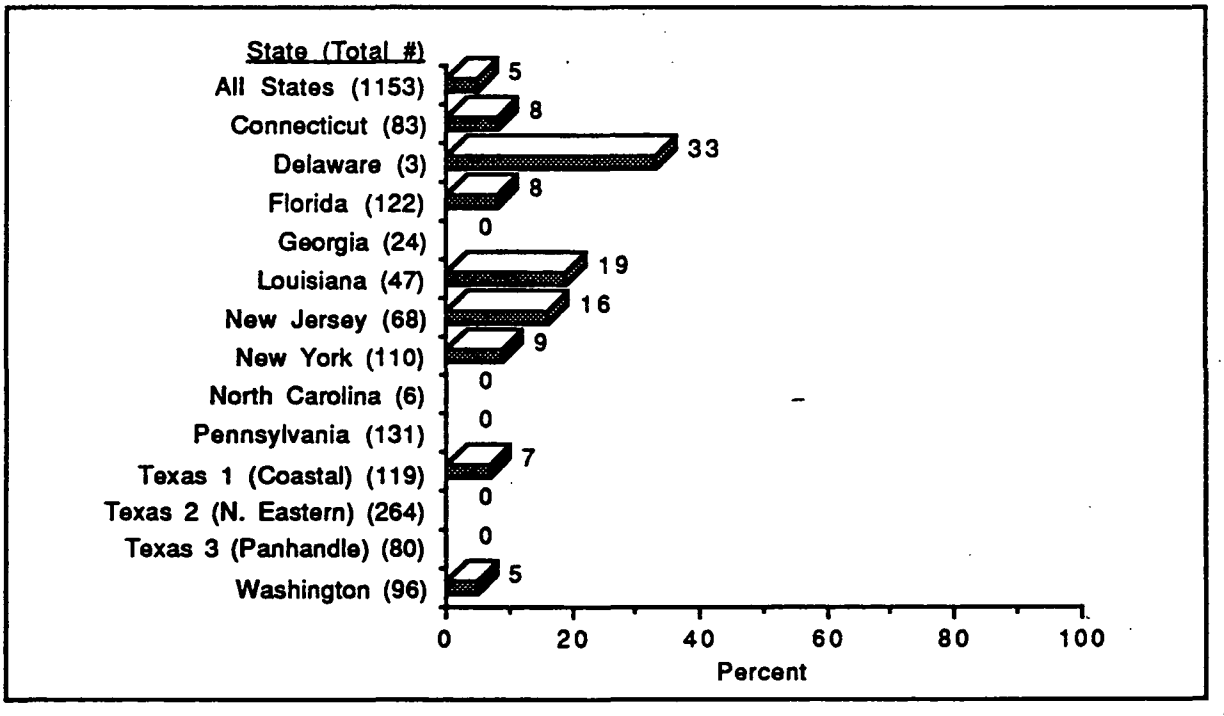


Figure 48. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of Estuarine deepwater habitats by state or region.

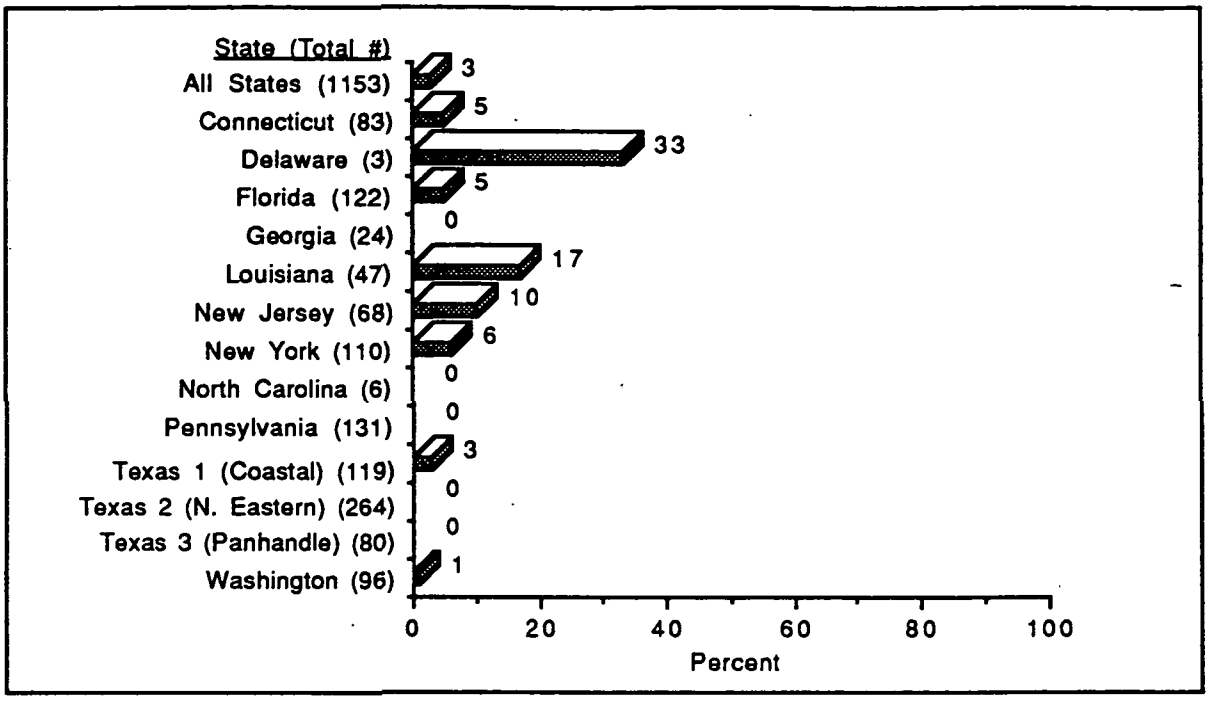


Figure 49. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of either Estuarine wetlands or deepwater habitats by state or region.

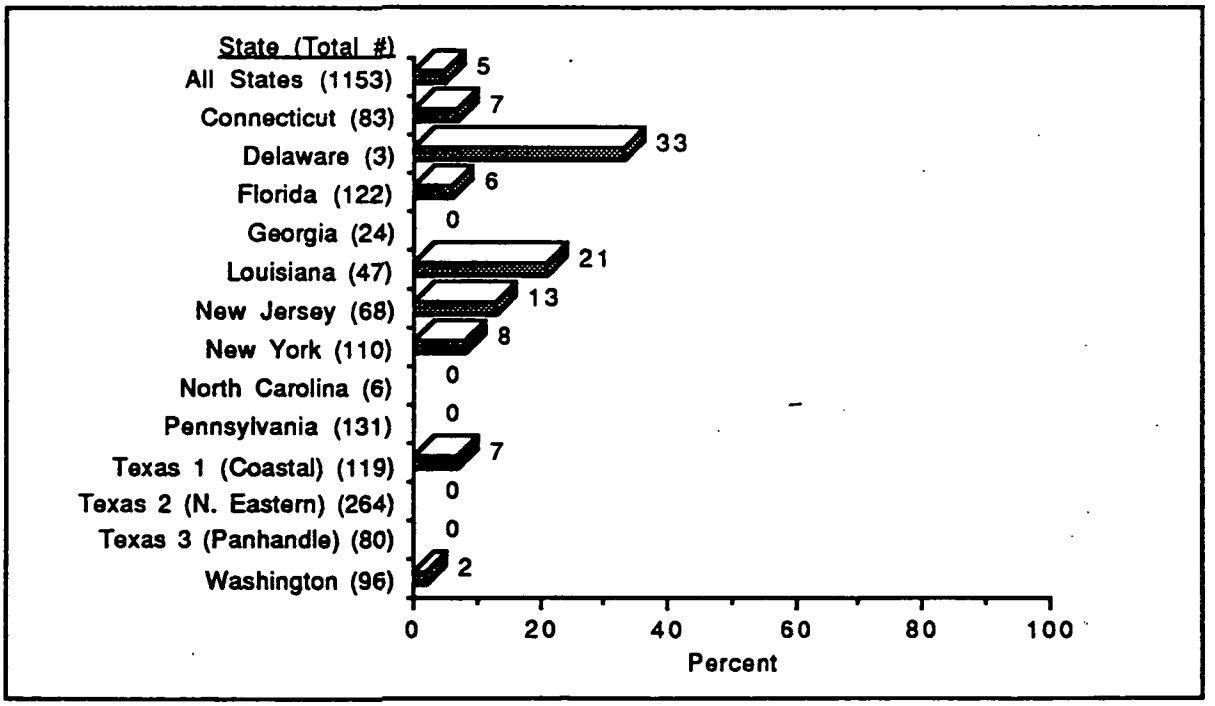


Figure 50. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of either Estuarine wetlands or deepwater habitats by state or region.

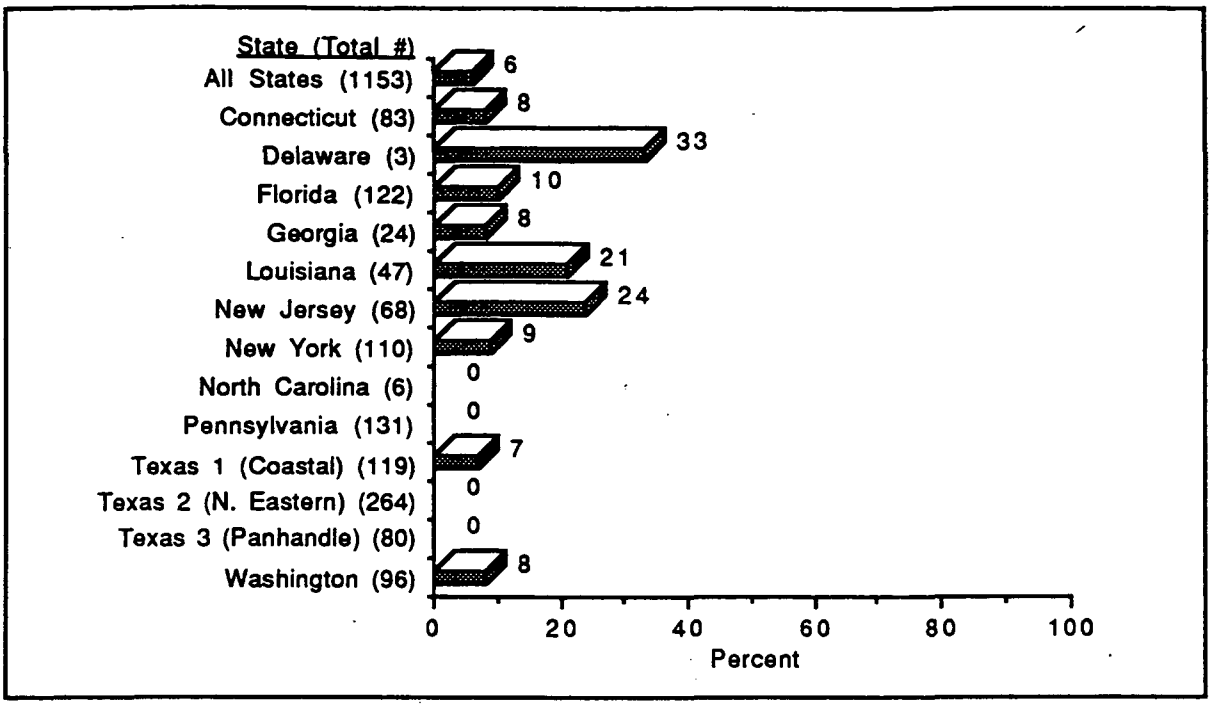


Figure 51. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of either Estuarine wetlands or deepwater habitats by state or region.

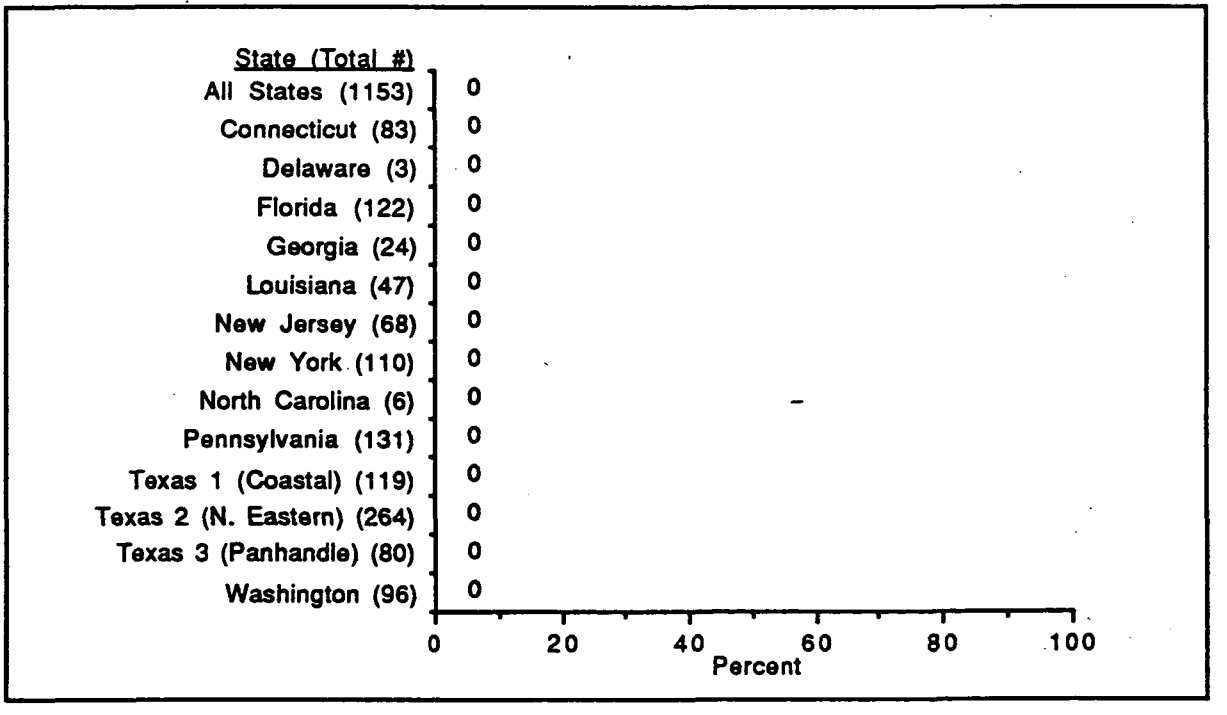


Figure 52. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of Marine wetlands by state or region.

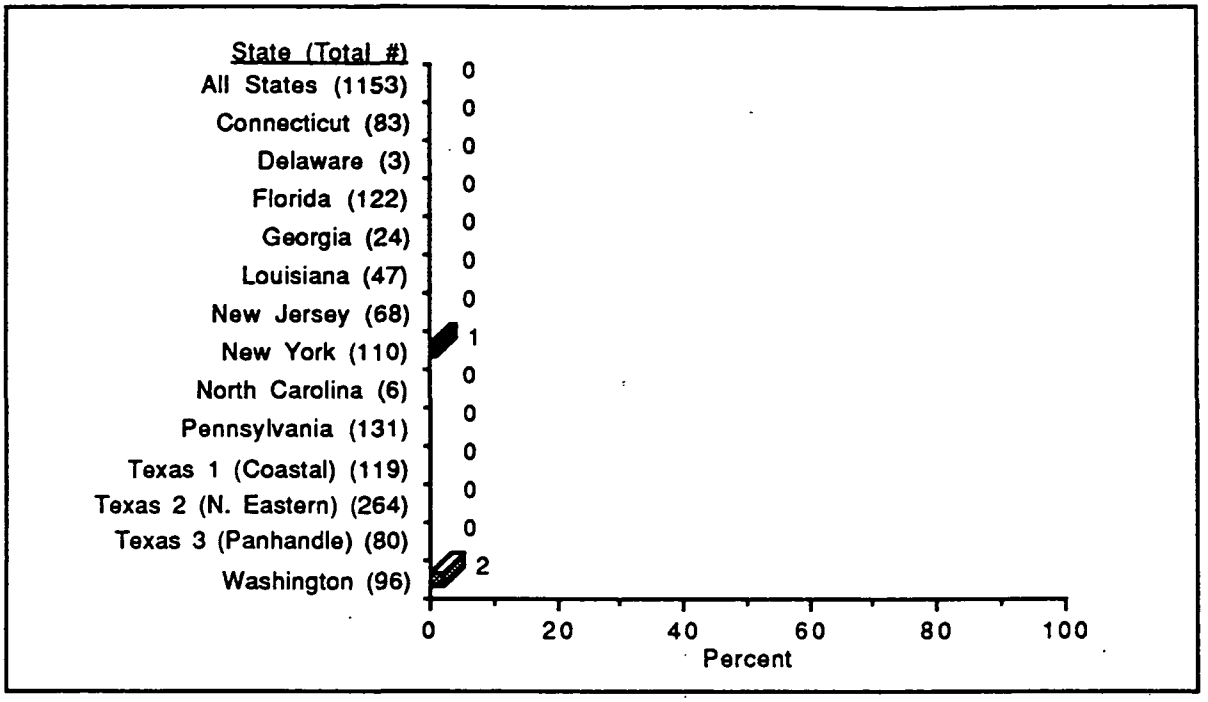


Figure 53. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of Marine wetlands by state or region.

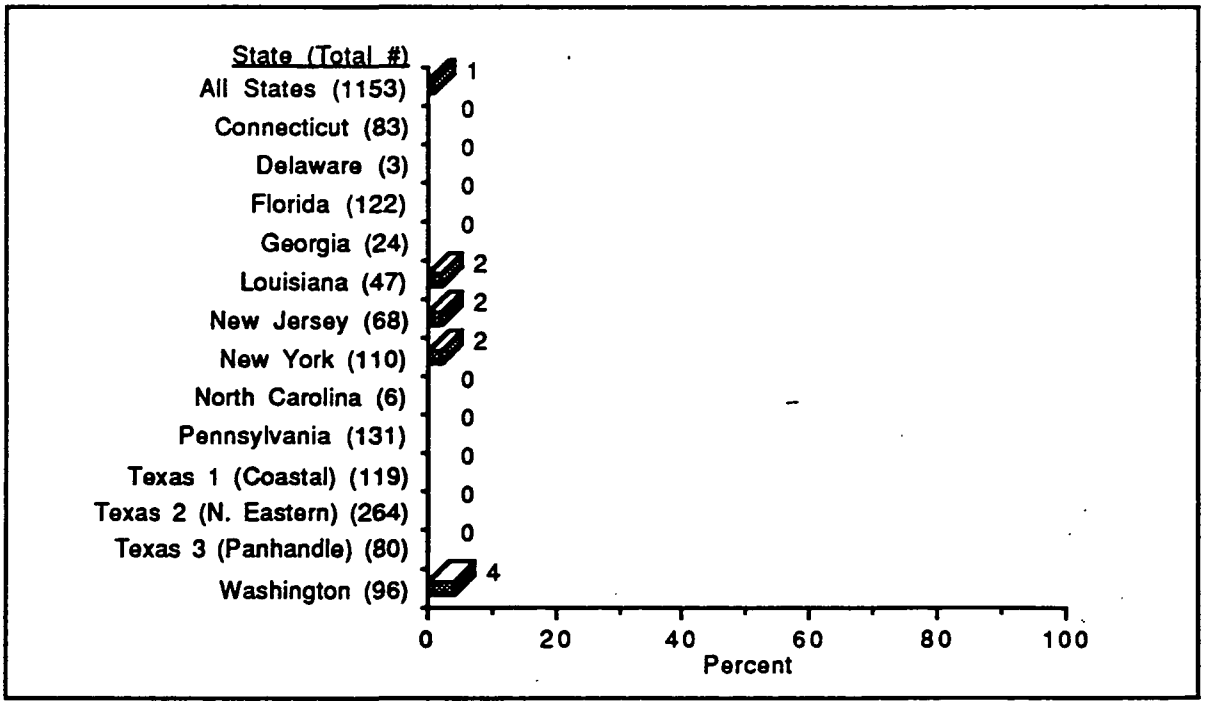


Figure 54. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of Marine wetlands by state or region.

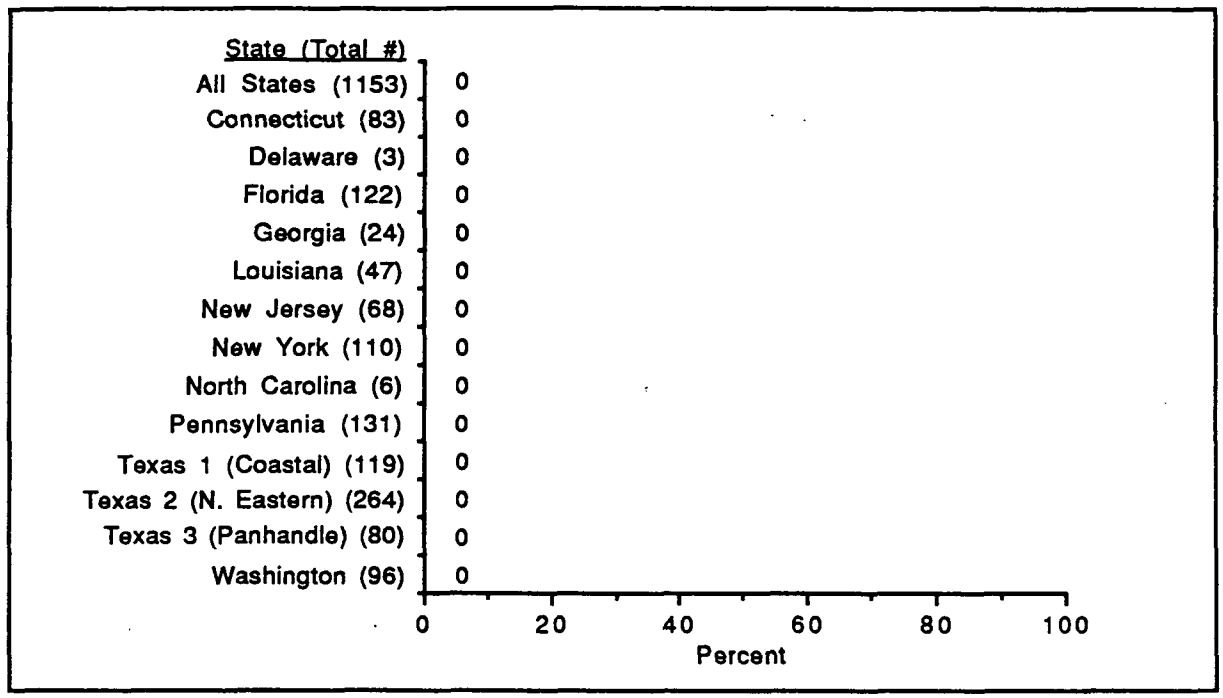


Figure 55. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of Marine deepwater habitats by state or region.

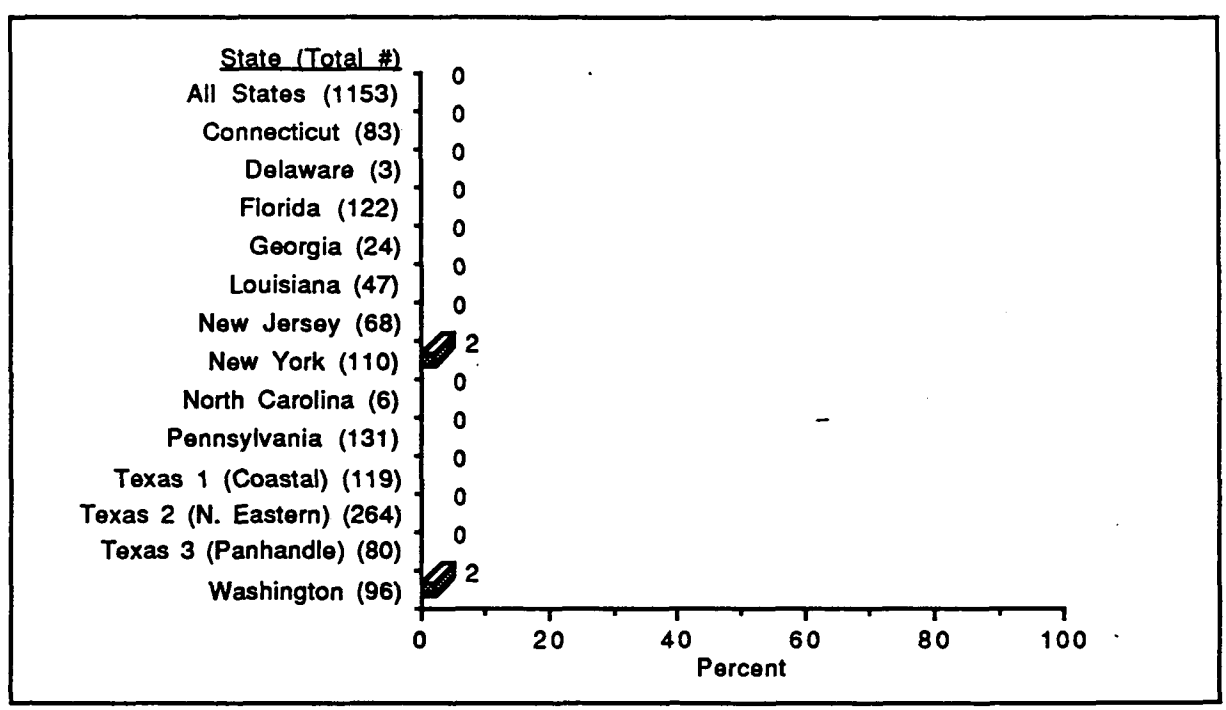


Figure 56. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of Marine deepwater habitats by state or region.

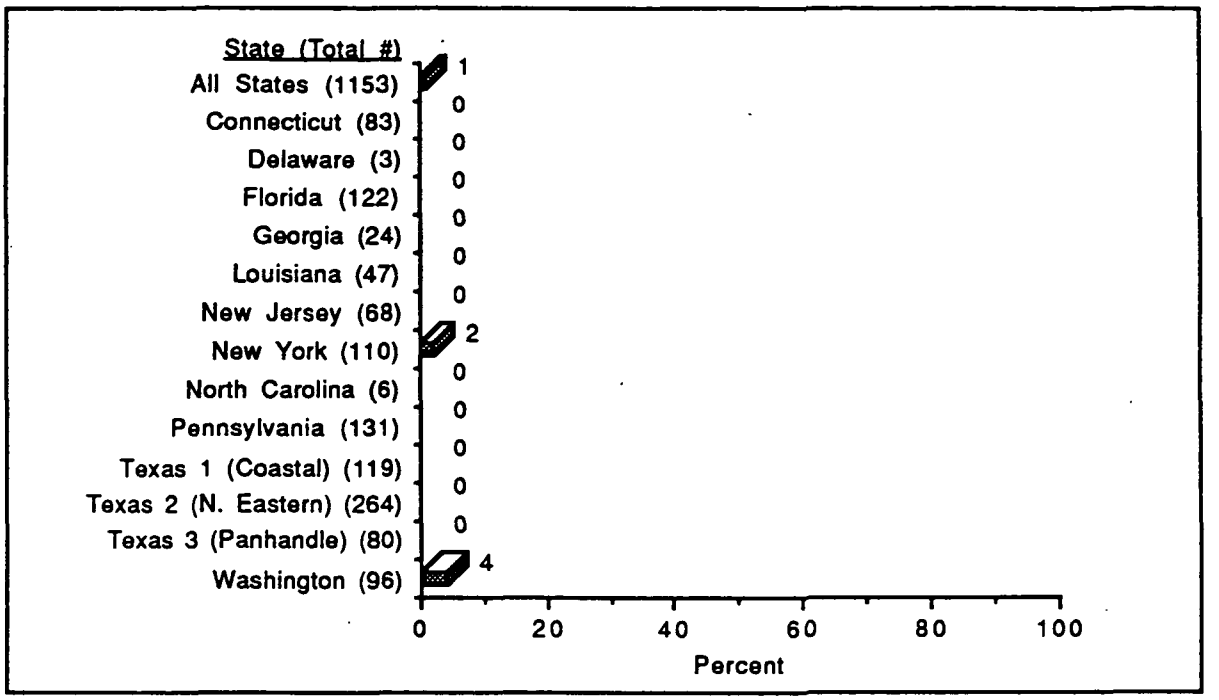


Figure 57. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of Marine deepwater habitats by state or region.

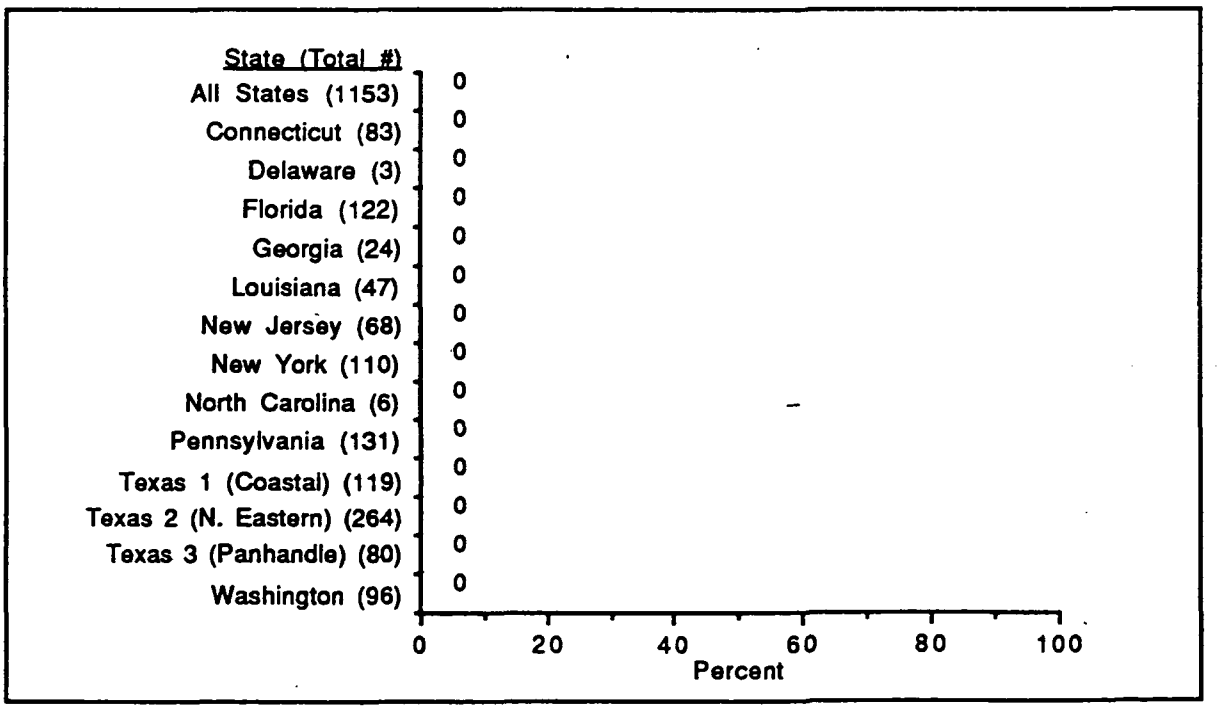


Figure 58. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/4 mile of either Marine wetlands or deepwater habitats by state or region.

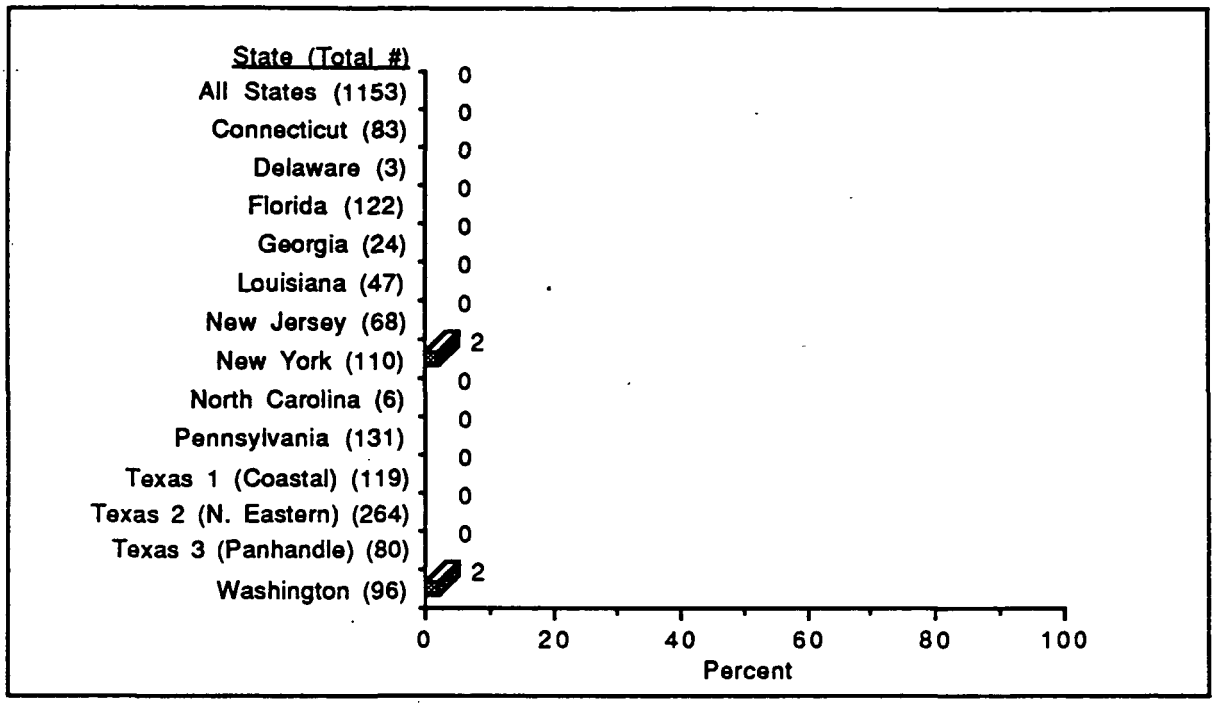


Figure 59. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1/2 mile of either Marine wetlands or deepwater habitats by state or region.

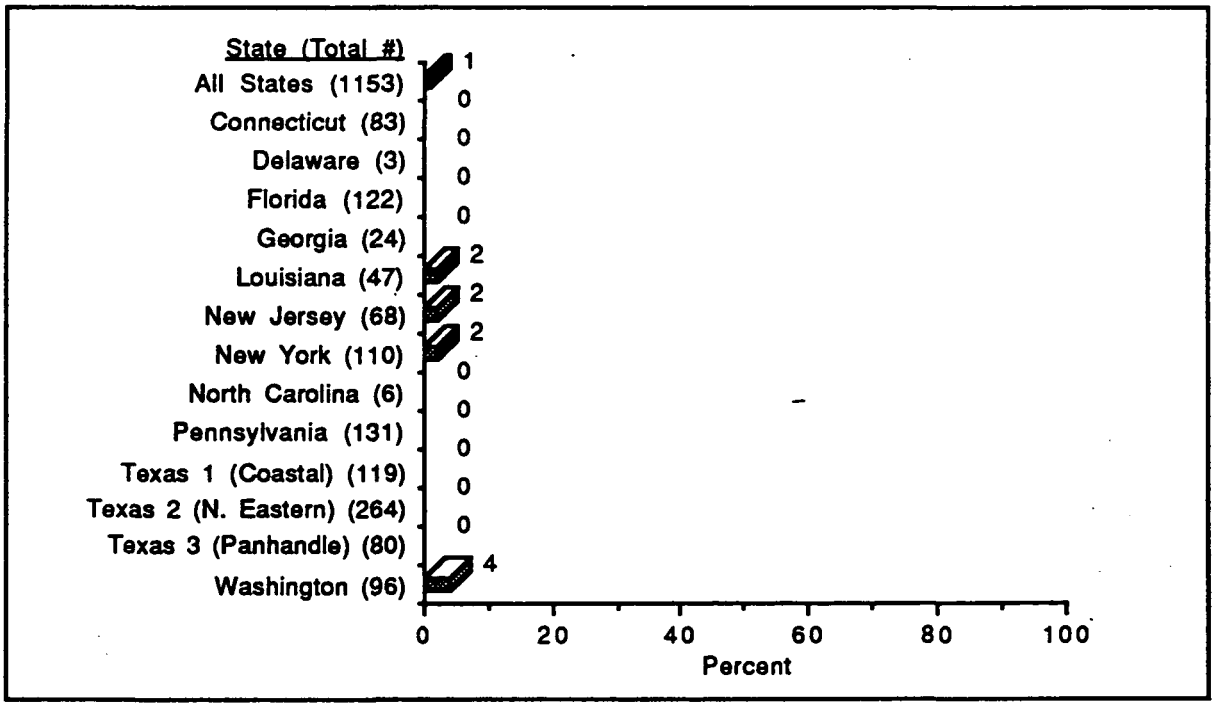


Figure 60. Percent of 1,153 sanitary landfills in 11 states that are located in or within 1 mile of either Marine wetlands or deepwater habitats by state or region.

TABLE 1. DEFINITION OF WETLANDS USED BY THE U.S. FISH AND WILDLIFE SERVICE FROM COWARDIN ET AL. (1979)

| | |
|---|---|
| Definition: | Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year. |
| Explanation: | The term wetland includes a variety of areas that fall into one of five categories: (1) areas with hydrophytes and hydric soils, such as those commonly known as marshes, swamps, and bogs; (2) areas without hydrophytes but with hydric soils-for example, flats where drastic fluctuation in water level, wave action, turbidity, or high concentration of salts may prevent the growth of hydrophytes; (3) areas with hydrophytes but nonhydric soils, such as margins of impoundments or excavations where hydrophytes have become established but hydric soils have not yet developed; (4) areas without soils but with hydrophytes such as the seaweed-covered portion of rocky shores; and (5) wetlands without soil and without hydrophytes, such as gravel beaches or rocky shores without vegetation. |

TABLE 1. (continued)

| | |
|---|---|
| Limits: | The upland limit of wetland is designated as (1) the boundary between land with predominantly hydrophytic cover and land with predominantly mesophytic or xerophytic cover; (2) the boundary between soil that is predominantly hydric and soil that is predominantly nonhydric; or (3) in the case of wetlands without vegetation or soil, the boundary between land that is flooded or saturated at some time each year and land that is not. The boundary between wetland and deepwater habitat in the Marine and Estuarine systems coincides with the elevation of the extreme low water of spring tide; permanently flooded areas are considered deepwater habitats in these systems. The boundary between wetland and deepwater habitat in the Riverine, Lacustrine, and Palustrine systems lies at a depth of 2 m (6.6 feet) below low water; however, if emergents, shrubs, or trees grow beyond this depth at any time, their deepwater edge is the boundary. |

TABLE 2. DEFINITION OF DEEPWATER HABITATS USED BY THE U.S. FISH AND WILDLIFE SERVICE FROM COWARDIN ET AL. (1979)

| | |
|---|---|
| Definition: | Deepwater Habitats are permanently flooded lands lying below the deepwater boundary of wetlands. Deepwater habitats include environments where surface water is permanent and often deep, so that water, rather than air, is the principal medium within which the dominant organisms live, whether or not they are attached to the substrate. As in wetlands, the dominant plants are hydrophytes; however, the substrates are considered nonsoil because the water is too deep to support emergent vegetation. |
| Explanation: | Wetlands and Deepwater Habitats are defined separately because traditionally the term wetland has not included deep permanent water; however, both must be considered in an ecological approach to classification. |
| Limits: | The boundary between wetland and deepwater habitat in the Marine and Estuarine systems coincides with the elevation of the extreme low water of spring tide; permanently flooded areas are considered deepwater habitats in these systems. The boundary between wetland and deepwater habitat in the Riverine, Lacustrine, and Palustrine systems lies at a depth of 2 m (6.6 feet) below low water; however, if emergents, shrubs, or trees grow beyond this depth at any time, their deepwater edge is the boundary. |

TABLE 3. DEFINITIONS OF THE FIVE MAJOR SYSTEMS* (MARINE, ESTUARINE, RIVERINE, LACUSTRINE, AND PALUSTRINE**) USED BY THE U.S. FISH AND WILDLIFE SERVICE IN CLASSIFYING WETLANDS AND DEEPWATER HABITATS FROM COWARDIN ET AL. (1979)

---

Marine:

Definition:

The Marine System consists of the open ocean overlying the continental shelf and its associated high-energy coastline. Marine habitats are exposed to the waves and currents of the open ocean and the water regimes are determined primarily by the ebb and flow of oceanic tides. Salinities exceed 30 $^{o}/_{oo}$ with little or no dilution except outside the mouths of estuaries. Shallow coastal indentations or bays without appreciable freshwater inflow, and coasts with exposed rocky islands that provide the mainland with little or no shelter from wind and waves, are also considered part of the Marine System because they support typical marine biota.

Limits:

The Marine System extends from the outer edge of the continental shelf shoreward to one of three lines: (1) the landward limit of tidal inundation (extreme high water of spring tides), including the splash zone from breaking waves; (2) the seaward limit of wetland emergents, trees, or shrubs; or (3) the seaward limit of the Estuarine System, where this limit is determined by factors other than vegetation.

---

* The term system refers to a complex of wetlands and deepwater habitats that shares the influence of similar hydrologic, geomorphologic, chemical, or biological factors.

** The first four systems, i.e., Marine, Estuarine, Riverine, and Lacustrine, include both wetland and deepwater habitats whereas the Palustrine System includes only wetland habitats.

TABLE 3. (continued)

Estuarine:

Definition:

The Estuarine System consists of deepwater tidal habitats and adjacent tidal wetlands that are usually semienclosed by land but have open, partly obstructed, or sporadic access to the open ocean, and in which ocean water is at least occasionally diluted by freshwater runoff from the land. The salinity may be periodically increased above that of the open ocean by evaporation. Along some low-energy coastlines there is appreciable dilution of sea water. Offshore areas with typical estuarine plants and animals, such as red mangroves (Rhizophora mangle) and eastern oysters (Crassostrea virginica), are also included in the Estuarine System.

Limits:

The Estuarine System extends (1) upstream and landward to where ocean-derived salts measure less than 0.5 $^{o}/_{oo}$ during the period of average annual low flow; (2) to an imaginary line closing the mouth of a river, bay, or sound; and (3) to the seaward limit of wetland emergents, shrubs, or trees where they are not included in (2). The Estuarine System also includes off-shore areas of continuously diluted sea water.

TABLE 3. (continued)

Riverine:

Definition:

The Riverine System includes all wetlands and deepwater habitats contained within a channel, with two exceptions: (1) wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens, and (2) habitats with water containing ocean-derived salts in excess of 0.5 $^{o}/_{oo}$. A channel is "an open conduit either naturally or artificially created which periodically or continuously contains moving water, or which forms a connecting link between two bodies of standing water" (Langbein and Iseri, 1960).

Limits:

The Riverine System is bounded on the landward side by upland, by the channel bank (including natural and man-made levees), or by wetland dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens. In braided streams, the system is bounded by the banks forming the outer limits of the depression within which the braiding occurs. The Riverine System terminates at the downstream end where the concentration of ocean-derived salts in the water exceeds 0.5 $^{o}/_{oo}$ during the period of annual average low flow, or where the channel enters a lake. It terminates at the upstream end where tributary streams originate, or where the channel leaves a lake. Springs discharging into a channel are considered part of the Riverine System.

TABLE 3. (continued)

Lacustrine:

Definition:

The Lacustrine System includes wetlands and deepwater habitats with all of the following characteristics: (1) situated in a topographic depression or a dammed river channel; (2) lacking trees, shrubs, persistent emergents, emergent mosses or lichens with greater than 30% areal coverage; and (3) total area exceeds 8 ha (20 acres). Similar wetland and deepwater habitats totaling less than 8 ha are also included in the Lacustrine System if an active wave-formed or bedrock shoreline feature makes up all or part of the boundary, or if the water depth in the deepest part of the basin exceeds 2 m (6.6 feet) at low water. Lacustrine waters may be tidal or nontidal, but ocean-derived salinity is always less than 0.5 $^{o}/_{oo}$.

Limits:

The Lacustrine System is bounded by upland or by wetland dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens. Lacustrine systems formed by damming a river channel are bounded by a contour approximating the normal spillway elevation or normal pool elevation, except where Palustrine wetlands extend lakeward of the boundary. Where a river enters a lake, the extension of the Lacustrine shoreline forms the Riverine-Lacustrine boundary.

TABLE 3. (continued)

Palustrine:

Definition:

The Palustrine System includes all nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5 $^{o}/_{oo}$. It also includes wetlands lacking such vegetation, but with all of the following four characteristics: (1) area less than 8 ha (20 acres); (2) active wave-formed or bedrock shoreline features lacking; (3) water depth in the deepest part of basin less than 2 m at low water; and (4) salinity due to ocean-derived salts less than 0.5 $^{o}/_{oo}$.

Limits:

The Palustrine System is bounded by uplands or by any of the other four systems.

TABLE 4. NUMBER OF SANITARY LANDFILLS BY STATE, NUMBER WITH NWI MAPS AVAILABLE, AND NUMBER CLASSIFIED AS TO THEIR PROXIMITY TO WETLANDS AND DEEPWATER HABITATS

| State | Number of sanitary landfills in state | Landfills classified | |
|---|---|---|---|
| | | Number | Percent |
| Connecticut | 91 | 83 | 91 |
| Delaware | 3 | 3 | 100 |
| Florida | 126 | 122 | 97 |
| Georgia | 198 | 24 | 12 |
| Louisiana | 93 | 47 | 51 |
| New Jersey | 73 | 68 | 93 |
| New York | 304 | 110 | 36 |
| North Carolina | 124 | 6 | 5 |
| Pennsylvania | 135 | 131 | 97 |
| Texas* | 926 | 463 | 50 |
| Texas 1 (Coastal) | 119 | 119 | 100 |
| Texas 2 (Northeastern) | 264 | 264 | 100 |
| Texas 3 (Panhandle) | 80 | 80 | 100 |
| Texas 4 (Central) | 463 | 0 | 0 |
| Washington | 118 | 96 | 81 |
| All states | 2,191 | 1,153 | 53 |
| All states except North Carolina and Region 4 (Central) of Texas | 1,604 | 1,147 | 72 |

* See Figure 2 for location of the regions in Texas.

## TABLE 5. DISTANCE OF 1,153 SANITARY LANDILLS IN 11 STATES TO THE CLOSEST WETLAND OR DEEPWATER HABITAT BY STATE OR REGION

| | Wetland | | | | | | | | Deepwater habitat | | | | | | | | Either wetland or deepwater habitat | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ≤1/4 mile | | 1/4-1/2 mile | | 1/2-1 mile | | ≥ 1 mile | | ≤1/4 mile | | 1/4-1/2 mile | | 1/2-1 mile | | ≥ 1 mile | | <1/4 mile | | 1/4-1/2 mile | | 1/2-1 mile | | ≥ 1 mile | |
| | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % |
| Connecticut | 80 | (96) | 2 | (2) | 1 | (1) | 0 | (0) | 25 | (30) | 20 | (24) | 19 | (23) | 19 | (23) | 82 | (99) | 1 | (1) | 0 | (0) | 0 | (0) |
| Delaware | 2 | (67) | 1 | (33) | 0 | (0) | 0 | (0) | 1 | (33) | 0 | (0) | 1 | (33) | 1 | (33) | 2 | (67) | 1 | (33) | 0 | (0) | 0 | (0) |
| Florida | 100 | (82) | 12 | (10) | 7 | (6) | 3 | (3) | 18 | (15) | 19 | (16) | 23 | (19) | 62 | (51) | 103 | (84) | 10 | (8) | 6 | (5) | 3 | (3) |
| Georgia | 20 | (83) | 4 | (17) | 0 | (0) | 0 | (0) | 0 | (0) | 4 | (17) | 4 | (17) | 16 | (67) | 20 | (83) | 4 | (17) | 0 | (0) | 0 | (0) |
| Louisiana | 37 | (79) | 4 | (9) | 3 | (6) | 3 | (6) | 15 | (32) | 7 | (15) | 9 | (19) | 16 | (34) | 38 | (81) | 4 | (9) | 3 | (6) | 2 | (4) |
| New Jersey | 52 | (77) | 11 | (16) | 5 | (7) | 0 | (0) | 14 | (21) | 4 | (6) | 22 | (32) | 28 | (41) | 53 | (78) | 11 | (16) | 4 | (6) | 0 | (0) |
| New York | 87 | (79) | 20 | (18) | 2 | (2) | 1 | (1) | 23 | (21) | 26 | (24) | 19 | (17) | 42 | (38) | 90 | (82) | 17 | (16) | 2 | (2) | 1 | (1) |
| North Carolina | 5 | (83) | 0 | (0) | 1 | (17) | 0 | (0) | 1 | (17) | 0 | (0) | 1 | (17) | 4 | (67) | 5 | (83) | 0 | (0) | 1 | (17) | 0 | (0) |
| Pennsylvania | 72 | (55) | 32 | (24) | 19 | (15) | 8 | (6) | 23 | (18) | 17 | (13) | 17 | (13) | 74 | (57) | 85 | (65) | 29 | (22) | 15 | (12) | 2 | (2) |
| Texas 1 (Coastal) | 76 | (64) | 33 | (28) | 10 | (8) | 0 | (0) | 18 | (15) | 19 | (16) | 18 | (15) | 64 | (54) | 80 | (67) | 32 | (27) | 7 | (6) | 0 | (0) |
| Texas 2 (N. Eastern) | 220 | (83) | 37 | (14) | 7 | (3) | 0 | (0) | 36 | (14) | 25 | (10) | 55 | (21) | 148 | (56) | 225 | (85) | 33 | (13) | 6 | (2) | 0 | (0) |
| Texas 3 (Panhandle) | 41 | (51) | 24 | (30) | 11 | (14) | 4 | (5) | 2 | (3) | 1 | (1) | 0 | (0) | 77 | (96) | 41 | (51) | 25 | (31) | 10 | (13) | 4 | (5) |
| Washington | 43 | (45) | 28 | (29) | 17 | (18) | 8 | (8) | 14 | (15) | 17 | (18) | 21 | (22) | 44 | (46) | 47 | (49) | 30 | (31) | 12 | (13) | 7 | (7) |
| All States | 835 | (72) | 208 | (18) | 83 | (7) | 27 | (2) | 190 | (17) | 159 | (14) | 209 | (18) | 595 | (52) | 871 | (76) | 197 | (17) | 66 | (6) | 19 | (2) |