The Florida Circuit Model, v. 2.1—a statewide map of local habitat connectivity

Summary report for conservation practitioners

A product of the Archbold Biological Station Conservation Program

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Contents

Introduction and rationale for the model

Connectivity is key for long-term retention of biodiversity in the face of increasingly fragmented habitats and climate change (Damschen et al. 2006; Haddad et al. 2015; Costanza et al. 2020). However, identifying specific areas for connectivity conservation is complex. The Florida Circuit Model visualizes statewide connectivity from easily understood inputs, with ecologically defensible assumptions, to allow local conservation priority setting.

The tool distinguishes large, intact habitats where species can move freely, local ecological corridors, and barriers. Local corridor are areas where species' movements are likely concentrated by surrounding land use unsuitable for species movement or where barriers limit movement option.

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

Second, the Florida Circuit Model requires only two input layers—land cover (the Florida Cooperative Land Cover database; FWC & FNAI 2021) and roads (FDOT 2021). Land cover naturalness (Table 1) 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 fewer inputs improves transparency of the modeling process.

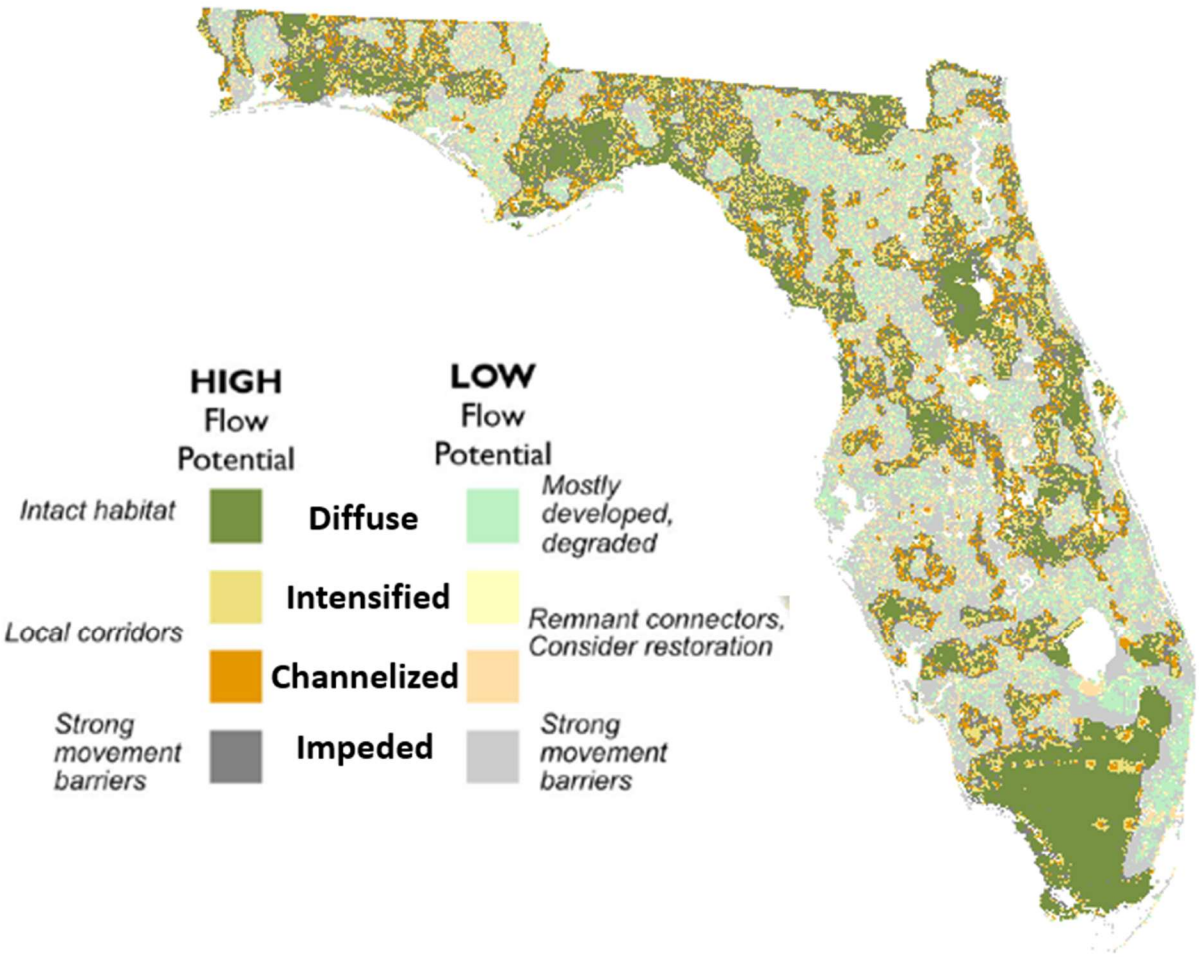
In addition, recently developed connectivity algorithms improve on first-generation methods including the popular least-cost-path models (Keeley et al. 2021). The Florida Circuit Model uses a newer algorithm to rate connectivity that does not assume organisms have perfect knowledge of the landscape and 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 *plus* land cover movement resistance to (b) flow potential. There are four categories of normalized current:
    - "**Impeded**" areas have low movement due to nearby barriers.
    - Local corridors are paths of least resistance around or through barriers. They have "**intensified**" movement, or "**channelized**" movement, if the funneling of movement into a narrow area is especially strong. These may be priorities for conservation where last options for connectivity are sought.
    - Areas without barriers are considered "**diffuse**," but can include both large areas of intact habitat and large areas of disturbed habitat. These cases are distinguished by high versus low flow potential. Diffuse areas with high flow potential are the best remaining large habitat areas.

      Here, the Florida Circuit Model is shown with "high" flow potential designated as the locations with the highest flow potential whose cumulative area sums to the size of the Florida Wildlife Corridor (FLWC; 18.1 million acres; the brighter areas in map below). This threshold could reasonably be adjusted to highlight relatively high flow potential within more local areas, if desired.



Model details

The Florida Circuit Model complements the Florida Ecological Greenways Network (FEGN; Hoctor et al., 2000; Hoctor and Volk, 2021), which defines the FLWC. Large, conserved areas show as diffuse 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).

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.
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 (Table 1).
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).

Full technical details for version 1 of the model are published in this paper. For questions, updates, access to GIS data, or help applying 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. The 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 226 land-cover types classified in Florida's Cooperative Land-Cover product (hereafter "CLC"; FWC & FNAI 2023). 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 16 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 2010). We reassigned resistance of land cover pixels overlapping roads to reflect their relatively high resistance.

Updates since from version 1 to version 2:

1. To avoid biasing connectivity around state borders, the National Land Cover Dataset was used for 50 km buffers into GA and AL. Specifically, resistance values were assigned to rasters from the 2019 version of the National Land Cover Database (Dewitz & USGS 2021) and the TIGERLine Primary and Secondary Roads respectively, as similarly to the CLC resistance assignments as possible (Table 2).
2. The rated resistance values for 26 of 226 land cover classes were slightly amended. These changes included increased resistance for areas dominated by exotic vegetation and decreased resistance for row crops, orchards, disturbed urban pine forests, and for mowed grass areas including cemeteries and community recreational parks.
3. The entire model is built from the version 3.7 (replacing of 3.5) of the Florida Cooperative Land Cover (CLC) classification which was updated by the agencies that produce it to reflect new site-level knowledge of ecological communities (FWC & FNAI 2023).
4. Thresholds used for delimiting the four normalized current categories were slightly amended to:
    a. below the 40th percentile is "impeded;"
    b. Between the 40th and 65th percentile is "diffuse;"
    c. From the 65th to the 85th percentile is "intensified;" and

Above the 85th percentile is "channelized."

Table 1—Land cover resistance ratings

Ratings of movement resistance for the 226 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 (from CLC 3_7)	NAME_SITE (from CLC 3.7)	Resistance (FCM1_2)	Group
1110	Upland Hardwood Forest	1	natural, not open water
1111	Dry Upland Hardwood Forest	1	natural, not open water
1112	Mixed Hardwoods	1	natural, not open water
1120	Mesic Hammock	1	natural, not open water
1122	Prairie Mesic Hammock	1	natural, not open water
1123	Live Oak	1	natural, not open water
1124	Pine - Mesic Oak	1	natural, not open water
1125	Cabbage Palm	1	natural, not open water
1130	Rockland Hammock	1	natural, not open water
1131	Thorn Scrub	1	natural, not open water
1140	Slope Forest	1	natural, not open water
1150	Xeric Hammock	1	natural, not open water
1210	Scrub	1	natural, not open water
1211	Oak Scrub	1	natural, not open water
1212	Rosemary Scrub	1	natural, not open water
1213	Sand Pine Scrub	1	natural, not open water
1214	Coastal Scrub	1	natural, not open water
1220	Upland Mixed Woodland	1	natural, not open water
1230	Upland Coniferous	1	natural, not open water
1231	Upland Pine	1	natural, not open water
1240	Sandhill	1	natural, not open water
1310	Dry Flatwoods	1	natural, not open water
1311	Mesic Flatwoods	1	natural, not open water
1312	Scrubby Flatwoods	1	natural, not open water
1320	Pine Rockland	1	natural, not open water
1330	Dry Prairie	1	natural, not open water
1340	Palmetto Prairie	1	natural, not open water
1400	Mixed Hardwood-Coniferous	1	natural, not open water

1410	Successional Hardwood Forest	1	natural, not open water
1500	Shrub and Brushland	1	natural, not open water
1600	Coastal Uplands	1	natural, not open water
1610	Beach Dune	1	natural, not open water
1620	Coastal Berm	1	natural, not open water
1630	Coastal Grassland	1	natural, not open water
1640	Coastal Strand	1	natural, not open water
1650	Maritime Hammock	1	natural, not open water
1670	Sand Beach (Dry)	1	natural, not open water
1710	Sinkhole	1	natural, not open water
1720	Upland Glade	1	natural, not open water
1740	Keys Cactus Barren	1	natural, not open water
1750	Bare Soil	1	natural, not open water
2111	Wet Prairie	1	natural, not open water
2112	Mixed Scrub-Shrub Wetland	1	natural, not open water
2113	Marl Prairie	1	natural, not open water
2114	Seepage Slope	1	natural, not open water
2120	Marshes	1	natural, not open water
2121	Isolated Freshwater Marsh	1	natural, not open water
2122	Coastal Interdunal Swale	1	natural, not open water
2123	Floodplain Marsh	1	natural, not open water
2124	Slough Marsh	1	natural, not open water
2125	Glades Marsh	1	natural, not open water
2131	Sawgrass	1	natural, not open water
2134	Maidencane	1	natural, not open water
2140	Floating/Emergent Aquatic Vegetation	1	natural, not open water
2141	Slough	1	natural, not open water
2142	Water Lettuce	1	natural, not open water
2145	Duck Weed	1	natural, not open water
2146	Water Lily	1	natural, not open water
2150	Submergent Aquatic Vegetation	1	natural, not open water

2210	Cypress/Tupelo (including mixed Cypress/Tupelo)	1	natural, not open water
2211	Cypress	1	natural, not open water
2212	Tupelo	1	natural, not open water
2213	Isolated Freshwater Swamp	1	natural, not open water
2214	Strand Swamp	1	natural, not open water
2215	Floodplain Swamp	1	natural, not open water
2220	Other Coniferous Wetlands	1	natural, not open water
2221	Wet Flatwoods	1	natural, not open water
2222	Pond Pine	1	natural, not open water
2223	Atlantic White Cedar	1	natural, not open water
2230	Other Hardwood Wetlands	1	natural, not open water
2231	Baygall	1	natural, not open water
2232	Hydric Hammock	1	natural, not open water
2233	Mixed Wetland Hardwoods	1	natural, not open water
2234	Titi Swamp	1	natural, not open water
2240	Mixed Hardwood Coniferous Swamps	1	natural, not open water
2241	Cypress/Hardwood Swamps	1	natural, not open water
2242	Cypress/Pine/Cabbage Palm	1	natural, not open water
2300	Non-vegetated Wetland	1	natural, not open water
2400	Cultural - Palustrine	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
5212	Non-vegetated	1	natural, not open water
5220	Tidal Flat	1	natural, not open water
5221	Mud	1	natural, not open water
5230	Oyster Bar	1	natural, not open water
5240	Salt Marsh	1	natural, not open water
5241	Salt Flat	1	natural, not open water
5250	Mangrove Swamp	1	natural, not open water

5251	Buttonwood Forest	1	natural, not open water
5252	Scrub Mangrove	1	natural, not open water
5300	Cultural - Estuarine	1	natural, not open water
5310	Estuarine Ditch/Channel	1	natural, not open water
18312	Rural Open Pine	1	natural, not open water
21111	Wiregrass Savanna	1	natural, not open water
21112	Cutthroat Seep	1	natural, not open water
21121	Shrub Bog	1	natural, not open water
21211	Depression Marsh	1	natural, not open water
21212	Basin Marsh	1	natural, not open water
21231	Freshwater Tidal Marsh	1	natural, not open water
22131	Dome Swamp	1	natural, not open water
22132	Basin Swamp	1	natural, not open water
22151	Freshwater Tidal Swamp	1	natural, not open water
22211	Hydric Pine Flatwoods	1	natural, not open water
22212	Hydric Pine Savanna	1	natural, not open water
22311	Bay Swamp	1	natural, not open water
22312	South Florida Bayhead	1	natural, not open water
22321	Coastal Hydric Hammock	1	natural, not open water
22322	Prairie Hydric Hammock	1	natural, not open water
22323	Cabbage Palm Hammock	1	natural, not open water
22331	Bottomland Forest	1	natural, not open water
22332	Alluvial Forest	1	natural, not open water
52111	Keys Tidal Rock Barren	1	natural, not open water
183111	Oak - Cabbage Palm Forests	1	natural, not open water
221312	Gum Pond	1	natural, not open water
222111	Cutthroat Grass Flatwoods	1	natural, not open water
222112	Cabbage Palm Flatwoods	1	natural, not open water
1660	Shell Mound	20	Highly compatible ag/ROW
1811	Vegetative Berm	20	Highly compatible ag/ROW
1831	Rural Open	20	Highly compatible ag/ROW
1880	Bare Soil/Clear Cut	20	Highly compatible ag/ROW

2430	Grazed Wetlands	20	Highly compatible ag/ROW
2440	Clearcut Wetland	20	Highly compatible ag/ROW
18311	Rural Open Forested	20	Highly compatible ag/ROW
183314	Unimproved/Woodland Pasture	20	Highly compatible ag/ROW
183331	Hardwood Plantations	20	Highly compatible ag/ROW
183332	Coniferous Plantations	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
1810	Mowed Grass	100	Low-impact anthropogenic
1812	Highway Rights of Way	100	Low-impact anthropogenic
1821	Low Intensity Urban	100	Highly compatible ag/ROW
1832	Rural Structures	100	Low-impact anthropogenic
18212	Residential, Low Density	100	Low-impact anthropogenic
18213	Grass	100	Low-impact anthropogenic
7000	Exotic Plants	250	Disturbed and exotic vegetation
7100	Australian Pine	250	Disturbed and exotic vegetation
7200	Melaleuca	250	Disturbed and exotic vegetation
7300	Brazilian Pepper	250	Disturbed and exotic vegetation
7400	Exotic Wetland Hardwoods	250	Disturbed and exotic vegetation
9100	Unconsolidated Substrate	150	Disturbed and exotic vegetation
182134	Cemeteries	100	Disturbed and exotic vegetation
18332	Orchards/Groves	150	Moderate compatibility agriculture
18334	Vineyard and Nurseries	150	Moderate compatibility agriculture
18335	Other Agriculture	150	Moderate compatibility agriculture
182111	Urban Open Forested	150	Moderate compatibility agriculture
182112	Urban Open Pine	150	Moderate compatibility agriculture
182135	Community rec. facilities	100	Moderate compatibility agriculture
183311	Row Crops	150	Moderate compatibility agriculture
183312	Field Crops	150	Moderate compatibility agriculture
183315	Other Open Lands - Rural	150	Moderate compatibility agriculture
183321	Citrus	150	Moderate compatibility agriculture

183322	Fruit Orchards	150	Moderate compatibility agriculture
183323	Pecan	150	Moderate compatibility agriculture
183324	Fallow Orchards	150	Moderate compatibility agriculture
183341	Tree Nurseries	150	Highly compatible ag/ROW
183342	Sod Farms	150	Moderate compatibility agriculture
183343	Ornamentals	150	Moderate compatibility agriculture
183344	Vineyards	150	Moderate compatibility agriculture
183345	Floriculture	150	Moderate compatibility agriculture
1833111	Irrigated Cropland	150	Moderate compatibility agriculture
1833151	Fallow Cropland	150	Moderate compatibility agriculture
1833121	Sugarcane	350	Sugarcane
1875	Reclaimed Lands	400	Moderate compatibility mining lands
1876	Abandoned Mining Lands	400	Moderate compatibility mining lands
1877	Spoil Area	400	Moderate compatibility mining lands
18211	Urban Open Land	500	Ballfields, feeding operations, urban vacant
182131	Parks and Zoos	500	Ballfields, feeding operations, urban vacant
182132	Golf courses	500	Ballfields, feeding operations, urban vacant
182133	Ballfields	500	Ballfields, feeding operations, urban vacant
183351	Feeding Operations	500	Ballfields, feeding operations, urban vacant
183352	Specialty Farms	500	Ballfields, feeding operations, urban vacant
18221	Residential, Med. Density - 2-5 Dwelling Units/AC	600	Residential, medium-density
18222	Residential, High Density > 5 Dwelling Units/AC	900	High-density residential, institutional
18225	Institutional	900	High-density residential, institutional
60	Low traffic road	1000	Low-traffic road
1822	High Intensity Urban	1200	Low compatibility extractive & built
1870	Extractive	1200	Low compatibility extractive & built
1871	Strip Mines	1200	Low compatibility extractive & built
1872	Sand & Gravel Pits	1200	Low compatibility extractive & built
1873	Rock Quarries	1200	Low compatibility extractive & built
1874	Oil & Gas Fields	1200	Low compatibility extractive & built

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18223	Commercial and Services	1200	Low compatibility extractive & built
18224	Industrial	1200	Low compatibility extractive & built
33	Medium traffic road	2000	Medium-traffic & transportation, rails
1840	Transportation	2000	Medium-traffic & transportation, rails
1841	Roads	2000	Medium-traffic & transportation, rails
1842	Rails	2000	Medium-traffic & transportation, rails
1	High traffic road	5000	High-traffic roads
1850	Communication	infinite	Incompatible & open water
1860	Utilities	infinite	Incompatible & open water
3000	Lacustrine	infinite	Incompatible & open water
3100	Natural Lakes and Ponds	infinite	Incompatible & open water
3111	Clastic Upland Lake	infinite	Incompatible & open water
3112	Coastal Dune Lake	infinite	Incompatible & open water
3113	Flatwoods/Prairie/Marsh Lake	infinite	Incompatible & open water
3114	River Floodplain Lake/Swamp Lake	infinite	Incompatible & open water
3115	Sinkhole Lake	infinite	Incompatible & open water
3116	Coastal Rockland Lake	infinite	Incompatible & open water
3117	Sandhill Lake	infinite	Incompatible & open water
3200	Cultural - Lacustrine	infinite	Incompatible & open water
3210	Artificial/Farm Pond	infinite	Incompatible & open water
3211	Aquacultural Ponds	infinite	Incompatible & open water
3220	Artificial Impoundment/Reservoir	infinite	Incompatible & open water
3230	Quarry Pond	infinite	Incompatible & open water
3240	Sewage Treatment Pond	infinite	Incompatible & open water
3250	Stormwater Treatment Areas	infinite	Incompatible & open water
3260	Industrial Cooling Pond	infinite	Incompatible & open water
4000	Riverine	infinite	Incompatible & open water
4100	Natural Rivers and Streams	infinite	Incompatible & open water
4110	Alluvial Stream	infinite	Incompatible & open water
4120	Blackwater Stream	infinite	Incompatible & open water
4130	Spring-run Stream	infinite	Incompatible & open water
4131	Major Springs	infinite	Incompatible & open water

4140	Seepage Stream	infinite	Incompatible & open water
4160	Tidally-influenced Stream	infinite	Incompatible & open water
4170	Riverine Sandbar	infinite	Incompatible & open water
4200	Cultural - Riverine	infinite	Incompatible & open water
4210	Canal	infinite	Incompatible & open water
4220	Ditch/Artificial Intermittent Stream	infinite	Incompatible & open water
5000	Estuarine	infinite	Incompatible & open water
5100	Subtidal	infinite	Incompatible & open water
5320	Estuarine Artificial Impoundment	infinite	Incompatible & open water
6000	Marine	infinite	Incompatible & open water
6100	Surf Zone	infinite	Incompatible & open water

Table 2—NLCD to resistance reclassification for 50km buffer around FL into GA and AL.

NLCD value	Resistance	Similar CLC class	NLCD descrip
11	NoData	Open water	Open water
21	100	low density residential	developed, open space
22	600	Medium-density residential	Developed, low instensity
23	900	High-density residential	Developed, medium intensity
24	1200	High intensity urban	Developed high intensity
31	20	Plantations	Barren land (on inspection, is logged forest)
41	1	forest	natural
42	1	forest	natural
43	1	forest	natural
52	1	scrub/shrub	natural
71	20	native pasture/grasslands	grassland/herbaceous
72	1	natural	grassland/herbaceous
81	40	planted pasture	improved pasture
82	250	row crops	cultivated crops
90	1	natural wetland types	woody wetland
95	1	natural wetland types	herbaceous wetland