Site Wind Right: Accelerating Clean, Low-Impact Wind Energy in the Central United States

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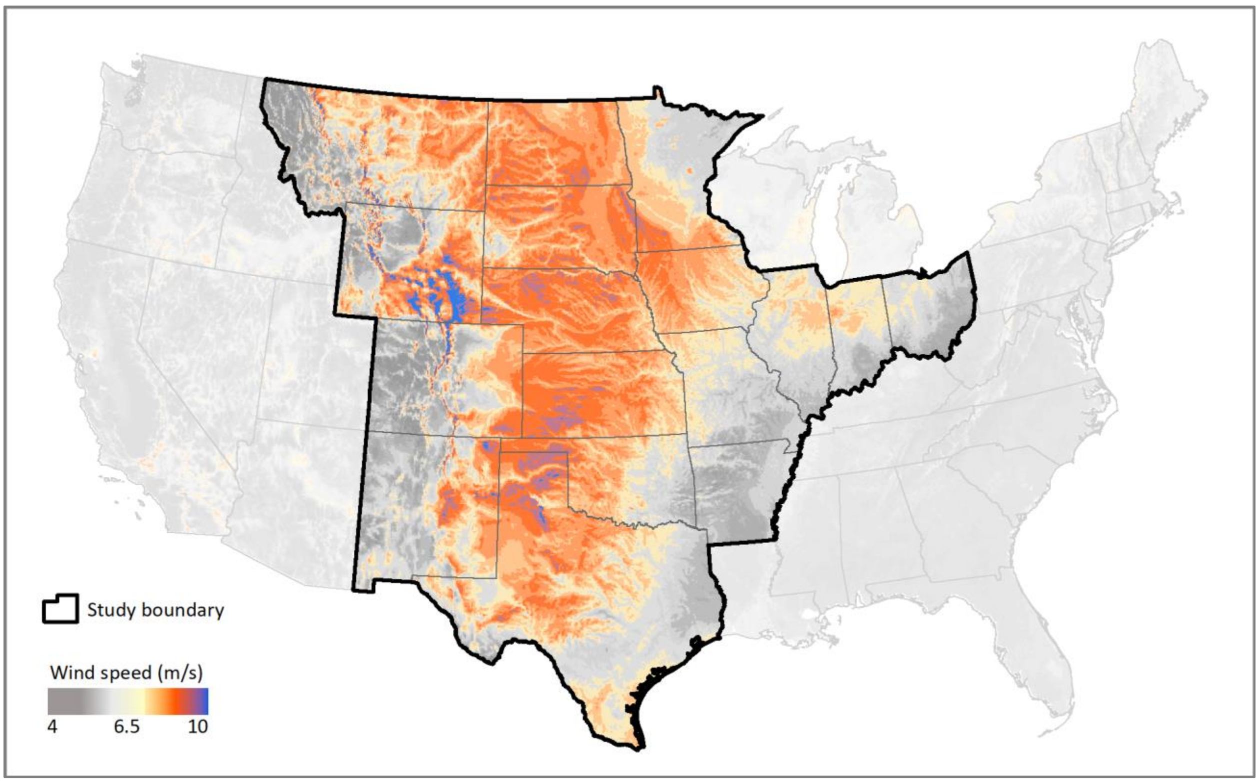
http://www.nature.org/sitewindright

Introduction

The Nature Conservancy supports the rapid expansion of renewable energy while protecting wildlife and natural habitats. This paper summarizes the data and assumptions included in The Conservancy's Site Wind Right assessment, as well as how we intend the results to be used. The Site Wind Right map was created to identify areas where wind development is unlikely to encounter significant wildlife-related conflict, project delays, and cost overruns. The map was designed to serve as an important source of information to inform screening early in the project siting process. It can be used to support application of the U.S. Fish and Wildlife Service Land-Based Wind Energy Guidelines, specifically Tier 1 and Tier 2 evaluations. By combining the Site Wind Right map with other land suitability factors, we demonstrate that over 1,000 GW of wind energy may be developed in the central U.S. exclusively in areas of low conservation impact. The results of this analysis indicate that we can accelerate a clean, low-impact energy future—one that advances energy, climate, and conservation goals.

Figure 1. The central U.S. Wind Belt (resource data modified from AWS Truepower 2010)



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Background

Energy development is the largest driver of land use change in North America, and poorly sited renewable energy projects can have significant impacts on wildlife and high-priority habitats (Trainor et al. 2016). In addition, siting in areas that would significantly impact wildlife and habitat can lead to conflict and slow the transition to a low-carbon energy future. These delays and increased costs can be minimized by evaluating siting considerations early in the project development process (Tegen et al. 2016). Siting wind in areas that are low-impact for wildlife can ensure that we meet *both* our renewable energy and habitat conservation goals.

The Nature Conservancy created the Site Wind Right map (Figure 2) to identify areas where wind development is unlikely to encounter significant wildlife-related conflict, project delays, and cost overruns. It builds upon previous studies by The Nature Conservancy (Kiesecker et al. 2011; Obermeyer et al. 2011; Fargione et al. 2012).

The study area includes a 17-state region of the central U.S. - the “Wind Belt” (Figure 1) - that encompasses nearly 80 percent of the country’s current and planned onshore wind capacity (AWEA 2019a). This region is also home to North America’s largest and most intact temperate grasslands, which are among the most altered and least protected habitats in the world (Hoekstra et al. 2005).

Existing Resources on Wind Siting and Wildlife

There are many sources of information that can be used to support low-impact wind development. Federal and state wildlife and natural resource agencies, science-based conservation organizations, and academic institutions have produced information that can and should support low-impact siting. Notably, the U.S. Fish and Wildlife Service developed the Land-Based Wind Energy Guidelines to provide “a structured, scientific process for addressing wildlife conservation concerns at all stages of land-based wind energy development” (USFWS 2012a). The Wind Energy Guidelines (WEGs) were developed over a four-year period by the Wind Turbine Guidelines Advisory Committee, a diverse group of stakeholders that included participation by The Nature Conservancy. The WEGs are very broad guidelines that outline the types of information to include at each stage of site evaluation and what organizations and agencies should be consulted. The WEGs do not identify low-impact areas.

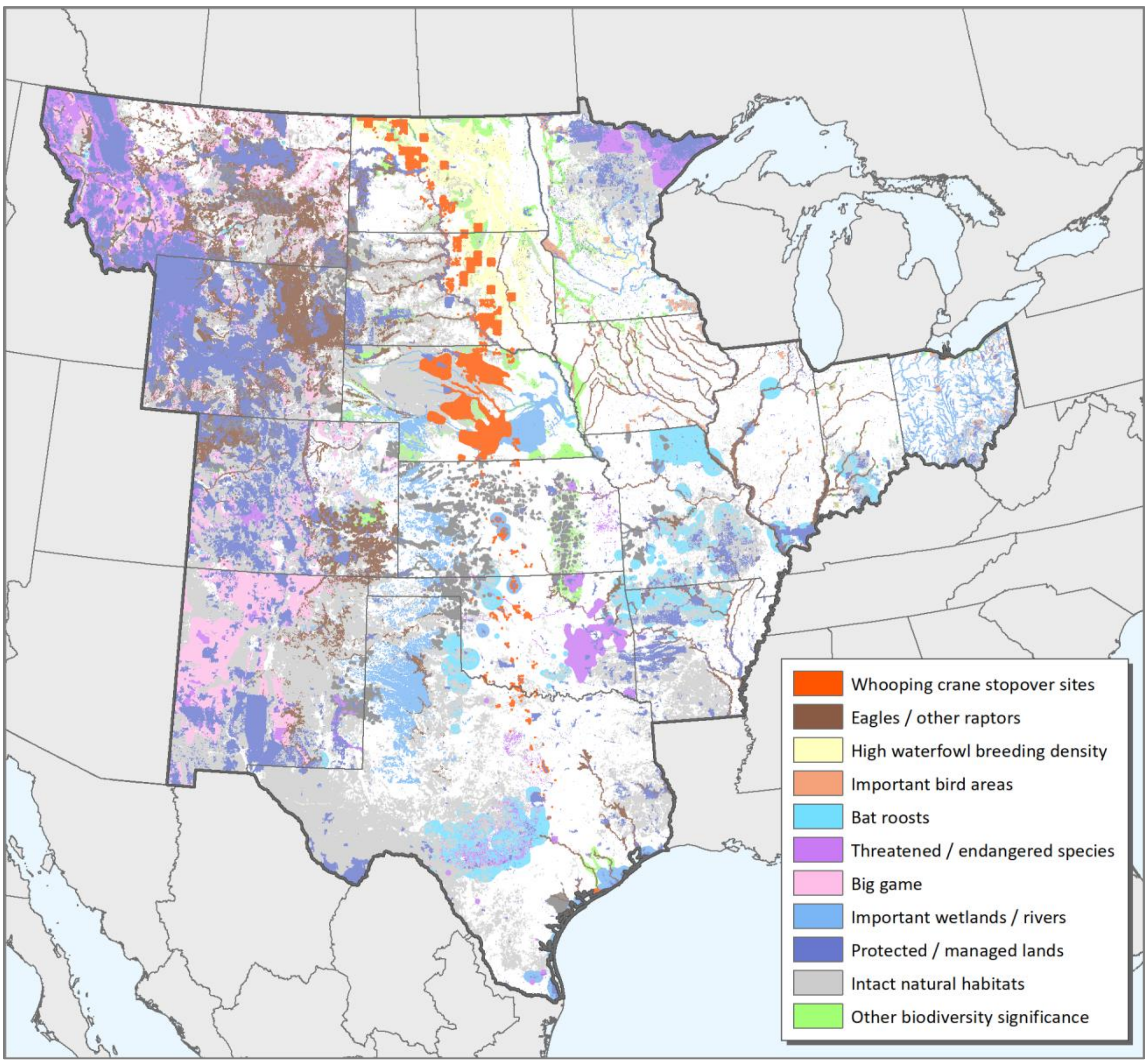
It is our understanding that most wind developers and operators take the WEGs very seriously (AWEA 2012). We applaud this commitment. We note, however, that successful implementation of the WEGs requires significant investment by developers. Early screening to identify areas of potential conflict could save costs associated with evaluating projects that ultimately may not move forward due to wildlife concerns. Further, the use of the WEGs is purely voluntary and good actors are not rewarded for adhering to good siting practices or abandoning problematic sites. There is no independent or regulatory process to verify that WEG analyses were rigorous, used the best available science, or identified risks to wildlife that can be adequately mitigated. Further, there is no independent confirmation that developers demonstrated a commitment to abandoning high risk projects. Developers also are not required to share results, making it difficult to ascertain the specific information used, what parties are consulted, the rigor of the overall analysis, what concerns were identified, and whether impacts to sensitive species can be adequately mitigated. This means that outside parties, including power purchasers, often struggle to understand the nature and extent of identified issues and whether conclusions are based on the best available science. Finally, WEG analyses are typically carried out after site-level investments have occurred, creating a disincentive to abandon even those projects that pose significant risk to habitat and species.

The Nature Conservancy believes that the WEGs can drive wind facilities to low-impact sites when the framework is used early in the project development process, when rigorously applied, and when developers commit to abandoning projects that are deemed “significant” and cannot be mitigated (USFWS 2012a). We commend wind developers for taking them seriously and intend for the Site Wind Right map to work in conjunction with the WEGs to support low-impact siting.

How to Use the Site Wind Right Map

The Nature Conservancy's Site Wind Right map (Figure 2) was designed to serve as an important source of information to support screening early in the project siting process. It can be used to inform application of the WEGs, specifically Tier 1 and Tier 2 evaluations. The map is not a "go/no-go map." Areas in white - those that have relatively low conservation value - are not "go areas" just as areas that are shaded are not "no-go areas." The map can be used as one source of information to inform Tier 1 and Tier 2 analyses, but it should not be the only source of information used. It was not intended to serve as a substitute for the WEGs, but rather used in conjunction with other appropriate information on habitat and species. The map does not replace the need to consider the data and information outlined in the WEGs, consult with state and federal wildlife agencies, or conduct detailed site-level analyses of impacts. In addition, there are other social and cultural factors that may make utility-scale renewable development inappropriate in some sites. If, however, proposed wind projects are located in an areas of high conservation value on the Site Wind Right map, we suggest a much more cautious and transparent approach to the WEGs. Specifically, we recommend that projects proposed in these areas make the following information available to state and federal wildlife agencies and, to the maximum extent possible, to the public: 1) results of the Tier 1

Figure 2. Site Wind Right map



and Tier 2 evaluations, specifically whether projects are anticipated to have a low, moderate, or high probability of significant adverse impacts to wildlife and habitat; 2) how determinations were made about the significance of impacts; and 3) proposed measures for mitigating impacts to projects that will have a moderate or high probability of adverse impact to wildlife and habitat (USFWS 2012a).

Site Wind Right promotes a positive vision for renewable energy by demonstrating that ambitious wind development goals are achievable on sites with minimal risk of wildlife conflicts. Power purchasers acquiring wind-generated electricity from low-impact sites may meet renewable energy goals while avoiding sensitive species and habitats. Likewise, developers are less likely to encounter wildlife-related project delays and cost overruns in low-impact areas, thus resulting in more reliable and efficient deployment of renewable energy.

The Site Wind Right Map

The Site Wind Right map identifies sensitive natural habitats and distributions of wildlife species that may be adversely impacted by wind energy development (Figure 2). These include:

- Whooping crane stopover sites
- Eagle and other raptor nesting areas
- High waterfowl breeding density
- Important bird areas
- Bat roosts
- Threatened and endangered species
- Big game habitats
- Important wetlands and rivers
- Protected and managed lands
- Intact natural habitats
- Other areas of biodiversity significance

Sources and delineation methods for component elements are detailed in Appendix A. An interactive map and GIS dataset are available to the public and may be accessed at http://www.nature.org/sitewindright.

Analysis and Results

To demonstrate the potential for low-impact wind development within the study area, we combined the wildlife and habitats reflected in the Site Wind Right map (Figure 2) with spatial information on engineering and land use constraints (Figure 3) identified in published assessments of renewable energy potential and consistent with historical patterns of wind development in the Great Plains. Data sources and delineation methods for modeled restrictions are detailed in Appendix A. We recognize that additional factors may affect development potential in specific locations, including transmission capacity and the availability of willing landowners (Tegen et al. 2016; Oteri et al. 2018).

Input data were rasterized at a ground sample distance of 30 m. We generated a preliminary Boolean map of areas suitable for wind development by excluding lands with potential engineering and land use restrictions. To eliminate isolated areas too small to support commercial wind development, the results were smoothed using a 1 km radius moving window, and patches less than 20 km^2 in size were removed. The component engineering and land use restrictions layers were then subtracted from the remaining smoothed patches to eliminate false positive values and other spatial artifacts introduced by the moving window analysis. To delineate suitable wind development areas with low potential for wildlife conflicts, wildlife and habitat data layers (see "The Site Wind Right map”) were subtracted from the preliminary Boolean suitability map, and the analysis repeated as above. For each state and for the analysis area as a whole, we quantified wind development potential on all suitable lands, as well as the subset of suitable lands identified as low-impact, based on a nameplate capacity density of 3 MW/km^2 (Denholm et al. 2009).

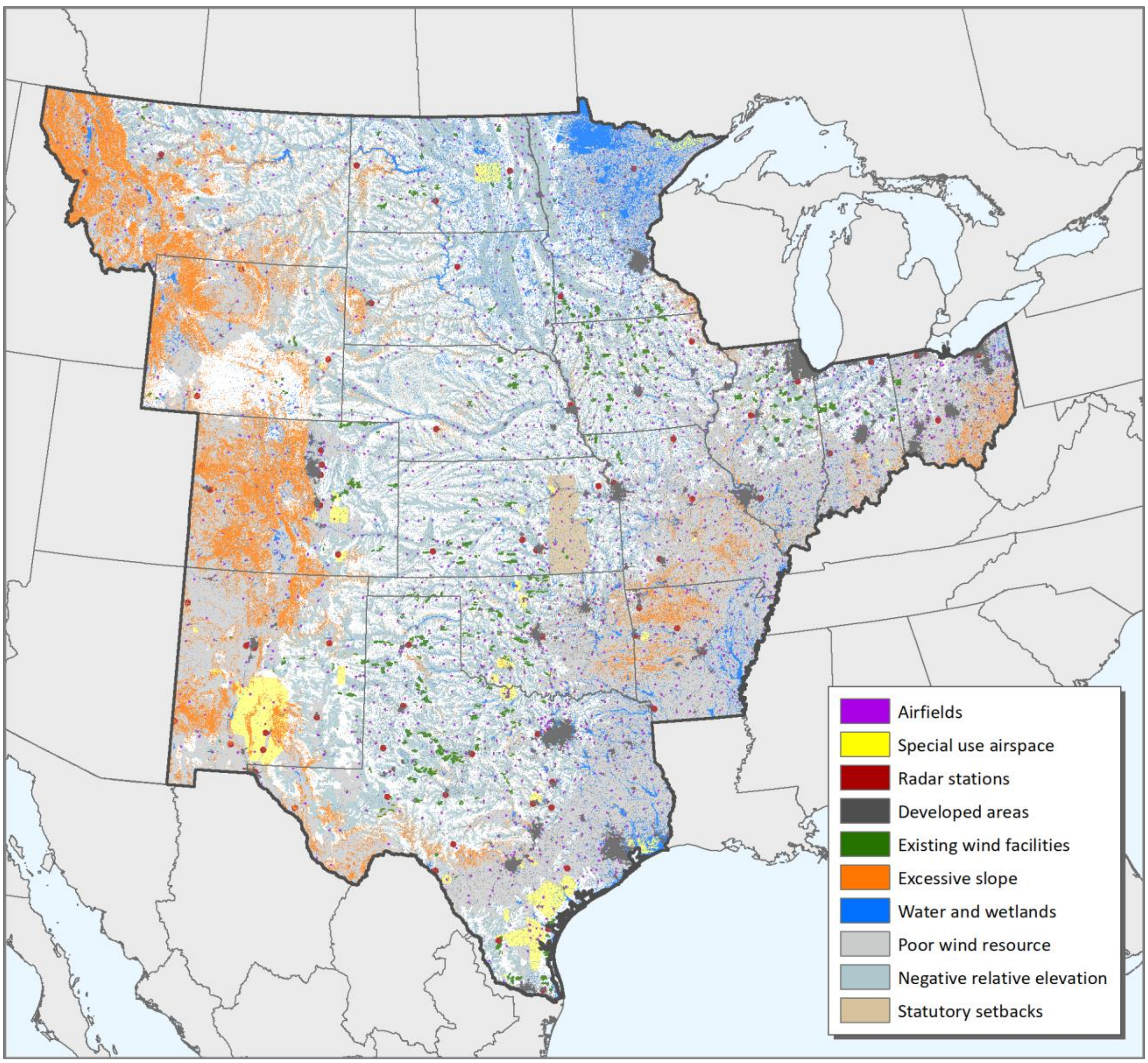
Within the study area, we found that nearly 90 million ha (222 million ac) of land may be suitable for development (based on wind speed and terrain, excluding previously developed sites, statutory setbacks, unsuitable land use, and small/isolated sites). If all these areas were developed for wind energy, they could support approximately 2,693 GW of electrical capacity. After removing sensitive wildlife habitats, approximately 37 million ha (91 million ac) remain as suitable for development (9% of the region) (Figure 4; Table 1). These low-impact areas are capable of yielding approximately 1,099 GW of electrical capacity. This is more than 10 times current U.S. wind capacity and equivalent to the total generating capacity from *all sources* (AWEA 2019b, USDOE 2018).

Discussion

Our analysis suggests that large areas of the central U.S. could be developed for wind energy without significant negative impacts to wildlife (Figure 4; Table 1). Because the availability of low-impact wind resources far exceeds development projections, our results should be applicable to any reasonable development scenario. Moreover, our estimates of development potential are likely conservative, as some areas we identified as having engineering and land use constraints may be viable for wind energy due to improvements in technology (USDOE 2017).

We note that our delineation of sensitive wildlife habitats is not exhaustive. Spatial data on species of concern are missing or incomplete in some areas. With all development projects, wildlife concerns should also be addressed through careful micrositing. Operational mitigation may be required to reduce mortality, particularly for bats

Figure 3. Map of potential engineering and land use restrictions



(Arnett et al. 2013). These issues highlight the importance of continued research to advance the science on low-impact wind energy siting.

The results of this assessment provide a positive vision for accelerating a clean, low-impact energy future. We can meet our climate goals and support the conservation of wildlife and natural habitats. While we recognize there is not a one-size-fits-all solution to "good" siting, the Site Wind Right map can be a valuable source of information to identify project sites that support clean, low-impact wind.

Figure 4. Map of low-impact development areas

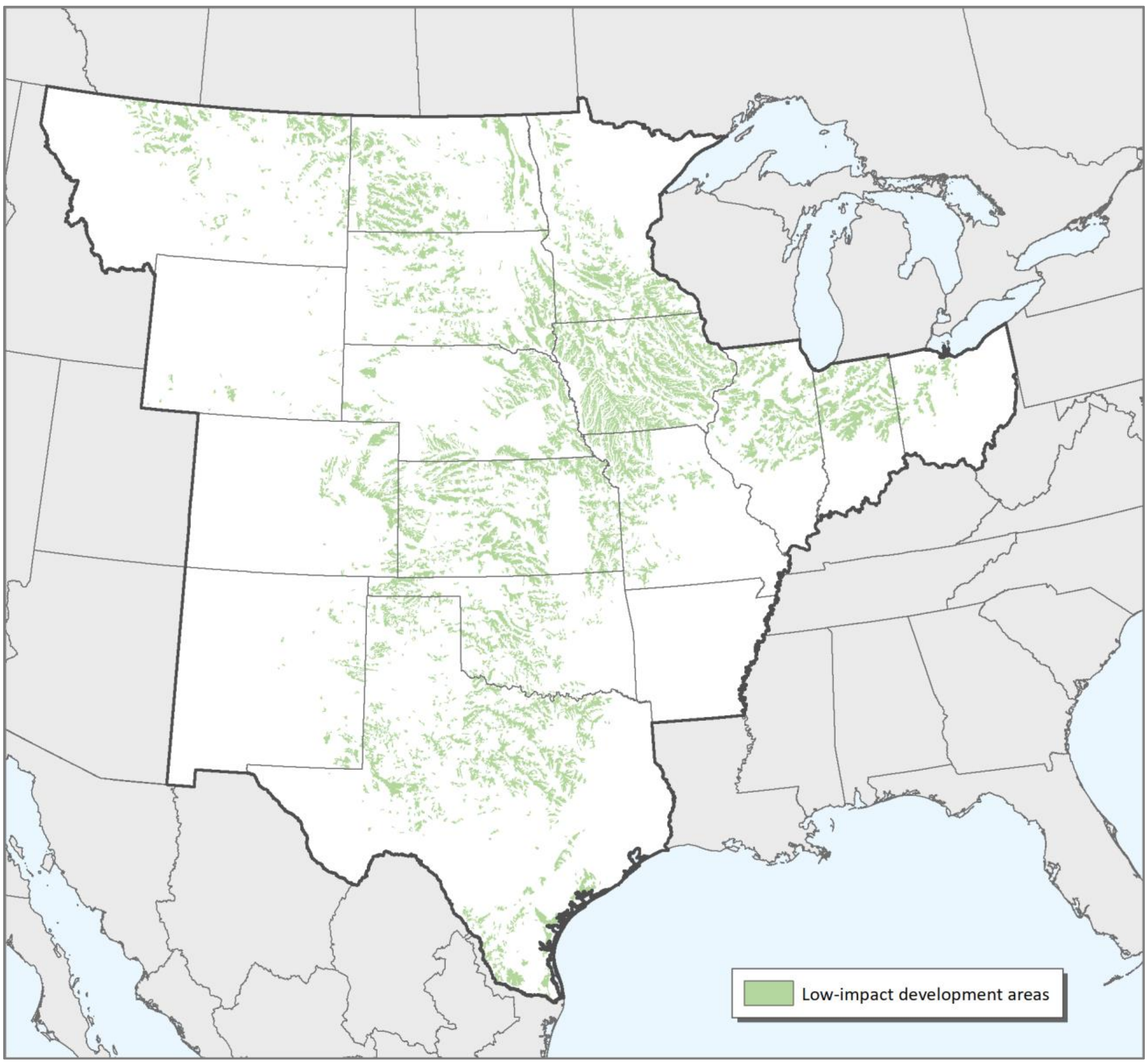


Table 1. Suitable land and low-impact development area statistics

State	Suitable land (ha)[1]	Percent of region[1]	Capacity (GW)[2]	Low-impact suitable land (ha)[3]	Percent of region[3]	Capacity on low-impact suitable land (GW)[2]
Texas	16,295,246	24%	489	5,949,204	9%	178
Iowa	5,095,929	35%	153	4,482,825	31%	134
Kansas	7,685,076	36%	231	4,456,486	21%	134
North Dakota	6,108,888	33%	183	2,717,512	15%	82
South Dakota	6,956,383	35%	209	2,622,635	13%	79
Nebraska	7,930,531	40%	238	2,349,375	12%	70
Minnesota	3,538,532	16%	106	2,334,814	11%	70
Montana	8,071,987	21%	242	2,221,824	6%	67
Oklahoma	3,676,994	20%	110	2,039,974	11%	61
Illinois	2,164,386	15%	65	2,021,177	14%	61
Indiana	1,681,702	18%	50	1,618,784	17%	49
Missouri	2,371,874	13%	71	1,461,704	8%	44
Colorado	3,992,396	15%	120	1,224,864	5%	37
New Mexico	5,145,711	16%	154	486,777	2%	15
Ohio	554,026	5%	17	447,384	4%	13
Wyoming	8,462,049	33%	254	201,897	1%	6
Arkansas	34,826	<1%	1	0	0%	0
combined area	89,766,534	23%	2,693	36,637,235	9%	1,099

[1] Based on engineering or land use constraints discussed in "Analysis and Results."
[2] Calculated based on a nameplate capacity density of 3 MW/km^2 (Denholm et al. 2009).
[3] Land identified as low impact for wildlife and habitat (Site Wind Right map, Figure 2) without engineering or land use constraints (discussed in "Analysis and Results," Figure 3). Depicted spatially in Figure 4.

Appendix A – Component Element Descriptions

Whooping crane stopover sites

The federally endangered whooping crane (*Grus americana*) depends on wetlands in the central Great Plains during migration (USFWS 2011). Whooping cranes may be at risk of turbine collisions when ascending or descending from high altitude migration flights, or when travelling short distances between roost and foraging areas (USFWS 2009a). To address this concern, we delineated areas within 3.2 km of whooping crane stopover sites to be avoided by wind energy development. Stopover sites include locations with two or more confirmed whooping crane observations (USFWS 2010) since 1985, as well as modeled suitable habitat (Austin and Richert 2001; Belaire et al. 2014) within portions of the migratory flyway frequently used by whooping cranes (Pearse et al. 2015). We also include critical habitat polygons designated by the U.S. Fish and Wildlife Service (USFWS 2018), and whooping crane priority landscapes in Nebraska (NWWWG 2016).

Sources: data - USFWS (2010, 2016b, 2018); Pearse et al. (2015); NWWWG (2016); spatial analysis – TNC (2019).

Eagles and other raptors

Raptors may be injured or killed by collisions with wind turbines (Stewart et al. 2007; Smallwood and Thelander 2008; Watson et al. 2018), and rates of mortality at commercial wind facilities may be underestimated due to lack of rigorous monitoring and reporting (Pagel et al. 2013). To reduce risk of population-level impacts to golden eagles (*Aquila chrysaetos*) in the western Great Plains, we recommend that developers avoid siting wind turbines within areas of highest golden eagle densities (top 2 of 7 area-adjusted frequency quantiles) in ecoregions assessed by the Western Golden Eagle Team (WGET; Bedrosian et al. 2018). Following general habitat management guidelines established by USFWS (1989), we recommend that developers avoid placing turbines within 1.6 km of streams and lakes with known high densities of bald eagle (*Haliaeetus leucocephalus*) nests. In states with available data, we also mapped 3.2 km buffers of active golden eagle nests (CPW 2013), occupied peregrine falcon (*Falco peregrinus*) habitat (WGFD 2004; CPW 2015a), 1.6 km buffers of other active raptor nests (CPW 2013), raptor occurrences (MTNHP 2018a), and modeled prairie dog (*Cynomys* spp.) complexes (WGFD 2006; CPW 2009; MTNHP 2018b; TXNDD 2018a) as these areas may attract birds of prey.

Sources: WGFD (2004, 2006); CPW (2009, 2013, 2015a); Bedrosian et al. (2018); MTNHP (2018a, 2018b); TXNDD (2018a); unpublished TNC and USFWS data.

Prairie grouse

Grouse species in the central U.S. have experienced substantial population declines since the early 20th century (Vohdenhal and Haufler 2007) and may be further threatened by improperly sited energy development (Pruett et al. 2009; Van Pelt et al. 2013; Hovick et al. 2014; Winder et al. 2015; LeBeau et al. 2017). To prevent grouse displacement and potential impacts on vital rates, we recommend that developers avoid siting wind facilities in the following areas: Attwater's prairie-chicken (*Tympanuchus cupido attwateri*) known occurrence records (TXNDD 2018b) and the Refugio-Goliad Prairie Conservation Area in Texas (TNC 2009); Columbian sharp-tailed grouse (*T. phasianellus columbianus*) production areas and winter range in Colorado (CPW 2015b), and 5 km buffers of known leks in Wyoming (WGFD 2016); greater prairie-chicken (*T. cupido*) modeled optimal habitat (Obermeyer et al. 2011) in Kansas and Oklahoma, production areas in Colorado (CPW 2015c), and grassland conservation opportunity areas in Missouri (MDOC 2015); greater sage-grouse (*Centrocercus urophasianus*) rangewide biologically significant units (BLM 2018), state-designated core and connectivity areas in Wyoming (WGFD 2015) and Montana (MTFWP 2016), and 2 km buffers of known leks in Wyoming (WGFD 2017a); Gunnison sage-grouse (*C. minimus*) critical habitat (USFWS 2018), and production areas, brood areas, winter range, and severe winter range in Colorado (CPW 2011a); lesser prairie-chicken (*T. pallidicinctus*) rangewide conservation focal areas and 5 km buffers of known leks (SGPCHAT 2018); plains sharp-tailed grouse (*T. phasianellus jamesi*) production areas in Colorado (CPW 2015d), and 5 km buffers of known leks in Wyoming (WGFD 2017b).

Due to lack of spatially explicit data, sharp-tailed grouse and greater prairie-chicken habitats in Illinois, Iowa, Minnesota, Nebraska, North Dakota, and South Dakota were not included in this assessment.

Sources: data – TNC (2009); CPW (2011a, 2015b, 2015c, 2015d); MDOC (2015); WGFD (2015, 2016, 2017a, 2017b); MTFWP (2016); BLM (2018); SGPCHAT (2018); TXNDD (2018b); spatial analysis – TNC (2019).

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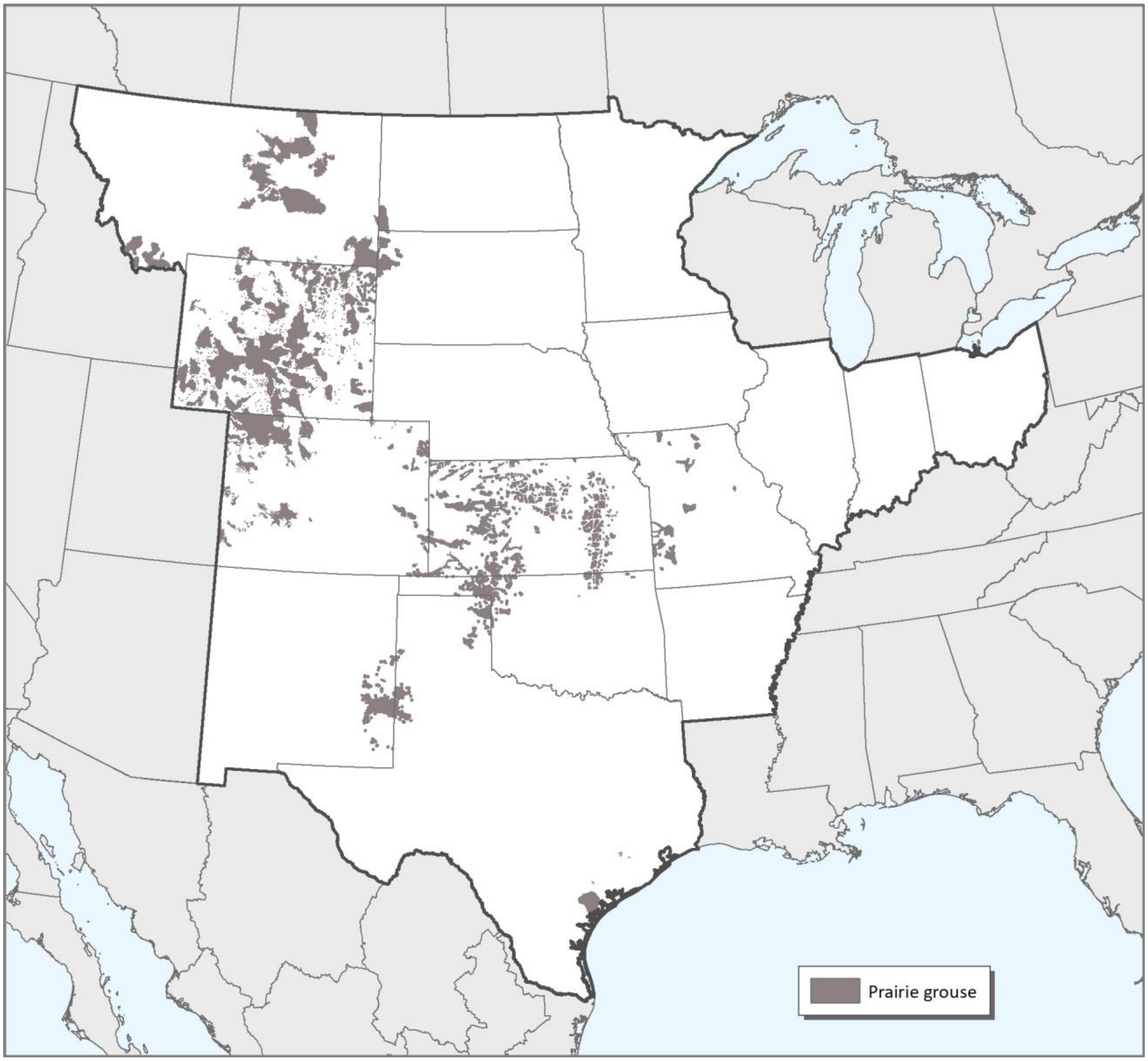
Prairie grouse (continued)



Bat roosts

Bat mortality has been documented at wind energy facilities across North America (Erickson 2002; USFWS 2003; Arnett and Baerwald 2013; AWWI 2018). Because bats concentrate in large numbers and have low reproductive rates, their viability is exceptionally vulnerable to population declines (Kunz and Fenton 2003). Therefore, caution is warranted when undertaking any activity that may adversely affect known bat populations.

While knowledge of bat and wind turbine interactions in the southern Great Plains is limited, evidence suggests that the Mexican free-tailed bat (*Tadarida brasiliensis*) may be particularly susceptible to fatal injury during encounters with turbine blades. This species accounts for a large percentage of documented wildlife mortality at wind facilities across the Southwestern U.S. (Kerlinger et al. 2006; Miller 2008; Piorkowski and O'Connell 2010; AWWI 2018), including in states with extensive wind development. Moreover, regional populations are comprised primarily of reproducing females (Caire et al. 1989; Schmidly 2004); as such, each early season fatality in the area may result in the deaths of two individuals (mother and young). Recent population estimates in Oklahoma are markedly lower than historical figures, possibly indicative of declines related to wind development or other factors (Caire et al. 2013). Due to the large foraging range of this species (Best and Geluso 2003) and concerns regarding population-level impacts, we recommend that developers avoid siting wind facilities within 32 km of Mexican free-tailed bat maternity roosts in New Mexico, Oklahoma, and Texas.

We followed USFWS's (2016a) recommendation to avoid wind development within 32 km of Indiana bat (*Myotis sodalis*) priority 1 hibernacula, 16 km of priority 2 hibernacula, and 8 km of other current and historical sites. We apply the same rationale and avoidance distances to gray bat (*Myotis grisescens*) hibernacula and other known cave bat roosts across our analysis area.

We also recommend avoidance of mapped bat roosts in Montana (MTNHP 2018c), mapped hibernacula in Nebraska (NWWWG 2016), townships with documented northern long-eared bat (*Myotis septentrionalis*) maternity roosts and/or hibernacula in Minnesota (MNDNR & USFWS 2018), a 12-county region of northeastern Missouri near Sodalis Nature Preserve (Cole 2018), and important forest habitats in Indiana (TNC and Audubon 2010).

We acknowledge that migratory tree bat mortality (Arnett et al. 2016; AWWI 2018) is a significant concern with wind development in the central U.S. A recent study suggests that the hoary bat (*Lasiurus cinereus*) population of North America could decline by as much as 90% in the next 50 years at current wind energy-associated fatality rates (Frick et al. 2017). At present, spatial data and knowledge of behavior are insufficient to effectively inform project siting decisions for these species. New methods to track seasonal bat movements are in development (Weller et al. 2016); we encourage the support of these studies to improve understanding of tree bat migration routes. In addition, we strongly encourage the use of proven operational mitigation strategies (Arnett et al. 2013) and new approaches such as smart curtailment (Hayes et al. 2019) to reduce impacts to bat populations.

Sources: KSU (2002); TNC (2003, 2019); TNC and Audubon (2010); Graening et al. (2011); INHDC (2014); KBS (2015a); NWWWG (2016); CNHP (2017a); MNDNR & USFWS (2018); MTNHP (2018c); TSS (2018).

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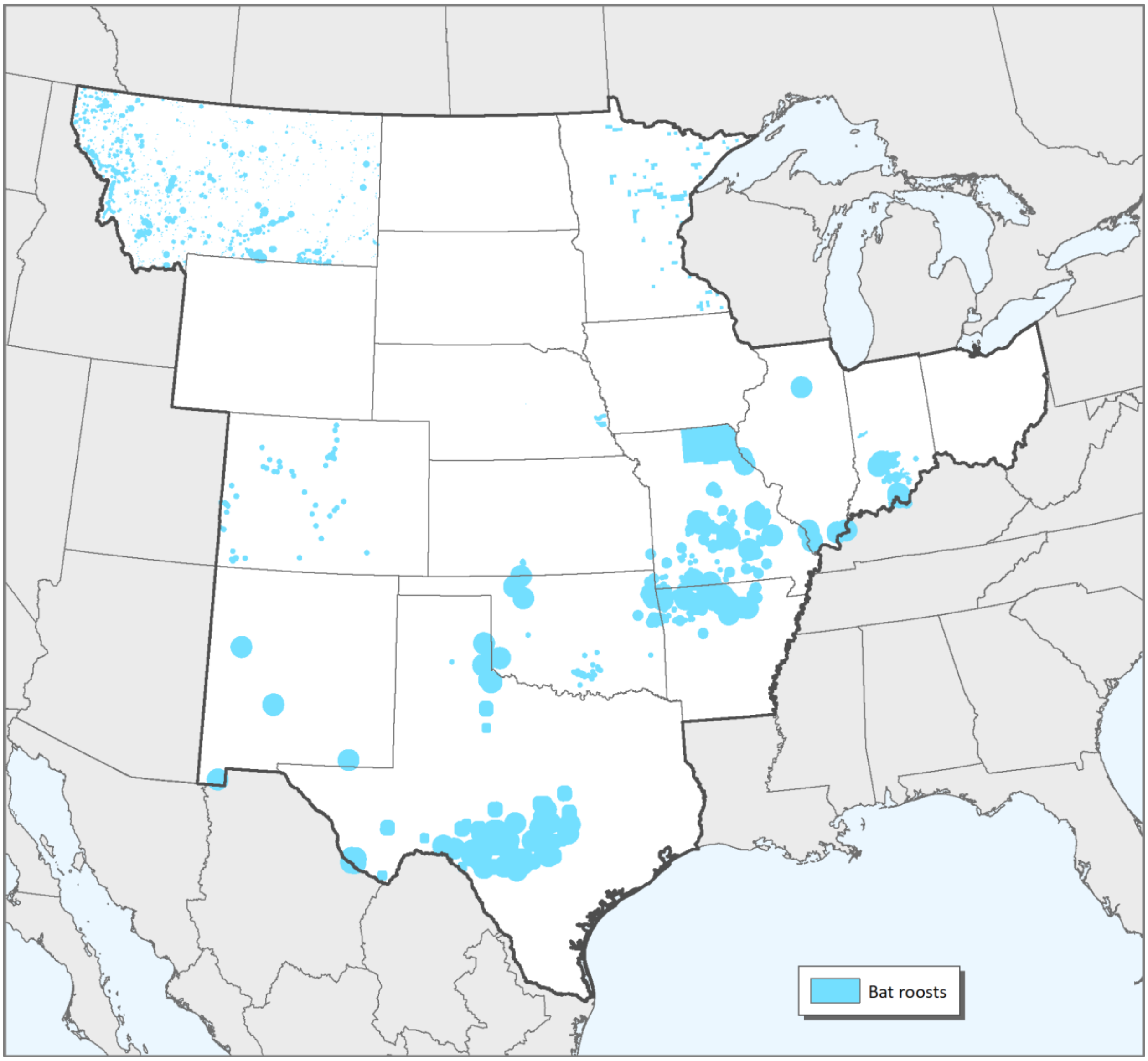
Bat roosts (continued)



High waterfowl breeding density

We recommend avoiding wind development in areas with high predicted waterfowl breeding pair density (104 pairs per km^2 or greater in North Dakota and South Dakota, 23.6 pairs per km^2 or greater in Minnesota) based on U.S. Fish and Wildlife Service Habitat and Population Evaluation Team data. This represents crucial habitat for many species of wetland-dependent birds in the Prairie Pothole region of North America (Reynolds et al. 2006; Niemuth et al. 2008.)

Source: Fargione et al. (2012)

Important bird areas

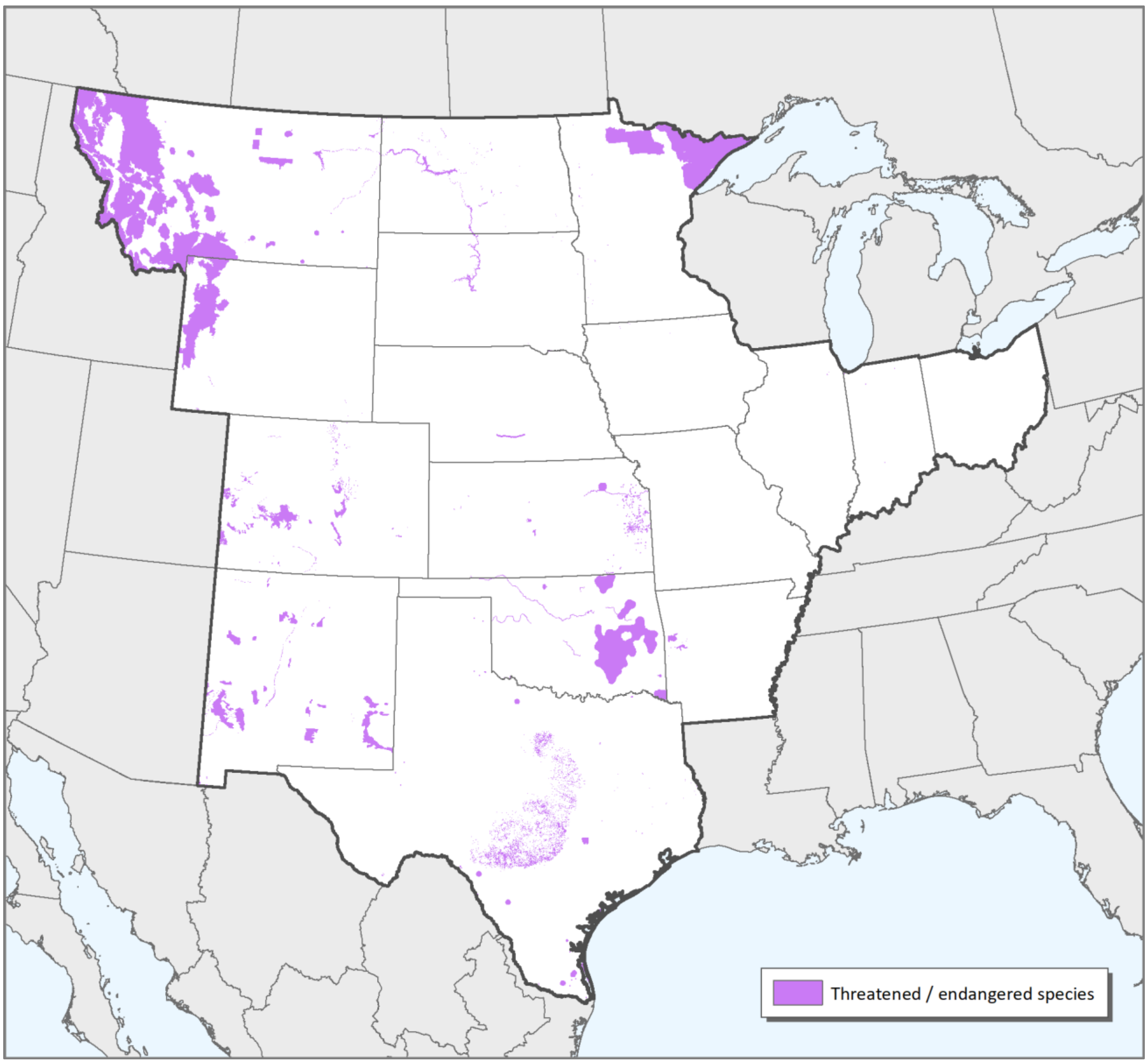
Important bird areas across the Great Lakes and Upper Midwest states may not be effectively captured by other spatial data layers used in this assessment. We recommend avoiding wind development within state bird conservation areas in Iowa (IADNR 2017) and Audubon important bird areas in Illinois, Indiana, Minnesota, and Ohio (NAS 2018).

Sources: IADNR (2017); NAS (2018).

Other threatened and endangered species (terrestrial)

Energy and infrastructure development are among the most significant threats to imperiled species in the U.S. (Wilcove et al. 1998). Projects with a federal nexus (i.e. carried out, funded, licensed, or permitted by a federal agency) that have potential to impact federally threatened and endangered species require consultation with the U.S. Fish and Wildlife Service under Section 7 of the Endangered Species Act (USFWS 2009b). To prevent impacts to at-risk wildlife, we recommend avoiding wind development within terrestrial threatened and endangered species habitats. Mapped sites include critical habitat delineated by state and federal agencies, current/recent species distributions, modeled priority habitats, and occurrence records.

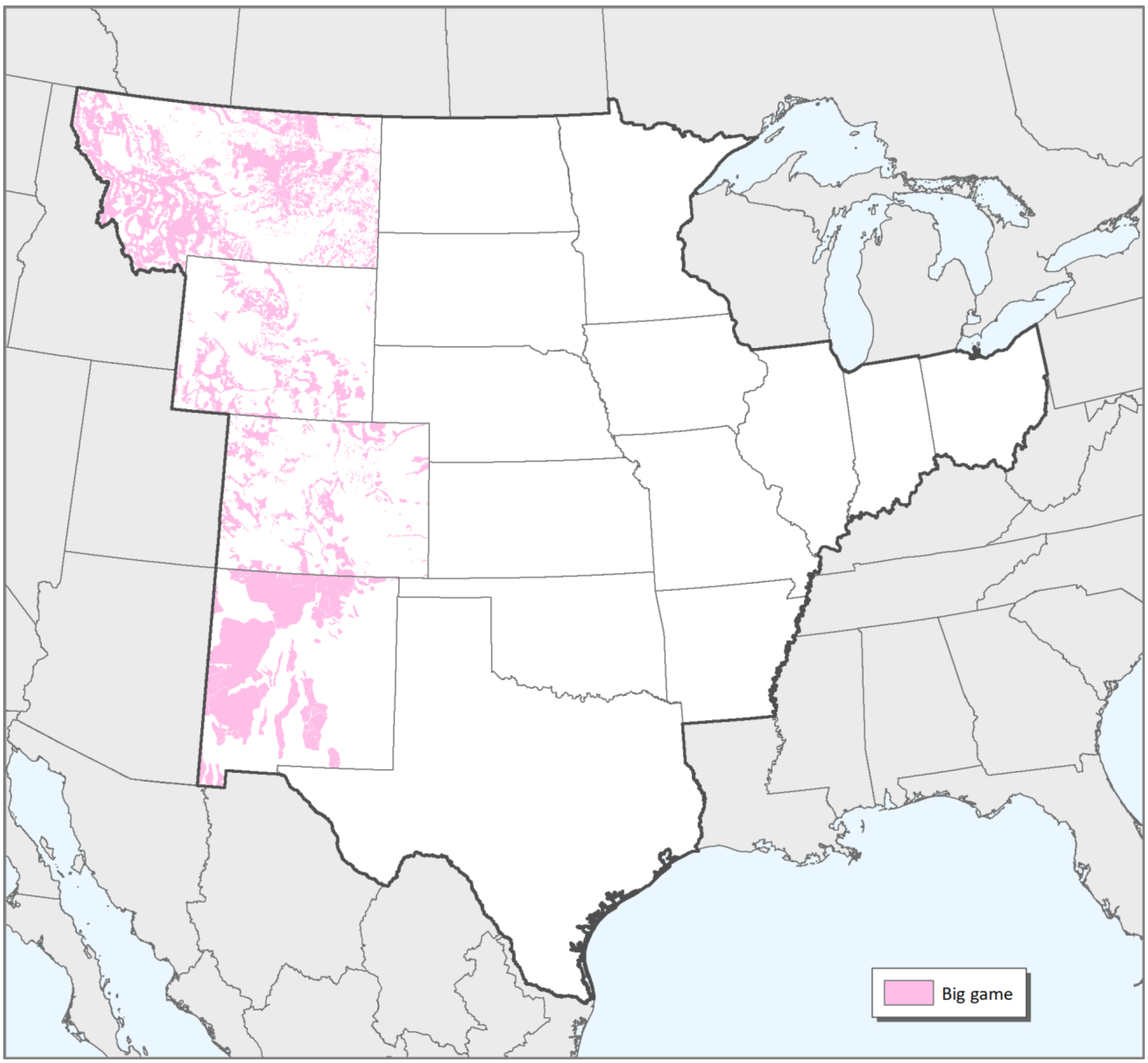
Sources: Masters et al. (1989); USFWS (1990); Diamond (2007); Laurencio and Fitzgerald (2010); CPW (2011a, 2011b, 2015e, 2015f), USFWS (2014a); KBS (2015b); KDWPT (2015); ODWC (2015); MTNHP (2018d); TXNDD (2018c); USFWS (2018); TNC (2019).



Big game

Roads and other anthropogenic features associated with energy development may alter the movements of big game animals and increase rates of mortality, particularly along migration routes and in crucial winter ranges of the western U.S. (Sawyer et al. 2006, 2009; WGFD 2011; Vore 2012; Taylor 2016). Due to the potential for loss and fragmentation of vital winter habitats, we recommend that developers avoid siting wind facilities within these areas.

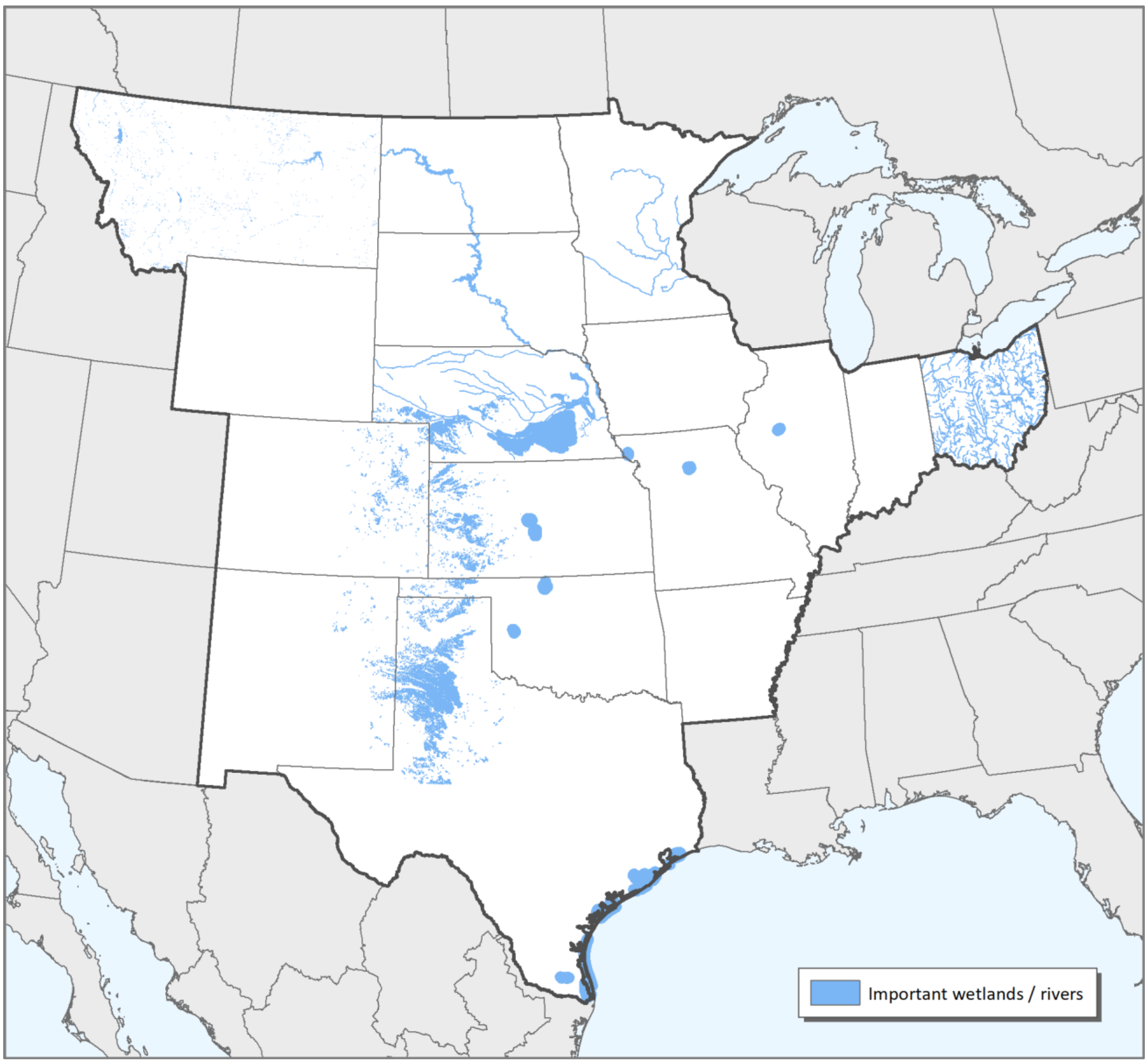
Sources: MTFWP (2010); WGFD (2011); CPW (2015g); WECC (2018).



Important wetlands and rivers

Wind energy development near wetland complexes and riparian corridors may cause adverse impacts to migratory birds and other wildlife (Ewert et al. 2011; Obermeyer et al. 2011; Grodsky et al. 2013; PLJV 2017). Significant wetland features identified by TNC and partners include playa clusters and large isolated playa lakes (PLJV 2015); 1.6 km buffers of important rivers in North Dakota and South Dakota (Fargione et al. 2012), Nebraska (NWWWG 2016), Minnesota (MNDNR 2018a), and Ohio (Ewert et al. 2011); 16 km buffers of Western Hemisphere Shorebird Reserve Network (WHSRN 2019) wetland sites in Illinois, Kansas, Missouri, Oklahoma, and Texas plus the Aransas and Washita National Wildlife Refuges (following Obermeyer et al. 2011); and wetlands of special significance (MTNHP 2016) and trumpeter swan (*Cygnus buccinator*) occurrence records (MTNHP 2018e) in Montana.

Sources: Ewert et al. (2011); Fargione et al. (2012); PLJV 2015; ABC (2015); MTNHP (2018e); NWWWG (2016); MNDNR (2018a); TNC (2019); WHSRN (2019).

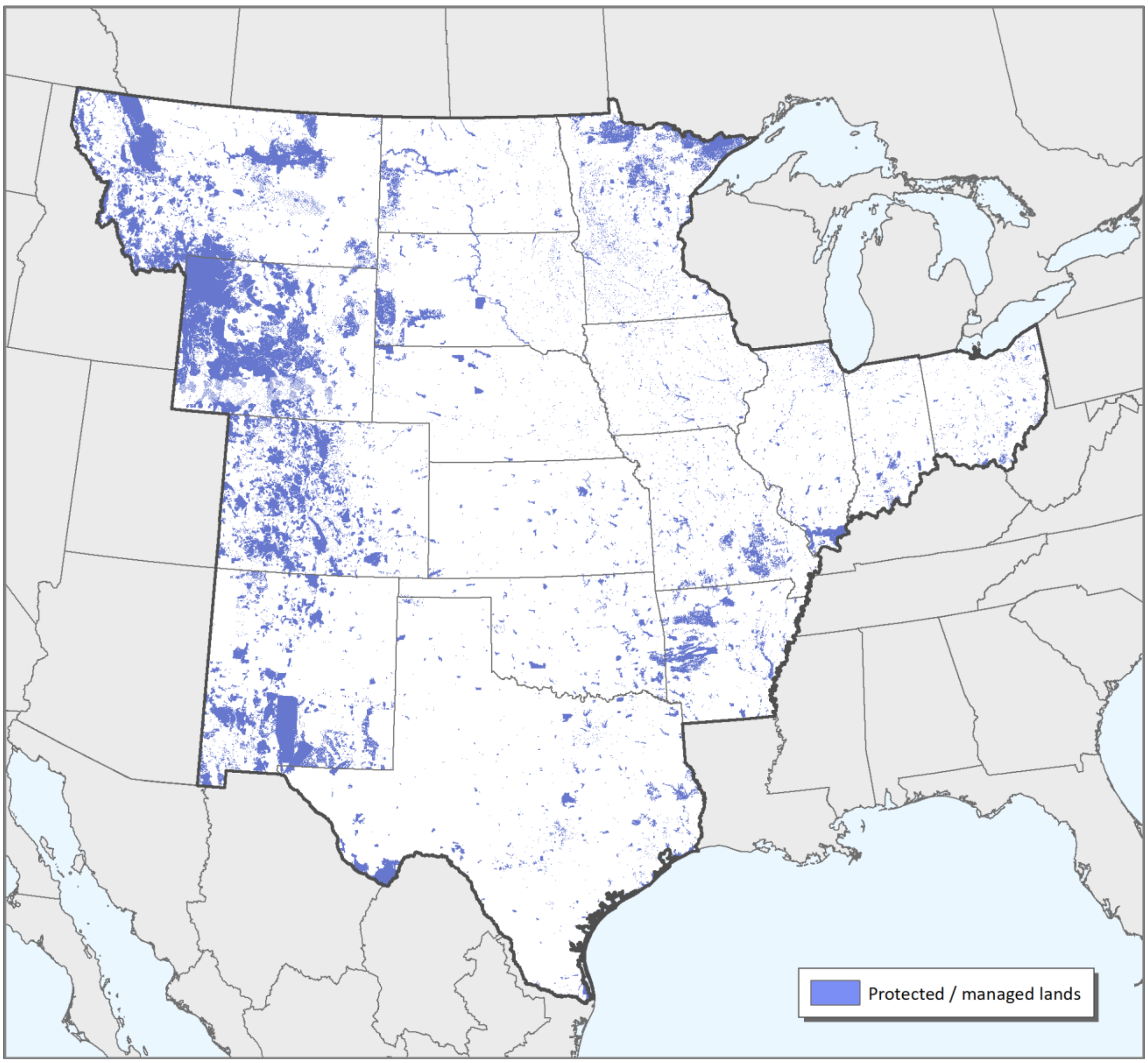


Protected and managed lands

Areas managed for long-term conservation of natural features include state parks and wildlife management areas; national monuments, parks, and wildlife refuges; military installations; other state and federal lands with development restrictions; private protected lands (including TNC preserves); and conservation easements.

Due to the relative scarcity and high conservation value of federal lands in the eastern portion the study area, all U.S. Forest Service properties outside of Colorado, Montana, New Mexico, and Wyoming were mapped regardless of planning designation status.

Sources: ANL (2016); USGS (2016); TNC (2019).

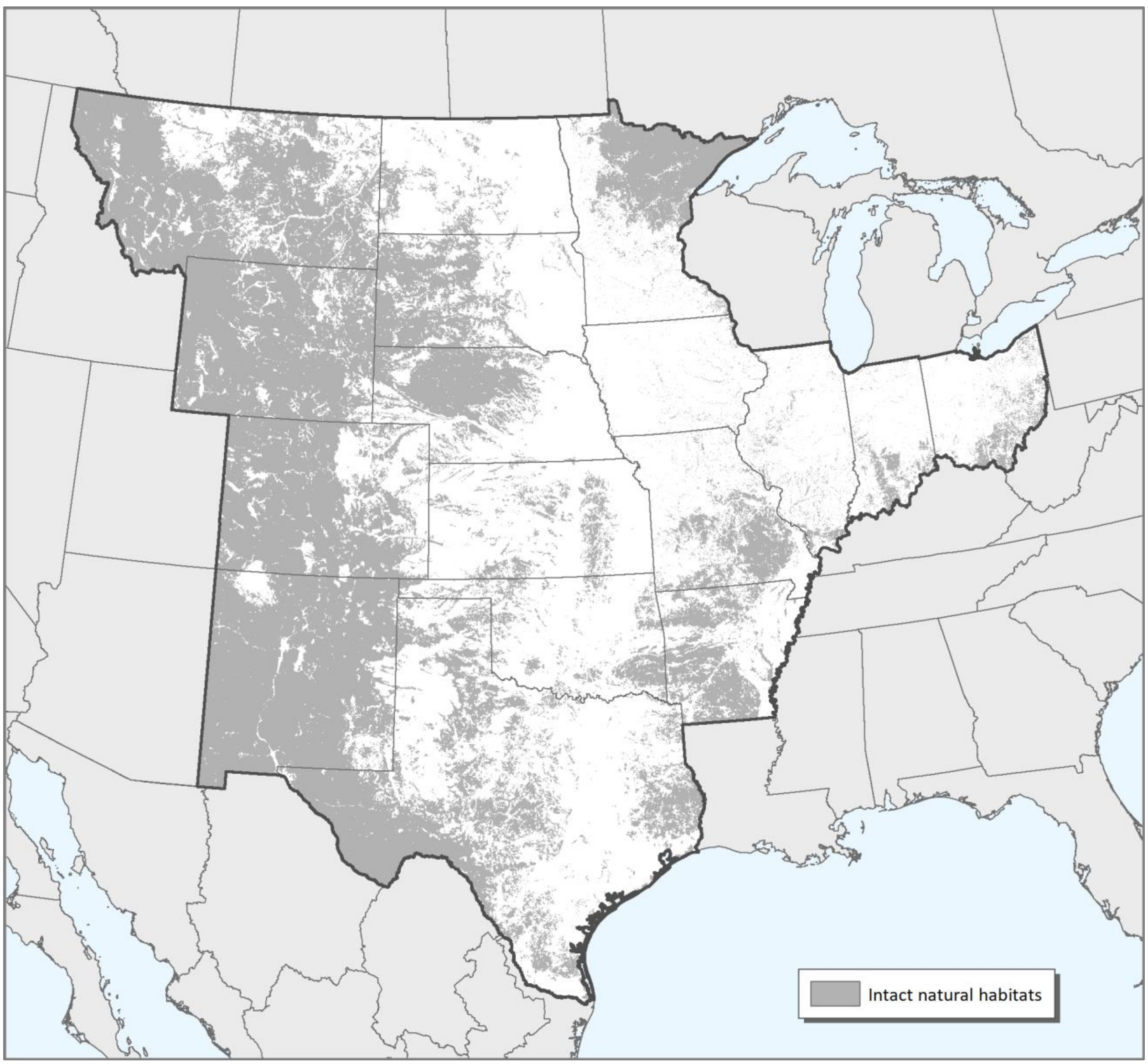


Intact natural habitats

Agricultural conversion and other land use changes across the central U.S. have resulted in a significant reduction in the spatial extent of prairie ecosystems and the loss of many associated species. Remaining intact habitats provide the basis for long-term viability of many species of conservation concern.

To delineate discrete patches of relatively undisturbed natural landcover, we processed the Theobald (2013) human modification (HM) model using a 1 km radius moving window and selected areas with HM index values less than 0.125. We then eliminated areas fragmented by oil and natural gas development (defined as sites with 1.5 active wells per km^2 or greater; see WGFD 2010) and excluded lands in the Great Plains bioregion altered by past tillage or other landscape disturbances (Ostlie 2003). Finally, we added core forest and core wetland areas (TCF 2014) to capture additional, functionally intact habitats in Illinois, Indiana, Iowa, Minnesota, Missouri, and Ohio.

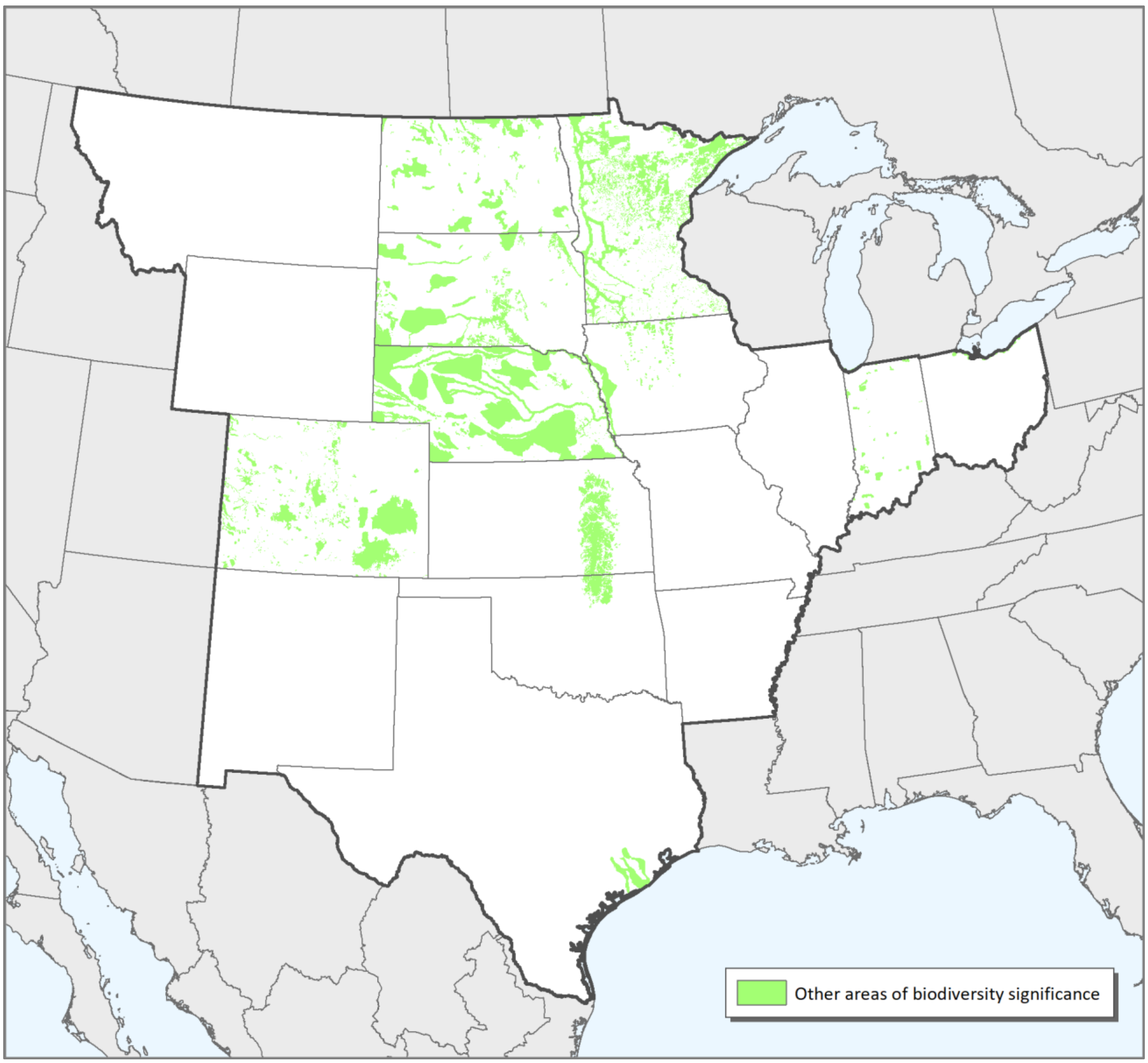
Sources: data - Ostlie (2003); Theobald (2013); AOGC (2014); TCF (2014); FracTracker Alliance (2016); COGCC (2018); KGS (2018); MGS (2018); MTDNRC (2018); NOGCC (2018); NMEMNRD (2018); NDDMR (2018); SDDENR (2018); TXRRC (2018); WYGCC (2018); TNC (2019); spatial analysis – TNC (2019).



Other areas of biodiversity significance

Sites identified in previous conservation assessments where wind development may present a threat to wildlife include the Flint Hills landscape of Oklahoma and Kansas (TNC 2000, 2007; WHSRN 2019); potential conservation areas with high, very high, or outstanding biodiversity significance in Colorado (CNHP 2017b); wind sensitive areas in Indiana (TNC and Audubon 2010); Prairie Pothole Joint Venture priority areas, and the Loess Hills ecoregion in Iowa (IADNR 2018); areas of moderate, high, or outstanding biodiversity significance (MNDNR 2015), and prairie conservation core areas, corridors, matrix habitat, and strategic habitat complexes in Minnesota (MNPPWG 2017); biologically unique landscapes, and medium and high sensitivity natural communities in Nebraska (NWWWG 2016); The Nature Conservancy's conservation priority areas in North Dakota and South Dakota (Fargione et al. 2012); areas within 8 km of the Lake Erie shoreline in Ohio (Ewert et al. 2011); and the Columbia Bottomlands Conservation Area in Texas (TNC 2002; USFWS 2012b).

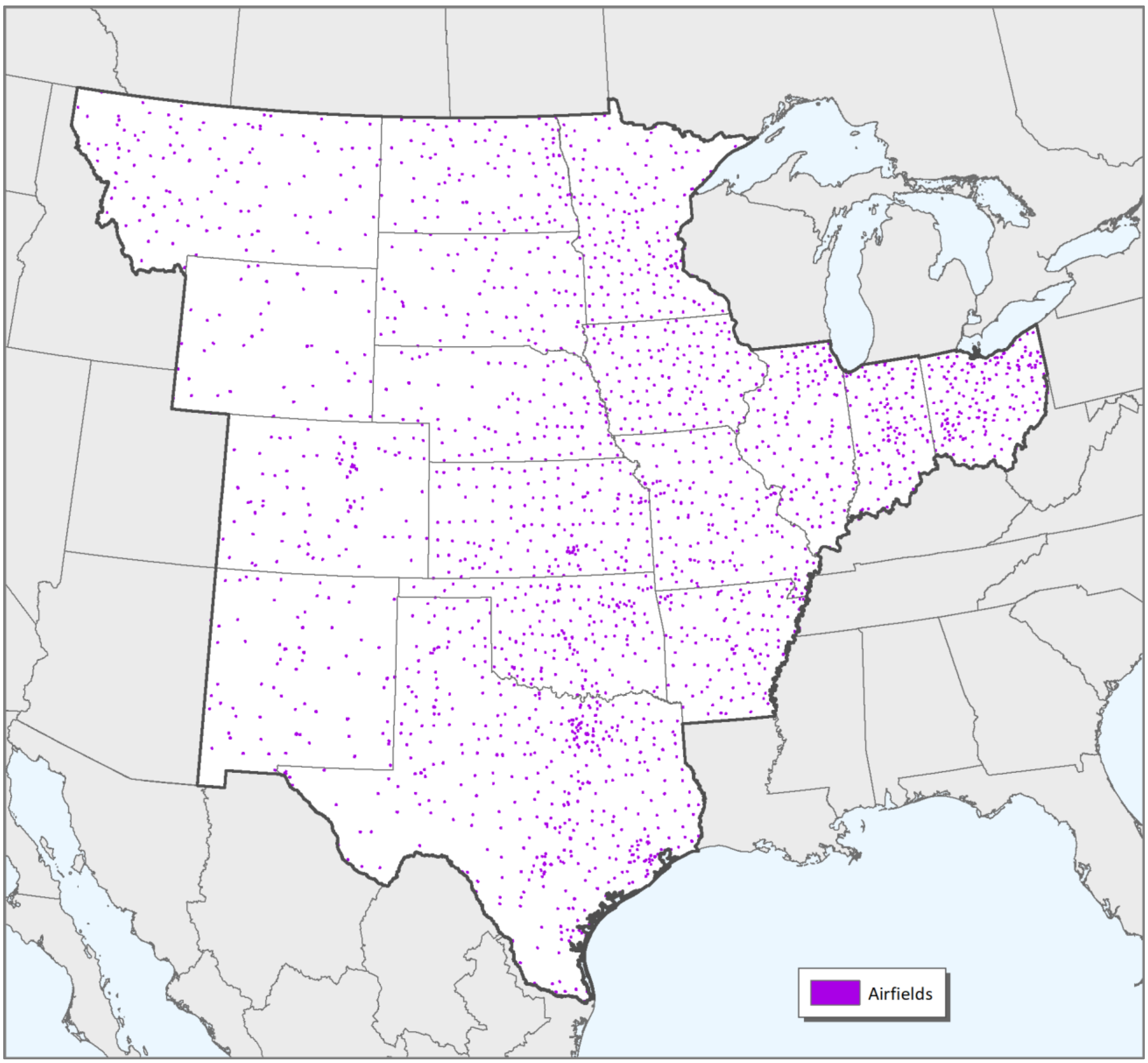
Sources: TNC (2000, 2002, 2007); TNC and Audubon (2010); Ewert et al. (2011); Fargione et al. (2012); USFWS (2012b); MNDNR (2015); NWWWG (2016); CNHP (2017b); MNPPWG (2017); IADNR (2018); WHSRN (2019).



Airfields

Commercial wind turbines require undisturbed airspace for operation and may present hazards to air travel. Areas within 3 km of public use and military airfield runways are considered unsuitable for wind development (USDOE 2008).

Source: USDOT (2017).

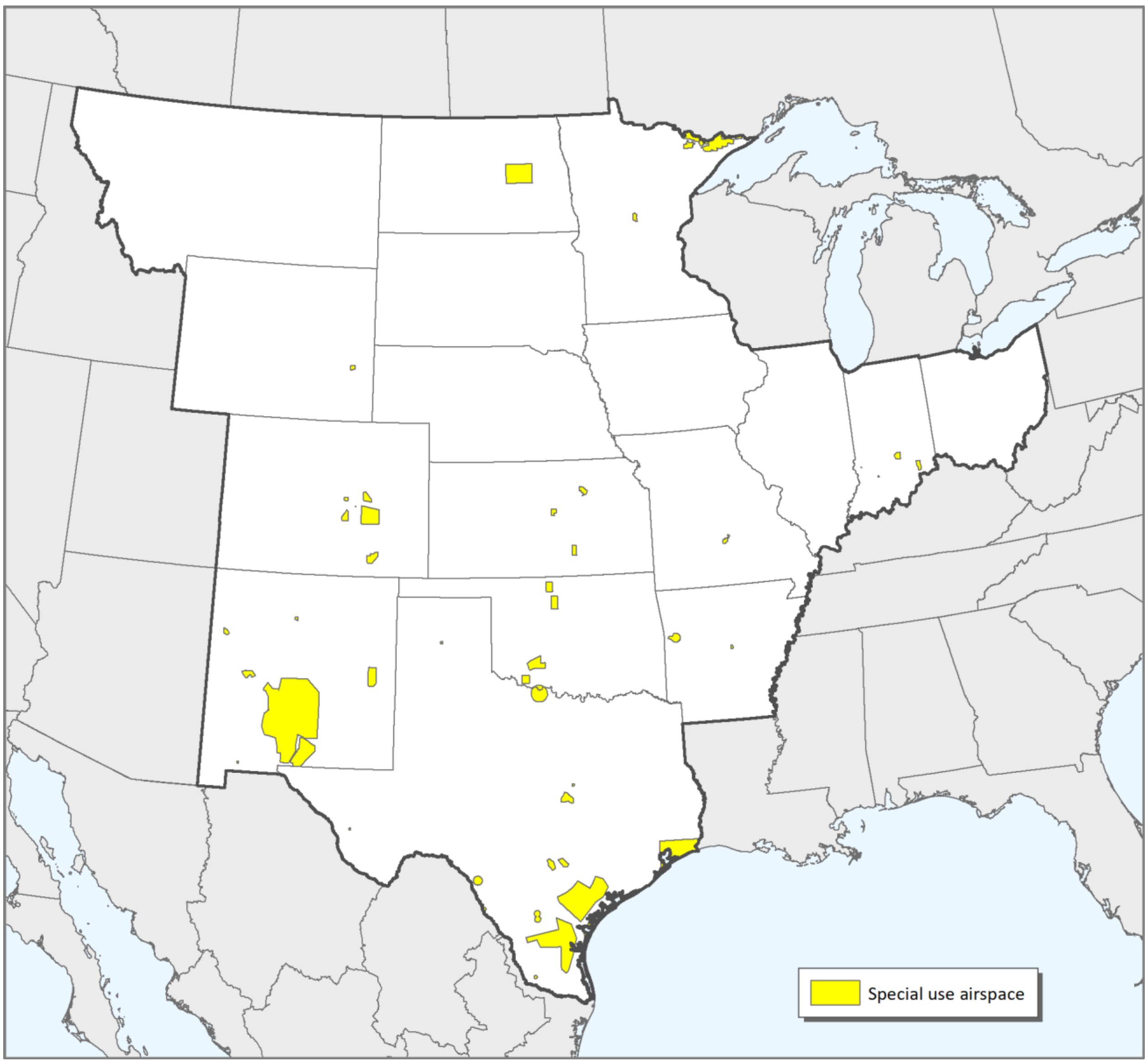


Special use airspace

Special use airspace areas managed by the Federal Aviation Administration contain unusual aerial activity, generally of a military nature. These include 'alert' areas which experience high volumes of training flights, 'restricted' areas near artillery firing ranges, and 'prohibited' areas with significant national security concerns (FAA 2010). Placement of wind turbines within these areas may create hazardous flight conditions and compromise military readiness (NRDC and USDOD 2013).

We consider alert, restricted, and prohibited airspace unsuitable for wind energy development. Outside of these areas, consultation with the U.S. Department of Defense may be required prior to constructing wind turbines within defined military operating areas, near low-level flight paths, and in areas that penetrate defense radar lines of sight.

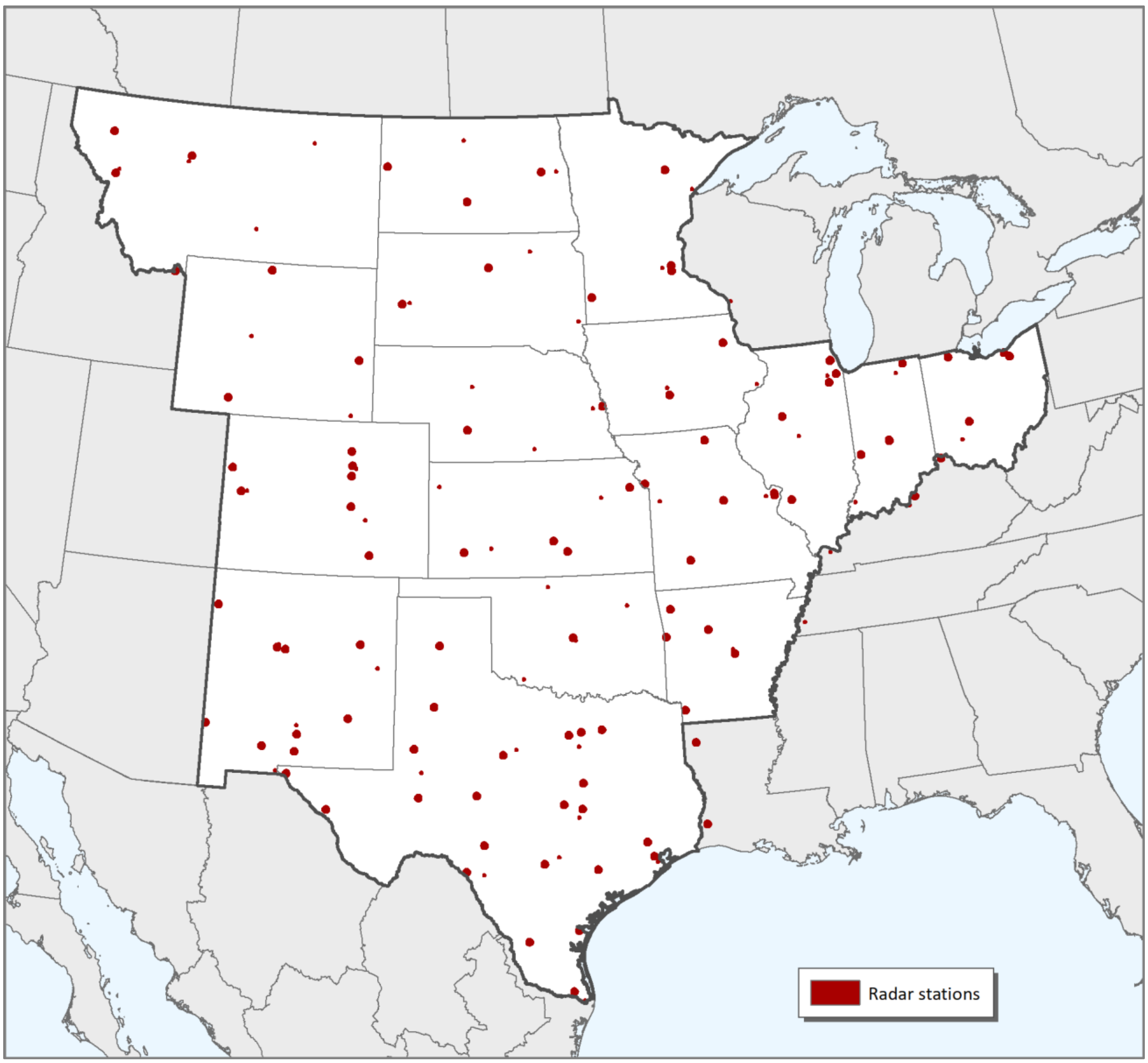
Sources: FAA (2017a, 2017b).



Radar stations

Wind turbines may cause interference with radar signals when sited in close proximity to weather stations and military installations (Vogt et al. 2011; NRDC and USDOD 2013). The National Oceanic and Atmospheric Administration requests that developers avoid constructing wind turbines within 3 km of NEXRAD radar installations (FAA 2018); a larger avoidance distance of 9.26 km is assumed for Department of Defense radar sites (Tegen et al. 2016). Outside of these areas, mitigation may be required for wind turbines that penetrate radar lines of sight, particularly for structures within 36 km (FAA 2018).

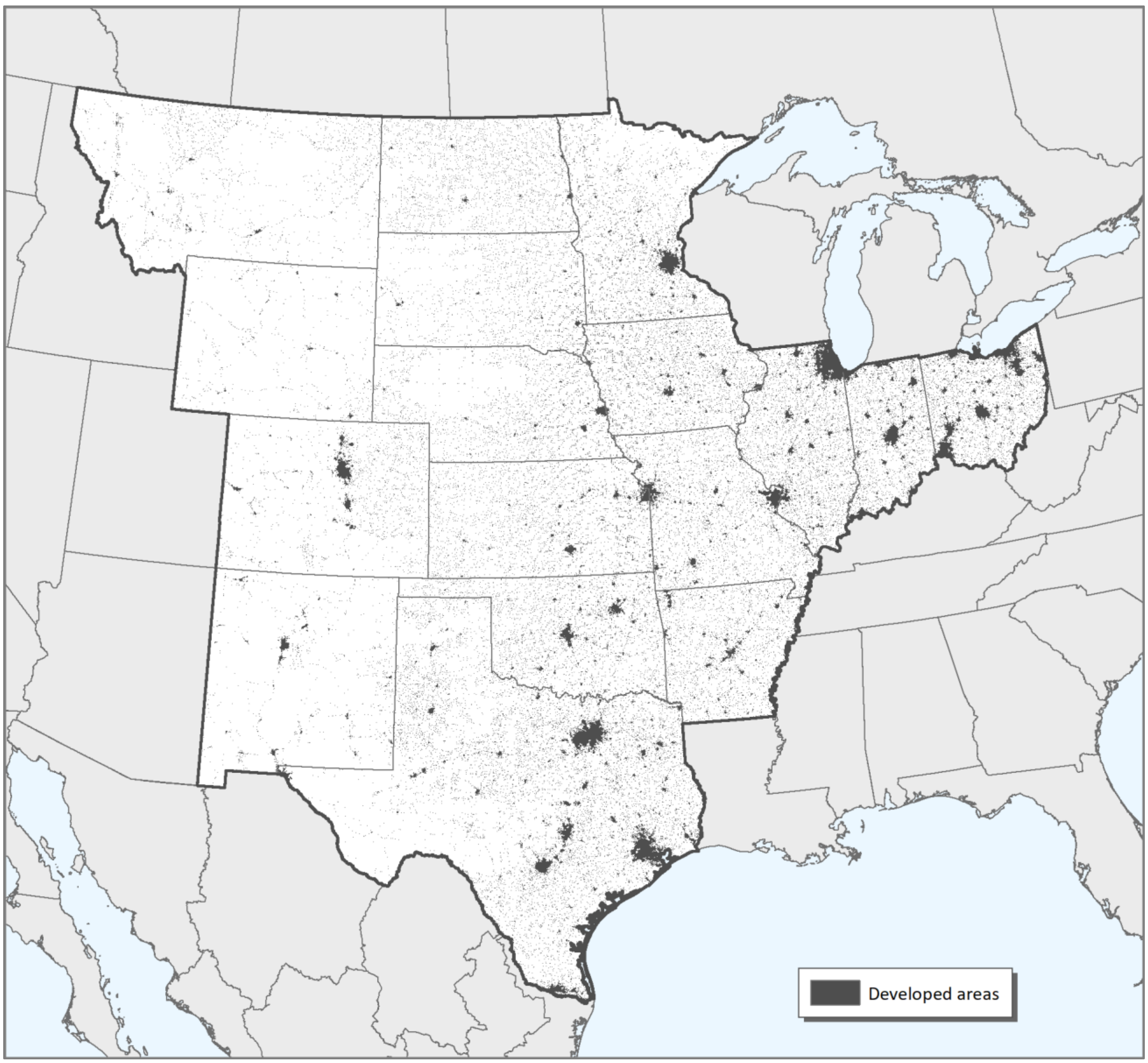
Sources: NOAA (2017); FAA (2018).



Developed areas

Urban lands and other developed areas (including roads, industrial sites, etc.) are considered unsuitable for commercial wind development (USDOE 2008).

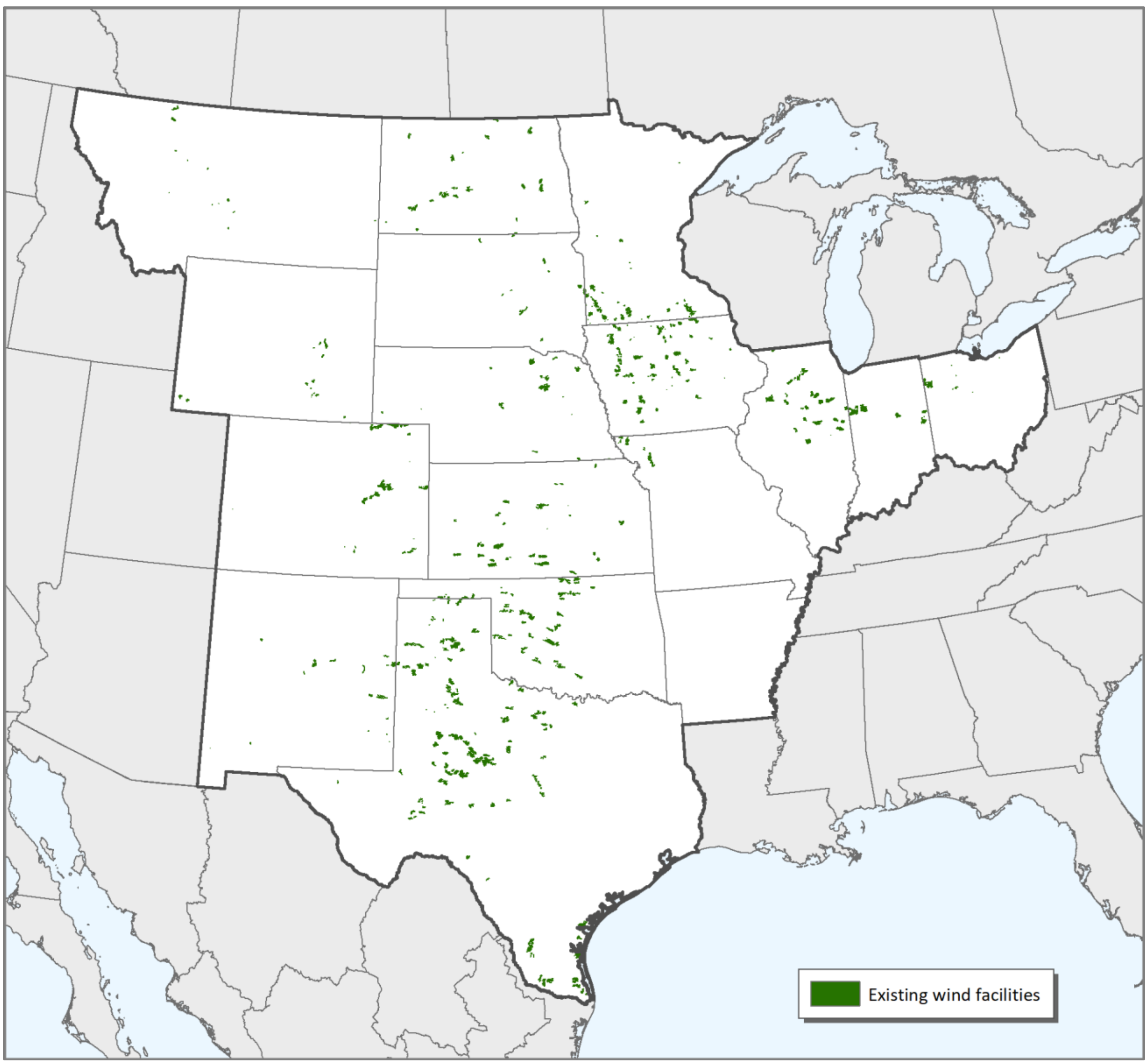
Sources: Fry et al. (2011); USCB (2016).



Existing wind facilities

Areas within 1.6 km of existing wind turbines are considered unsuitable for new wind development. This distance represents the typical spacing of turbine strings oriented perpendicularly to prevailing winds in the Great Plains.

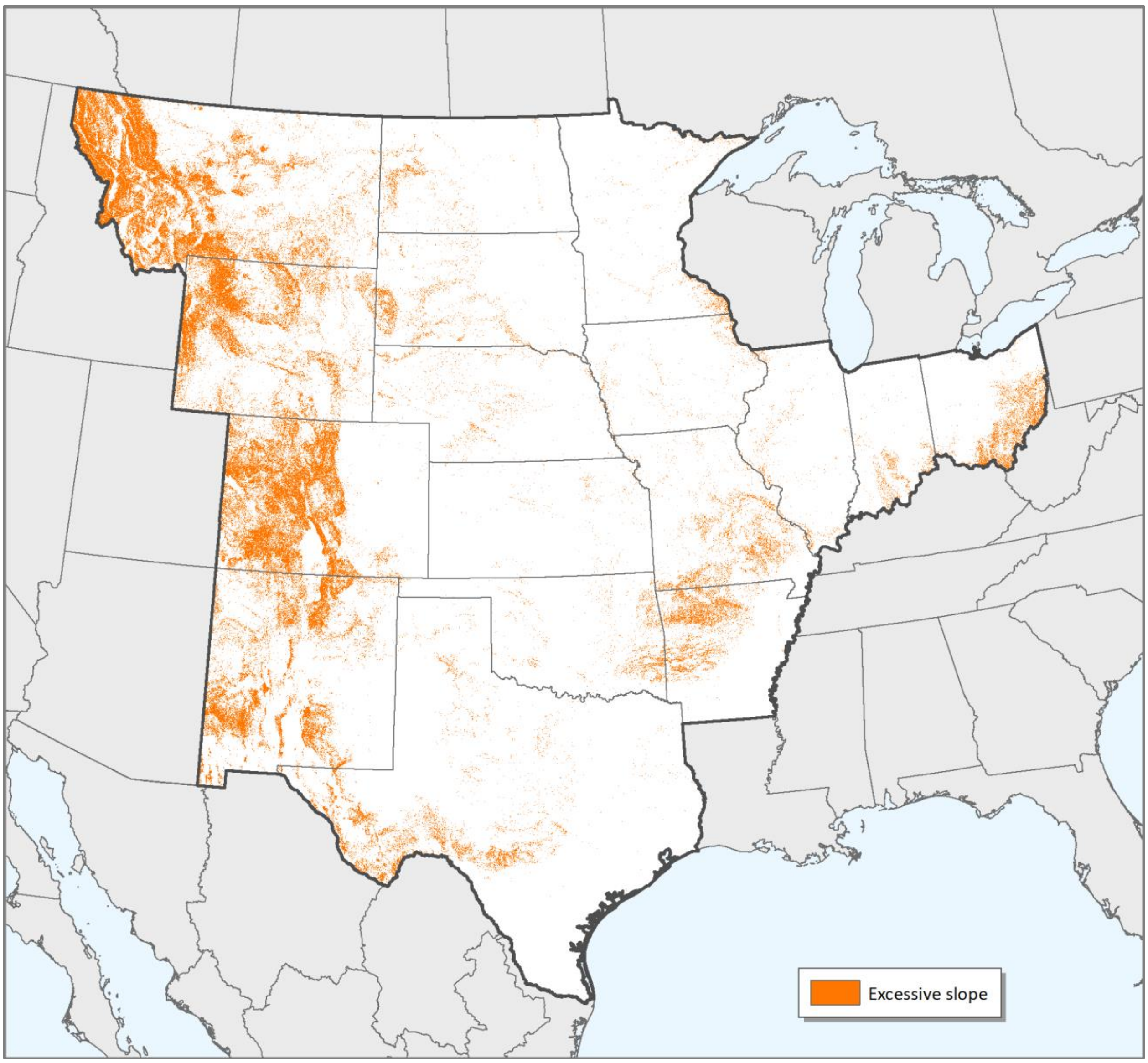
Source: FAA (2018).



Excessive slope

Steeply sloping terrain may significantly increase capital costs associated with turbine construction. Areas of slope exceeding 20% are considered unsuitable for wind development (USDOE 2008).

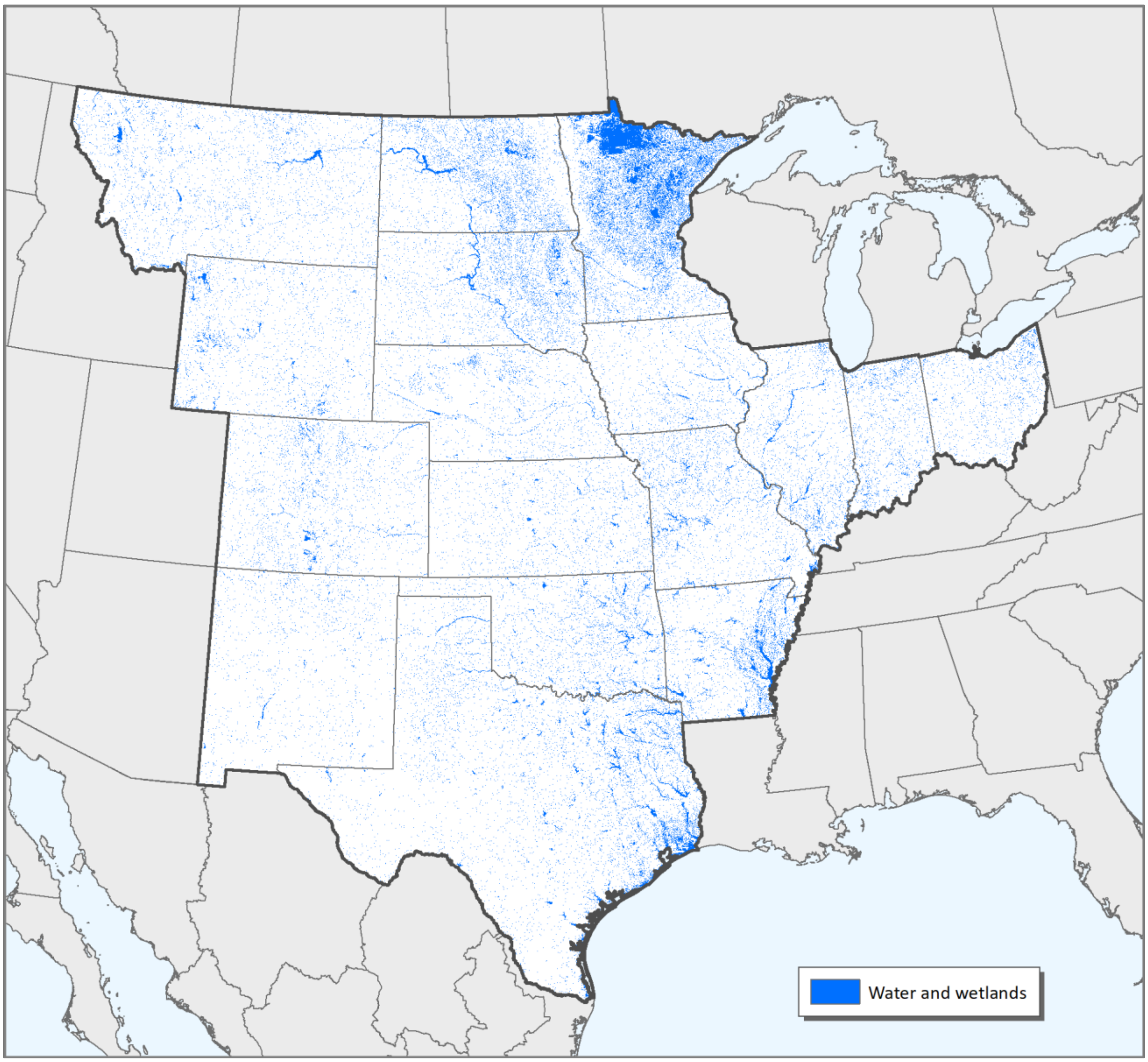
Source: USGS (2017a).



Water and wetlands

Open water and wetland areas are considered unsuitable for wind development (USDOE 2008).

Sources: Fry et al. (2011); PLJV (2015); USFWS (2016b).



Poor wind resource

Areas with annual average wind speeds of less than 6.5 m/s at 80 m height may be unsuitable for wind development (AWS Truepower 2010).

Source: AWS Truepower (2010).

Negative relative elevation

Mesoscale wind maps are often generalized and may not accurately depict wind energy potential at a given site (Bailey et al. 1997; Tennis et al. 1999). Wind developers employ a variety of computational models to assess local wind resources based on orography, measured wind speed, and other factors (Langreder 2010; Hau and von Renouard 2013). Most commercial wind facilities in the central U.S. are situated on topographic ridges which experience higher winds than the general surroundings. To identify terrain conducive to development, we calculated relative elevation based on the mean elevation of annuli extending 3, 6, 12, and 24 km from a given point (White et al. 2014). Negative values represent areas that lie below the adjacent landscape and thus have decreased wind exposure. Mountainous and coastal regions were not analyzed or excluded based on relative elevation as wind resources in these areas may be influenced by more complex topographic and meteorological factors.

Sources: methods – White et al. (2014); data – USGS (2017); analysis – TNC (2019).

Statutory restrictions

Wind development may be legally (or functionally) restricted in some areas of the central U.S., including within 2.8 km buffers of airport runways, public schools, and hospitals in Oklahoma (17 O.S., Section 160. 20, as amended); the "Heart of the Flint Hills" region in Kansas (Rothschild 2005; KBS 2015c); 1.6 km and 800 m buffers of certain state-protected properties in Illinois, as supported by the Illinois Natural Areas Preservation Act (525 ILCS 30/1-26); and 150 m buffers of state trails in Minnesota (cf. MNDNR 2018b).

Many additional state, county, and local regulations pertaining to wind development may exist across the region; however, a detailed examination of these constraints was beyond the scope of this assessment.

Sources: KBS (2015c); OKSDE (2015); PSCC (2015); MNDNR (2016); USDOT (2017); USGS (2017b).

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