2009

CENTRAL INDIANA GREEN INFRASTRUCTURE:
GIS DESIGN AND ANALYSIS

Prepared by: Jazmin Varela,

Information Manager

Strategic Conservation Planning

The Conservation Fund

CENTRAL INDIANA GREEN INFRASTRUCTURE

GIS DESIGN AND ANALYSIS

A. Key Definitions for the Green Infrastructure Network Protocol

1. OVERVIEW

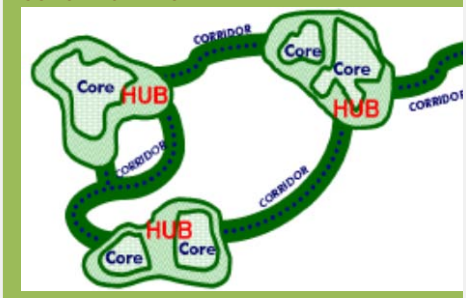
Green Infrastructure offers a conceptual approach for identifying conservation opportunities at an ecosystem level. Specifically, Green Infrastructure is technically defined as "a strategically planned and managed network of natural lands, working landscapes, and other open spaces that conserve ecosystem values and functions and provide associated benefits to human populations." Please see http://www.greeninfrastructure.net for more information.

Projection: NAD 83 UTM Zone 16N

Cell Size: 30 meters

Utilizing a green infrastructure approach in this planning process will help the residents of Central Indiana integrate species habitat within the context of an interconnected network of lands and waters, providing multiple benefits across the entire 9-county region in Central Indiana. The Central Indiana Green Infrastructure Network was the key product of the planning process and delineates core areas, hubs and a corridor network using criteria based in part on habitat requirements for selected umbrella species. This document is the key reference for the green infrastructure network design protocol which defines scales, establish criteria for key ecosystem

FIGURE 1: GREEN INFRASTRUCTURE (GI) CONCEPTUAL MODEL



attributes, and delineate network elements (e.g. core forests, core aquatic systems, etc.). Based on the methodology described, in this protocol, the Fund delineated cores, hubs and corridors for each of the three major ecosystem types.

2. TECHNICAL DETAILS

Core areas contain well-functioning natural ecosystems, and provide high-quality habitat for native plants and animals that meet a minimum size threshold based on species requirements and landscape conditions. These are the nucleus of the green infrastructure network. **Hubs** are aggregations of core areas, other habitat, and other natural land, divided by major roads or gaps. Hubs are intended to be large enough to support populations of native species, and serve as sources for emigration into the surrounding landscape. Not all core areas, other habitat, or other ecological features will fall within hubs, if they are isolated and below the size threshold. However, this does not mean such areas are unimportant.

Umbrella and keystone species native to an area are used to determine size, connectivity, and other thresholds in the green infrastructure network design. **Umbrella species** are a species or group of species, such as forest interior dwelling birds, whose habitat needs overlap those of other animals and plants. **Keystone species** are those with an important role in ecosystem function, such as pollinators and top carnivores. Habitat preferences of umbrella and keystone species help identify core areas and hubs. Connectivity requirements of less vagile (i.e. mobile) species (e.g., amphibians and small mammals) are used to model corridors. When sufficient habitat is protected to sustain umbrella and keystone species, other important components and microhabitats will be encompassed and are more likely to be protected as well.

Core Forests are contiguous areas of relatively undisturbed, mature forest with a minimum size threshold based on landscape conditions. For a current green infrastructure project ongoing in Maryland, core forest areas had to include forest blocks with at least 100 hectares of mature interior deciduous or mixed forest habitat that provided habitat for a majority of forest interior dwelling birds in the study area.

Core Wetlands are contiguous natural areas with relatively unimpacted wetlands that meet a minimum size threshold based on landscape conditions. For a recent green infrastructure project in Delaware, core wetland areas had to be at least 10 hectares in size and include habitat for umbrella species dependent upon riparian forest (Louisiana waterthrush, wood turtle), forested wetlands (Prothonotary warbler), wetland-forest complexes (amphibians, turtles), and/or marsh (Least bittern).

Core Aquatic Systems contain a threshold amount of relatively unimpaired streams plus associated riparian forest and wetlands. Umbrella species for aquatic systems often include fish, mussels, and benthic macro invertebrates. For a recent green infrastructure project in Delaware, core aquatic systems had to contain at least a kilometer of streams with minimal impacts from channelization, dams, and road culverts.

Corridors are linear features linking core areas together, to allow animal and plant propagule movement between them, in the hope of creating viable and persistent metapopulations. We assess the landscape between core areas for its linkage potential, identifying conduits and barriers to wildlife and seed movement. Corridor umbrella species can include reptiles, amphibians, fish, and mammals, depending on the type of linkage.

3. BACKGROUND

The area of interest is a 9-county region (3.1 million acres) centered on Marion County in Central Indiana (Figure 2). It is an area marked by the effects of multiple glaciations thousands of years ago. The terrain of central Indiana called the Tipton Till Plain is characterized by flat to gently rolling terrain, the result of continental glaciations during which glacial till and outwash were deposited as the ice advanced and melted from Indiana more than eight times (IN Geological Survey, 2008). All of the bedrock in Indiana is composed of sedimentary rock including limestone, dolomite, shale, sandstone, and siltstone. Two ecoregions transect the area, the Eastern Corn Belt Plains and the Interior Plateau.

TABLE 1: CENTRAL INDIANA'S LANDSCAPE IS DOMINATED BY CULTIVATED LAND (68%)

Landscape Type	Acres	Percent
Open Water	22,874	0.7%
Developed Land Cover	523,568	16.7%
Forest Land Cover	405,025	12.9%
Shrub/Scrub/Grasslands/Herbaceous	48,144	1.5%
Cultivated/Hay/Pasture	2,133,965	67.9%
Wetland	8,025	0.3%
Total	3,141,602	100.0%

Currently, more than 67% of the landscape (Table 1) is dominated by agriculture (63% row crops and 4% hay/pasture) with most of the crops being corn or soybeans. Additionally, more than 16% of the landscape has been developed and it is likely that this number is a conservative estimate given that it was based on satellite images collected more than 10 years ago. Only 17% of the landscape remains in a natural state but the amount and quality of those natural lands varies widely. Using a GIS program ArcGIS 9.3 (ESRI, 2009) this analysis looked at that 17% of the land to identify both quantity and quality

of terrestrial and aquatic environments in the region. Human benefits will come in the form of improvements to water quality, flood attenuation, recreational and educational opportunities, and the health benefits and improvement of quality of life associated with green infrastructure.

TABLE 2: ACREAGE COVERED BY STUDY AREA.

Total land area of Indiana:	**35,867 square miles or 22,954,880 acres**
Size of study area:	**3,141,601 acres (13.7% of state land)**

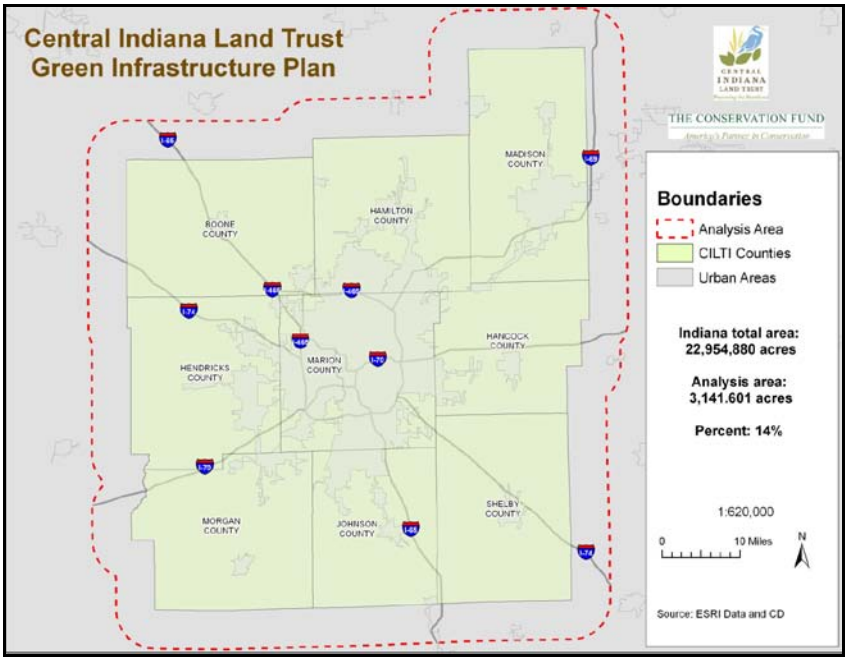
B. GIS Methods

1. Identify study area

1.1 The study area is defined by a 9-county area (Boone, Hamilton, Madison, Hendricks, Marion, Hancock, Morgan, Johnson, Shelby) plus a five mile buffer (Figure 2).

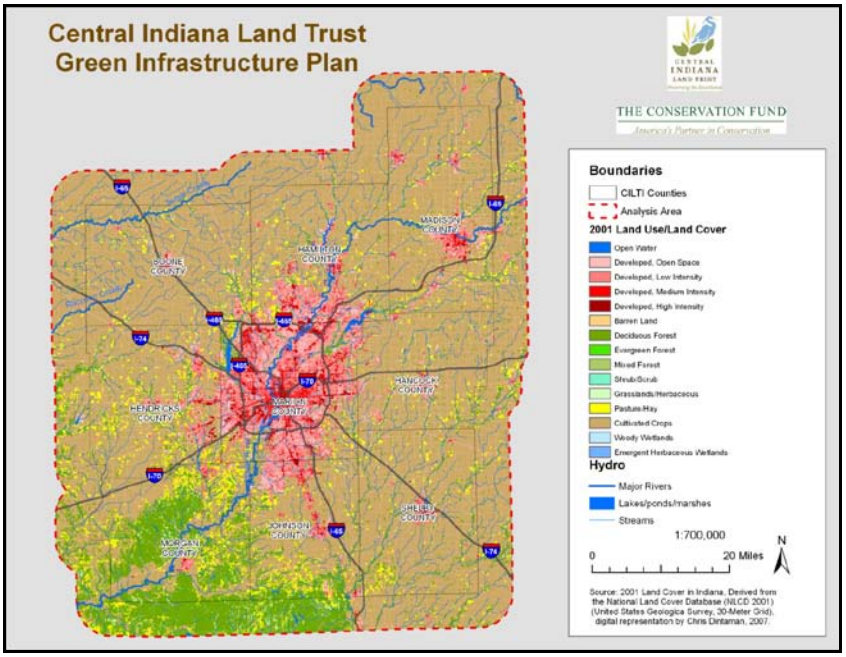
1.2 Also included are all overlapping 14-digit Hydrological Unit Codes (HUCs) for core aquatics delineation.

FIGURE 2: 9-COUNTY REGION PLUS 5 MILE BUFFER CONSTITUTE THE ANALYSIS EXTEND.



The State of Indiana has a surface area of approximately 33 million acres (Table 2) and approximately 14% of the land is contained in the Central Indiana region.

FIGURE3: CULTIVATED LAND DOMINATES THE LANDSCAPE OF CENTRAL INDIANA BUT DECIDUOUS FOREST REMAINS THE SECOND LARGEST LAND COVER IF DEVELOPMENT IS BROKEN DOWN INTO SEVERAL CATEGORIES.



2. Define core forest areas

2.1 Identify forest using Gap Analysis land cover. GAP's land cover map was derived from the classification of Landsat TM imagery. Coverage for the state of Indiana required the use of nine Landsat scenes. Image dates ranged from 1989 - 1993. The minimum mapping unit is one hectare.

2.2 Core areas contain fully functional natural ecosystems, and provide high quality habitat for native plants and animals. These are the nucleus of the ecological network. Both upland and bottom land (floodplain) forest are still present in the study area.

2.3 Upland forest umbrella species in the Interior Plateau Ecoregion: **Ovenbird *(Seiurus aurocapilla)***. Typically, the ovenbird nests in mid-late successional, closed-canopied deciduous or deciduous-coniferous forests that have deep leaf litter and limited understory. Inhabited forest types include oak (Quercus)-hickory (Carya), oak-pine (Pinus), maple (Acer)-basswood (Tilia), maple-birch (Betula), maple-birch-beech (Fagus Grandifolia), hemlock (TSsuga Canadensis)-oak, Trembling Aspen (Populus tremuloides), and spruce (Picea), fir (Abies). The ovenbird is classified as a forest-interior, area sensitive species, minimum area requirements

vary across the region with the Midwest requiring larger tracks than in the eastern and northeastern parts of the country. Minimum area requirements found by other studies are 100 hectares in Maryland, 341hectares in Missouri, and 380 in Ontario (NatureServe, 2009). Based on this assumption this plan will highlight upland deciduous forest tracks larger than 750 acres (approximately 300 hectares).Use GAP Classes 9 and 10 (see below for description).

2.4 For the Interior Corn Belt Plains Ecoregion use **Wood Thrush (*Hylocichla mustelina)*.** In general, it appears that forest patches exceeding 100 ha are best suited for successful nesting because rates of nest predation and sometimes cowbird brood parasitism are lower (NatureServe, 2009). Thrushes require only small territories (< 1 ha) and seem to be able to maintain stable populations on small, isolated forest fragments in some cases (e.g., a 15-ha woodlot (Roth and Johnson 1993)). Some woodlots as small as 5 ha may be acceptable (Pinkowski 1991). For this area the threshold used was 3 acres.

Please note when looking at land cover categories that they are not exclusively designed for Central Indiana and thus you may see an association more commonly found in other parts of the State. These are general categories and should be viewed as a general approximation to what we expect to see on the ground.

- Class 9: *Deciduous Woodland* (canopy closure 50-75%) description: Late-immature old fields, successional woods (sassafras, oaks, cherry, poplar, etc).
- Class 10: *Deciduous Forest* description: Closed canopy mixed hardwood successional forest (sassafras, oaks, cherry, tulip poplar, etc...)

2.5 Nest parasitism by brown-headed cowbirds decreases with distance away from

forest edge but extended >=300 m into the forest (ELI, 2003). In Conservation Thresholds for Land Use Planners, the reviewers found the 75% of surveyed studies estimated edge influence to be approximately 230 meters or less, and the report recommends 230-300 meters buffer around edge peripheries. Use 100 m as edge. Mask out all major roads.

2.6 Umbrella species selected for deciduous successional shrubland (Class 8) in the Interior Plateau ecoregion **is American Woodcock *(Scolopax minor)*:** requires a mix of habitats that vary with activity, time of day, and season. These include forest openings or clearings for singing displays in spring, alder or other young hardwoods on moist soils for feeding and daytime cover, young second-growth hardwoods for nesting, and large fields for night-time roosts (Mendall and Aldous 1943, Andrle and Carroll 1988, Boothe and Parker 2000). NatureServe calls for deciduous succesional shrubland > 3 acres for American Woodcock (based on 1.2 ha minimum display grounds and 170 m adult mean travel distance, NatureServe, 2008). The American Woodcock Conservation Plan (Kelley et al., 2008), however, established habitat goals for Bird Conservation Region (BCR) 22 of 18.8 acres of early succesional habitat per singing male and 63.3 acres for BCR 23. BCR 23 was probably never an important source of woodcock production (Kelley, et al., 2008). Given that BCR 22 has the most reliable and most recent estimates the network will identify deciduous succesional shrubland > 20 acres (note that after analysis no significant amounts of deciduous shrubland were found on the land cover data and thus is was excluded from the analysis).

2.7 Umbrella species for deciduous successional shrubland in the Corn Belt Plains ecoregion: **Yellow-breasted Chat *Icteria virens***. Yellow-breasted Chat shrubby openings of any shape of greater than five ha, even when surrounded by unfavorable habitat, are sufficient to support breeding populations (NatureServe, 2009). Use Gap Analysis Class 8.

- Class 8: *Deciduous Successional Shrubland (canopy closure <50%)* description: immature old field woods (sassafras, oaks, poplar, etc...)

2.6 For bottomlands and floodplain forest see wetlands 3.3

3. Define wetland core areas:

3.1 The study area falls within the White River and the East Fork of the White River watersheds. According to the IN Wetland Conservation Plan, special concerns in these watersheds include: urban areas, agricultural runoff, mining, rural septics, and siltation. See Table 3 for descriptions of wetland communities present in the analysis area (Indiana Department of Natural Resources, 1996).

3.2 Use Ducks Unlimited National Wetlands Inventory updated data layer (USFWS, 2009).

TABLE3: WETLANDS IN THE WHITE RIVER AND EAST FORK WHITE RIVER WATERSHED

Wetland Type (IN Wetland Conservation Plan)	USGS: Classification of Wetlands and deepwater of the U.S. (Cowardin, 1979)	Description
Shrub swamp	Forested Wetland	Shrub dominated wetland that is more or less permanently inundated. It commonly occurs in depressions
Marsh	Emergent Wetland	Herbaceous wetland of more or less permanent, non-flowing water bodies, either in lakes or water-filled depressions; water levels may fluctuate, but rarely recede to expose the soil surface.
Wet prairie	Emergent Wetland	Herbaceous wetland that occurs in deep swales; substrates range from very black mineral soils to muck.
Floodplain forest	Forested Wetland	Broadleaf deciduous forest of river floodplains. It has traits of long flooding and hydric soils that are intermediate between wetlands and terrestrial systems.
Fen		Calcareous, groundwater-fed wetlands
Northern and Southern swamp	Forested Wetland	Permanently inundated wetlands of large river bottoms. They normally occur in depressions and sloughs of the bottomlands. The soils are usually very poorly drained and are seasonally to permanently saturated or ponded.
Tillplain flatwoods	Forested Wetland	Forest on level upland terrain characterized by a mosaic of wet depressions and slightly elevated soils. Soils are typically poorly drained. Water levels, an accumulation of direct precipitation (not flooding), are normally ephemeral above the soil surface.
Seep		Graminoid wetlands dominated by sedges
Pond	Palustrine	In study area several glacial relict ponds or small kettle lake are found. A kettle is a depression caused by collapse of sediment due to the melting of buried blocks of ice.
Sinkhole pond	Palustrine	A water-containing depression, generally smaller than four acres, in limestone topography; normally consists of open water and marshy borders with little or no water flow.
Spring	Palustrine	A water-containing depression, generally smaller than four acres, in limestone topography; normally consists of open water and marshy borders with little or no water flow.

3.3 Umbrella species for emergent wetlands/marshes (avoid woody vegetation) is **King Rail (*Rallus elegans*)**: utilizes other habitat but prefers marsh, upland-wetland marsh edges, rice fields or similar flooded farmlands, shrub swamps. Breeding range unknown but possibly small, use 20 acres as absolute

minimum (Cooper, T. and Feaster, Brad, Personal communication) and 10 meter edge subtracted. Use updated National Wetland Inventory (Ducks Unlimited, draft version).

According to the King Rail Conservation Plan (Cooper, 2008) other species, with habitat needs similar to those of the King Rail, are likely to benefit through the implementation of the actions presented in the plan. A partial list of species identified at the November 2006 King Rail Workshop that may benefit throughout a portion or all of their annual lifecycle include: American Bittern (*Botaurus lentiginosus*), Black Tern (*Chlidonias niger*), Black-bellied Whistling-Duck (*Dendrocygna autumnalis*), Common Moorhen (*Gallinula chloropus*), Fulvous Whistling-Duck (*Dendrocygna bicolor*), Least Bittern (*Ixobrychus exilis*), Marsh Wren (*Cistothorus palustris*), Purple Gallinule (*Porphyrula martinica*), Sedge Wren (*Cistothorus platensis*), Sora (*Porzana carolina*), Virginia Rail (*Rallus limicola*), and various species of egrets and herons. Species that would benefit during migration and/or wintering periods include: Greater Yellowlegs (*Tringa melanoleuca*), Lesser Yellowlegs (*Tringa flavipes*), Blacknecked Stilt (*Himantopus mexicanus*), Long-billed Dowitcher (*Limnodromus scolopaceus*), and Stilt Sandpiper (*Calidris himantopus*).Use National Wetland Inventory (NWI) or GAP Class 16 (Herbaceaous).

3.3 Umbrella species for riparian forest/forested wetlands/floodplain forest is **Indiana bat (*Myotis sodalis*)** core habitat. This region is mostly summer roosting habitat. This plan will concentrate on the conservation of known summer habitat to maximize survival and fecundity. The counties with recorded maternity colonies in the study area are: Hendricks (2), Johnson (3), Marion (2), Morgan (4), Shelby (2), (USFWS, 2007). Indiana bat hibernacula are not present or not recorded in the nine county study area. Mature forest is more likely to contain large dead trees with sloughing bark. Maternity roosts are commonly located in bottomland or riparian areas (Menzel et al. 2001). Another study in the Upper Wabash watershed (Duchamp et al., 2008) found that bat diversity was positively correlated with forest area and that some species

including *M. sodalis* were more prominent in landscapes with greater forest area, forest aggregation and tree corridors and less urban development. Other species like Red-shouldered Hawk (*Buteo lineatus*) may use similar habitat, nesting typically in mature floodplain forest with a well-developed high canopy and variable amounts of understory vegetation usually near water (NatureServe, 2009).

3.4 IN Bat suitable habitat was modeled using Maxent software. Weber (Weber, 2009) calculated 17 variables within the study area (Table 4), using ArcGIS Model Builder. Based on results from this group of variables and the pilot study, The Fund then examined the variables in Table 4. The Fund also sought to compare NLCD to GAP land cover and based the 1 km scale on the average foraging range of 11 individuals tracked by Sparks et al. (2005), and the 3 km scale on their averaged maximum linear distance from roost. To speed computations, which otherwise would have taken many hours, we resampled landcover variables to a resolution of 90m for 3 km focal statistics. We did not think this would introduce appreciable error. We used 10-fold cross-validation and examined the mean and standard deviation of the replicate runs. Similar to running with the variables in Table 1, the average test area under the receiver operating characteristic curve (AUC) for the replicate runs was 0.877 (standard deviation 0.017). Percent area within 1 km of blocks of closed canopy hardwood forest, floodplain forest, or swamp containing unchannelized streams or rivers (pct_forstr_1k) had the greatest contribution to the Maxent models (Table 4). This was followed by the length of unchannelized streams or rivers in closed canopy hardwood forest, floodplain forest, or swamp within 1 km (str_dfor_m_1k). Jackknife tests showed that the environmental variable with highest gain when used in isolation was pct_forstr_1k, which therefore appeared to have the most useful

information by itself. The environmental variable that decreased the gain the most when it was omitted was str_dfor_m_1k, which therefore appeared to have the most information that wasn't present in the other variables. Percent development (pct_devel_1k and pct_devel_3k) and distance to busy roads (dist_busy_rds) provided minimal contributions to the models. Predicted habitat suitability was greater as the

TABLE 4: ENVIRONMENTAL VARIABLES USED IN MAXENT MODELING

Variable name	Variable description	Source data
pct_decfor_1k	Percent closed canopy hardwood forest, floodplain forest, and swamps within 1 km	GAP
pct_forstr_1k	Percent area within 1 km of blocks of closed canopy hardwood forest, floodplain forest, or swamp containing unchannelized streams or rivers	GAP and NHD; Ftype = STREAM/RIVER or ARTIFICAL PATH
str_dfor_m_1k	Length of unchannelized streams and rivers in closed canopy hardwood forest, floodplain forest, or swamp within 1 km	NHD; Ftype = STREAM/RIVER or ARTIFICAL PATH
pct_devel_1k	Percent development within 1 km	GAP
pct_edges_1k	Length of forest edges with fields or open water within 1 km	GAP
pct_decfor_3k	Percent closed canopy hardwood forest, floodplain forest, and swamps within 3 km	GAP
pct_forstr_3k	Percent area within 3 km of blocks of closed canopy hardwood forest, floodplain forest, or swamp containing unchannelized streams or rivers	GAP and NHD; Ftype = STREAM/RIVER or ARTIFICAL PATH
str_dfor_m_3k	Length of unchannelized streams and rivers in closed canopy hardwood forest, floodplain forest, or swamp within 3 km	NHD; Ftype = STREAM/RIVER or ARTIFICAL PATH
pct_devel_3k	Percent development within 3 km	GAP
pct_edges_3k	Length of forest edges with fields or open water within 3 km	GAP
dist_busy_rds	Distance from busy roads (Average Annual Daily Traffic >10,000)	IN DOT roads with traffic
		counts
dist_caves	Distance to karst caves	
dist_hibernac	Distance to known winter hibernacula	USFWS

amount of nearby closed canopy hardwood forest, floodplain forest, or swamp containing unchannelized streams or rivers (pct_forstr_1k, str_dfor_m_1k, pct_forstr_3k, and

str_dfor_m_3k) increased, and distance from winter hibernacula (dist_hibernac) and distance from caves (dist_caves) decreased. Predicted suitability increased as percent closed canopy hardwood forest, floodplain forest, and swamps (pct_decfor_1k and pct_decfor_3k) increased, but this was only apparent when the variables were used alone, not in combination with othervariables. Similarly, predicted suitability decreased as percent development (pct_devel_1k andpct_devel_3k) increased, this was only apparent when the variables were used alone. Percent edges within 1 km provided minimal information, but when considered alone, percent edges within 3 km seemed to predict better habitat between around 25-40% somewhat arbitrary, but was based on standard practice, as well as time limitations.

TABLE 5: HEURISTIC ESTIMATE OF RELATIVE CONTRIBUTIONS OF THE ENVIRONMENTAL VARIABLES IN TABLE 4

Variable	Percent contribution
pct_forstr_1k	33
str_dfor_m_1k	20.9
dist_hibernac	9.6
pct_decfor_1k	7.2
pct_edges_3k	6.7
str_dfor_m_3k	6.0
dist_caves	3.6
pct_forstr_3k	3.1
dist_busy_rds	2.9
pct_devel_3k	2.1
pct_decfor_3k	1.9
pct_devel_1k	1.8
pct_edges_1k	1.1

the Maxent model. To determine the estimate, in each iteration of the training algorithm, the increase in regularized gain is added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of lambda is negative. As with the jackknife, variable contributions should be interpreted with caution when the predictor variables are correlated. Values shown are averages over replicate runs.

3.5 Identify woodlands larger than 257 acres within IN bat foraging range (8.37km to 8km buffer) of any roosts with agriculture/old field component.

3.6 Use NWI or GAP analysis Class 13 (flood plain: deciduous forest, closed canopy hardwood successional forest for summer habitat).

3.7 Other wetland habitat: deciduous shrubland (river bar complex and swamp/bog series, GAP class15). Use **Yellow Warbler (*Dendroica petechia*) and White-eyed Vireo (*Vireo griseus*)** found in deciduous scrub, overgrown pastures, old fields, wood margins, streamside thickets. Yellow Warbler breeds in wet, deciduous thickets, especially in willows. Also in shrubby areas and old fields (http://www.birds.cornell.edu, 2008). Deciduous shrublands >30 acres should provide enough edge habitat. A study in the Georgia Piedmont found that large isolated forest patches more than 27 acres (10ha) had much greater diversity than smaller patches including edge species like Yellow Warbler. White-eyed vireos were more frequently observed in smaller isolated patches, average size 1.32 ha. (McIntyre, 1995).

4. Define freshwater aquatic core area

4.1 For core aquatics use 12-digit Hydrological Unit Code watershed s (HUCs).

4.2 Umbrella species for streams: fish, mussels, benthic macroinvertebrates

4.3 Identify core watersheds using water quality data collected by Indiana Department of Environmental Management (IDEM). By using a combination of Qualitative Habitat Evaluation Index (QHEI) scores and the Hilsenhoff Biotic Index (HBI) scores, we can get a more accurate view of a stream's physical and biological conditions. Use a HBI < =5.50 and a QHEI of >= 50 (mean score is 65.7 and sd of 14.24).

4.4 Umbrella species: **River otter (*Lontra canadensis*)**: Individual otters regularly move

large distances. Home ranges are large and often generally linear along streams and shorelines, typically 30-50 kilometers long for males or pairs (Jackson 1961). Thus populations and metapopulations generally occupy large areas. For this and other wide-ranging, low density mammals, it seems most reasonable to base occurrences (and conservation efforts) on major occupied landscape features rather than on specific prescribed separation distances (NatureServe, 2008). Currently three occurrences are registered in the natural heritage database at Indian Creek, Little Sugar Creek and Fishback Creek. Use a linear distance of 50 km from the centroid of each EO to delineate river otter occupied landscape features.

4.5 Other focal species

4.7.1 Because little is known about fresh water mussels habitat requirements one first needs to know where the species prefers to live, and what its requirements are for survival (Phillips et al. 2004). Stream mussels were manually delineated per expert recommendation of where current mussel occurrences are present.

6. Hubs

6.1 Hubs in the green infrastructure network represent the most important large ecological patches remaining in Central Indiana. Use GAP Class 7 (agriculture: pasture and grasslands) for potential habitat but need to refine more, possibly use Cropland Data layer to mask land currently in production. Examine GAP Class 8 (deciduous successional shrubland, canopy closure <50%).

6.2 Hubs contain one or more of the following:

6.2.1 Add all core areas

6.2.3 Significant sites as delineated by IN Natural Heritage Program.

6.2.4 Pasture lands and hay fields surrounding core areas with 300 meters of core edge.

6.2.5 Combine all and extract those hubs that are larger than 100 hectares.

7. Corridors

Corridors were develop using the least cost path tool in ArcGIS 9.3 (ESRI).

TABLE 6: FOCAL SPECIES FOR CORRIDOR DELINEATION

Core areas	Sample species	Details
Forest	Bobcat, gray fox, wild turkey, Eastern box turtle	Width: > 100 meters Corridors included forested areas, wetlands with 30m/buffer, no impervious surfaces and road less areas.
Wetlands	River otter, mink, beaver, semi-aquatic snakes, salamanders, frogs, crayfish	Width : >180 meters Wide riparian forest and wetlands preferred. Other wetlands and forest are
Aquatics	Fish and mussels	Width: varies. Unblocked perennial streams with unpolluted water and 100 meter riparian buffer. No impervious surfaces, roads or bridges.

Barriers: roads and highways are barriers for most species as well as most urban and developed lands. Also wide and fast moving rivers can act as barriers for some species.

Impedance layers were developed by assigning a cost to a series of surfaces. The higher the cost the more difficult it is for a species to traverse the landscape. For each landscape type a GIS model was developed to determine the least cost path for each.

7.1 Based on the latest scientific literature forest corridors should be at least 200m wide, based on interior forest bird requirements (Hodges and Krementz, 1996; Jones et al., 2000). Vidra (2004) showed that corridors >150m wide generally had <10% exotic invasive plants. According to Bond (2003) a width of 300 m or more is preferable.

7.2 Corridors for forest in this region were set at 100 meters (328 feet) based on the landscape condition and the unrealistic probability that 300 meter corridors can be protected or even existent.

7.3 Calculate wetland corridors using 180 meter width (approximately 600 feet).

7.4 Aquatic corridors are at least 30 meters (98 feet) in width.

8. Network Characterization: use independent data to evaluate the GI Network and calibrate accordingly.

8.1 Compute amount of Green Infrastructure already protected (use Ducks Unlimited Conservation and Recreation Lands (CARL) with easement information.

8.2 Compute GI acreage and percent per county.

8.3 Compute percent of Flood plains contained in the Green Infrastructure Network.

9. Maps and Tables

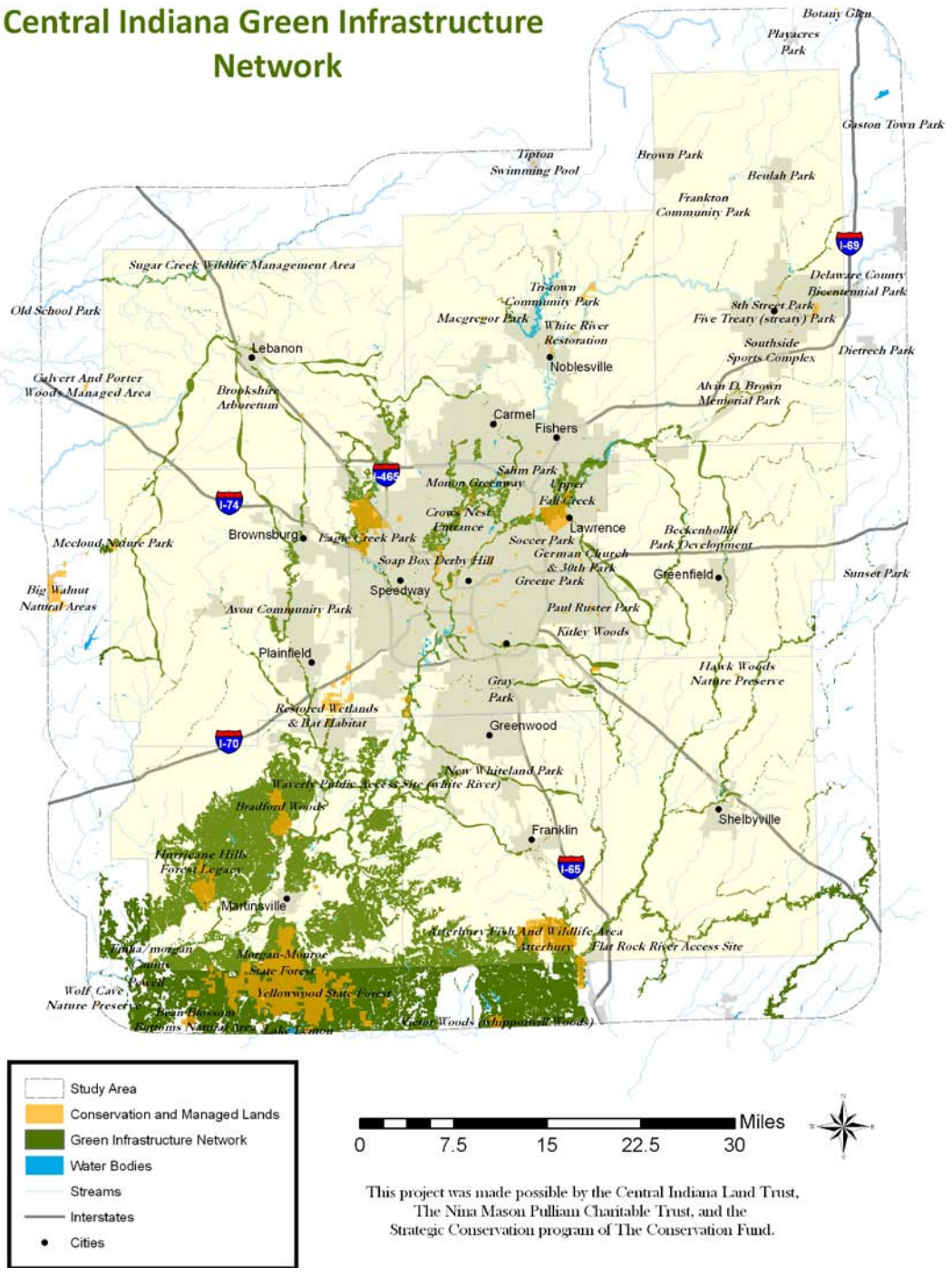
The results suggest that approximately 10% of the 3.1 million acres in the study area constitute part of the Green Infrastructure Network. There are approximately 173,000 acres (Table 7) of core forest mostly in Morgan County (Figure 4)where the hilly terrain did not allow for agricultural development. About 10,000 acres of core wetlands are in the network and approximately 13,000 acres of core aquatics.

TABLE 7: GI COMPONENTS AND RESPECTIVE ACREAGE.

By Core area, hubs and corridors	squared meters	Study area (9-counties plus 5 mile buffer)
Core Forest	701320512.00	173,300.07
Core Wetlands	42268500.00	10,444.77
Core Aquatics	55744200.00	13,774.69
Hubs	904736000.00	223,565.13
Corridors	367119904.00	90,717.30
Total area		511,801.98

Approximately 167,000 acres of land are under protection in the area of interest. Of those acres only about half are within the green infrastructure network and overall only 18% of the Green Infrastruture Network is currently protected (Figure 4). Finally, 1.6% of the land within the GI network is enrolled in the Classified Forest and Wildlands Program, a state sponsored effort to encourage the voluntary stewardship of woodlands and wildlands by private landowners. While land enrolled in the program is not permanently protected, there are significant incentives for landowners to not develop their property.

FIGURE 4: CENTRAL INDIANA GREEN INFRASTRUCTURE NETWORK



This project was made possible by the Central Indiana Land Trust, The Nina Mason Pulliam Charitable Trust, and the Strategic Conservation program of The Conservation Fund.

Table 8: Total GI network acreage

Central Indiana Green Infrastructure Network

	Total Area (acres)	GI acres (cores, hubs, and corridors)	Percent Of GI
Study area (9-counties plus 5 mile buffer)	3,141,601.38	331,103.91	10.54%
9 Counties	2,265,058.91	224,551.83	9.91%
Protected Lands	127,079.61	62,750.04	49.38%
Classified Lands	16,375.89	5,516.50	33.69%

Table 9 displays the Green Infrastructure breakdown per county. Morgan and Marion Counties have over 10% of their land classified as part of the Network while the rest of the counties have less than 10%. These numbers are significant in that the approach for implementation will be different. Morgan and Marion Counties can benefit from more overall connectivity between the existing protected lands. The other seven counties need an aggressive plan to target more strict protection, in particular, along riparian and stream corridors.

Table 9: County distribution of GI acreage

	Total County Area (acres)	**Total GI area (acres) in each County**	
MADISON	289,735.61	2,773.26	1.0%
HAMILTON	257,349.46	4,642.49	1.8%
BOONE	270,768.42	10,747.68	4.0%
HANCOCK	196,406.92	7,166.23	3.6%
MARION	257,685.82	26,357.50	10.2%
HENDRICKS	261,474.85	9,216.04	3.5%
SHELBY	263,961.79	12,112.74	4.6%
MORGAN	205,857.80	32,901.34	16.0%

TABLE 10: FLOODPLAINS AND GI ACREAGES DISTRIBUTION PER COUNTY

	Total County Area (acres)	Total GI area inside floodplain (A and AE) in m2	Total GI area inside floodplain (A and AE)	Percent of GI area in floodplains
MADISON	289,735.61	8050500.00	1989.32	**0.69%**
HAMILTON	257,349.46	8479800.00	2095.40	**0.81%**
BOONE	270,768.42	11083500.00	2738.79	**1.01%**
HANCOCK	196,406.92	12145500.00	3001.22	**1.53%**
MARION	257,685.82	40809600.00	10084.27	**3.91%**
HENDRICKS	261,474.85	14194800.00	3507.61	**1.34%**
SHELBY	263,961.79	31489200.00	7781.15	**2.95%**
JOHNSON	205,857,.80	22693500.00	5607.69	**2.72%**
MORGAN	261,818.25	49615200.00	12260.18	**4.68%**

According to a recent report on Climate Change (Union of Concerned Scientist, 2009), found that precipitation is more likely to come in the form of heavy rains, downpours and flooding. Already, heavy downpours are twice as frequent as they were a century ago. In 2008, Indiana suffered billions of dollars in damage due to flooding. Table 10 highlights the amount of GI acres that also considered high risk flood plain. These are areas that need not to be developed because they are subject to frequent flooding and flood damage may constitute "low hanging fruit" in terms of conservation opportunities. In addition to protecting intact flood plains there are many opportunities for restoring these water storage areas (Figure 6) where no riparian forest currently exists.

Results from IN bat modeling are depicted in Figure11, significant overlap of suitable IN bat habitat and GI corridors along streams and riparian corridors exits. As the model results indicated, percent closed canopy hardwood forest, floodplain forest, and swamps within 1 km appear to be one of the most important factors during summer roosting. This could indicative that bats favor habitat where insect and other food sources are widely available.

FIGURE 5: IN BAT HABITAT MODEL RESULTS USING MAXENT (MAXIMUM ENTROPY MODEL)

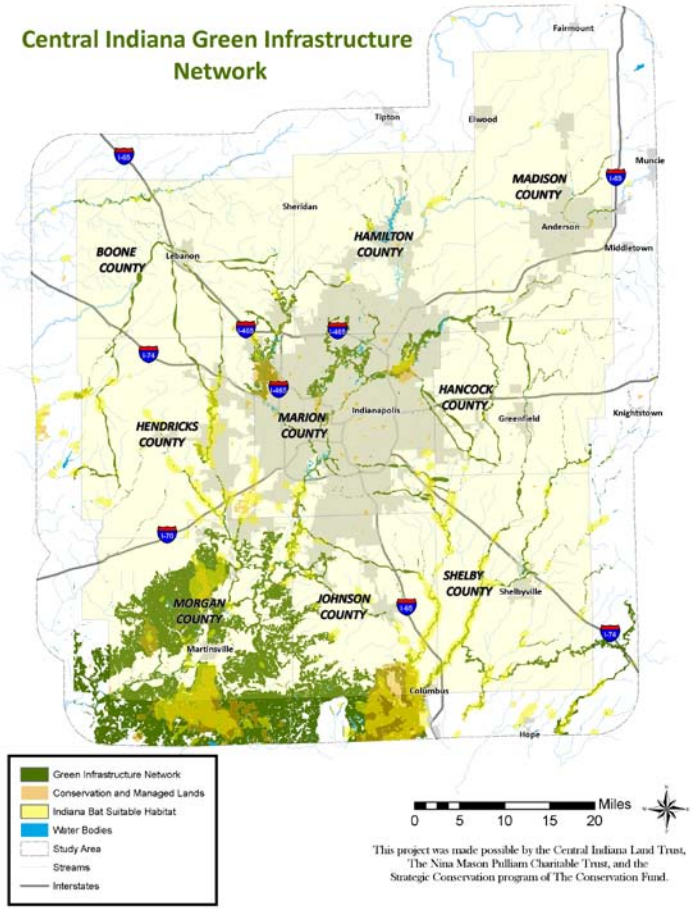
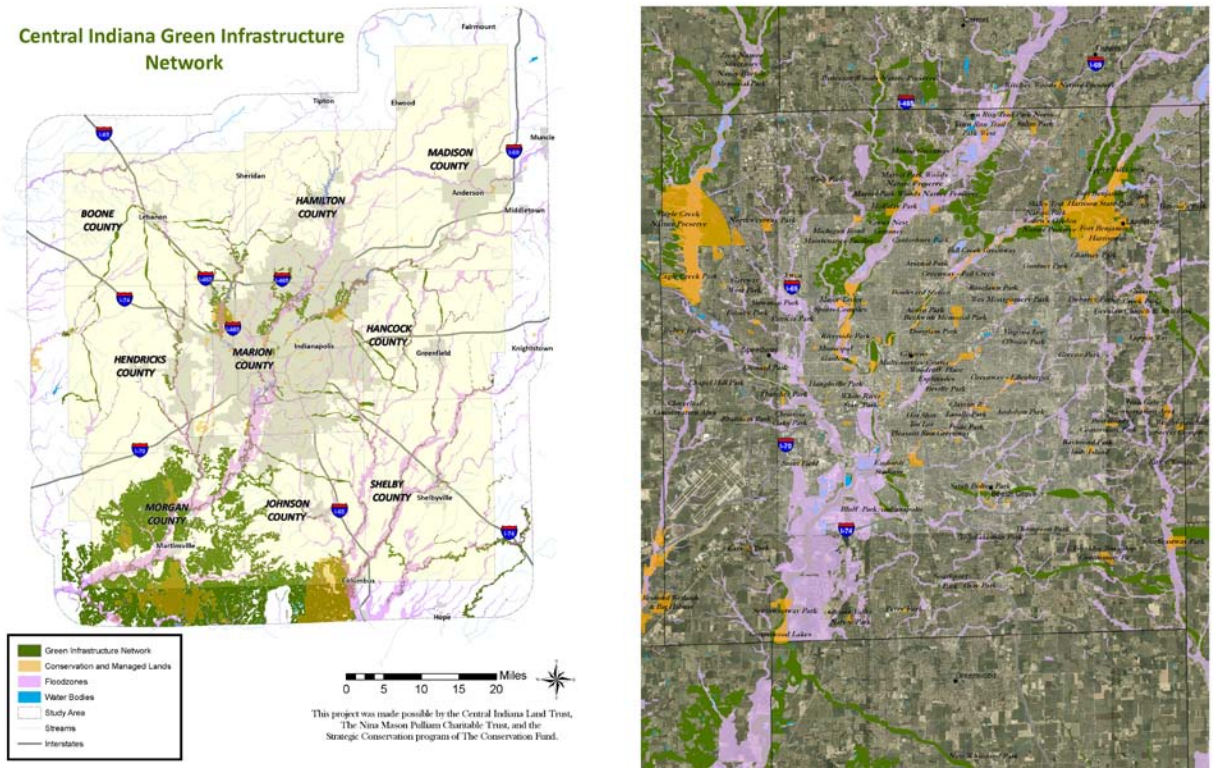
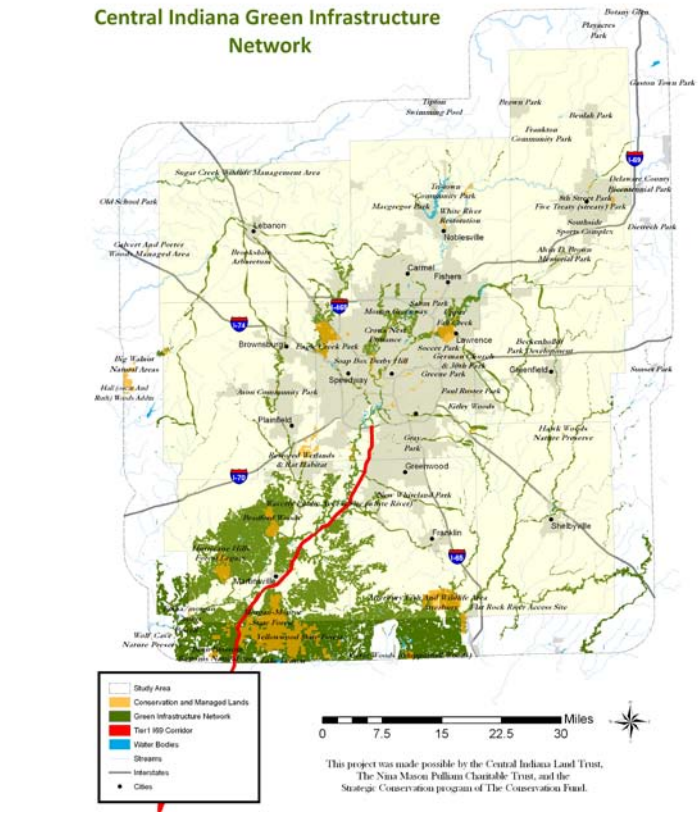


FIGURE 6: HIGH RISK FLOOD PLAINS



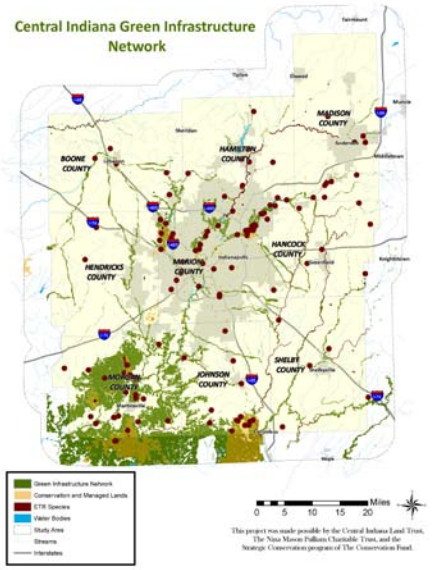
Another important aspect of evaluating GI is the location of flood plains which play a significant role as habitat, water storage and purification. Multiple programs are currently available at the state and federal government level to protect floodplains (see implementation quilt for details). As seen in the second panel of Figure 6, it is not surprising that Marion County suffers from severe flooding issues. In addition to the impervious surface, a great portion

FIGURE7: TIER2 I-69 CORRIDOR



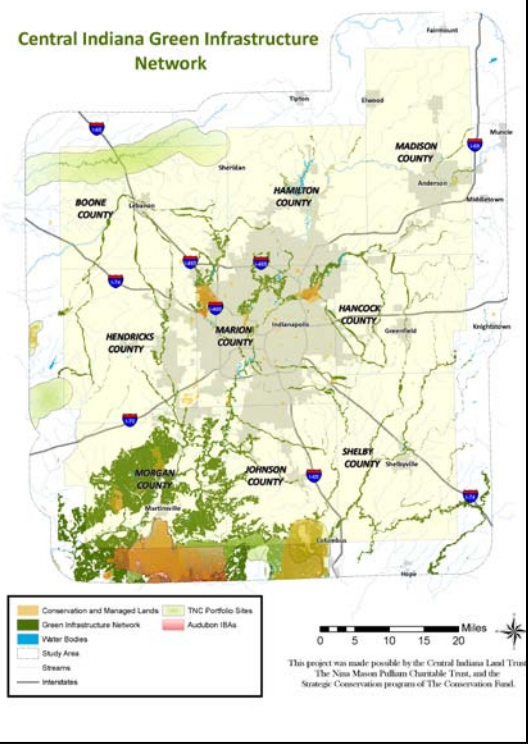
of the flood plain remains unprotected. Other threats in the region include the development of roads that both fragment habitat and contribute runoff to the water ways. The future of some of the best and habitat patches in the region is currently jeopardized by the future construction of the I69 corridor (Figure 7). The new highway could have anywhere from 8-10 lanes or an average of 2000 feet in width and it would fragment some of the best habitat remaining in the region.

FIGURE 8: EOS IN THE AREA OF INTEREST



Central Indiana sits in what used to be a continental hot spot for fresh water mussels. Neotropical birds and resident birds are also part of the biodiversity in the region. Endangered, rare, and threatened species (ETRs) are tracked by the Indiana Natural Heritage Program. In the area of interest many of these species include the IN Bat, various species of fresh water mussels and many migrating Neotropical birds and waterfowl. In Figure 8 the red dots depict rare and threatened species occurrences in Central Indiana.

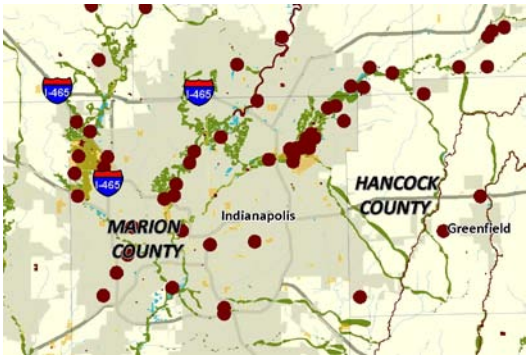
FIGURE10: GI RELATED TO OTHER CONSERVATION PRIORITIES IN THE REGION



A close up in the area reveals a heavy concentration of ERTs along the White River, Falls Creek, and Eagle Creek (Figure 9). These water ways are also impaired and suffer from a number of contaminants that put them into non-attainment for their designated uses. Other areas of concentration of rare species include the forested land in Morgan and Johnson Counties.

The GI Network was compared to other conservation priorities set by The Nature conservancy and The Indiana Chapter of the Audubon Society. Figure 10 is useful in that it shows areas where ownership between conservation groups can be formed but also areas where one no one is currentl y working. In Boone County, Sugar Creek corridor is of interest to the Nature Conservancy and also part of the GI Network. In Johnson County, an important corridor between Atterbury and Yellowwood State Forest is currently under-protected but could potentially link two of the largest protected areas in the region.

FIGURE 9: ETR SPECIES AROUND MARION COUNTY COMPARED TO IMPAIRED WATER



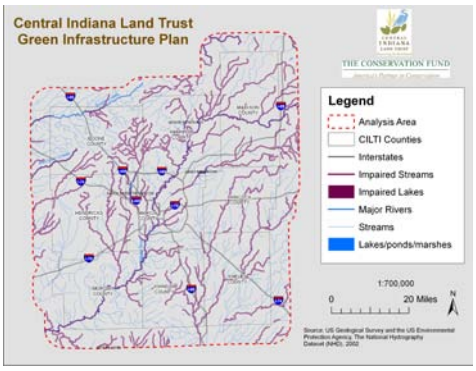


TABLE 8: MAPS AND GIS DATA SOURCES

Geospatial files	Source
State and County Boundaries	Environmental Science Resource Institute (ESRI) 2008 Data and Maps CD
Endangered, Rare and Threaten Species	Indiana Natural Heritage Program
Roads, highways and bridges	Indiana Department of Transportation (IDOT)
Streams and water bodies	The National Hydrography Dataset (NHD)
Water Quality Database	Indiana Department of Environmental Management (IDEM)
Trails	Indiana Department of Natural Resources/Division of Outdoor Recreation
2001 Land Use/Land	National Land Cover Data, USGS (Multi-Resolution Land Characteristics (MRLC) Consortium)
Floodplains	FEMA, Marion County, and Johnson County
Important Bird Areas	IN Chapter of the Audubon Society
TNC Portfolio Sites	IN Chapter of the Nature Conservancy
Conservation and Managed Lands	CARL database, Ducks Unlimited, Indiana Departments of Natural Resources, Indianapolis Airport Authority, and USDA Forest Service (Forest Legacy Program)
Classified Lands	IN Department of Natural Resources
Level III and Level IV Ecoregions	U.S. Geological Survey
GAP Ecological System	Indiana State University, U.S. Fish and Wildlife Service, Indiana University GIS Lab, Pangaea Tech
2003 Color Orthophotos	The National Agriculture Imagery Program (NAIP)

C. References

Andrle, R. F., and J. R. Carroll, editors. 1988. The atlas of breeding birds in New York State. Cornell University, Ithaca, New York. 551 pp.

Badra, P.J. 2001. Special Animal Abstract for *Pleurobema clava* (Northern clubshell). Michigan Natural Features Inventory. Lansing, MI. 4 pp.

Baker, E.M., Weller, E.D., Jordan, E.T. 2006. Improved methods for quantifying potential nutrient interception by riparian buffers. Landscape Ecology: 21:1327-1345.

Bond, M. 2003. Principles of wildlife corridor design. Center for Biological Diversity. 4pp.

Boothe, S. and K. Parker. 2000. American Woodcock. Species-specific management abstracts. Lasting Forests. Dept. of Fish. and Wildlife Science, Virginia Polytechnic Institute and Univ. Available online at: http://fwie.fw.vt.edu/rhgiles/speciesssm/wcock.htm

Cowardin, L. M., V. Carter, F. C. Golet, E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Department of the Interior, Fish and

Cornell Ornithology Lab. All About Birds. Available at [http://www.birds.cornell.edu, 2008]. Accessed on December 18th, 2008.

Carr, M. H., Zwick, P.D. 2007. Smart land-use analysis: the LUCIS model land use identification strategy. 1st ed. 46-72.

Cooper, Thomas R. (Plan Coordinator). 2008. King Rail Conservation Plan, Version 1. U.S. Fish and Wildlife Service, Fort Snelling, Minnesota. 121pp.

Duchamp, J.E., Swilhart, R.K. 2008. Shifts in bat community structure related to evolved traits and features of human-altered landscapes. Landscape Ecology 23:849-860.

Ducks Unlimited. The Great Lakes Conservation and Recreation Lands (CARL). Great Lakes /Atlantic Regional Office, 2008.

Environmental Law Institute. 2003. Conservation Thresholds for Land Use Planners. Washington, D.C.

Environmental Research System Institute (ESRI). ArcGIS Desktop 9.3.1. Redlands California, 2009.

Hands, H. M., R. D. Drobney, and M. R. Ryan. 1989. Status of the cerulean warbler in the north central United States. Missouri Coop. Fish Wildly. Res. Unit Rep. 11 pp.

Hamel, P. B. 1992. Cerulean warbler, DENDROICA CAERULEA. Pages 385-400 in K. J. Schneider and D. M. Pence, editors. Migratory nongame birds of management concern in the Northeast. U.S. Fish and Wildlife Service, Newton Corner, Massachusetts. 400 pp.

Hodges, M.E. Jr., and Krementz, D. G. 1996. Neotropical migratory breeding bird communities in riparian forests of different widths along the Altamaha River, Georgia. Wilson Bull. 108 (3):496-506.

Indiana Department of Natural Resources. 1996. *Indiana Wetlands Conservation Plan* (*IWCP*). Indianapolis, IN.

Indiana Geological Survey. Indiana Map. Available at [http://inmap.indiana.edu/download.html, 2009]. Accessed on various dates.

Jackson, H.H.T. 1961. Mammals of Wisconsin. Univ. Wisk. Press, Madison, WI. 504pp.

Johnson et al. 2000. The Eastern Massasauga Rattlesnake: A Handbook for Land Managers. U.S. Fish and Wildlife Service, Fort Snelling, MN 55111-4056 52 pp. + appdx.

Kelley, J., Williamson, S., and Cooper, T.R., eds. American Woodcock Management Plan. 2008.

Maryland Department of Natural Resources. 2003. Maryland's Green Infrastructure Assessment: A comprehensive Strategy for Land Conservation and Restoration.

McIntyre, E.N. 1995. Effects of forest patch size on avian diversity. Landscape Ecology. Vol.10:85-99.

Mendall, H. L. and C. M. Aldous. 1943. The ecology and management of the American Woodcock. Maine Cooperative Wildlife Research Unit. 201pp.

Menzel, M.A., Menzel, J.M., Carter, T.C., Ford, M.W., Edwards, J.W. 2001 Review of the Forest Habitat Relationships of the Indiana Bat (*Myotis sodalis*). USDA Forest Service, Northeastern Research Station.

NatureServe. 2008. NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.0. NatureServe, Arlington, Virginia. Available http://www.natureserve.org/explorer. (Accessed: multiple dates, 2008).

NatureServe. 2009. NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.0. NatureServe, Arlington, Virginia. Available http://www.natureserve.org/explorer. (Accessed: multiple dates, 2009).

Sparks, D. W., C. M. Ritzi, J. E. Duchamp, and J. O. Whitaker, Jr. 2005. foraging habitat of the Indiana bat (Myotis sodalis) at an urban-rural interface. Journal of Mammalogy 86:713-718.

Phillips, J.S., Dud´ık, M., Schapire, E. R. 2004. Princeton University, *Proceedings of the* 21st *International Conference on Machine Learning*, Banff, Canada.

Pinkowski, B. 1991. Wood Thrush. Pages 356-7 in R. Brewer, G. A. McPeek, and R. J. Adams Jr. (editors). The atlas of breeding birds of Michigan. Michigan State University Press, East Lansing, Michigan.

Robbins, C. S., J. W. Fitzpatrick, and P. B. Hamel. 1992. A warbler in trouble: DENDROICA CERULEA. Pages 549-562 IN J. M. Hagan III, and D. W. Johnston, editors. 1992. Ecology and conservation of neotropical migrant land birds. Smithsonian Institution Press, Washington, D.C. xiii + 609 pp.

Roth, R. R., and R. K. Johnson. 1993. Long-term dynamics of a wood thrush population breeding in a forest fragment. Auk 110:37-48.

USFWS. Cerulean Warbler (*Dendroica cerula)* Fact Sheet. December 2006. Available at [http://www.fws.gov/Midwest/Eco_Serv/soc/birds/cerw/cerw-fctsheet.html], accessed on November 19, 2008.

Vidra, R. 2004. Implications of exotic species invasion for reforestation of urban riparian forests. PhD Thesis, North Carolina State University, Raleigh, NC.

Wildlife Service, Washington, D.C. Jamestown, ND: Northern Prairie Wildlife Research Center Online. http://www.npwrc.usgs.gov/resource/wetlands/classwet/index.htm (Version 04DEC1998).