The Florida Circuit Model, v. 1.1—a new statewide map of local habitat connectivity

A summary report for practitioners of connectivity conservation

A product of the Archbold Biological Station Conservation Program

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Contents

Introduction and rationale for a new model

Connectivity is key for long-term retention of biodiversity in the face of increasingly fragmented habitats and climate change (Damschen et al. 2006). *However,* identifying specific areas for connectivity conservation is complex. *The Florida Circuit Model is a new model quantifying statewide connectivity from easily understood inputs, with ecologically defensible assumptions, and meaningful outputs that allow local conservation priority setting.*

Many organizations (government agencies, land trusts, landowners, and others) working to conserve, restore, and connect habitat around the state have interest in identifying fine-scale bottlenecks where only narrow area of habitat (some already degraded) can be maintained for species movement. However, identification of these areas is often done by visually scanning maps for narrow sections of habitat, with few data on species' movement at-hand. A tool distinguishing local ecological corridors (areas likely to concentrate species' movements) can help identify critical priorities for connectivity conservation.

The Florida Circuit Model has several advantages over existing models. First, it provides a statewide map of connectivity allowing planning for its conservation anywhere within the state and at all spatial scales.

Second, the Florida Circuit Model requires only 2 input layers—land cover (the Florida Cooperative Land Cover database; FWC & FNAI 2021) and roads (FDOT 2021). Land cover naturalness is assumed to correlate positively with habitat value and ability to support species' movement. Roads with heavier traffic are stronger barriers to connectivity for many species. Using few inputs improves transparency of the modeling process.

In addition, new connectivity algorithms improve on first-generation methods including the popular least-cost-path models (Keeley et al. 2021). The Florida Circuit Model uses a new algorithm to rate connectivity that does not assume organisms have perfect knowledge of the landscape and that they choose a single best ("least-cost") travel route (McRae et al. 2008). Inclusion of multiple possible paths between habitats yields a more realistic model.

The two key model outputs are called "flow potential" and "normalized current."

1. Flow potential is species' movement modeled from the abundance and quality of local (10km radius for this analysis) habitat. It indicates expected volume of movement in the absence of barriers (e.g., roads) and increases with more natural habitat in the area.

2. Normalized current is the ratio of (a) modeled species' movement based on local habitat abundance and quality *plus* land cover resistance to movement to (b) flow potential. There are four categories of normalized current:
    - "Impeded" areas have less flow than expected, given surrounding habitat quality, indicating low movement due to barriers.
    - Local corridors or paths of least resistance around or through major barriers and where species' movement is funneled through are considered to have "intensified" movement, or "channelized" movement, if the effect is especially strong. These may be priorities for conservation but should be investigated on the ground and/or using additional geospatial data.
    - Finally, areas without barriers are considered "diffuse" and have movement near the expected value given surrounding habitat. Large areas of intact habitat are diffuse. However, large areas of disturbed habitat often are, too, because the low volume of high-quality habitat means modeled species movement is low, regardless of barriers in the landscape. These cases are distinguished by high versus low flow potential.

      The Florida Circuit Model designates locations with the highest flow potential whose cumulative area sums to the size of the Florida Wildlife Corridor (FLWC; 18.1 million acres) to have high flow potential (brighter areas in map below), but this threshold could be adjusted to highlight relatively high flow potential within more local areas, if desired.

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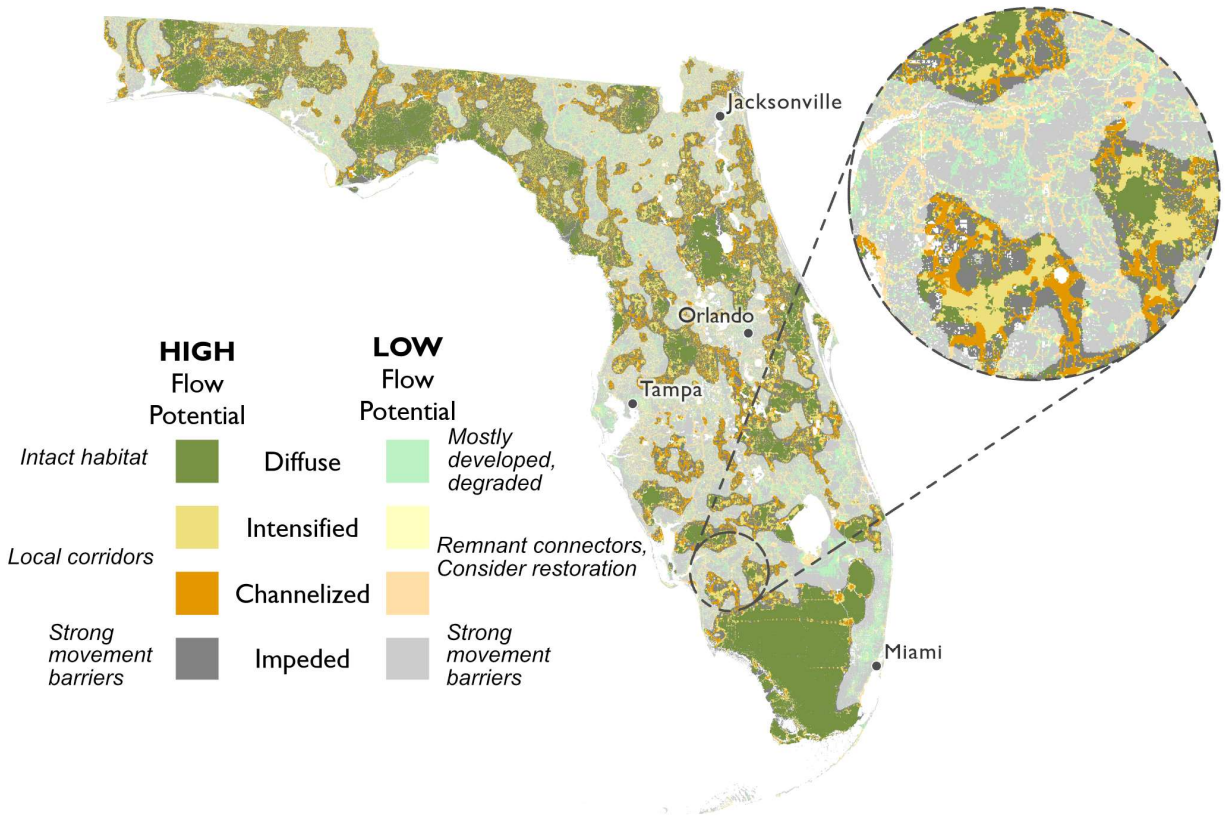

Model features

The Florida Circuit Model generally reproduces the salient features of the Florida Ecological Greenways Network (FEGN; Hoctor et al., 2000; Hoctor and Volk, 2021) and the FLWC. Large, conserved areas show as diffuse areas with high flow potential. Heavily converted areas like Pinellas County and Miami are mostly impeded or diffuse with low flow potential. Major remnant connectors in the landscape (e.g., around the Apalachicola River in the FL panhandle, the Suwanee River in north FL, and the Peace River from Charlotte Harbor to the Green Swamp) are intensified and channelized. Major roads through otherwise natural areas (most clearly Tamiami Trail through the Everglades) show as barriers (impeded).

The FLWC has 35% less impeded and 33% more diffuse and intensified area than the whole state's composition. A similar proportion of the state and the FLWC are composed of channelized areas.

There are some differences between the Florida Circuit Model and the FLWC. Four areas not included in the FLWC are identified by the Florida Circuit Model as having high importance to local connectivity:

1. the area surrounding the Nassau River in Duval and Nassau Counties;
2. central east St. John's County;
3. riparian and relatively natural areas west of the Green Swamp in Hillsborough and Pasco Counties; and
4. St. Sebastian River State Park and its surroundings in Indian River and Brevard Counties on the east coast.

All four of these regions are identified in the FEGN as P4 areas, the next highest priorities for connectivity that are not within the FLWC.

To complete a statewide connected network, the FLWC includes a small number of connections that the Florida Circuit Model shows have lower flow potential. These are the Peace River from the south of the Green Swamp to the Myakka River watershed, and a stretch of the Panhandle bridging the west of the Apalachicola Basin and the Econfina Creek/Choctawatchee River region. The identification of these areas as having relatively low flow

potential in the Florida Circuit model indicates they are not among the highest flow potential areas of the state, but it does not mean they are not the most important remaining connectors locally. They may be required to complete a statewide conserved corridor and may be good targets for habitat restoration.

Like any model, the Florida Circuit model has advantages and disadvantages.

Advantages of the Florida Circuit Model:

1. The Florida Circuit Model covers the entire state and shows a location's value to connectivity within a 10km radius. This allows location-specific conservation planning.
2. The model is built with relatively simple inputs, requiring only a land cover classification and road locations. This eases communication of the modeling methods and any future updates.
3. The four normalized current classes—impeded, diffuse, intensified, and channelized—are quantitatively defined and have specific ecologically relevant meanings related to expected intensity of species movement due to surrounding habitat quality and resistance to movement.
4. A newer connectivity algorithm reduces unrealistic assumptions about species' movement that are imposed by older algorithms, especially least-cost path modeling which assumes species' know and select the single best route of travel.

Limitations of the Florida Circuit model:

1. The model is not specific to any particular species. It assumes land cover naturalness is good for all species' movements. Similar models could be built for specific species, though, and may reveal species-specific priorities.
2. The model does not designate any set geography, such as the FLWC defined by the FEGN. Rather, it shows local connectivity statewide.
3. Like many, though not all, connectivity models, the Florida Circuit Model relies on expert ratings of different land cover types' relative resistance to species' movement (see Supplemental Methods for details).
4. As for any connectivity model, it is key to validate modeled movement pathways with on-the-ground knowledge before making conservation decisions (McRae et al. 2016 p. 28).

There may be future updates to this model following peer review or ongoing land cover change. For updates or for questions about data access, the modeling methods, or application of the Florida Circuit Model contact:

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Supplemental methods

The Florida Circuit model uses circuit theory (McRae et al. 2008; Dickson et al. 2019) to consider landscapes and their resistance to species' movements as analogous to electrical circuits and their resistance to electrical current (McRae et al. 2008; Dickson et al. 2019). A given route between two points has a cost defined by the resistance to movement along the path, which is parameterized by a resistance layer. Our model is a species-agnostic one, based on land cover naturalness for the years 2019–2020 and built using the program Omniscape (McRae et al. 2016; Landau et al. 2021). Current is initiated into the landscape from each grid cell having a resistance below a given threshold (99 in our model) and in volumes inversely related to resistance.

We rated resistance for each of 225 land-cover types classified in Florida's Cooperative Land-Cover product (hereafter "CLC"; FWC & FNAI 2021). Natural areas that were not open water were all assigned lowest resistance, followed by rural areas with little human footprint, tree plantations, and ranchlands. Areas dominated by exotic invasive vegetation and some anthropogenic but unbuilt land-cover (e.g., large grassy areas and cemeteries) were assigned moderate resistance. More intensive agriculture such as row crops, along with heavily modified recreational areas (e.g., golf courses) and extractive industry lands had moderate-to-high resistance. Urban and other developed areas, plus buildings, and heavy industry had the highest resistances. Our resistance surface had 18 unique values ranging from 1 for natural lands to infinity (complete resistance) for open water and some large-scale utilities (Table S1).

To include the often-detrimental impact of roads, we rasterized the Florida Department of Transportation's Annual Average Daily Traffic polyline data for state-maintained roads (FDOT 2021) and combined them with CLC data. We defined low- and moderate-traffic roads to be those with up to 1440 and 7200 vehicles / day (1 and 5 vehicles / min), respectively. High-traffic roads were defined as those with greater than 7200 / day. These thresholds are similar to those used for low, moderate, and high annual average daily traffic (AADT) in other studies of wildlife mortality from vehicle collisions (Jacobson et al. 2016) and spanning the range of AADT within which vehicle impacts to wildlife population likely increase in Florida and elsewhere (Fahrig et al. 2001; Charry & Jones 2009). We reassigned resistance of land cover pixels overlapping roads to reflect their relatively high resistance.

To operationalize the definitions of "impeded," "diffuse," "intensified," and "channelized," we considered any pixel with normalized current below the statewide 40th percentile (0.64) to be impeded (affected by barriers). Pixels with normalized current between 0.64 and 1.36 (at least as far above 1 as the impeded threshold is below 1) were considered diffuse. Those between 1.36 and 1.77 (the statewide 85th percentile) were considered to have intensified flow, and normalized current above 1.77 was considered channelized.

Table 1—Land cover resistance ratings

Ratings of movement resistance for the 225 Cooperative Land Cover (CLC) land cover classes and 3 levels of road traffic. These were grouped into 18 types of landcover, each with a single resistance value.

Value (CLC)	NAME_SITE (CLC)	Resistance	Group
22332	Alluvial Forest	1	natural, not open water
2223	Atlantic White Cedar	1	natural, not open water
1750	Bare Soil	1	natural, not open water
21212	Basin Marsh	1	natural, not open water
22132	Basin Swamp	1	natural, not open water
22311	Bay Swamp	1	natural, not open water
2231	Baygall	1	natural, not open water
1610	Beach Dune	1	natural, not open water
22331	Bottomland Forest	1	natural, not open water
5251	Buttonwood Forest	1	natural, not open water
1125	Cabbage Palm	1	natural, not open water
222112	Cabbage Palm Flatwoods	1	natural, not open water
22323	Cabbage Palm Hammock	1	natural, not open water
1620	Coastal Berm	1	natural, not open water
1630	Coastal Grassland	1	natural, not open water
22321	Coastal Hydric Hammock	1	natural, not open water
2122	Coastal Interdunal Swale	1	natural, not open water
1214	Coastal Scrub	1	natural, not open water
1640	Coastal Strand	1	natural, not open water
1600	Coastal Uplands	1	natural, not open water
5300	Cultural - Estuarine	1	natural, not open water
2400	Cultural - Palustrine	1	natural, not open water
222111	Cutthroat Grass Flatwoods	1	natural, not open water
21112	Cutthroat Seep	1	natural, not open water
2211	Cypress	1	natural, not open water
2241	Cypress/Hardwood Swamps	1	natural, not open water
2242	Cypress/Pine/Cabbage Palm	1	natural, not open water
2210	Cypress/Tupelo(incl Cy/Tu mixed)	1	natural, not open water

21211	Depression Marsh	1	natural, not open water
22131	Dome Swamp	1	natural, not open water
1310	Dry Flatwoods	1	natural, not open water
1330	Dry Prairie	1	natural, not open water
1111	Dry Upland Hardwood Forest	1	natural, not open water
2145	Duck Weed	1	natural, not open water
5310	Estuarine Ditch/Channel	1	natural, not open water
2140	Floating/Emergent Aquatic Vegetation	1	natural, not open water
2123	Floodplain Marsh	1	natural, not open water
2215	Floodplain Swamp	1	natural, not open water
21231	Freshwater Tidal Marsh	1	natural, not open water
22151	Freshwater Tidal Swamp	1	natural, not open water
2125	Glades Marsh	1	natural, not open water
221312	Gum Pond	1	natural, not open water
2232	Hydric Hammock	1	natural, not open water
22211	Hydric Pine Flatwoods	1	natural, not open water
22212	Hydric Pine Savanna	1	natural, not open water
2410	Impounded Marsh	1	natural, not open water
2420	Impounded Swamp	1	natural, not open water
5200	Intertidal	1	natural, not open water
2121	Isolated Freshwater Marsh	1	natural, not open water
2213	Isolated Freshwater Swamp	1	natural, not open water
1740	Keys Cactus Barren	1	natural, not open water
52111	Keys Tidal Rock Barren	1	natural, not open water
1123	Live Oak	1	natural, not open water
2134	Maidencane	1	natural, not open water
5250	Mangrove Swamp	1	natural, not open water
1650	Maritime Hammock	1	natural, not open water
2113	Marl Prairie	1	natural, not open water
2120	Marshes	1	natural, not open water
1311	Mesic Flatwoods	1	natural, not open water
1120	Mesic Hammock	1	natural, not open water

2240	Mixed Hardwood Coniferous Swamps	1	natural, not open water
1400	Mixed Hardwood-Coniferous	1	natural, not open water
1112	Mixed Hardwoods	1	natural, not open water
2112	Mixed Scrub-Shrub Wetland	1	natural, not open water
2233	Mixed Wetland Hardwoods	1	natural, not open water
5221	Mud	1	natural, not open water
5212	Non-vegetated	1	natural, not open water
2300	Non-vegetated Wetland	1	natural, not open water
183111	Oak - Cabbage Palm Forests	1	natural, not open water
1211	Oak Scrub	1	natural, not open water
2220	Other Coniferous Wetlands	1	natural, not open water
2230	Other Hardwood Wetlands	1	natural, not open water
5230	Oyster Bar	1	natural, not open water
1340	Palmetto Prairie	1	natural, not open water
1124	Pine - Mesic Oak	1	natural, not open water
1320	Pine Rockland	1	natural, not open water
2222	Pond Pine	1	natural, not open water
22322	Prairie Hydric Hammock	1	natural, not open water
1122	Prairie Mesic Hammock	1	natural, not open water
1130	Rockland Hammock	1	natural, not open water
1212	Rosemary Scrub	1	natural, not open water
18312	Rural Open Pine	1	natural, not open water
5241	Salt Flat	1	natural, not open water
5240	Salt Marsh	1	natural, not open water
5222	Sand	1	natural, not open water
1670	Sand Beach (Dry)	1	natural, not open water
1213	Sand Pine Scrub	1	natural, not open water
1240	Sandhill	1	natural, not open water
2131	Sawgrass	1	natural, not open water
1210	Scrub	1	natural, not open water
5252	Scrub Mangrove	1	natural, not open water
1312	Scrubby Flatwoods	1	natural, not open water

2114	Seepage Slope	1	natural, not open water
1500	Shrub and Brushland	1	natural, not open water
21121	Shrub Bog	1	natural, not open water
1710	Sinkhole	1	natural, not open water
1140	Slope Forest	1	natural, not open water
2141	Slough	1	natural, not open water
2124	Slough Marsh	1	natural, not open water
22312	South Florida Bayhead	1	natural, not open water
2214	Strand Swamp	1	natural, not open water
2150	Submergent Aquatic Vegetation	1	natural, not open water
1410	Successional Hardwood Forest	1	natural, not open water
1131	Thorn Scrub	1	natural, not open water
5220	Tidal Flat	1	natural, not open water
2234	Titi Swamp	1	natural, not open water
2212	Tupelo	1	natural, not open water
1230	Upland Coniferous	1	natural, not open water
1720	Upland Glade	1	natural, not open water
1110	Upland Hardwood Forest	1	natural, not open water
1220	Upland Mixed Woodland	1	natural, not open water
1231	Upland Pine	1	natural, not open water
2142	Water Lettuce	1	natural, not open water
2146	Water Lily	1	natural, not open water
2221	Wet Flatwoods	1	natural, not open water
2111	Wet Prairie	1	natural, not open water
21111	Wiregrass Savanna	1	natural, not open water
1150	Xeric Hammock	1	natural, not open water
1880	Bare Soil/Clear Cut	20	Highly compatible ag/ROW
2440	Clearcut Wetland	20	Highly compatible ag/ROW
183332	Coniferous Plantations	20	Highly compatible ag/ROW
2430	Grazed Wetlands	20	Highly compatible ag/ROW
183331	Hardwood Plantations	20	Highly compatible ag/ROW
1821	Low Intensity Urban	20	Highly compatible ag/ROW

1831	Rural Open	20	Highly compatible ag/ROW
18311	Rural Open Forested	20	Highly compatible ag/ROW
1660	Shell Mound	20	Highly compatible ag/ROW
183341	Tree Nurseries	20	Highly compatible ag/ROW
183314	Unimproved/Woodland Pasture	20	Highly compatible ag/ROW
1811	Vegetative Berm	20	Highly compatible ag/ROW
1833321	Wet Coniferous Plantation	20	Highly compatible ag/ROW
183313	Improved Pasture	40	Compatible ag
1800	Cultural - Terrestrial	100	Low-impact anthropogenic
18213	Grass	100	Low-impact anthropogenic
1812	Highway Rights of Way	100	Low-impact anthropogenic
1810	Mowed Grass	100	Low-impact anthropogenic
18212	Residential, Low Density	100	Low-impact anthropogenic
1832	Rural Structures	100	Low-impact anthropogenic
7100	Australian Pine	150	Disturbed and exotic vegetation
7300	Brazilian Pepper	150	Disturbed and exotic vegetation
182134	Cemeteries	150	Disturbed and exotic vegetation
7000	Exotic Plants	150	Disturbed and exotic vegetation
7400	Exotic Wetland Hardwoods	150	Disturbed and exotic vegetation
7200	Melaleuca	150	Disturbed and exotic vegetation
9100	Unconsolidated Substrate	150	Disturbed and exotic vegetation
183321	Citrus	250	Moderate compatibility agriculture
182135	Community rec. facilities	250	Moderate compatibility agriculture
1833151	Fallow Cropland	250	Moderate compatibility agriculture
183324	Fallow Orchards	250	Moderate compatibility agriculture
183312	Field Crops	250	Moderate compatibility agriculture
183345	Floriculture	250	Moderate compatibility agriculture
183322	Fruit Orchards	250	Moderate compatibility agriculture
1833111	Irrigated Cropland	250	Moderate compatibility agriculture
18332	Orchards/Groves	250	Moderate compatibility agriculture
183343	Ornamentals	250	Moderate compatibility agriculture
18335	Other Agriculture	250	Moderate compatibility agriculture

183315	Other Open Lands - Rural	250	Moderate compatibility agriculture
183323	Pecan	250	Moderate compatibility agriculture
183311	Row Crops	250	Moderate compatibility agriculture
183342	Sod Farms	250	Moderate compatibility agriculture
182111	Urban Open Forested	250	Moderate compatibility agriculture
182112	Urban Open Pine	250	Moderate compatibility agriculture
18334	Vineyard and Nurseries	250	Moderate compatibility agriculture
183344	Vineyards	250	Moderate compatibility agriculture
1833121	Sugarcane	350	Sugarcane
1876	Abandoned Mining Lands	400	Moderate compatibility mining lands
1875	Reclaimed Lands	400	Moderate compatibility mining lands
1877	Spoil Area	400	Moderate compatibility mining lands
182133	Ballfields	500	Ballfields, feeding operations, urban vacant
183351	Feeding Operations	500	Ballfields, feeding operations, urban vacant
182132	Golf courses	500	Ballfields, feeding operations, urban vacant
182131	Parks and Zoos	500	Ballfields, feeding operations, urban vacant
183352	Specialty Farms	500	Ballfields, feeding operations, urban vacant
18211	Urban Open Land	500	Ballfields, feeding operations, urban vacant
18221	Residential, Med. Density - 2-5 Dwelling Units/AC	600	Residential, medium-density
18225	Institutional	900	High-density residential, institutional
18222	Residential, High Density > 5 Dwelling Units/AC	900	High-density residential, institutional
6	Low traffic road	1000	Low-traffic road
18223	Commercial and Services	1200	Low compatibility extractive & built
1870	Extractive	1200	Low compatibility extractive & built
1822	High Intensity Urban	1200	Low compatibility extractive & built
18224	Industrial	1200	Low compatibility extractive & built
1874	Oil & Gas Fields	1200	Low compatibility extractive & built
1873	Rock Quarries	1200	Low compatibility extractive & built
1872	Sand & Gravel Pits	1200	Low compatibility extractive & built
1871	Strip Mines	1200	Low compatibility extractive & built
33	Medium traffic road	2000	Medium-traffic & transportation, rails
1842	Rails	2000	Medium-traffic & transportation, rails

1841	Roads	2000	Medium-traffic & transportation, rails
1840	Transportation	2000	Medium-traffic & transportation, rails
1	High traffic road	5000	High-traffic roads
4110	Alluvial Stream	infinite	Incompatible & open water
3211	Aquacultural Ponds	infinite	Incompatible & open water
3220	Artificial Impoundment/Reservoir	infinite	Incompatible & open water
3210	Artificial/Farm Pond	infinite	Incompatible & open water
4120	Blackwater Stream	infinite	Incompatible & open water
4210	Canal	infinite	Incompatible & open water
3111	Clastic Upland Lake	infinite	Incompatible & open water
3112	Coastal Dune Lake	infinite	Incompatible & open water
3116	Coastal Rockland Lake	infinite	Incompatible & open water
1850	Communication	infinite	Incompatible & open water
3200	Cultural - Lacustrine	infinite	Incompatible & open water
4200	Cultural - Riverine	infinite	Incompatible & open water
4220	Ditch/Artificial Intermittent Stream	infinite	Incompatible & open water
5000	Estuarine	infinite	Incompatible & open water
5320	Estuarine Artificial Impoundment	infinite	Incompatible & open water
3113	Flatwoods/Prairie/Marsh Lake	infinite	Incompatible & open water
3260	Industrial Cooling Pond	infinite	Incompatible & open water
3000	Lacustrine	infinite	Incompatible & open water
3110	Limnetic	infinite	Incompatible & open water
4131	Major Springs	infinite	Incompatible & open water
6000	Marine	infinite	Incompatible & open water
3100	Natural Lakes and Ponds	infinite	Incompatible & open water
4100	Natural Rivers and Streams	infinite	Incompatible & open water
3230	Quarry Pond	infinite	Incompatible & open water
3114	River Floodplain Lake/Swamp Lake	infinite	Incompatible & open water
4000	Riverine	infinite	Incompatible & open water
4170	Riverine Sandbar	infinite	Incompatible & open water
3117	Sandhill Lake	infinite	Incompatible & open water
4140	Seepage Stream	infinite	Incompatible & open water

3240	Sewage Treatment Pond	infinite	Incompatible & open water
3115	Sinkhole Lake	infinite	Incompatible & open water
4130	Spring-run Stream	infinite	Incompatible & open water
3250	Stormwater Treatment Areas	infinite	Incompatible & open water
5100	Subtidal	infinite	Incompatible & open water
6100	Surf Zone	infinite	Incompatible & open water
4160	Tidally-influenced Stream	infinite	Incompatible & open water
1860	Utilities	infinite	Incompatible & open water