ENVIRONMENTAL SENSITIVITY INDEX: WESTERN LAKE MICHIGAN

SHORELINE HABITAT MAPPING

The shoreline habitats of Western Lake Michigan were mapped during overflights conducted from 16-19 September 1991. The surveys were conducted at elevations of 300-500 feet and slow air speed, using a H-65 helicopter provided by the U.S. Coast Guard. An experienced coastal geologist delineated the coastal types directly onto 1:24,000 scale U.S. Geological Survey topographic maps, using a standardized classification scheme. Where appropriate, multiple habitats were delineated for each shoreline segment. For complicated areas or where the shoreline had changed significantly from that shown on the base maps, color infra-red aerial photographs (August 1988) provided by the U.S. Army Corps of Engineers were used to update the maps.

Prediction of the behavior and persistence of oil on intertidal habitats is based on an understanding of the dynamics of coastal environments, not just the substrate type and grain size. The vulnerability of a particular intertidal habitat is an integration of the following factors:

1) Shoreline type (substrate, grain size, tidal elevation, origin)
2) Exposure to wave and tidal energy
3) Biological productivity and sensitivity
4) Ease of cleanup

All of these factors are used to determine the relative sensitivity of shorelines. Key to the sensitivity ranking is an understanding of the relationships between: physical processes, substrate, shoreline type, product type, sediment transport, and product fate and effect. Thus, the intensity of energy expended upon a shoreline by wave action and river currents directly affects the persistence of stranded oil. The need for shoreline cleanup activities is determined, in part, by the lack or slowness of natural processes in removal of oil stranded on the shoreline.

These concepts have been used in the development of the Environmental Sensitivity Index (ESI), which ranks shoreline environments as to their relative sensitivity to oil spills, potential biological injury, and ease of cleanup. Generally speaking, areas exposed to high levels of physical energy, such as wave action and river currents, and low biological activity rank low on the scale, while sheltered areas with associated high biological activity have the highest ranking. These rankings follow a shoreline classification system that has been applied nationwide during the preparation of oil spill sensitivity maps. The list below includes the shoreline habitats delineated for Western Lake Michigan, presented in order of increasing sensitivity to spilled oil.

1A. Exposed Rocky Cliffs
1B. Exposed, Hard Man-made Structures
2. Shelving Bedrock Shores
3. Eroding Scarps in Unconsolidated Sediments
4. Sand Beaches
5. Mixed Sand and Gravel Beaches
6A. Gravel Beaches
6B. Riprap Revetments, Groins, and Jetties
7. Exposed Flats (not present in study area)
8A. Sheltered Scarps in Bedrock
8B. Sheltered Man-made Structures
9A. Sheltered Vegetated Low Banks
9B. Sheltered Sand/Mud Flats
10A. Fringing Wetlands
10B. Extensive Wetlands

SENSITIVE BIOLOGICAL RESOURCES

The biological resource information on the maps was compiled by the U.S. Fish and Wildlife Service in Green Bay, Wisconsin. Depicted on the maps are the key biological resources of the area that are most likely at risk in the event of an oil spill. There were four major categories of biological resources considered during the production of the maps. These categories are birds, fish, plants, and mammals.

The areal distributions on the maps represent a group of species that are present in that area. In many cases, a certain group of species will occur in many different places. These groups are combined into species assemblages. There are five assemblages of birds with 6-28 species in each assemblage. Instead of listing all of the species each time they occur, only the assemblage is listed, with the species list for the assemblage identified in the legend.

Birds

The birds are divided into several species groupings or subelements based on behavior and genealogy. The species table shows the listing of all the birds and their subelements included on the maps. These species were included because of the potential for impact by an oil spill, or because they had a special protected status. All bird distributions are shown on the map as polygons in one color and pattern (green hatching). There is an identification number in each of the polygons that can be referenced back to a table with the list of species and seasonalities for the birds present in that particular polygon. Bird polygons have numbers in the range of 1,001-1,999. The tables for the polygons are presented on the page opposite the map. To identify the birds in a particular area, find the polygon number on the map for the birds. Then go to the table and look up the polygon number. Following the number will be a list of species that are present in the polygon. For each species an X is placed in the column corresponding to the month the species is present in the area encompassed by the polygon. The T/E column indicates if the species is threatened (T) or endangered (E). The last four columns in the table indicate the months that the species is nesting, laying, hatching, and fledging.

Fish

The fish areas depicted on the maps are either the spawning areas for many species of fish, or areas of particularly high fish concentrations. Species shown on the maps are important commercial or recreational fish or species that are an important part of the ecosystem. Only one polygon color and pattern was used to represent fish distribution (blue hatching). There is an identification number within the polygon that references a table with the complete list of species and seasonal distributions. Fish polygons have numbers in the range of 1-999. The tables for the polygons are presented on the page opposite the map. To identify the fish in a particular area, find the polygon number on the map for the fish. Then go to the table and look up the polygon number. Following the number will be a list of species that are present in the polygon. For each species an X is placed in the column corresponding to the month the species is present in the area encompassed by the polygon. The T/E column indicates if the species is threatened (T) or endangered (E). The last two columns in the table indicate the months that the species is spawning and when the juvenile are outmigrating.

Terrestrial Plants

All of the terrestrial plants included in this atlas are species that are on the State or Federal list of threatened or endangered plants, and found in the areas near the shoreline. These plants may not be impacted directly by a spill of oil since they are found above the normal high water line, but they could be impacted during the cleanup operations. The polygons for the plants represent the general location where the plants are found. The exact location is not identified in order to protect the plants. In the event of a spill in the vicinity of one of the indicated areas, the Wisconsin Department of Natural Resources Bureau of Endangered Resources (608/266-7012) should be contacted to determine the location of the plants and proper procedures for working in the area.

Mammals

Although mammals were considered for inclusion in the atlas, none are depicted on the maps or included in the database. There are several species of mammals which are likely to be impacted by oil spills along the shore of Lake Michigan. Even though they are considered very sensitive resources, they were not depicted because they do not occur in appreciable concentrations at any location and are widely scattered throughout their range. The species of mammals in the area that might be impacted are raccoon (*Procyon lotor*), mink (*Mustela vison*), river otter (*Lutra canadensis*), and beaver (*Castor canadensis*). Only the raccoon is found throughout the study area, with the other species being restricted to the northern portion of the region.

HUMAN-USE FEATURES

Many different human use features are depicted on the maps using a range of symbols. The features shown on the map are those that would either be impacted by an oil spill, would provide access to the cleanup operations, or both. All of the features are represented on the maps by symbols that indicate the type of feature. For most of the features a line is drawn from the symbol to the exact location of the feature. The features shown on the map include:

Access–Sites where beach access by vehicle is possible. This information was provided by the U.S. Coast Guard.

Airport–Location of airports or airfields whether they are manned or unmanned. The locations were obtained from visual observations during the overflights, airports depicted on topographic maps, and from information provided by the U.S. Coast Guard.

Known archeological sites–The symbol does not show the exact location of the archeological site but indicates that there is a site in the vicinity. The State Historic Preservation Society of Wisconsin (608/264-6509) should be contacted if one of these sites is likely to be impacted by a spill or the associated response activities. The information on the map was provided by Historic Preservation Society.

Boat ramp–This information was provided by the U.S. Coast Guard.

Coast Guard–Identifies the location of U.S. Coast Guard stations.

Ferry–Shows the location of ferry docks. The information was provided by the state.

Historical site–This symbol shows the location of historical sites as provided by the Historic Preservation Society.

Hoist–This symbol indicates facilities which have the capability to hoist boats into and out of the water. Many times hoists are associated with marinas. The information was provided by the U.S. Coast Guard.

Marina–These symbols show the locations of all the marinas that were identifiable in the area. Marina locations were provided by the U.S. Coast Guard and visual observations during the overflights. More detailed information for the marinas can be obtained from the U.S. Coast Guard MSO Area Plan.

Park–This symbol identifies both state and federal parks. Local parks are not shown on the map. The park locations were obtained from USGS topographic maps.

Water intake–This symbol is placed where the actual water intake is located in the lake. The location information was provided by the U.S. Coast Guard.

GEOGRAPHIC INFORMATION SYSTEM DATA

The entire atlas product is stored in digital form in a Geographic Information System (GIS). The information is stored as maps and associated databases. The format for the data varies depending on the type of information or features for which the data are being stored. The three major formats are shoreline habitat classification, human-use features, and biological resources.

Shoreline Habitat Classification

The shoreline habitat classification is stored as lines or polygons with the data identifying the type of habitat associated with the line. In many cases a shoreline segment may have two or three different classifications. These multiple classifications are represented on the maps by double and triple lines, and in the data base by ESI#1/ESI#2 where ESI#1 is the landward-most classification and ESI#2 is the lakeward-most classification.

Human-Use Features

The human-use features are represented on the maps as an icon describing the feature. In the digital file the icon location is represented by a point. Attached to the point is a data file that contains fields for the name of the owner/manager, phone number at which the person can be contacted, identification of the type of feature, and a brief description of the feature. This information is incomplete and frequently changes, so it is not included in the atlas.

Sensitive Biological Resources

Biological resources are shown on the map by colored and shaded polygons and lines. The color of the polygon indicates whether the resources is a bird, fish, or plant. The shading is used to identify the extent of the polygon. In the digital copy the biological resources are also represented by polygons and lines. Associated with each feature is an identification number. This identification number is linked to a series of databases that describe the resource for that particular polygon or line. The first data set is a list of the species (indicated by a species identification number) present in the polygon, the concentration of each species (when available), and links the database with expert contacts for that species in that area, temporal distribution information (by month) for that species at that location, and identification of the species. The expert contacts list contains the name, phone number, address, and agency of the person most suited to contact about information on the species of concern in the area of concern. The temporal distribution data base includes the months the species is present, and the months of certain phases of breeding activity. For birds, it indicates the times of nesting, laying, hatching, and fledging. For fish, spawning and outmigration times are identified. The identification database identifies the species by common name, scientific name, species grouping by genealogy and behavior, and state or federal threatened or endangered status.

PRIMARY REFERENCES

Becker, G.C., 1983, Fishes of Wisconsin. The University of Wisconsin Press, Madison, Wis., 1052 pp.

Coberly, C. and R.M. Horrall, 1980, Fish spawning grounds in Wisconsin waters of the Great Lakes. University of Wisconsin Sea Grant Institute, Madison, Wis., 43 pp.

Robbins, S.D., 1991, Wisconsin birdlife, population and distribution, past and present. University of Wisconsin Press, 702 pp.

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SPECIES TABLES*

ID	Common Name	Species Name
Birds		
1	Piping plover	*Charadrius melodus*
2	Common snipe	*Capella gallinago*
3	American woodcock	*Philohela minor*
4	Great blue heron	*Ardea herodias*
5	Green heron	*Butorides striatus*
6	Virginia rail	*Rallus limicola*
7	Sora rail	*Porzana carolina*
8	Sandhill crane	*Grus canadensis*
9	Black-crowned night heron	*Nycticorax nycticorax*
10	American bittern	*Botaurus lentiginosus*
11	Belted kingfisher	*Megaceryle alcyon*
12	Black tern	*Chilidonias niger*
13	Double-crested cormorant	*Phalacrocorax auritus*
14	Caspian tern	*Sterna caspia*
15	Common loon	*Gavia immer*
16	Mute swan	*Lygnus olor*
17	Canada goose	*Branta canadensis*
18	Mallard	*Anas platyrhynchos*
19	Black duck	*Anas rubripes*
20	Green-winged teal	*Anas crecca*
21	Blue-winged teal	*Anas discors*
22	Wood duck	*Aix sponsa*
23	Ring-necked duck	*Aythya collaris*
24	Redhead	*Aythya americana*
25	Greater scaup	*Aythya marila*
26	Common goldeneye	*Bucephala clangula*
27	Bufflehead	*Bucephala albeola*
28	Common merganser	*Mergus merganser*
29	Bald eagle	*Haliaeetus leucocephalus*
30	Marsh hawk	*Circus cyaneus*
31	Osprey	*Pandion haliaetus*
32	Peregrine falcon	*Falco peregrinus*
33	Red-shouldered hawk	*Buteo lineatus*
34	Sharp-shinned hawk	*Accipiter straitus*
35	Pigeon hawk	*Falco columbarius*
36	Coopers hawk	*Accipiter cooperii*
37	Barred owl	*Strix varia*
38	Red-breasted merganser	*Mergus serrator*
39	Pintail	*Anas acuta*
40	American coot	*Fulica americana*
41	Pied-billed grebe	*Podilymbus podiceps*
42	Common gallinule	*Gallinula chloropus*
43	Whistling swan	*Olor columbianus*
44	Snow goose	*Chen caerulescens*
45	Lesser scaup	*Aythya affinis*
46	Oldsquaw	*Clangula hyemalis*
47	White-winged scoter	*Melanitta deglandi*
48	Surf scoter	*Melanitta perspicillata*
49	American wigeon	*Anas americana*
50	Great egret	*Casmerodius albus*
51	Snowy egret	*Egretta thula*
52	Cattle egret	*Bubulcus ibis*
53	Yellow-crowned night heron	*Nyctanassa violacea*
54	Yellow rail	*Coturnicops noveboracensis*
55	Killdeer	*Charadrius vociferus*
56	Spotted sandpiper	*Actitis macularia*
57	Greater yellowlegs	*Tringa melanaleuca*
58	Lesser yellowlegs	*Tringa flavipes*
59	Red knot	*Calidris canutus*
60	Least sandpiper	*Calidris minutilla*
61	Dunlin	*Calidris alpina*
62	Western sandpiper	*Calidris mauri*
63	Sanderling	*Calidris alba*
64	Ruddy turnstone	*Arenaria interpres*
65	Semipalmated sandpiper	*Calidris pusilla*
66	Herring gull	*Larus argentatus*
67	Ring-billed gull	*Larus delawarensis*
68	Common tern	*Sterna hirundo*
69	Glaucous gull	*Larus hyperboreus*
70	Great black-backed gull	*Larus marinus*
71	Least bittern	*Ixobrychus exilis*
72	Bonapartes gull	*Larus philadelphia*
74	Southern bald eagle	*Haliaeetus leucocephalus*
75	Forster's tern	*Sterna fosteri*
76	King rail	*Rallus elegans*
82	Upland sandpiper	*Bartramia longicauda*
83	Northern shoveller	*Anas clypeata*
84	Gadwall	*Anas strepera*
85	Horned grebe	*Podiceps auritus*
86	Ruddy duck	*Oxyura jamaicensis*
87	Canvasback	*Aythya valisineria*
88	Short-billed marsh wren	*Cistothorus platensis*
89	Marsh wren	*Cistothorus sp.*
90	Pectoral sandpiper	*Calidris melanotos*
91	Red-winged blackbird	*Agelaius phoeniceus*
92	Yellow-headed blackbird	*Xanthocephalus xanthocephalus*
93	Brewer's blackbird	*Euphagus cyanocephalus*
94	Swamp sparrow	*Melospiza georgiana*
95	Red-tailed hawk	*Buteo jamaicensis*
96	Broad-winged hawk	*Buteo platypterus*
97	Rough-legged hawk	*Buteo lagopus*
98	Northern goshawk	*Accipiter gentilis*
99	American kestrel	*Falco sparverius*
100	Brant	*Branta bernicla*
103	Hooded merganser	*Lophodytes cucullatus*
104	Red-necked grebe	*Podiceps grisegena*
105	Purple sandpiper	*Calidris maritima*
107	Long-billed marsh wren	*Cistothorus palustris*
108	Short-billed marsh wren	*Cistothorus platensis*
109	Baird's sandpiper	*Calidris bairdii*
110	White-rumped sandpiper	*Calidris fuscicollis*
112	Black-bellied plover	*Pluvialis squatarola*
113	Semipalmated plover	*Charadrius semipalmatus*
Fish		
1	Alewife	*Alosa pseudoharengus*
2	Rainbow smelt	*Osmerus mordax*
3	Spottail Shiner	*Notropis hudsonius*
4	River redhorse	*Moxostoma carinatum*
5	Lake trout	*Slavelinus namaycush*
6	Brown trout	*Salmo trutta*
7	Rainbow trout	*Salmo gairdneri*
8	Lake whitefish	*Coregonus clupeaformis*
9	Chinook salmon	*Oncorhynchus tshawytscha*
10	Coho salmon	*Oncorhynchus kisutch*
11	Atlantic salmon	*Salmo salar*
12	Lake sturgeon	*Acipenser fulvescens*
13	Northern pike	*Esox lucius*
14	Bluegill	*Lepomis macrochirus*
15	White crappie	*Pomokis annylaris*
16	Black crappie	*Pomoxis nigromaculatus*
17	Yellow perch	*Perca flavescens*
18	Largemouth bass	*Micropterus salmoides*
19	Smallmouth bass	*Micropterus dolomieui*
20	Rock bass	*Ambloplites rupestris*
21	Pumpkinseed	*Lepomis gibbosus*
22	Walleye	*Stizostedion vitreum*
23	White bass	*Morone chrysops*
24	Tiger musky	
25	Muskellunge	*Esox masquinongy*
26	Channel catfish	*Ictalurus punctatus*
27	Carp	*Cyprinus carpio*
28	Gizzard shad	*Dorosoma cepedianum*
29	Cisco	*Coregonus artedii*
30	Brook trout	*Slavelinus fontinalis*
31	Blackchin shiner	*Notropis heterodon*
32	Blacknose shiner	*Notropis heterolepis*
33	Fathead minnow	*Pimephales promelas*
34	Banded killifish	*Fundulus diaphanus*
35	Shorthead redhorse	*Moxostoma macrolepidotum*
36	Longnose sucker	*Catostomus catostomus*
37	White sucker	*Catostomus commersoni*
38	Yellow bullhead	*Ictalurus natalis*
39	Brown bullhead	*Ictalurus nebulosus*
40	Green sunfish	*Lepomis cyanellus*
41	Grass pickeral	*Esox americanus*
42	Sauger	*Stizostedion canadense*
43	Pink salmon	*Oncorhynchus gorbuscha*
44	Burbot	*Lota lota*
45	Round whitefish	*Prosopium cylindraceum*
46	Atlantic sturgeon	*Acipenser oxyrhynchus*
47	Splake	*Salvelinus namaycush*
48	Greater redhorse	*Moxostoma valenciennesi*
49	Striped shiner	*Notropis chrysocephalus*
50	Redfin shiner	*Notropis umbratilis*
51	Longear sunfish	*Lepomis megalotis*
52	Golden redhorse	*Moxostoma erythrurum*
53	Silver redhorse	*Moxostoma anisurum*
54	Shorthead redhorse	*Moxostoma macrolepidotum*
55	Black bullhead	*Ictaluras melas*
56	Emerald shiner	*Notropis atherinoides*
57	White perch	*Morone americana*
58	Common shiner	*Notropis cornutus*
59	Log perch	*Percina caprodes*
Plants		
1	Pitcher's thistle	*Cirbium pitcheri*
2	Clustered broomrape	*Orobanche fasciculata*
3	Smartweed	*Polygonum careyi*
4	Spurge	*Euphorbia polygonifolia*
5	Rock Sandwort	*Arenaria stricta*
6	Bald-rush	*Psilocarys scirpoides*
7	Clubmoss	*Lycopodium appressum*
8	Rose mallow	*Hibiscus palustris*
9	Wild bean	*Strophostyles helvola*
10	Sea rocket	*Cakile edentula*
11	Ginseng	*Panax quinquefolius*
12	Sedge	*Carex platphylla*
13	Thickspike wheatgrass	*Agropyron dasystachyum*
14	Moonwort	*Botrychium lunaria*
15	Sand reed	*Calamovilfa longifolia*
16	Garber's sedge	*Carex garberi*
17	Chestnut sedge	*Fimbristylis puberula*
18	Northern comandra	*Geocaulon lividum*
19	Pale false foxglove	*Gerardia skinneriana*
20	Dwarf lake iris	*Iris lacustris*
21	Small-flower Grass-of-Parnassus	*Parnassia parviflora*
22	Smooth phlox	*Phlox glaberrima*
23	Prairie white-fringed orchid	*Platanthera leucophaea*
24	Seaside crowfoot	*Ranunculus cymbalaria*
25	Sand dune willow	*Salix cordata*
26	Lake Huron tansy	*Tanacetum huronense*
27	False asphodel	*Tofieldia glutinosa*

* Threatened and endangered species are designated by underlining.

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BIRD SPECIES ASSEMBLAGES

Species present in Assemblage A

2 Common snipe
3 American woodcock
5 Green heron
6 Virginia rail
7 Sora rail
10 American bittern
12 Black tern
17 Canada goose
18 Mallard
19 Black duck
20 Green-winged teal
21 Blue-winged teal
22 Wood duck
40 American coot
41 Pied-billed grebe
42 Common gallinule
54 Yellow rail
56 Spotted sandpiper
71 Least bittern
76 King rail
83 Northern shoveller
88 Sedge wren
89 Marsh wren
91 Red-winged blackbird
92 Yellow-headed blackbird
93 Brewer's blackbird
94 Swamp sparrow

Species present in Assemblage B

4 Great blue heron
5 Green heron
9 Black-crowned night heron
11 Belted kingfisher
13 Double-crested cormorant
51 Snowy egret
52 Cattle egret
68 Common tern
75 Forster's tern

Species present in Assemblage C

14 Caspian tern
15 Common loon
17 Canada goose
18 Mallard
19 Black duck
20 Green-winged teal
21 Blue-winged teal
22 Wood duck
23 Ring-necked duck
24 Redhead
25 Greater scaup
26 Common goldeneye
27 Bufflehead
28 Common merganser
38 Red-breasted merganser
40 American coot
41 Pied-billed grebe
43 Whistling swan
45 Lesser scaup
46 Oldsquaw
66 Herring gull
67 Ring-billed gull
68 Common tern
75 Forster's tern
83 Northern shoveller
85 Horned grebe
86 Ruddy duck
87 Canvasback

Species present in Assemblage D

1 Piping plover
2 Common snipe
56 Spotted sandpiper
60 Least sandpiper
61 Dunlin
63 Sanderling
65 Semipalmated sandpiper
90 Pectoral sandpiper

Species present in Assemblage E

29 Bald eagle
31 Osprey
32 Peregrine falcon
33 Red-shouldered hawk
35 Pigeon hawk
98 Northern goshawk

Shoreline Habitat Descriptions

EXPOSED ROCKY CLIFFS — ESI = 1A

DESCRIPTION

- Steep (>30 degrees) bedrock cliff with a width too narrow to have any accumulated sediments. There is no evidence of a platform cut into the bedrock.
- This shoreline type is never used in combination with another shoreline type. However, they are frequently found interspersed with shelving bedrock ledges.
- The rock surface can be highly irregular, with numerous cracks and crevices.
- Exposure to wave energy occurs on a regular basis.
- This shoreline type is most common on the northern part of the Door Peninsula, and it represents less than 1 percent of the shoreline in the western Lake Michigan region.

PREDICTED OIL BEHAVIOR

- Oil will be held offshore by wave reflection off steep cliffs.
- Any oil that is deposited will be rapidly removed from exposed faces, although oil persistence on any specific shoreline is related to the incoming wave energy
- The most resistant oil would remain as a patch band at or above the high-water line.
- Greatest impacts are likely to be to birds when present at nesting colonies or feeding in nearshore waters.

RESPONSE CONSIDERATIONS

- On most shorelines, cleanup is not necessary and may be dangerous.
- Access is usually very difficult.
- Washing techniques with ambient water are only effective while oil is still fresh.

EXPOSED, HARD MAN-MADE STRUCTURES — ESI = 1B

DESCRIPTION

- These structures are vertical, hard, and impermeable seawalls and piling exposed to direct wave action.
- They are present along developed shorelines where beach erosion has occurred or where harbors have been built, comprising 2 percent of the shoreline.

PREDICTED OIL BEHAVIOR

- Any oil that is deposited will be rapidly removed from exposed faces, although oil persistence on any specific shoreline is related to the incoming wave energy.
- The most resistant oil would remain as a patchy band at or above the high-water line.

RESPONSE CONSIDERATIONS

- High-pressure spraying may be required to remove oil for aesthetic reasons and prevent leaching of the oil from the structure.
- Cleanup crews should make sure to recover all released oil.

SHELVING BEDROCK SHORES — ESI = 2

DESCRIPTION

- Shelving bedrock shores occur where flat or gently dipping rock layers are exposed and extend into the shallow nearshore zone.
- Sometimes the rock platforms can be very wide, up to 100 meters, though normally they are less than 10 meters.
- They generally are exposed to seasonally high wave action that strips most sediment from the rock surface.
- The rock surface can be very irregular.
- They are most common on the northern half of the Door Peninsula.
- They represent nearly 4 percent of the shoreline.

PREDICTED OIL BEHAVIOR

- Oil will be held offshore by waves reflecting off the most exposed platforms.
- Any oil that comes ashore will form a band along the high-water line.
- Once deposited, the oil will be rapidly removed from exposed faces, although oil persistence on any specific shoreline is related to the incoming wave energy.

RESPONSE CONSIDERATIONS

- In areas of high exposure to waves, no cleanup is necessary.
- Manual removal of residual surface oil may be needed in wave shadows, both on the platform and along the high-water line.

ERODING SCARPS IN UNCONSOLIDATED SEDIMENTS ESI = 3

DESCRIPTION

- These scarps are composed of soft, unconsolidated sediments (mostly sand).
- The scarps show evidence of active erosion, and beaches in front of the scarps are narrow or absent.
- They are very uncommon along western Lake Michigan, comprising less than 1 percent of the shoreline.

PREDICTED OIL BEHAVIOR

- Any stranded oil will form a band along the high-water line.
- There is some potential for oil penetration into any sediment accumulations at the base of the scarp, but active erosion of the scarp will also erode the oil.

RESPONSE CONSIDERATIONS

- In most cases, cleanup is not necessary because of the short residence time of the oil.
- The need for removal of oiled sediments should be carefully evaluated because of the potential for increased erosion.
- Manual labor and close supervision should be used so that the minimal amount of sediment is removed during cleanup.

SAND BEACHES ESI = 4

DESCRIPTION

- Sand beaches are composed of sediments that range in size from fine-grained sand to granules (2-4 millimeters).
- When the sediments are fine-grained sand, beaches may be wide and flat; where the sediments are coarser, they usually are steeper and narrower.
- These beaches may be used by migrating shorebirds.
- They are very common along the western Lake Michigan shore and are heavily used during the summer months for recreation.
- They comprise over 16 percent of the shoreline.

PREDICTED OIL BEHAVIOR

- During small spills, oil will concentrate in a band along the swash line.
- Maximum penetration of oil into fine-grained sand will be less than 15 cm; penetration into coarse-grained sand can reach 25 cm.
- Burial of oiled layers by clean sand within the first few weeks after the spill will be limited usually to less than 30 cm, whereas burial by up to 60 cm on coarse-grained beaches is possible.
- Deepest burial will occur if the oil is stranded onshore at the beginning of an accretionary period, such as after a storm.
- Much of the oil will be removed during the next storm.
- Heavy accumulations of residual oil can form tar mats.
- Biological impacts are likely to be low, except for when the beaches are being used by shorebirds for resting and foraging.

RESPONSE CONSIDERATIONS

- Because of their heavy recreational use, most beaches will require extensive cleanup efforts to remove as much of the oil as possible.
- Sand removal should be kept to a minimum, to avoid erosional problems.
- Use of heavy equipment for oiled sediment removal may result in the removal of excessive amounts of sand; manual cleanup may be preferable.
- All activity through the oiled sand should be limited to prevent mixing the oil deeper into the sediments and contamination of adjacent clean areas.
- When possible, cleanup crews should wait for all of the oil to come ashore prior to removal of oiled sediment.

MIXED SAND AND GRAVEL BEACHES — ESI = 5

DESCRIPTION

- These beaches are composed of a wide range of mixtures of sand and gravel (greater than 10 percent of each).
- Because of the mixed sediment sizes, there may be zones of pure sand, pebbles, or cobbles.
- Where the beach is depositional, there can be multiple berms from the different water levels generated during storms.
- Where the beach is stable or erosional, the sediments are a jumble of grain sizes with the gravel scattered over a relatively wide, flat surface.
- These beaches may be used by migrating shorebirds.
- Mixed sand and gravel beaches are common throughout the study area, comprising 20 percent of the shoreline.

PREDICTED OIL BEHAVIOR

- Small oil spills will be deposited at the high-water line.
- Large spills will spread across the entire beachface.
- Oil penetration into the beach sediments may be up to 50 cm; however, the sand fraction can be quite mobile, and oil behavior is much like on a sand beach if the sand fraction exceeds about 40 percent.
- Burial of oil may be deep at and above the swash line, where oil tends to persist, particularly where beaches are only intermittently exposed to waves.
- On more sheltered beaches, extensive pavements of asphalted sediments can form if there is no removal of heavy oil accumulations, because most of the oil remains on the surface.
- Once formed, these pavements are very stable and can persist for many years.
- Biological impacts are likely to be low, except for when the beaches are being used by shorebirds for resting and foraging.

RESPONSE CONSIDERATIONS

- Remove heavy accumulations of pooled oil.
- All oiled debris should be removed.
- Sediment removal should be limited as much as possible.
- Low-pressure flushing can be used to float oil away from the sediments for recovery by skimmers or sorbents; high-pressure spraying should be avoided because of potential for transporting oiled sediments to the subtidal zones.
- Tilling may be used to reach deeply buried oil layers on exposed, depositional beaches.

GRAVEL BEACHES — ESI = 6A

DESCRIPTION

- These beaches are composed of a mixture of gravel and less than 10 percent sand.
- On depositional beaches, the gravel is formed into multiple berms from the different water levels generated during storms.
- On stable or erosional beaches, the sediments are a jumble of grain sizes with the gravel scattered over a relatively wide, flat surface.
- Gravel beaches are common along the Door Peninsula.
- They represent 11 percent of the shoreline.

PREDICTED OIL BEHAVIOR

- Deep penetration and rapid burial of stranded oil is likely on exposed beaches.
- During storms, oil can be pushed over the berms, pooling and persisting above the normal zone of wave wash.
- Long-term persistence will be controlled by the depth of penetration versus the depth of routine reworking by storm waves.
- On relatively sheltered beaches, formation of asphalt pavements is likely where accumulations are heavy.

RESPONSE CONSIDERATIONS

- Remove heavy accumulations of pooled oil from the upper beachface.
- All oiled debris should be removed.
- Sediment removal should be limited as much as possible.
- Moderate-pressure flushing can be used to float oil away from the sediments for recovery by skimmers or sorbents; high-pressure spraying should be avoided because of potential for transporting oiled sediments to the subtidal zones.
- Tilling may be used to reach deeply buried oil layers on exposed beaches.

RIPRAP REVETMENTS, GROINS, AND JETTIES — ESI = 6B

DESCRIPTION

- These structures are composed of cobble- to boulder-sized quarried rocks that have been placed along the shoreline for protection and stabilization.
- Riprap is placed behind beaches, along harbors, and as groins perpendicular to the shoreline.
- Riprap is common along much of the developed shoreline of western Lake Michigan, where it comprises 21 percent of the shoreline.

PREDICTED OIL BEHAVIOR

- Deep penetration of oil between the boulders is likely where the riprap is placed at the water line.
- Oil adheres readily to the rough rock surfaces.
- If oil is left uncleaned, it may cause chronic leaching until the oil hardens into an asphalt deposit.

RESPONSE CONSIDERATIONS

- When the oil is fresh and liquid, high-pressure spraying and/or water flooding may be effective, making sure to recover all released oil.
- Heavy and weathered oils are more difficult to remove, requiring scraping and/or hot-water spraying.
- It may be necessary to replace heavily oiled riprap.

EXPOSED FLATS — ESI = 7

Not present in study area

SHELTERED SCARPS IN BEDROCK — ESI = 8A

DESCRIPTION

- They mostly occur as vertical rock walls and boulder-strewn rocky ledges inside of bays and coves, sheltered from most wave attack.
- In places the shore is a very complex arrangement of rubble on a flat rock surface.
- Sheltered scarps are very uncommon, comprising less than 1 percent of the shoreline.

PREDICTED OIL BEHAVIOR

- On all rocky shores, oil will adhere readily to the rough rocky surface, particularly along the water line, forming a distinct oil band.
- Fractures in the bedrock will be sites of pooling and oil persistence.
- Even on wide ledges, the lower zone usually stays wet, preventing oil from adhering to the rock surface.
- Heavy and weathered oils readily adhere to the dry, rough rock surface and between the surface sediments.

RESPONSE CONSIDERATIONS

- Low- to high-pressure spraying at ambient water temperatures is most effective when the oil is fresh.
- Heavy and weathered oils will have to be manually removed.

SHELTERED, MAN-MADE STRUCTURES — ESI = 8B

DESCRIPTION

- These structures include revetments, seawalls, piers, and docks constructed of concrete or wood.
- They usually extend to the water surface.
- They are found inside harbors in highly developed areas, comprising 6 percent of the shoreline.

PREDICTED OIL BEHAVIOR

- On impermeable surfaces, the oil will form a band at the water line.
- If oil is left uncleaned, it may cause chronic leaching until the oil hardens into an asphalt deposit.

RESPONSE CONSIDERATIONS

- High-pressure spraying may be required to remove oil for aesthetic reasons and prevent leaching of the oil from the structure.
- Cleanup crews should make sure to recover all released oil.

SHELTERED VEGETATED LOW BANKS — ESI = 9A

DESCRIPTION

- Sheltered vegetated low banks are colonized by terrestrial plants that grow in aerated soils.
- They occur along the upper reaches of small streams and embayments.
- They are not common, representing less than 1 percent of the shoreline.

PREDICTED OIL BEHAVIOR

- Oil will adhere to any vegetation along the water line.
- Very heavy accumulations will be trapped along shoreline irregularities and pool in any surface depressions.

RESPONSE CONSIDERATIONS

- All free oil should be removed by vacuum, low-pressure flushing, etc.
- Vegetation removal should be conducted only when deemed necessary and under close supervision.

SHELTERED SAND/MUD FLATS — ESI = 9B

DESCRIPTION

- Sheltered flats are flat areas composed of sand, silt, and clay that have been exposed by lowered water levels.
- They are uncommon, only occurring in front of marshes along the western shore of Green Bay, representing less than 1 percent of the shoreline.

PREDICTED OIL BEHAVIOR

- Oil does not usually adhere to the surface of sheltered flats, but rather is blown across the flat and accumulates at the water line.
- Very heavy accumulations will cover the flat at low water levels.
- Oil will not penetrate the water-saturated sediments at all, but rather remain on the surface.
- In areas of high suspended sediments, sorption of oil can result in contaminated sediments that can be deposited on the flats.
- When sediments are contaminated, oil will persist for many years.
- Biological impacts can be severe.

RESPONSE CONSIDERATIONS

- Any cleanup activity must be sure not to mix the oil deeper into the sediments.
- The soft substrate will not support any foot or vehicular traffic, so all operations should be conducted from shallow-draft boats.
- Cleanup should focus on removal of oil accumulated at the water line; sorbents can be used to recover oil as it is naturally removed over time.

FRINGING WETLANDS — ESI = 10A

DESCRIPTION

- Fringing wetlands occur as a narrow band of vegetation that requires saturated soils for growth and reproduction.
- Wetland soils are mostly composed of silt and clay, although the vegetation can grow in sandy sediments behind sheltered beaches and rocky shores.
- They are exposed to relatively high wave energy, compared to extensive wetlands.
- Fringing marshes are denoted on the maps as a single band of color along the shoreline. They represent 8 percent of the shoreline.

EXTENSIVE WETLANDS — ESI = 10B

DESCRIPTION

- Extensive wetlands occur as wide areas of vegetation that requires saturated soils for growth and reproduction. The soils are composed of silt and clay.
- The most extensive wetlands are associated with river mouths or at the head of sheltered bays. Thus, they are sheltered from direct wave attack.
- Extensive wetlands comprise nearly 7 percent of the shoreline length along western Lake Michigan.

PREDICTED OIL BEHAVIOR (all wetlands)

- Oil adheres readily to wetland vegetation.
- The band of coating will vary widely, depending upon the water level at the time oil slicks are in the vegetation. There may be multiple bands.
- If the vegetation is thick, heavy oil coating will be restricted to the outer fringe.
- Medium to heavy oils do not readily adhere to or penetrate the fine sediments, but they can pool on the surface and in burrows.
- Light oils can penetrate the top few centimeters of sediment and deeply into burrows and cracks (up to one meter).
- Fluctuating water levels will have great effects on which wetlands are susceptible to oiling.
- Rates of natural removal are a function of the site-specific exposure to wave energy. At exposed sites, oil can be removed within months; heavy accumulations of oil can persist in sheltered wetlands for years.

RESPONSE CONSIDERATIONS (all wetlands)

- Under light to moderate oiling, natural recovery is the best option.
- Any cleanup activity must be sure not to mix the oil deeper into the sediments. Trampling of the roots must be minimized.
- Cutting of oiled vegetation should only be considered when other resources present are at great risk from leaving the oiled vegetation in place.
- Heavy accumulations of pooled oil can be removed by vacuum, sorbents, or low-pressure flushing. During flushing, care must be taken to prevent transport of oil to sensitive areas downslope or along shore.