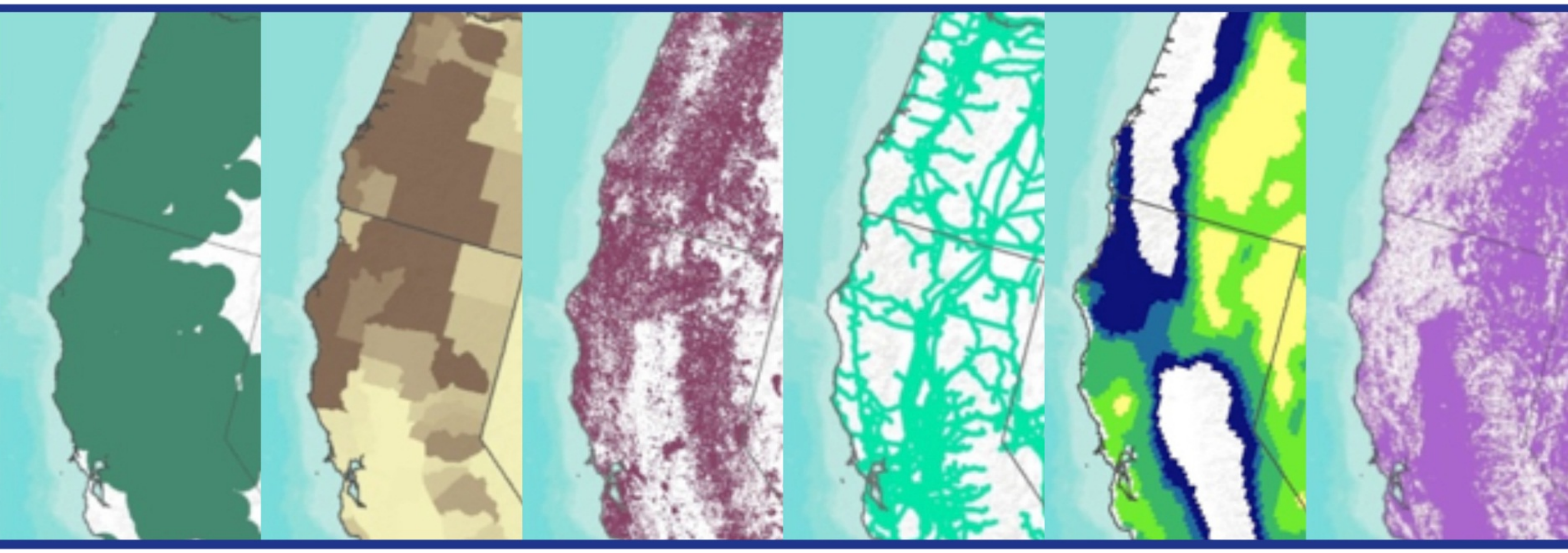
Analysis of Renewable Energy Potential on U.S. National Forest Lands



ANL/EVS-13/1
December 2013

prepared by

Argonne National Laboratory

for

**U.S. Department of Agriculture – Forest Service
Lands and Realty Management
Washington, D.C.**

U.S. Department of Agriculture
Forest Service

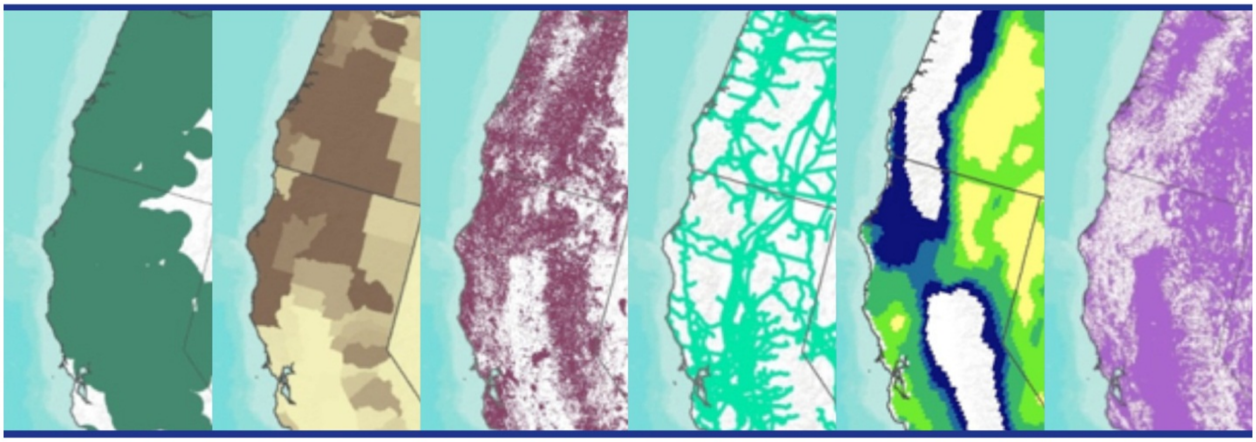
About Argonne National Laboratory

Argonne is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC under contract DE-AC02-06CH11357. The Laboratory's main facility is outside Chicago, at 9700 South Cass Avenue, Argonne, Illinois 60439. For information about Argonne and its pioneering science and technology programs, see www.anl.gov.

Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor UChicago Argonne, LCC, nor any of their employees or officers, makes any warrantee, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of document authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, Argonne National Laboratory, or UChicago Argonne, LLC.

Analysis of Renewable Energy Potential on U.S. National Forest Lands



ANL/EVS-13/1
December 2013

prepared by
E. Zvolanek, J. Kuiper, A. Carr, and K. Hlava
Environmental Sciences Division
9700 South Cass Avenue
EVS/Bldg 240
Argonne, IL 60439

Argonne National Laboratory

U.S. Department of Agriculture
Forest Service

Table of Contents

Table of Contents (Cont.)

List of Figures

List of Figures (Cont.)

List of Figures (Cont.)

List of Tables

List of Tables (Cont.)

Acknowledgements

The authors would like to thank the U.S. Department of Agriculture, Forest Service, Lands and Realty Management Office for providing funding support for this project. The authors also offer special thanks to Scott O. Schlueter of Argonne National Laboratory for preparing the cartographic figures in this report.

Definitions

BLM	U.S. Bureau of Land Management
CSP	Concentrating Solar Power
DEM	Digital Elevation Model
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
EERE	Office of Energy Efficiency and Renewable Energy (DOE)
EGS	Enhanced Geothermal System
EISPC	Eastern Interconnection States' Planning Council
FWS	U.S. Fish and Wildlife Service
GIS	Geographic Information System
Gpm	gallons per minute
NREL	National Renewable Energy Laboratory
ORNL	Oak Ridge National Laboratory
PEIS	Programmatic Environmental Impact Statement
PV	Photovoltaic
R&D	Research and Development
ROD	Record of Decision
ROW	Right-of-Way
RPS	Renewable Portfolio Standard
SEZ	Solar Energy Zone
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
WPC	Wind Power Class

Executive Summary

In 2005, the National Renewable Energy Laboratory (NREL) completed an assessment of the potential for solar and wind energy development on National Forest System (NFS) public lands managed by the US Department of Agriculture, U.S. Forest Service (USFS). This report provides an update of the analysis in the NREL report, and extends the analysis with additional siting factors for solar and wind energy. It also expands the scope to biomass and geothermal energy resources. Hydropower is acknowledged as another major renewable energy source on NFS lands; however, it was not analyzed in this project primarily because of the substantially different analysis that would be needed to identify suitable locations.

Details about each renewable energy production technology included in the study are provided following the report introduction, including how each resource is converted to electrical power, and examples of existing power plants.

The analysis approach was to use current and available Geographic Information System (GIS) data to map the distribution of the subject renewable energy resources, major siting factors, and NFS lands. For each major category of renewable energy power production, a set of siting factors were determined, including minimum levels for the renewable energy resources, and details for each of the other siting factors. Phase 1 of the analysis focused on replicating and updating the 2005 NREL analysis, and Phase 2 introduced additional siting factors and energy resources. Source data were converted to a cell-based format that helped create composite maps of locations meeting all the siting criteria. Acreages and potential power production levels for NFS units were tabulated and are presented throughout this report and the accompanying files.

NFS units in the southwest United States were found to have the most potentially suitable land for concentrating solar power (CSP), especially in Arizona and New Mexico. In total, about 136,032 acres of NFS lands were found potentially suitable for CSP development, potentially yielding as much as 13,603 megawatts (MW) of electricity, assuming 10 acres per MW.

For photovoltaic solar power (PV), the top NFS units were more widely distributed than CSP. Notably, more than 150,000 acres in Comanche National Grassland in Colorado were found to be potentially suitable for PV development, accounting for more than 25% of the potentially suitable NFS lands combined. In total, about 564,698 acres of NFS lands were found potentially suitable for PV development, potentially yielding as much as 56,469 MW of electricity, assuming 10 acres per MW.

NFS units most suitable for wind power are concentrated in the northern Great Plains. In total, about 3,357,792 acres of NFS lands were found potentially suitable for wind development, potentially yielding as much as 67,156 MW of electricity, assuming 50 acres per MW. Of that area, 571,431 acres (11,429 MW) are located within the Bankhead-Jones Farm Tenant Act Land in Montana. NFS lands in Alaska have considerable wind resources, but other siting factors eliminated almost the entire area. The southwest coast of Chugach National Forest, near Seward, Alaska, maintains the majority of the remaining acreage.

NFS units with highly suitable biomass resources are located from Idaho to Louisiana. In total, about 13,967,077 acres of NFS lands are potentially highly suitable for biomass from logging and thinning

residue development. Of that, 1,542,247 acres is located in Fremont-Winema National Forest in Oregon. Not surprisingly, most NFS units have at least some level of potentially suitable biomass resources. In general, biomass resources such as these could significantly offset consumption of coal and petroleum-based fuels.

NFS units deemed potentially highly suitable for enhanced geothermal system (EGS) development were distributed widely from California to Virginia, accounting for some 6,475,459 acres. Mark Twain National Forest in Missouri has the largest area of all the NFS units, with 900,637 acres. While more rigorous studies are needed for siting geothermal plants, especially those regarding the geological characteristics of specific sites, current results suggest a significant potential for geothermal power generation within many NFS units.

The first phase of analysis for solar and wind resources sought to replicate the 2005 NREL methodology using updated source data.[1] The total acres meeting the criteria for all NFS lands were lower in the updated assessment compared to the 2005 NREL analysis because the earlier assessment included all land that fell within NFS administrative boundaries rather than only NFS-managed land within them. Acreages were again lower when refined screening factors were added, as would be expected. These remaining areas are of greater interest because they adhere to a broader set of criteria.

As this study illustrates, GIS data availability for renewable energy resources and major screening factors has reached a point where national screening level studies can effectively assess the levels and spatial distributions for potentially renewable energy technology development. More detailed siting studies, land use planning, and environmental compliance assessments are essential before individual projects can be permitted and built. However, this study can serve to inform resource managers and planners of where these technologies are most likely to be investigated and proposed; help prioritize efforts to continue informed and sustainable development of renewable power generation within the United States; and help characterize the role of the USFS in this arena. The authors caution against using the areas reported in the results as a final and definitive estimate of suitability for these technologies. The analysis is most useful for determining locations that should be examined more fully, and for identifying regional and national trends.

[1] A side-by-side comparison of the 2005 NREL assessment, Phase 1 with updated data, and Phase 2 with additional screening factors is provided at the end of the Results and Discussion section.

1 Introduction

The Energy Policy Act of 2005 (Public Law 109-58) and subsequent National Energy Policy from recent administrations has a strong emphasis on developing domestic renewable energy resources to help meet the demands for increased electrical power production. The U.S. Department of Agriculture, U.S. Forest Service (USFS) strategic plan (USFS 2007a) includes objectives to help meet energy resource needs, protect forests and grasslands from conversion to other uses, and improve accountability through effective strategic land-management planning and efficient use of data and technology in resource management.

This study assesses the potential energy production contributions of USFS National Forest System (NFS) lands while accounting for environmental stewardship, sustainability, and multiple-use functions. It updates and expands upon an earlier assessment of wind and solar energy resources on NFS lands (NREL 2005) and was facilitated by the Geographic Information System (GIS) data maintained by the authors for the *Renewable Energy Atlas of the United States* (Argonne 2012c) produced for the USFS. The objectives of this study include:

1. Assessing the potential for biomass, geothermal, solar, and wind energy involving NFS lands;

2. Updating wind and solar energy results of the 2005 NREL assessment using new data and refined siting criteria; and

3. Identifying the National Forest and Grassland units in the NFS that have the highest potential for industry development of power production facilities for each of the renewable energy types analyzed.

Hydropower is acknowledged as another major renewable energy source on NFS lands; however, it was not analyzed in this project primarily because of the substantially different analysis that would be needed to identify suitable locations. The screening criteria used in the study include areas with high-quality resources for biomass, geothermal, solar, and wind energy; engineering; cost; land protections; and environmentally sensitive areas. The results will help inform decision makers in the USFS, and other stakeholders, of promising energy development opportunities in areas with the aforementioned energy resources and proximity to transmission lines, while excluding areas protected for other uses or having high environmental sensitivity.

The 2005 NREL assessment included concentrating solar power (CSP), photovoltaic solar (PV), and wind energy for 50-m turbine heights. This study expands the scope to include biomass and geothermal in the energy resources analyzed, and increases wind turbine heights to 80 m and 100 m in the wind energy analysis. The geographic scope of this report includes all national forest and grassland units in the United States. Analysis for Alaska includes only wind energy due to insufficient quality and detail of available biomass, geothermal, and solar energy resource data. Hawaii lacks any national forest or grassland units and is therefore omitted.

Accompanying this report is a DVD with an Adobe Portable Document Format (PDF) version of the document, GIS files used for the analysis, and an ESRI ArcReader project file suitable for viewing the GIS data using free ArcReader software distributed by ESRI (ESRI 2013).

This page intentionally left blank.

2 Renewable Energy Technologies

This section provides a brief summary of the technologies for power generation associated with the biomass, geothermal, solar, and wind renewable energy resources included in this study. Unless otherwise indicated, the content in this section is taken from *The Renewable Energy Atlas of the United States* (Argonne 2012c) also written by the authors.

2.1 Biofuels and Power Generation from Biomass

Biomass is living, or once living, matter, including plants and animals. Plants harness carbon dioxide from the surrounding environment to create energy from the sun through photosynthesis. When animals consume plant material, the chemical energy found in plants is transferred to the animal. That energy remains in plants and animals until they start to decompose or are altered by processes such as burning. Forms of plant matter and animal matter used to produce energy include crop residue, landfill waste, manure, sanitary wastewater, animal waste from slaughterhouses, grease from restaurants, and forest residue.

Some crops are grown for the specific purpose of being used for energy production. Termed “dedicated energy crops,” they can be used directly as fuel or processed for use in biofuel applications. Agricultural crops used for biofuel fall within two categories: crop biomass used to make biofuels; and crops raised for oily seeds that can be converted into biodiesel. Corn, sugarcane, and switchgrass are crops that are currently being used to make biofuels. Soybeans, sunflowers, rapeseed, and castor beans are some of the oily seeds used to create biodiesel. Research is being conducted on algae for the production of energy because algae mass grows quickly and includes lipids and triglycerides that are also found in vegetable oils.

The primary woody crops include trees (e.g., hybrid willow and hybrid poplar trees) that are grown in forest plantations for the sole purpose of generating heat and energy. A conversion process is needed to turn woody plants, agricultural crops, or waste into biofuels. There are two general types of conversion processes: biochemical conversion and thermochemical conversion.

The biochemical conversion process has five steps: (1) biomass is pretreated with heat, water, acid, or bases to break down the biomass into sugars and make the cellulose more accessible; (2) carbohydrates are separated and the sugar is released through hydrolysis; (3) the sugar is separated and cleaned to increase the efficiency and purity of the biomass (cleanup/separation); (4) organisms are added to ferment the sugar into carbon dioxide and alcohol; and (5) the fermented material is distilled to separate the ethanol/alcohol from water and other solid matter. The solid matter can then be burned to produce heat or create energy, or go through a thermochemical process to produce fuel additives.

Thermochemical conversion is a four-step process: (1) biomass is broken down to a synthesis gas (gasification) and is oxidized with air, oxygen, or steam; (2) contaminants (e.g., tars, acid gas, alkali metals, and other particles) are removed and the gas is conditioned until it has the correct hydrogen and carbon monoxide ratio (gas cleanup and conditioning); (3) the feedstock is heated in the absence of oxygen, which breaks down the product into oil (pyrolysis); and (4) the oil is cleaned and processed into different hydrocarbon fuels by reducing the oil's oxygen content (bio-oil cleanup).

Forest residues—leftover wood and plant material from logging operations and forest management procedures—are not dedicated energy crops, but are still a sustainable biomass option. Through the use of forest residues, agricultural residues, and dedicated energy crops, the DOE estimates that the United States can grow enough productive biomass to offset more than 30% of the nation's petroleum consumption.

Toward this end, ThermoChem Recovery International is working on methods of processing forest residues for uses other than in co-firing or for heat. The company has tested and validated a process to convert forest residues into diesel fuel and paraffin waxes. Biomass technologies have proven effective in large or small scale productions and can be sustainably maintained. Increasing the use of biomass for energy would reduce the United States' dependency on foreign oil and stimulate the economy (DOE EERE 2012b).

There are a number of biofuel research endeavors currently underway at working production centers around the country. The Biofuels Center of North Carolina, in Oxford, conducts research on using forest residues and mill residues, and studies tree species suitable for conversion into biofuels. Farms in the Emmetsburg, Iowa, area are using crop residues and corncobs to generate cellulosic biofuels (ethanol) using a biorefining process. Methane from the Puente Hills Landfill in Whittier, California, is converted into electricity using a steam turbine system that has the capacity to generate 50 MW of electricity. The King County South Treatment Plant, of Renton, Washington, generates combined heat and power (CHP) using a molten carbonate fuel cell to generate up to 1 MW of electricity from wastewater-derived methane. The Michigan State University Forest Biomass Innovation Center, in Escanaba, Michigan, researches and develops ways to make fuels from cellulose using dedicated energy crops.

2.2 Enhanced Geothermal Systems

Geothermal energy originates from the naturally occurring heat of the earth's interior. The heat energy can be retrieved by drilling water or steam wells, or it can be found directly on the surface of the earth in the form of steam vents, geysers, mud pots, and hot springs. Heat resources found deeper than a mile below the earth's surface are termed geothermal reservoirs. Wells can be drilled to access their steam and very hot water for use by a geothermal power plant to spin turbines that, in turn, drive generators, creating electricity.

In addition to power plants, geothermal energy can be harnessed through direct use and geothermal heat pump systems. Direct use of geothermal fluids involves piping hot water directly from the source into buildings or other facilities for heating purposes. Geothermal heat pump systems use the stable temperatures at the upper 10 feet of the earth's surface to heat and cool buildings by circulating water through the shallow ground and employing a heat-exchange system.

Three types of technologies are used for geothermal power plants: dry steam, flash steam, and binary cycle. All three types recycle the hot water and inject the remaining geothermal fluid back into a reservoir. In addition, geothermal power plants require a cooling system that prevents the turbines from overheating, which ultimately extends the life of the facility.

1. In dry steam plants, the steam is used directly to spin turbines that drive a generator to create electricity.

2. In flash steam plants, steam or water under high temperatures and/or pressures is directed into a tank at lower pressure, thereby flashing the vapor. The flashed vapor is used to spin turbines that drive an electrical generator.

3. In a binary cycle plant, geothermal fluids are used to boil a "working" fluid such as butane or pentane that has a boiling point lower than water, and the flash of the binary fluid is used to spin the turbines.

Governing bodies and institutions such as DOE and the Massachusetts Institute of Technology (MIT) are researching and experimenting with Enhanced Geothermal Systems (EGS) for areas with suitable subsurface heat, but insufficient natural permeability or fluid saturation. An EGS is a man-made reservoir where fluid (typically water) is strategically injected underground to further open pre-existing fractures, and increase subsurface permeability. Once greater permeability has been established, the fluid circulates throughout the hot rock and transports heat to the surface just like naturally occurring geothermal systems. The DOE believes that EGS has the potential to serve as a significant energy source for the nation.

The Mammoth Pacific Complex is a binary-cycle geothermal power plant located in central California, near Bishop (Ormat 2013). The plants are fueled by geothermal brine from the Casa Diablo Hot Springs. Mammoth Pacific I was built in 1984 and generates 10 megawatts. The two other projects were built in 1990 and generate 15 megawatts. The projects consist of 12 production wells and 8 injection wells. A total of eight single-stage, radial-flow gas expanders are used (GEA 2013). A federal permit for the Casa Diablo IV Geothermal Development Project, a 33-megawatt expansion of the plant on Inyo National Forest and adjacent private lands, was approved in 2013 (BLM et al. 2013). The USFS has also completed an Environmental Impact Statement and Record of Decision for Geothermal Leasing on the Humbolt-Toiyabe National Forest in Northeast Nevada. The action made approximately 662,700 acres of NFS lands available for geothermal leasing (USFS 2012a).

The Geysers, located in Northern California, near Healdsburg, includes 22 individual dry steam power plants that utilize steam from over 350 wells on 8,095 acres of land. The Geysers has the capacity to generate 1,517 MW of electricity and is the largest dry steam power plant in the United States. It is also the first successful demonstration of EGS technologies in the US. Approximately 250 MW of energy are generated at The Geysers on land leased from the federal government. Puna Geothermal Venture, located in Puna, on the Big Island of Hawaii, uses binary cycle technology to generate up to 30 MW of energy. The facility is situated on 30 acres of land within the Kilauea East Rift Zone. The electricity generated at Puna Geothermal Venture is sold to Hawaiian Electric Light Company, which distributes the energy to various customers.

Eventually, these technologies could allow for development beyond optimal naturally occurring geothermal areas, and can supply base load energy without the need for energy storage technologies (DOE EERE 2012d).

2.3 Hydropower

The energy in moving water can be converted to electric power (hydropower) using turbine systems, or the energy can be used directly to power machinery. The amount of energy in water is determined by its fall (potential energy) or velocity (kinetic energy). According to the DOE:

> "[h]ydropower remains the largest source of renewable energy generation, and an important component of the energy mix; primarily large-scale hydropower accounts for 6.2% of U.S. electricity generation" (DOE 2011).

In conventional hydropower systems, river water is stored behind a dam and is released through a penstock that transmits the water to turbines that spin generators to create electricity. Conventional hydropower systems utilize the fall of water to create electricity from the potential energy of the water stored behind the dam. Run-of-the-river systems also use the fall of water to create electricity but do not store a large reservoir of water behind a dam. In these systems, some or all of the river water is diverted through a penstock and into turbines to generate electricity, then returned to the river downstream. Small hydro (<10 MW generating capacity) and micro hydro (<100 kW) projects can provide power on smaller rivers and to isolated areas, usually at a relatively low cost. Small and micro hydro power projects include those that extract kinetic energy from flowing water, such as tidal energy or hydrokinetic river energy. Hydrokinetic and tidal power systems use turbines to extract energy from the velocity of flowing water, similar to the way wind turbines extract energy from the velocity of the air. Other forms of water power that are currently under development include tidal stream power, wave power, and marine current power.

Federal government sources indicate that approximately 2,350 dams exist on NFS lands, and about 18% generate hydropower (USFS 2007b, USACE 2013). Shasta Dam, within Shasta National Forest in Northern California, is one of the largest hydropower facilities within NFS lands. It is operated by the U.S. Bureau of Reclamation and had a net generation of 1,806,476,000 kWh in 2009 (USBR 2009).

At the other end of the generation range, the Spotted Bear Ranger Station in the Flathead National Forest in western Montana features an example of a USFS micro-hydro project. When water levels are adequate, the system can supply enough electricity to power the 31-building compound (USDA 2012).

2.4 Solar Power

Solar collectors harness solar energy—the light and heat radiated from the sun—to produce electricity. There are two general categories of solar technologies: CSP and PV. CSP technologies use reflective surfaces (usually mirrors) to concentrate the sun’s energy to heat a fluid. The heated fluid then drives either a steam turbine or an external heat engine to produce electricity. Linear concentrator, power tower, and dish engine technologies fall into the CSP category. In contrast to CSP, PV technologies convert the photons in sunlight directly to electricity.

Through evolutionary and revolutionary changes in technology, the DOE postulates that the cost of solar energy can decrease about 75% by 2020. Via its SunShot Initiative, the DOE envisions a future where the costs of CSP and PV technologies have drastically decreased. If the DOE's price reductions are met, solar energy could provide 14% of the nation's electricity by 2030. This scenario would result in 181 million metric tons fewer carbon dioxide emissions annually and create 290,000 new jobs by 2030 (DOE EERE 2012).

Solar power generation is variable due to the daily cycle of the sun’s angle and weather factors such as cloud cover. PV panels also vary in efficiency at different temperatures. The variable and somewhat unpredictable nature of solar power generation adds complexity to integrating these plants into the electrical transmission grid. Co-locating them with energy storage systems such as pumped hydroelectric storage or compressed air energy storage is advantageous for mitigating the variability.

Linear Concentrators. These are CSP systems that use mirrors to focus solar energy on receiver tubes containing a heat transfer fluid. The fluid in the receiver tubes is heated by the solar energy and used to create superheated steam, which spins turbines that run a generator to create electricity. The major components of a typical utility-scale linear concentrator facility are the solar field, the power block, and the cooling system. The solar field consists of long rows of solar collectors (100 to 150 ft.) that typically track the sun from east to west each day. There are two types of linear concentrator systems: the more common parabolic trough systems, and Fresnel reflector systems. In the parabolic trough systems, fluid is heated in the receiver tube that is the focal line in a parabola-shaped mirror. The linear Fresnel reflector system uses flat mirrors to heat water directly in the receiver tubes. Parabolic trough facilities may include thermal energy storage capability, whereby excess generated heat is stored in a thermal storage medium, typically molten salt, then used during hours without sunlight.

One example of a linear concentrator project is the Nevada Solar One project, which encompasses 400 acres and has a power capacity of 75 MW. This system consists of 760 parabolic troughs with 182,000 mirrors and 18,240 receiver tubes, each 4 m in length.

Solar Power Tower. The major components of a typical utility-scale power tower facility are the solar field, tower, power block, and cooling system. Utility-scale power tower facilities are CSP plants consisting of thousands of flat mirrors called heliostats that direct solar energy towards a central tower. The typical height of a solar power tower is about 300 to 450 ft. The heliostats are equipped with systems that track the sun from east to west to maximize power capture, then concentrate the solar energy on a central point at the top of the tower, where a heat transfer fluid (HTF) absorbs the heat. The HTF creates superheated steam, which spins turbines that run a generator to create electricity. Molten salts have replaced water as the HTF, because they have greater thermal energy storage capabilities. Power tower facilities may include thermal energy storage capability, whereby excess generated heat is stored in a thermal storage medium, typically molten salt, then used during hours without sunlight.

Sierra Sun Tower is a power tower demonstration facility located outside of Lancaster, California, encompassing 20 acres and operated by eSolar. The eSolar system is modular, using multiple 180‑ft power towers, each with a set of 12,000 heliostats. The Lancaster facility has two modules, each with a capability of generating 2.5 MW of power, for a total of 5 MW.

Solar Dish Engine. These systems are stand-alone CSP energy generation systems that can generate from 3 to 50 kW each. A typical dish system consists of a parabola-shaped concentrator, a receiver, an external heat engine, and a generator. Sunlight is concentrated onto the receiver, which transfers the heat to a gas, usually hydrogen or helium contained in the sealed external heat engine. As the gas is heated, its increasing pressure drives a piston, which powers the generator and produces electricity. Cooling occurs within the engine on the side that faces away from the concentrator, so no cooling water is required. A sun tracking system, powered by the dish engine unit, is used to maximize sun concentration throughout the day. Individual dish engines can be grouped together into facilities with widely varying power capacities.

The Maricopa Solar Power Plant in Peoria, Arizona, uses 60 SunCatcher dish engines, each with a 25-kW capacity. Each dish is 38 ft in diameter and automatically tracks the sun throughout the day. The 1.5-MW system extends over 15 acres and began operating in January 2010.

Photovoltaic Systems. Photovoltaic cells, also known as solar cells, are primarily made up of semiconductor material that absorbs the energy of sunlight and transforms it into electrical energy. The semiconductor material can be made of silicon, polycrystalline thin films, or single-crystalline thin films. To produce electricity at the utility scale, modules made up of many individual solar cells are combined to make individual solar panels, and these panels are grouped into arrays that produce direct current (DC) electricity. The modular nature of PV systems allows great flexibility in sizing facilities to accommodate factors such as the amount of power needed or the amount of land area available. There are two types of PV systems: flat plate and PV concentrator systems. PV concentrator systems use reflective material to concentrate the sun's energy onto a smaller area. As such, it requires less solar cell material compared to flat plate systems that generate the same amount of electricity. While solar cell efficiency is increased in PV concentrator systems, disadvantages include their expensive optics, the added cost of sun-tracking systems, and excess heat.

Two examples of PV projects are the DeSoto Next Generation Solar Energy Center in DeSoto County, Florida, and the Nellis Air Force Base Solar Power System. The 180-acre DeSoto facility has over 90,000 solar panels that have the capacity to generate 25 MW. These solar panels are equipped with single-axis trackers, which increase energy production throughout the day. The Nellis Air Force Base Solar Power System is a PV facility located in Las Vegas, Nevada with a generation capacity of 14.2 MW. The facility spans over 140 acres and is equipped with 72,416 solar panels, each of which generates 200 W. A SunPower Tracker system made up of 5,821 units is used to maximize generation capability throughout the day.

2.5 Wind Power

Wind energy is the movement of air in the earth's atmosphere relative to a fixed point on the earth's surface. The air movement is primarily caused by the uneven heating of the earth's surface by solar radiation. The spinning motion of wind turbine blades is used to convert kinetic wind energy to mechanical energy, and a generator converts the mechanical energy to electricity.

There are two major types of wind turbines: horizontal axis and vertical axis. Horizontal axis wind turbines are the predominant technology used in commercial wind farms. Commercial utility wind turbines can generate anywhere from 100 kW to several MW of electricity. Some smaller scale wind turbines (100 kW or lower) are used by individuals and businesses. With a cost between 5 and 8 cents per kWh, wind power is one of the cheapest forms of renewable energy. In addition, wind turbines can be erected on ranches and farms with minimal or no change to agricultural uses.

The main disadvantages of wind power include the following: it is usually an intermittent resource, and a backup source of energy may be needed for utility-scale facilities; a significant proportion of wind resources are in remote areas without existing transmission lines, thereby increasing the costs of tying them to the grid; wind turbines can produce considerable noise; some people dislike the aesthetics of wind turbines in their landscapes; and wind turbines may potentially harm wildlife (e.g., birds and bats).

Despite the potential disadvantages, the DOE estimates that wind power has the potential to supply 20% of the nation's electricity by 2030. In order to achieve the 20% goal, the U.S. wind industry needs 300,000 MW of installed power capacity by 2030. As of August 2012, more than 50,000 MW of installed power capacity were available in the United States (DOE EERE 2012c).

The Horse Hollow Wind Energy Center and the Foote Creek Rim Project are two examples of wind energy development facilities. The Horse Hollow Wind Energy Center, located on 47,000 acres of land in Taylor and Nolan counties in Texas, has the capacity to generate 735 MW of electricity. The facility consists of 291 1.5-MW wind turbines and 130 2.3-MW wind turbines. The Foote Creek Rim Project near Arlington, Wyoming, sits on top of a treeless plateau in one of the windiest places in the United States. Foote Creek Rim was the first commercial wind energy facility in Wyoming, and can operate with 8- to 65-mph winds. The facility currently has 183 turbines and a generating capacity of 134.7 MW.

3 Methods

The primary factor in determining potential sites for power plants such as those listed in the prior section, is the availability and quality of the renewable energy resource on which they depend. For each technology, spatial data for the renewable energy resources was obtained, starting with updated versions of the data sources used in the 2005 NREL study, and adding biomass, geothermal, and expanded wind resource data. The details of these layers are listed in the sections below.

Many other factors must be considered to determine suitable locations, such as land use designations, and engineering and cost considerations. This analysis is intended to provide a national screening-level assessment rather than a comprehensive siting study for individual power plants. Accordingly, the assessment used the major siting factors listed in the sections below. The first level of the analysis followed the methodology of the 2005 NREL study as closely as possible, using updated data. The second phase included revised and additional screening factors based on advancements in suitability models, and improved availability of the corresponding data.

3.1 Concentrating Solar Power

NREL's analysis included six criteria for concentrating solar power:

- Direct normal solar resource potential greater than or equal to 7 kWh/m^2/day.
- Topographic slope less than or equal to 1%.
- Within 25 miles of transmission lines at least 69 kV in capacity.
- Within 25 miles of roads (down to rural local road classes) or railroads.
- Outside of USFS Inventoried Roadless and Special Designated Areas.
- Contiguous land parcel size of at least 40 acres.

The second phase of the analysis included the additional screening factors listed below:

- Within 20 miles of surface water sources with flow of at least 64,500 gpm.[2]
- Outside of wetlands and floodplains.
- Outside of open water, vegetated, forested, urban or developed land cover types.
- Outside of protected areas, including USFS experimental forests; FWS designated critical habitat; national scenic and historic trails; wilderness study areas; wild and scenic rivers; wilderness areas; national monuments; and national conservation areas.

The scope of this report includes Alaska. However, CSP data of comparable and sufficient quality as that for the contiguous states are not yet available. Available low-resolution CSP data have insolation values well below the threshold set for this analysis, as would be expected for the northern latitudes of Alaska.

[2] Water is used primarily for cleaning reflective surfaces which direct sunlight toward the fluid being heated.

3.2 Photovoltaic Solar Power

NREL's analysis included six criteria for photovoltaic solar power, the same as CSP except for the solar resource potential layer and slope. The criteria used in this study were as follows:

- Stationary panel solar resource potential greater than or equal to 5.8 $kWh/m^2/day$ (see below).
- Topographic slope less than or equal to 1%.
- Within 25 miles of transmission lines at least 69 kV in capacity.
- Within 25 miles of roads (down to rural local road classes) or railroads.
- Outside of USFS Inventoried Roadless and Special Designated Areas.
- Contiguous land parcel size of at least 40 acres.

Single-axis tracking flat plate collector insolation data with a minimum threshold of 7 $kWh/m^2/day$ were used in the 2005 NREL analysis. However, results in this study are based on current stationary panel solar resource data because current single-axis tracking data were not available. Values in the stationary panel data were not directly comparable to the single-axis tracking data. A threshold level of 5.8 $kWh/m^2/day$ best resembled the geographic distribution of the older single-axis PV data, and was used for the analysis so that the results of the NREL study could be more directly compared to this study.

The second phase of the analysis included the additional screening factors listed below. They were the same as the CSP analysis, except for the removal of water source availability because of the considerably lower water requirement for PV technology. Results were generated with and without the final distance-to-transmission factor given that it is a significant cost factor but eliminates most of the suitable locations (see Appendix B):

- Outside of wetlands and floodplains.
- Outside of open water, vegetated, forested, urban, or developed land cover types.
- Outside of protected areas, including USFS experimental forests; FWS designated critical habitat; national scenic and historic trails; wilderness study areas; wild and scenic rivers; wilderness areas; national monuments; and national conservation areas.

PV data for Alaska of comparable and sufficient quality as that for the contiguous states are not yet available. Available low resolution PV data have insolation values well below the threshold set for this analysis, as would be expected for the northern latitudes of Alaska.

3.3 Methods in the Solar Energy Development Programmatic Environmental Impact Statement

For the six southwestern states, a programmatic environmental impact statement (Solar PEIS) was recently completed by Argonne National Laboratory for the Bureau of Land Management (BLM) and the DOE. The project identified and analyzed 17 solar energy zones (SEZs) on BLM-administered lands, and it also established programmatic approaches to manage the permitting and development of utility-scale solar energy plants on BLM-administered lands. The final Solar PEIS was published in July 2012 (BLM and DOE 2012), and the Record of Decision (ROD) was signed in October 2012 (BLM 2012).

The ROD prioritizes utility-scale solar energy development on approximately 285,000 acres of SEZs and allows for responsible development on approximately 19 million acres of variance land (BLM-administered lands that are outside of excluded areas and Solar Energy Zones), in accordance with a newly-established variance process and additional environmental, socioeconomic, and cultural studies.

The ROD excludes about 79 million acres of BLM-administered land from solar energy development due to a number of agency-wide and location-specific constraints. The following is a brief synopsis of Solar PEIS exclusions and how they compare to the siting factors for solar energy development in this study.

The lowest solar insolation level assumed to be suitable for the Solar PEIS was 6.5 kWh/m^2/day for CSP siting, whereas this study considered solar insolation levels greater than or equal to 7 kWh/m^2/day for CSP suitability and 5.8 kWh/m^2/day for PV suitability. The Solar PEIS excluded lands with terrain slope greater than 5%. Initially, this assessment favored inclusion of lands with topographic slope less than 5% but then refined that screening factor to less than or equal to 1% to be consistent with the original 2005 report. Congressionally designated wild and scenic rivers, federally designated critical habitat, lands in the National Landscape Conservation System, and national scenic and historic trails, were excluded in both studies.

There are a number of region-specific siting factors that the Solar PEIS considered, which this study did not, such as particular lands in the Ivanpah, Coal, and Garden valleys of California and Nevada. One such area used as an exclusion in the Solar PEIS is the Draft Garden Valley Proposed National Conservation Area in the Garden Valley of Nevada. Some exclusions implemented in the PEIS pertained to specific sensitive wildlife species occurring in the areas being studied, such as the greater sage-grouse and desert tortoise. These factors were too specific for this national study and would vary considerably for different parts of the US. This more detailed analysis is more appropriate once areas of high renewable energy potential have been assessed and located.

Conversely, this study addresses some siting factors that the Solar PEIS did not, particularly proximity to electrical transmission infrastructure and cooling water sources. In the Solar PEIS, proximity to electrical transmission infrastructure was a criterion for siting SEZs, but not for identifying variance areas. A cooling water source criterion was not used in the Solar PEIS.

3.4 Wind Power

NREL's analysis included six criteria for wind power:

- Wind power class of 4 or greater for 50-m turbine hub heights.
- Topographic slope less than or equal to 20%.
- Within 25 miles of transmission lines at least 69 kV in capacity.
- Within 25 miles of roads (down to rural local road classes).
- Outside of USFS Inventoried Roadless Areas and Special Designated Areas.
- At least 3 km from urban areas.

The NREL study also screened their initial wind power analysis to be in the proximity of a major load center or major transmission line connecting to a load center, but their assumptions were not quantified so the analysis in this study was limited to the transmission line criteria listed above.

The second phase of the analysis included the revised and additional screening factors listed below. The urban area criterion from the first phase was omitted because the developed land cover types in the criteria below served the same purpose:

- Wind power class of 4 or greater for 50-, 80-, and 100-m hub heights.
- Outside of wetlands and floodplains.

- Outside of open water, vegetation, forest, urban and developed land cover types.
- Outside of protected areas, including USFS experimental forests; FWS designated critical habitat; national scenic and historic trails; wilderness study areas; wild and scenic rivers; wilderness areas; national monuments; and national conservation areas.
- At least 500 m from radar systems.[3]

Wind power data were available for Alaska, and using the threshold of a wind power class of 4 or greater at a 100 m hub height, 2,357,633 acres of NFS land met the criterion. But its lower overall population density, smaller and more isolated communities, rugged terrain, large but remote NFS lands, and limited electrical transmission infrastructure cause nearly all of Alaska's NFS lands to be eliminated based on the screening factors used for the rest of the analysis.

3.5 Biomass Power

Biomass is an important renewable energy resource for NFS lands. While not included in the original 2005 NREL study, it was recently studied and documented by the NREL in *U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis* (NREL 2012c). The *Biopower Technical Strategy Workshop Summary Report* (DOE EERE 2010) was also consulted in developing the screening criteria for this study. The majority of the resource-specific screening criteria used in this study were based on Argonne's recent work on the Eastern Interconnection States' Planning Council's (EISPC) Energy Zones Study. The project is a collaboration between EISPC, Argonne, NREL, and Oak Ridge National Laboratory (ORNL) to create a web-based interactive mapping and modeling tool designed to identify areas most suitable for clean energy resource development, and ultimately facilitate the analysis and planning of energy zones. During the study, biomass energy subject matter experts assisted in identifying and collecting the needed data and designing the suitability models. Approaches used in the EISPC study are consistent with the other documents. The final report for the EISPC's Energy Zones Study project, and documents detailing the EISPC data sources and model design are available on the EISPC website (Argonne 2013, EISPC 2012,b).

The seven criteria used for biomass energy were as follows:

- 2012 county-level biomass estimates for logging residues and forest thinning from the Bioenergy Knowledge Discovery Framework (KDF) Billion-Ton Update ($60/dry ton price assumption).
- Topographic slope less than or equal to 12%.
- Within 25 miles of roads (down to rural local road classes), railroads, or navigable waterways.
- Outside of areas with population density greater than or equal to 500 people per square mile.
- Outside of open water, woody wetlands, and herbaceous wetlands National Land Cover Database land cover types.

[3] Documentation regarding the effects of wind turbines on radar systems offered conflicting arguments about the preferred offset of wind turbines from radar systems. Therefore, the point vector data were converted to raster data without a buffer, yielding a 500-m offset (the size of the cell).

- Outside of protected areas, including USFS Inventoried Roadless Areas; USFS Special Designated Areas; USFS experimental forests; FWS designated critical habitat; national scenic and historic trails; wilderness study areas; wild and scenic rivers; wilderness areas; national monuments; and national conservation areas.
- Outside of floodplains.

A minimum threshold for biomass resources has not been generally established, and in this study biomass resources were divided into 3 quantiles so that each category represents one-third of the area, denoted as low, medium, and high suitability.

Biomass data for Alaska of comparable and sufficient quality as that for the contiguous states are not yet available. Alaska has considerable biomass energy resources that are promising for power production, so this is an important area for future analysis.

Unlike the other energy resources in the study, biomass can be transported from the source to a power plant by road, railroad, barge, or a combination of these routes, though it is expensive to transport it long distances. This analysis combines the resource availability with a limited transport distance, assuming the power plant would be located in a suitable location close to a high level of biomass resources. A power plant using the biomass resources might not be located on NFS lands, but that assumption was made in this study.

Biomass resources are also used to produce liquid fuels and heat. This study concentrates on biomass used for electrical power production for consistency with the other technologies, and the criteria are designed to address power plants which use biomass for their primary fuel, or for co-firing with other fuels.

3.6 Geothermal Power

Geothermal power was also newly added in this study, and suitability criteria were primarily based on the EISPC's Energy Zones Study. The final report, and documents detailing the EISPC data sources and model design are available on the EISPC website (Argonne 2013, EISPC 2012,b). These criteria were also consistent with the MIT Energy Initiative report, *The Future of Geothermal Energy* (MIT 2006), and comparable to the other technologies in this study.

The eight criteria used for geothermal power were as follows:

- Enhanced geothermal system potential (NREL 2009).
- Topographic slope less than or equal to 12%.
- Within 25 miles of roads (down to rural local road classes) or railroads.
- Outside of areas with population density greater than or equal to 500 people per square mile.
- Outside of open water and wetland land cover classes.
- Within 20 miles of surface water sources with flow of at least 130,000 gpm.[4]
- Outside of protected areas, including USFS Inventoried Roadless Areas; USFS Special Designated Areas; USFS experimental forests; FWS designated critical habitat; national scenic and historic

[4] The water availability criteria are for make-up water to offset losses during circulation through the geothermal reservoir.

trails; wilderness study areas; wild and scenic rivers; wilderness areas; national monuments; and national conservation areas.

The enhanced geothermal potential data is categorized into 5 groups, ranging from low to high potential. Lacking a standard threshold, all categories were included in the suitability analysis.

3.7 Hydropower

Hydropower is a major source of renewable energy but was not included in the scope of analysis for this study. Suitability criteria are considerably different for hydropower, with the energy resource depending primarily on surface water flow, elevation differentials, and geologic setting. Potential environmental impacts are also considerably different and include changes to river flow characteristics, inundation, groundwater, aquatic species habitat, and siltation. The potential for hydropower has been extensively analyzed in many other studies, such as those listed below:

- New output from existing non-hydropower dams (DOI et al. 2007, USBR 2011, DOE EERE 2012e).
- Efficiency improvements to existing hydropower dams (DOI et al. 2007).
- Marine and hydrokinetic technologies (Defne et al. 2012, FERC 2013a).
- Low head/low power resources (Hall et al. 2004).
- Pumped storage projects (FERC 2013b).

3.8 Additional Transmission Constraint Analysis

In Appendix A, an additional analysis for each of the renewable technologies examines the results of a 3-mile distance-to-transmission criterion, rather than the 25 miles previously cited. Proximity to existing transmission is a significant cost factor, but most otherwise-suitable locations on NFS lands are more than 3 miles from existing transmission lines.

3.9 Analysis Methods

The GIS data used in this study are listed in Table 1 with their original sources. The analysis was completed using ESRI ArcGIS 10.1 software. Each input GIS layer was projected to an Albers equal area projection and converted to raster (cell-based) format with a cell size of 500 m. With the exception of the biomass and geothermal resource datasets, the value of each cell was coded to represent the presence or absence of a specific screening factor. For example, if a cell had a suitable topographic slope level, it was coded as a 1, and unsuitable slopes were coded as 0s. In addition, when GIS layers are converted to raster format, cells having more than one category are coded with the value that covers the largest area in the cell. For example, if a land use cell had 45% open water, 30% forest, and 25% barren land, it would be coded as open water.

To map the suitable area for a particular technology, the set of layers for the analysis were multiplied. Cells with suitable values (1s) for all the siting factors had products of 1, whereas cells lacking one or more of the siting factors had products of 0. These results were categorized by NFS and state jurisdictions and used to create the tables of results.

The solar analyses included criteria for parcels of at least 40 acres. The area of a 500- × 500-m cell is slightly less than 62 acres, so that even half of a cell, 31 acres, would come close enough to meeting the criteria for which it was coded. It is acknowledged that a small minority of cells coded as meeting the 40-acre criteria could contain as few as 31 acres, yet have a marginal difference on overall effectiveness.

Table 1. Data sources.

Theme	Source
2010 Census Tracts	U.S. Census Bureau (2010)
Airport Surveillance Radar Sites	Natural Resources Defense Council (NRDC), National Oceanic and Atmospheric Association (NOAA), and Federal Aviation Administration (FAA) (Argonne 2012)
Airports	Environmental Systems Research Institute (ESRI) (ESRI 2010a)
County Boundaries	National Transportation Atlas Database (NTAD), (RITA BTS 2011)
Designated Critical Habitat	U.S. Fish and Wildlife Service (FWS) (FWS 2010)
Digital Elevation Model, 500 Meter	U.S. Geological Survey (USGS) (Walkes 2011)
Direct Normal Solar Resource Potential	National Renewable Energy Laboratory (NREL) (NREL 2012)
Enhanced Geothermal System Potential	NREL (NREL 2009)
Experimental Forests	USFS (Arthaud 2012)
Federal Land Ownership	Bureau of Land Management (BLM) (Reitsma 2010)
Floodplains	Federal Emergency Management Agency (FEMA) (FEMA 2011)
FWS National Trails	U.S. Department of Transportation, Federal Highway Administration (FWS 2009)
Grand Portage National Monument	National Atlas of the United States (USGS 2001)
Inventoried Roadless Areas	USFS (USFS 2012)
Logging and Forest Thinning Residue Biomass	Bioenergy Knowledge Discovery Framework (DOE and ORNL 2011,b)
National Conservation Areas	BLM (BLM 2010)
National Historic and Scenic Trails	Argonne (Argonne 2011b)
National Monuments	Argonne (Argonne 2009)
Next Generation Weather Radar Systems (NEXRAD)	NRDC and NOAA (Argonne 2012b)
NLCD 2006 Land Cover	USGS (Fry et al. 2011)
Railroads	Federal Railroad Administration (RITA BTS 2011c)
Roads	National Highway Planning Network (RITA BTS 2011b)
Special Designated Areas	USFS (USFS 2012)
State Boundaries	ESRI (ESRI 2010b)
Stationary Panel Solar Resource Potential	NREL (NREL 2012b)
Stream Centerlines	National Atlas of the United States (ESRI 2010c)
Stream Flow and Velocity	Horizon Systems Corporation (EPA and USGS 2012)
Terminal Doppler Weather Radar System (TDWR)	NRDC and NOAA (Argonne 2012e)
Tethered Aerostat Radar System (TARS)	NRDC, Department of Defense (DOD), and US Air Force (USAF) (Argonne 2012d)
Topeka Shiner Critical Habitat	FWS (Argonne 2011)
Transmission Lines	Bentek (Bentek 2012)

Theme	Source
Water Bodies	National Atlas of the United States (ESRI 2010d)
Wetlands	National Wetland Inventory (FWS 2011)
Wild and Scenic Rivers	National Wild and Scenic Rivers System (USFS 2009a)
Wilderness Areas	Wilderness Institute (Wilderness Institute 2012)
Wilderness Study Areas	Argonne (Argonne 2008)
Wind Power Class at 50-, 80-, and 100-m above ground	AWS Truepower (AWS Truepower 2012,b,c)

Figure 1 depicts the federal lands managed by the U.S. Forest Service in the contiguous states. Figure 2 depicts the same information for Alaska. Figures of all other input layers without use constraints are provided in Appendix B. Except for the proprietary wind resource data used in the study, all of the input screening layers for the analysis and the result layers are provided in the database and ArcReader projects accompanying this report.

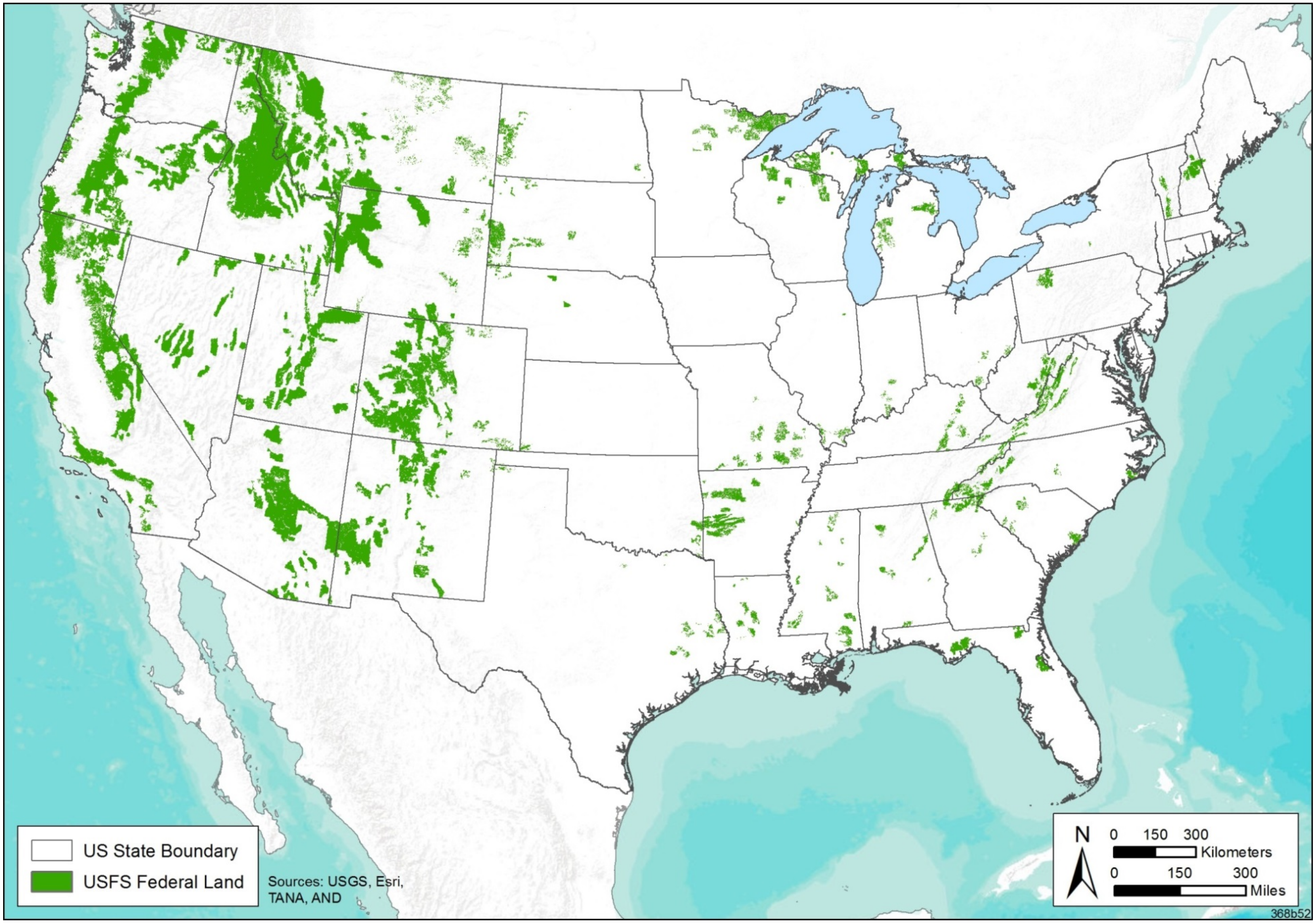


Figure 1. Federal land managed by the USFS in the contiguous states.

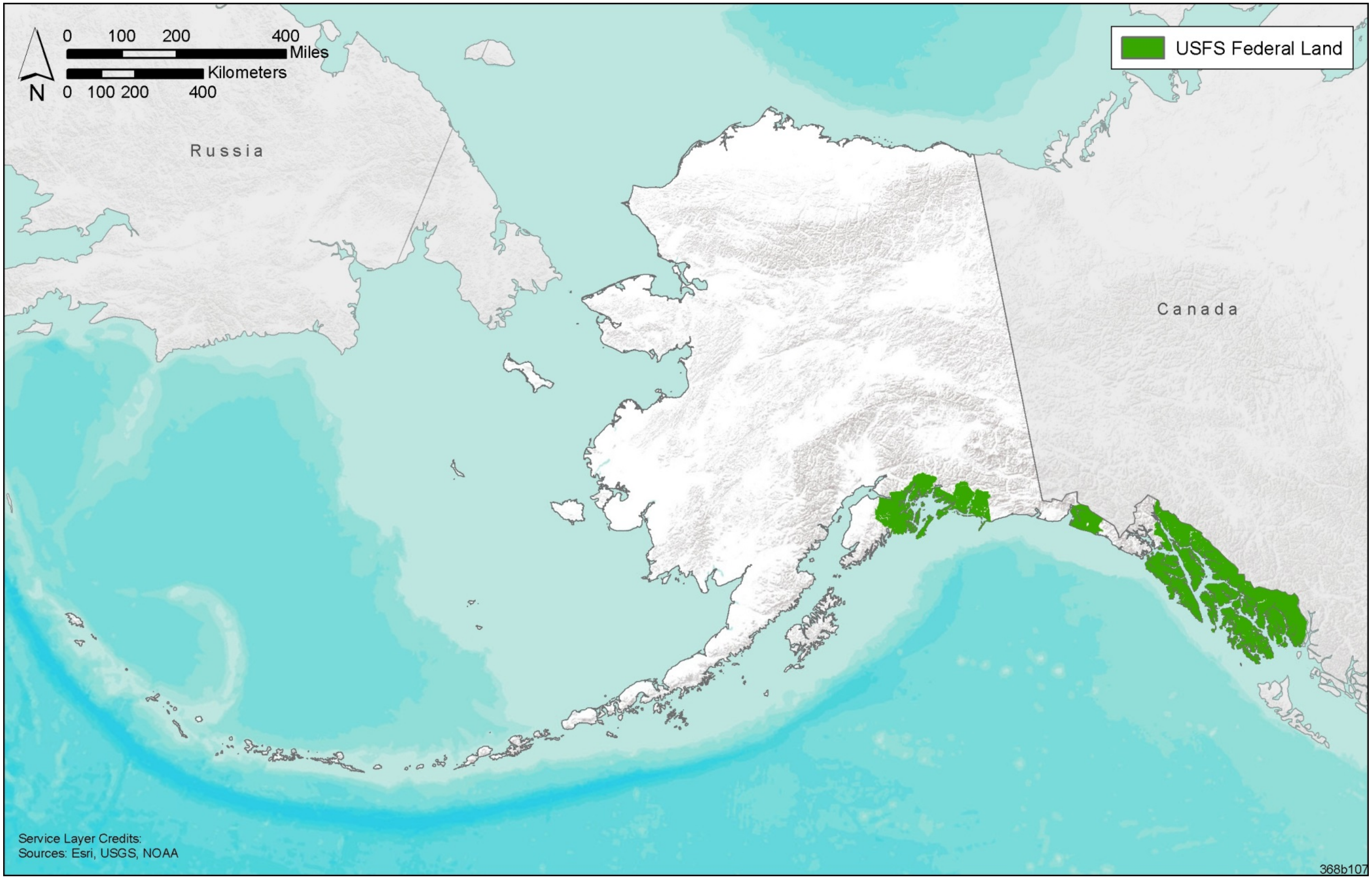


Figure 2. Federal land managed by the USFS in Alaska.

4 Results and Discussion

4.1 Concentrating Solar Power

The results presented in Tables 2 and 3 and in Figures 3 and 4 represent the NFS lands that are potentially suitable for CSP development. The results include the Phase 2 screening factors, assuming a solar resource with a minimum insolation of 7 kWh/m^2/day. Table 2 lists the 10 NFS units with the largest amount of potentially suitable land for CSP, ordered by acreage. Table 3 alphabetically lists all NFS units where land was found to be potentially suitable for CSP development. Except for California's Inyo National Forest, all National Forests in Table 2 are located in Arizona or New Mexico. This finding is highlighted in the inset of Figure 3, where potentially suitable land is most noticeable in those states.

In total, about 136,032 acres of NFS lands were found potentially suitable for CSP development, potentially yielding as much as 13,603 MW of electricity, assuming 10 acres per MW. Of that area, 34,471 acres (3,447 MW) are located within Coconino National Forest in Arizona, which has the most potentially suitable land for CSP development out of the 24 USFS units where suitable land was found. Figure 4 displays the locations of potentially suitable land for CSP development within Coconino National Forest.

The assumption of 10 acres per MW used for both CSP and PV sections in this report is based on *Land-Use Requirements for Solar Power Plants in the United States* (NREL 2013). Total land area was found to range from 4.7 to 13 acres per MW across a variety of power plant types. Linear Fresnel technology had the lowest land requirement of 4.7, but only one plant in the United States utilized this technology.

The 1% criterion for topographic slope was used for consistency with the 2005 NREL study, but CSP plants have been sited in areas with greater slopes. If steeper slopes were included, the area found to meet the suitability measures would be increased.

Table 2. Top 10 NFS units with the most potentially suitable land for CSP development, listed by acreage.

Forest	State	Acres	MW[a]
Coconino National Forest	Arizona	34,471	3,447
Cibola National Forest	New Mexico	23,166	2,317
Kaibab National Forest	Arizona	19,830	1,983
Apache-Sitgreaves National Forests	Arizona	14,950	1,495
Carson National Forest	New Mexico	9,637	964
Tonto National Forest	Arizona	8,896	890
Prescott National Forest	Arizona	5,622	562
Santa Fe National Forest	New Mexico	5,498	550
Inyo National Forest	California	4,695	470
Gila National Forest	New Mexico	2,718	272

[a] Assuming 10 acres per MW.

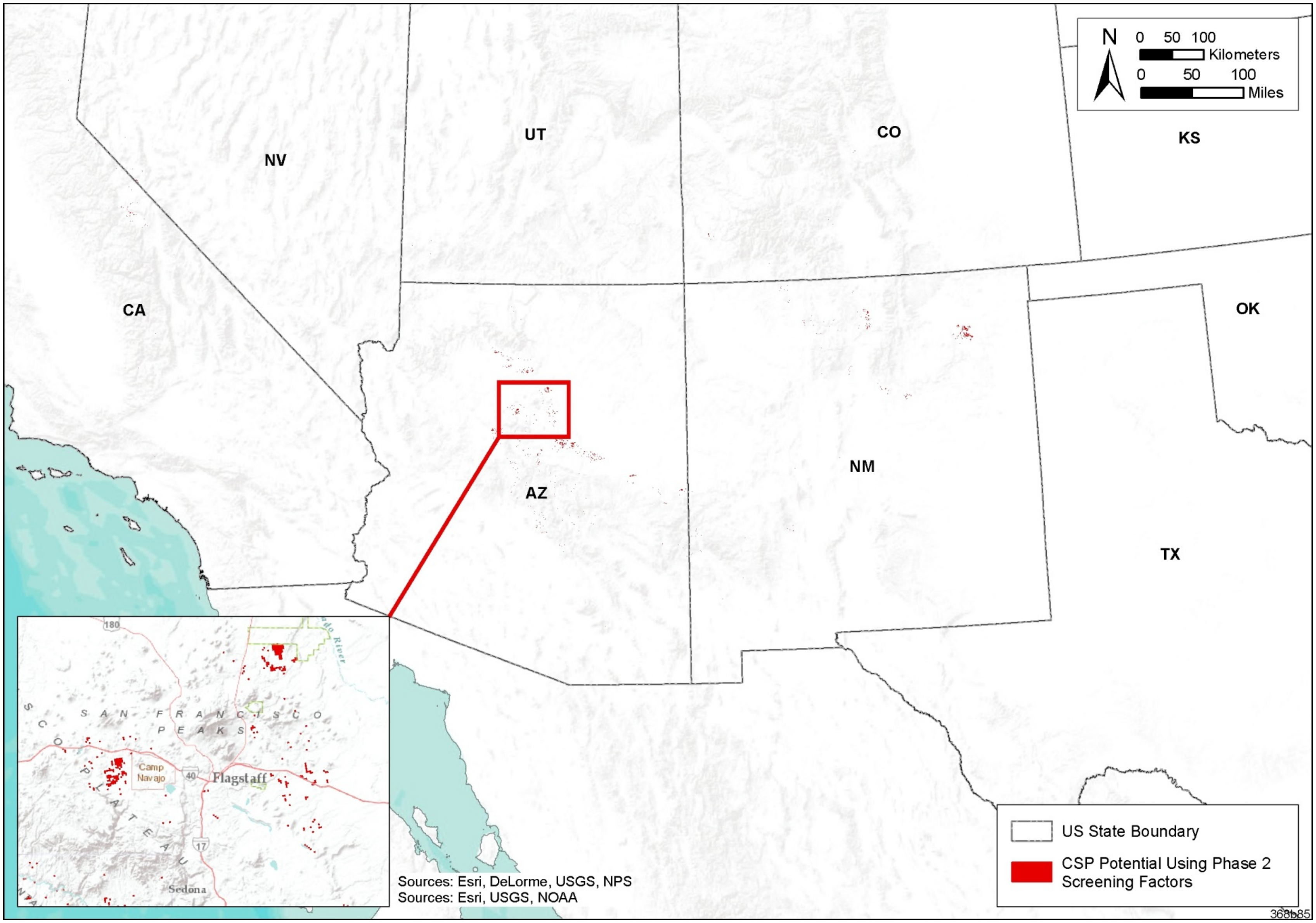


Figure 3. USFS land that is potentially suitable for CSP energy development, using Phase 2 screening factors.

Table 3. USFS units with largest total land area for concentrating solar power, listed alphabetically.

Forest	State	Acres	MW[a]
Angeles National Forest	California	185	19
Apache-Sitgreaves National Forests	Arizona	14,950	1,495
Carson National Forest	New Mexico	9,637	964
Cibola National Forest	New Mexico	23,166	2,317
Cleveland National Forest	California	62	6
Coconino National Forest	Arizona	34,471	3,447
Coronado National Forest	Arizona	124	12
Dixie National Forest	Utah	247	25
Fishlake National Forest	Utah	124	12
Gila National Forest	New Mexico	2,718	272
Humboldt-Toiyabe National Forest	California	185	19
	Nevada	2,100	210
Inyo National Forest	California	4,695	470
Kaibab National Forest	Arizona	19,830	1,983
Lake Tahoe Basin Management Unit	California	62	6
Los Padres National Forest	California	62	6
Pike and San Isabel National Forests	Colorado	309	31
Prescott National Forest	Arizona	5,622	562
Rio Grande National Forest	Colorado	556	56
San Juan National Forest	Colorado	1,853	185
Santa Fe National Forest	New Mexico	5,498	550
Sequoia National Forest	California	247	25
Sierra National Forest	California	185	19
Tahoe National Forest	California	247	25
Tonto National Forest	Arizona	8,896	890
Total		**136,032**	**13,603**

[a] Assuming 10 acres per MW.

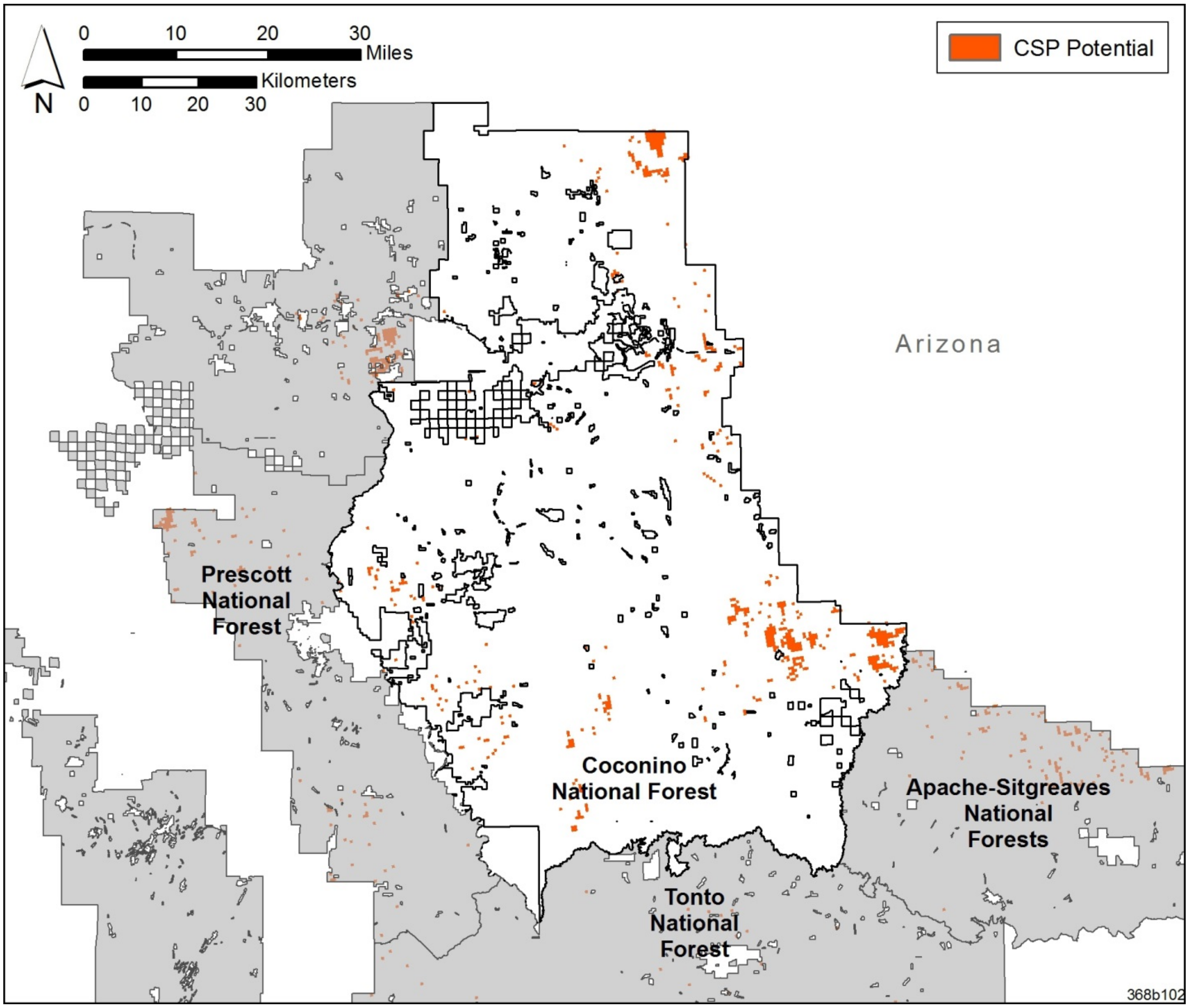


Figure 4. Potentially suitable land for CSP development in Coconino National Forest, Arizona.

Photovoltaic Power

The results shown in Tables 4 and 5 and in Figures 5 and 6 represent the NFS lands that are potentially suitable for PV solar development. The results include the Phase 2 screening factors, assuming a solar resource with a minimum insolation threshold of 5.8 $kWh/m^2/day$. Table 4 lists the 10 NFS units with the largest amount of potentially suitable land for PV, ordered by acreage. Table 5 alphabetically lists all the NFS units where land potentially suitable for PV development was found. The majority of these NFS units were located in desert areas of the Southwest, an area where rapid development of solar energy power plants is already occurring. These areas are shown in Figure 6.

In total, about 564,698 acres of NFS lands were found potentially suitable for PV development, potentially yielding as much as 56,469 MW of electricity, assuming 10 acres per MW. Of that area, 150,920 acres (15,092 MW) are located within Comanche National Grassland in Colorado, which has the most potentially suitable land for PV development out of the 37 USFS units where suitable land was found. Figure 5 displays the locations of potentially suitable land for PV development within Comanche National Grassland.

The 1% criterion for topographic slope was used for consistency with the 2005 NREL study, but PV plants have been sited in areas with greater slopes. If steeper slopes were included, the area found to meet the suitability measures would be increased.

Table 4. Top 10 NFS units with the most potentially suitable land for PV development, listed by acreage.

Forest	State	Acres	MW[a]
Comanche National Grassland	Colorado	150,920	15,092
Cibola National Forest	New Mexico	71,166	7,116
Cimarron National Grassland	Kansas	65,298	6,529
Rita Blanca National Grassland	Oklahoma and Texas	53,807	5,380
Coconino National Forest	Arizona	52,819	5,281
Apache-Sitgreaves National Forests	Arizona	38,363	3,836
Kaibab National Forest	Arizona	37,004	3,700
Gila National Forest	New Mexico	12,355	1,235
Carson National Forest	New Mexico	12,108	1,210
Tonto National Forest	Arizona	8,896	889

[a] Assuming 10 acres per MW.

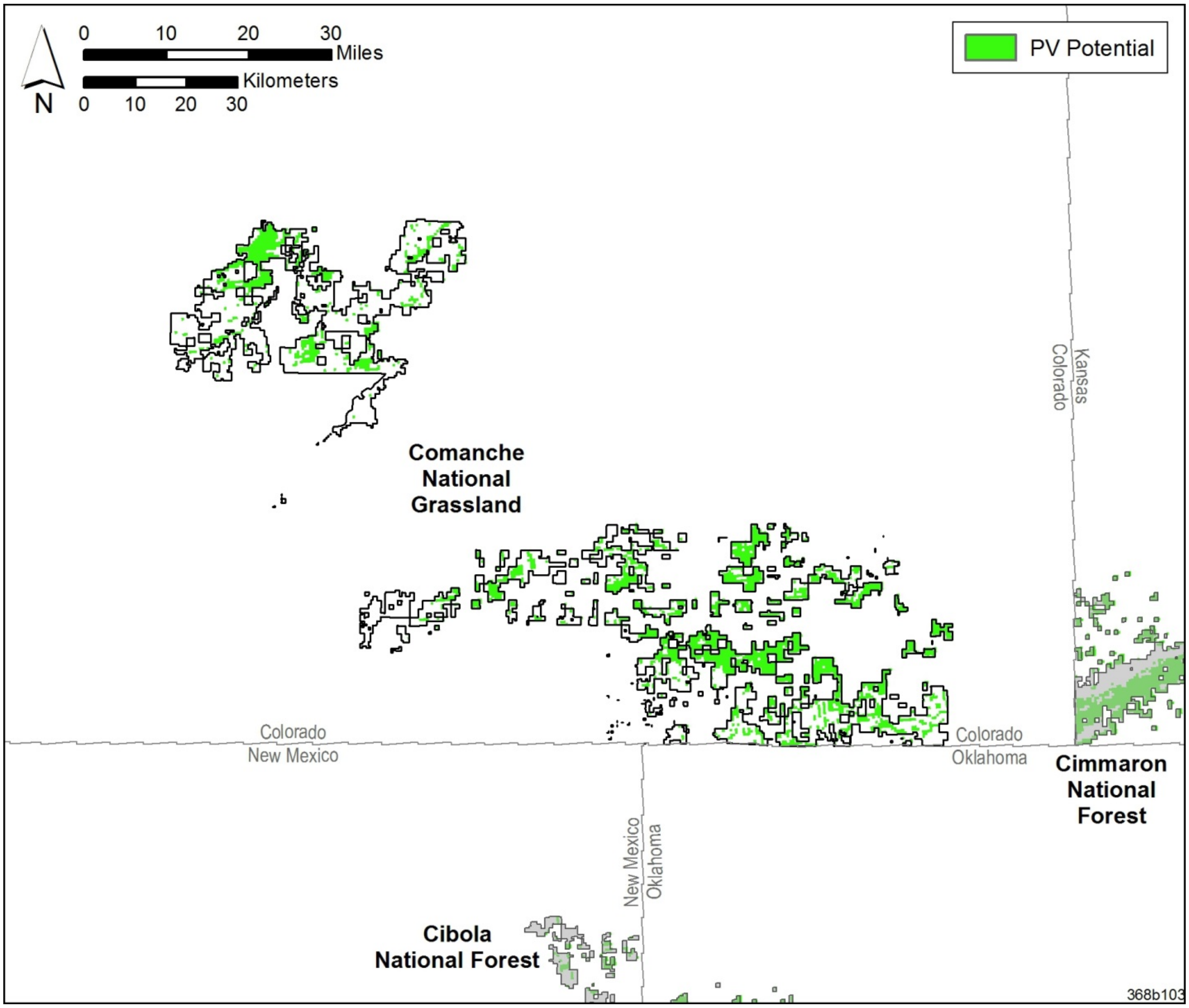


Figure 5. Location of land potentially suitable for PV solar development in Comanche National Grassland, Colorado.

Table 5. USFS units with the largest total land area for PV power, listed alphabetically.

Forest	State	Acres	MW[a]
Angeles National Forest	California	927	92
Apache-Sitgreaves National Forests	Arizona	38,363	3,836
Carson National Forest	New Mexico	12,108	1,210
Cibola National Forest	New Mexico	71,166	7,116
Cimarron National Grassland	Kansas	65,298	6,529
Cleveland National Forest	California	741	74
Coconino National Forest	Arizona	52,819	5,281
Comanche National Grassland	Colorado	150,920	15,092
Coronado National Forest	Arizona	3,830	383
Dixie National Forest	Utah	4,695	469
Eldorado National Forest	California	309	30
Fishlake National Forest	Utah	432	43
Gila National Forest	New Mexico	12,355	1,235
Grand Mesa, Uncompahgre and Gunnison National Forests	Colorado	432	43
Humboldt-Toiyabe National Forest	California	309	30
	Nevada	6,487	648
Inyo National Forest	California	4,757	475
	Nevada	309	30
Kaibab National Forest	Arizona	37,004	3700
Lake Tahoe Basin Management Unit	California	62	6
Lassen National Forest	California	7,475	747
Lincoln National Forest	New Mexico	3,830	383
Los Padres National Forest	California	432	43
McClellan Creek National Grassland	Texas	62	6
Mendocino National Forest	California	309	30
Modoc National Forest	California	494	49
Pike and San Isabel National Forests	Colorado	927	92
Plumas National Forest	California	3,521	352
Prescott National Forest	Arizona	7,537	753
Rio Grande National Forest	Colorado	680	68
Rita Blanca National Grassland	Oklahoma	1,606	160
	Texas	52,201	5,220
San Bernardino National Forest	California	247	24
San Juan National Forest	Colorado	3,459	345
Santa Fe National Forest	New Mexico	7,598	759
Sequoia National Forest	California	309	30
Sierra National Forest	California	309	30
Stanislaus National Forest	California	494	49
Tahoe National Forest	California	988	98
Tonto National Forest	Arizona	8,896	889
Total		**564,698**	**56,469**

[a] Assuming 10 acres per MW.

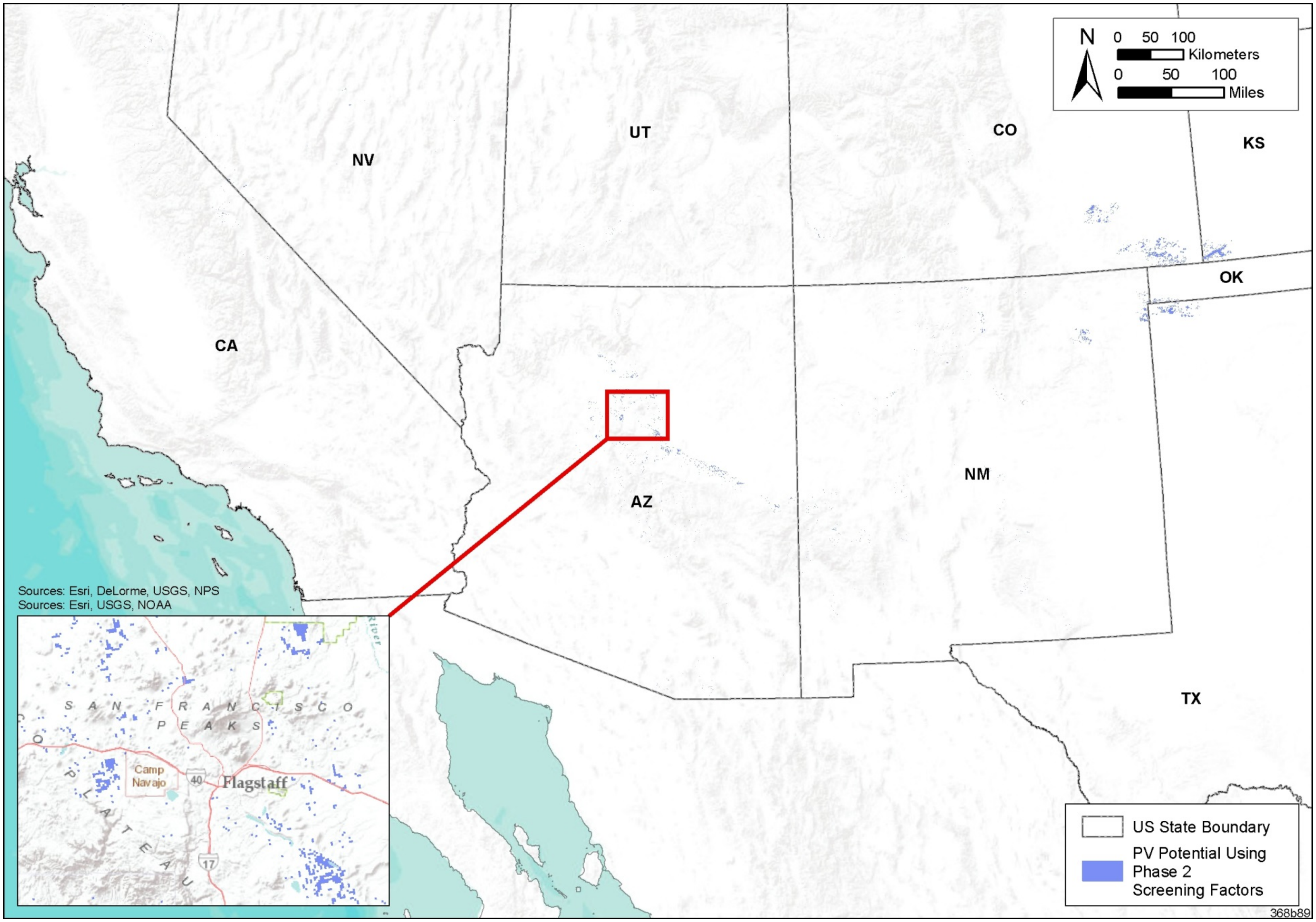


Figure 6. USFS land that is potentially suitable for PV energy development, based on Phase 2 screening factors.

4.2 Wind Power

The results displayed in Tables 6 and 7 and in Figures 7, 8, and 9 represent NFS lands that are potentially suitable for wind energy development. The results include Phase 2 screening factors, such as wind resource at a 100-m hub height and at radar sites, and a wind power class of 4 as the minimum resource threshold. The results presented in this section are based on wind resource calculated for 100-m hub height turbines, as most current wind turbine installations fall into that height range. This assumption also allows for the maximum amount of suitable land among the 50-, 80-, and 100-m hub height data, as wind power increases with heights in this range. Results of the 80-m hub height analysis are included in the accompanying GIS database and ArcReader project.

Table 6 lists the 10 NFS units with the largest amount of potentially suitable land for wind power, ordered by acreage. These units are generally located in the northern Great Plains region of the United States, consistent with the greater wind resources in that region. (This finding is reflected in Figure 9, where potentially suitable land is most noticeable in that region.) Table 7 alphabetically lists all NFS units where land suitable for wind energy development was found.

In total, about 3,357,792 acres of NFS lands were found potentially suitable for wind development, potentially yielding as much as 67,156 MW of electricity, assuming 50 acres per MW. Of that area, 571,431 acres (11,429 MW) are located within the Bankhead-Jones Farm Tenant Act Land in Montana, which has the most potentially suitable land for wind energy development of the 92 USFS units where suitable land was found. Figure 7 displays the locations of potentially suitable land for wind energy development within the Bankhead-Jones Farm Tenant Act Land.

An area of 2,357,633 acres of NFS land in Alaska has a wind power class of 4 or greater at a 100-m hub height. When the slope, proximity to transmission lines, and proximity to roads siting factors are introduced, the area drops to 188,789 acres of potentially suitable land. A full screening, including the same type of exclusionary factors used in the contiguous analysis, yields only 4,015 acres (80 MW) in Alaska that are potentially suitable for development. Most of this land resides along the southwest coast of Chugach National Forest, near Seward, Alaska (Figure 8). Protected areas and sensitive lands were the main prohibiting factors: most of the land excluded was due to Inventoried Roadless Areas, Special Designated Areas, and wilderness areas. The introduction of new electrical transmission infrastructure and roads could increase the amount of potentially suitable land for wind power in Alaska.

Table 6. Top 10 NFS units with the most potentially suitable land for wind development, listed by acreage.

Forest	State	Acres	MW[a]
Bankhead-Jones Farm Tenant Act Land	Montana	571,431	11,429
Dakota Prairie National Grasslands	North Dakota	538,319	10,766
Buffalo Gap National Grassland	South Dakota	339,090	6,782
Thunder Basin National Grassland	Wyoming	304,125	6,083
Comanche National Grassland	Colorado	223,198	4,464
Custer National Forest	Montana and South Dakota	139,243	2,785
Samuel R. McKelvie National Forest	Nebraska	108,726	2,175
Fort Pierre National Grassland	South Dakota	89,637	1,793
Medicine Bow-Routt National Forest	Colorado and Wyoming	87105	1,742
Grand River National Grasslands	South Dakota	83,831	1,677

[a] Assuming 50 acres per MW.

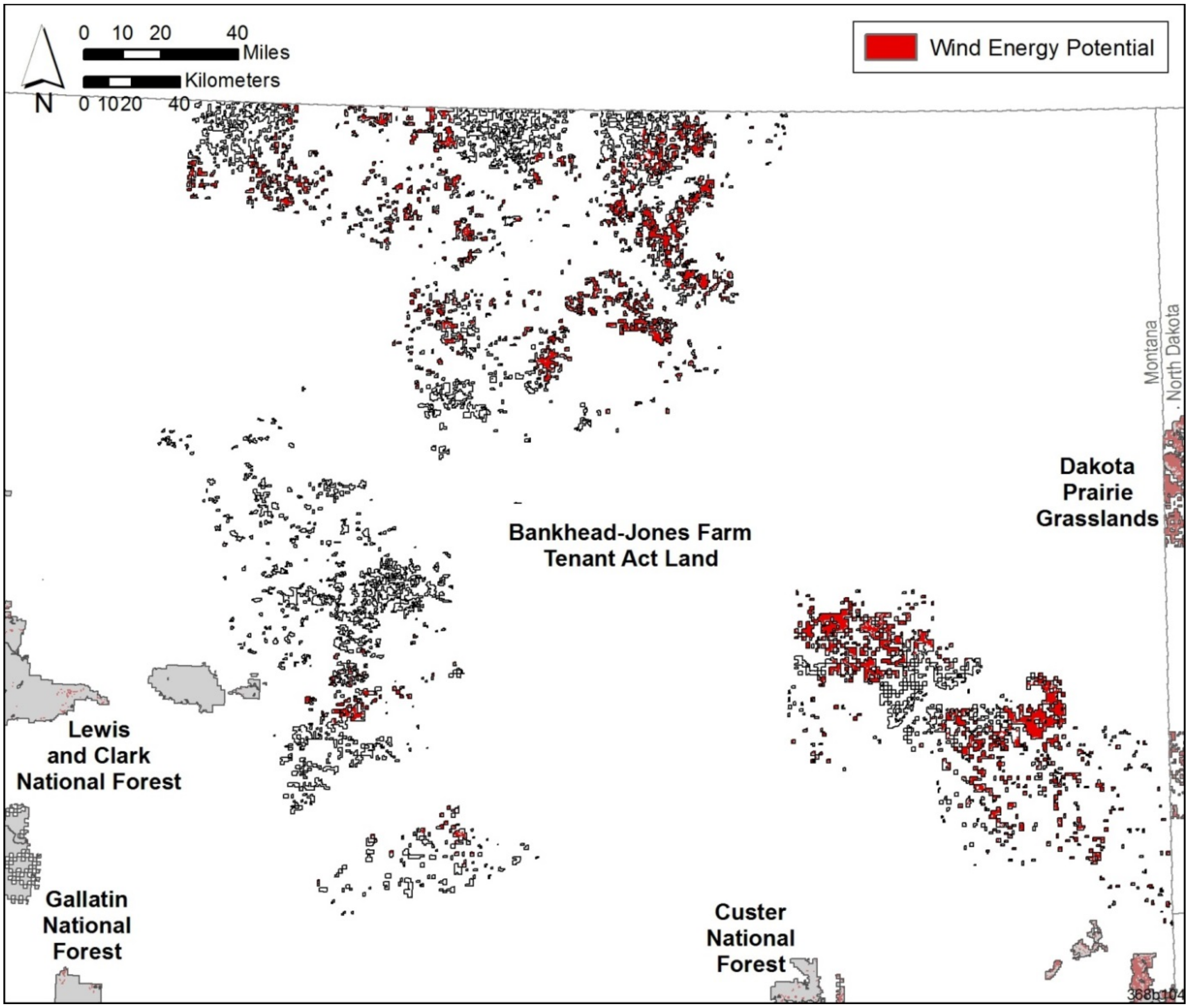


Figure 7. Location of land potentially suitable for wind energy development within Bankhead-Jones Farm Tenant Act Land.

Table 7. USFS units with the largest total land area for wind power, listed alphabetically.

Forest	State	Acres	MW[a]
Angeles National Forest	California	33,421	668
Apache-Sitgreaves National Forests	Arizona	865	17
Arapaho and Roosevelt National Forests	Colorado	40,155	803
Ashley National Forest	Utah	865	17
Bankhead-Jones Farm Tenant Act Land	Montana	571,431	11,429
Beaverhead-Deerlodge National Forest	Montana	20,077	402
Bighorn National Forest	Wyoming	22,487	450
Bitterroot National Forest	Montana	309	6
Black Hills National Forest	South Dakota	22,989	460
	Wyoming	5,189	104
Boise National Forest	Idaho	618	12
Bridger-Teton National Forest	Wyoming	247	5

Forest	State	Acres	MW[a]
Buffalo Gap National Grassland	South Dakota	339,090	6,782
Caddo-Lyndon B. Johnson National Grasslands	Texas	1,112	22
Caribou-Targhee National Forest	Idaho	4,880	98
	Wyoming	309	6
Carson National Forest	New Mexico	11,552	231
Chugach National Forest	Alaska	4,015	80
Cibola National Forest	New Mexico	78,888	1,578
Cimarron National Grassland	Kansas	75,800	1,516
Cleveland National Forest	California	62	1
Coconino National Forest	Arizona	1,730	35
Colville National Forest	Washington	124	2
Comanche National Grassland	Colorado	223,198	4,464
Coronado National Forest	Arizona	247	5
Custer National Forest	Montana	92,108	1,842
	South Dakota	47,135	943
Dakota Prairie National Grasslands	North Dakota	538,319	10,766
Deschutes National Forest	Oregon	3,398	68
Dixie National Forest	Utah	124	2
Eldorado National Forest	California	124	2
Fishlake National Forest	Utah	247	5
Flathead National Forest	Montana	62	1
Fort Pierre National Grassland	South Dakota	89,637	1,793
Fremont-Winema National Forest	Oregon	5,992	120
Gallatin National Forest	Montana	3,768	75
George Washington and Jefferson National Forests	West Virginia	62	1
Gifford Pinchot National Forest	Washington	2,842	57
Gila National Forest	New Mexico	2,842	57
Grand Mesa, Uncompahgre and Gunnison National Forests	Colorado	2,039	41
Grand River National Grasslands	South Dakota	83,831	1,677
Green Mountain and Finger Lakes National Forests	Vermont	618	12
Helena National Forest	Montana	3,954	79
Humboldt-Toiyabe National Forest	California	1,483	30
	Nevada	2,595	52
Huron-Manistee National Forest	Michigan	62	1
Idaho Panhandle National Forests	Idaho	2,286	46
Inyo National Forest	California	124	2
Kaibab National Forest	Arizona	3,583	72
Klamath National Forest	California	62	1
	Oregon	185	4
Kootenai National Forest	Idaho	62	1
	Montana	247	5
Lake Tahoe Basin Management Unit	California	309	6
	Nevada	309	6
Lassen National Forest	California	432	9
Lewis and Clark National Forest	Montana	23,351	467

Forest	State	Acres	MW[a]
Lincoln National Forest	New Mexico	67,151	1,343
Lolo National Forest	Montana	3,398	68
Los Padres National Forest	California	2,100	42
McClellan Creek National Grassland	Texas	494	10
Medicine Bow-Routt National Forest	Colorado	1,483	30
	Wyoming	85,622	1,712
Midewin National Tallgrass Prairie	Illinois	3,336	67
Modoc National Forest	California	680	14
Mt. Baker-Snoqualmie National Forest	Washington	680	14
Mt. Hood National Forest	Oregon	10,008	200
Nantahala National Forest	North Carolina	185	4
Nebraska National Forest	Nebraska	82,286	1,646
Nez Perce-Clearwater National Forests	Idaho	124	2
Ochoco National Forest	Oregon	1,174	23
Oglala National Forest	Nebraska	75,182	1,504
Okanogan-Wenatchee National Forest	Washington	6,487	130
Olympic National Forest	Washington	432	9
Ouachita National Forest	Arkansas	309	6
Ozark-St. Francis National Forests	Arkansas	62	1
Pawnee National Grassland	Colorado	34,533	691
Payette National Forest	Idaho	1,421	28
Pike and San Isabel National Forests	Colorado	14,765	295
Plumas National Forest	California	1,668	33
Rio Grande National Forest	Colorado	8,278	166
Rita Blanca National Grassland	Oklahoma	1,421	28
	Texas	58,873	1,177
Rogue River-Siskiyou National Forest	Oregon	4,695	94
Salmon-Challis National Forest	Idaho	3,336	67
Samuel R. McKelvie National Forest	Nebraska	108,726	2,175
San Bernardino National Forest	California	6,178	124
Santa Fe National Forest	New Mexico	25,081	502
Sawtooth National Forest	Idaho	26,378	528
	Utah	124	2
Sequoia National Forest	California	618	12
Shoshone National Forest	Wyoming	31,259	625
Siuslaw National Forest	Oregon	741	15
Tahoe National Forest	California	680	14
Thunder Basin National Grassland	Wyoming	304,125	6,083
Tonto National Forest	Arizona	741	15
Uinta-Wasatch-Cache National Forest	Utah	1,050	21
Umatilla National Forest	Oregon	5,251	105
	Washington	1,915	38
Umpqua National Forest	Oregon	1,112	22
Wallowa-Whitman National Forest	Oregon	1,544	31
White Mountain National Forest	New Hampshire	62	1

Forest	State	Acres	MW[a]
White River National Forest	Colorado	2,533	51
Willamette National Forest	Oregon	1,668	33
Total		**3,357,792**	**67,156**

[a] Assuming 50 acres per MW.

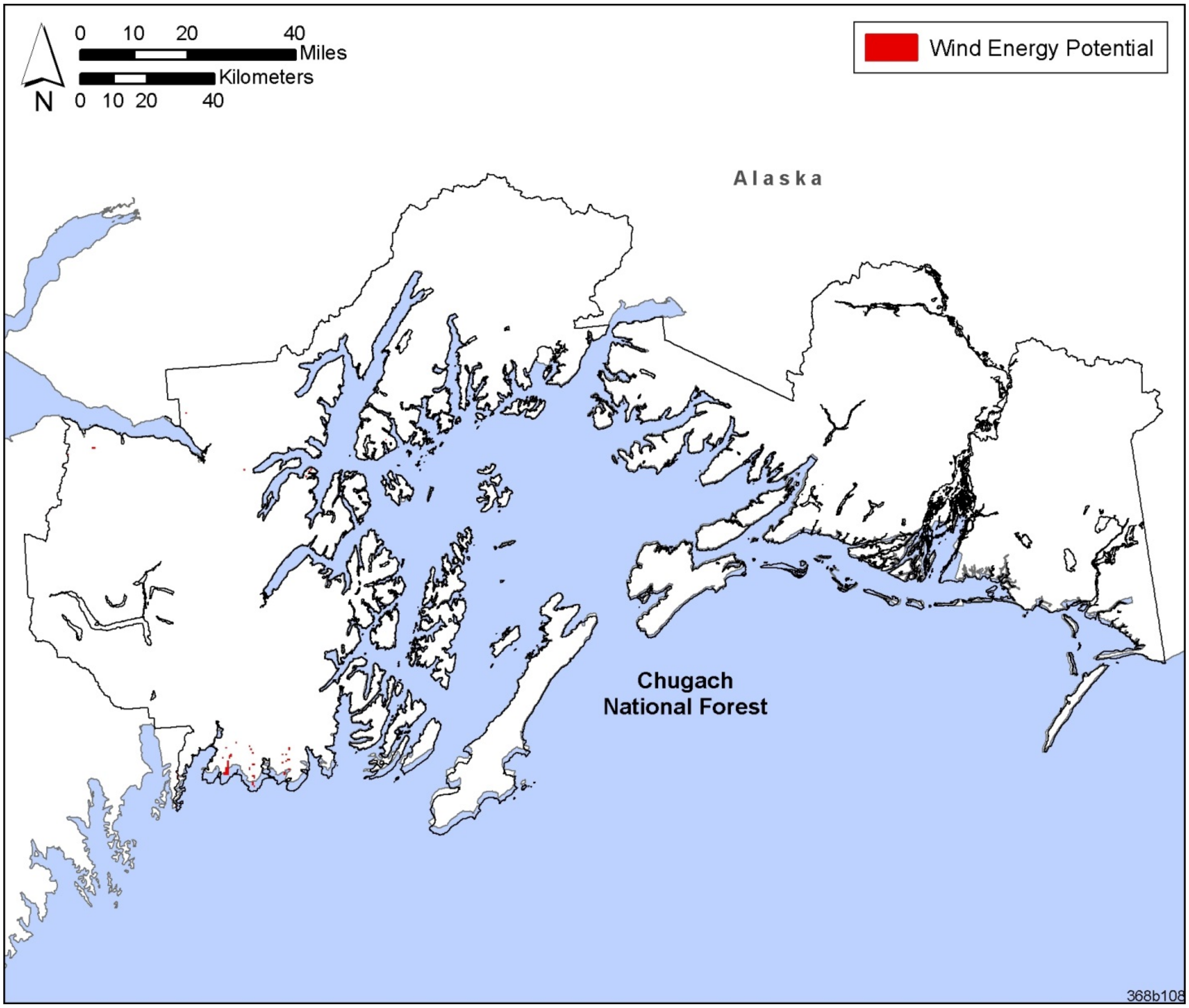


Figure 8. NFS land potentially suitable for wind energy development at a 100-m hub height in Chugach National Forest, Alaska, using Phase 2 screening factors.

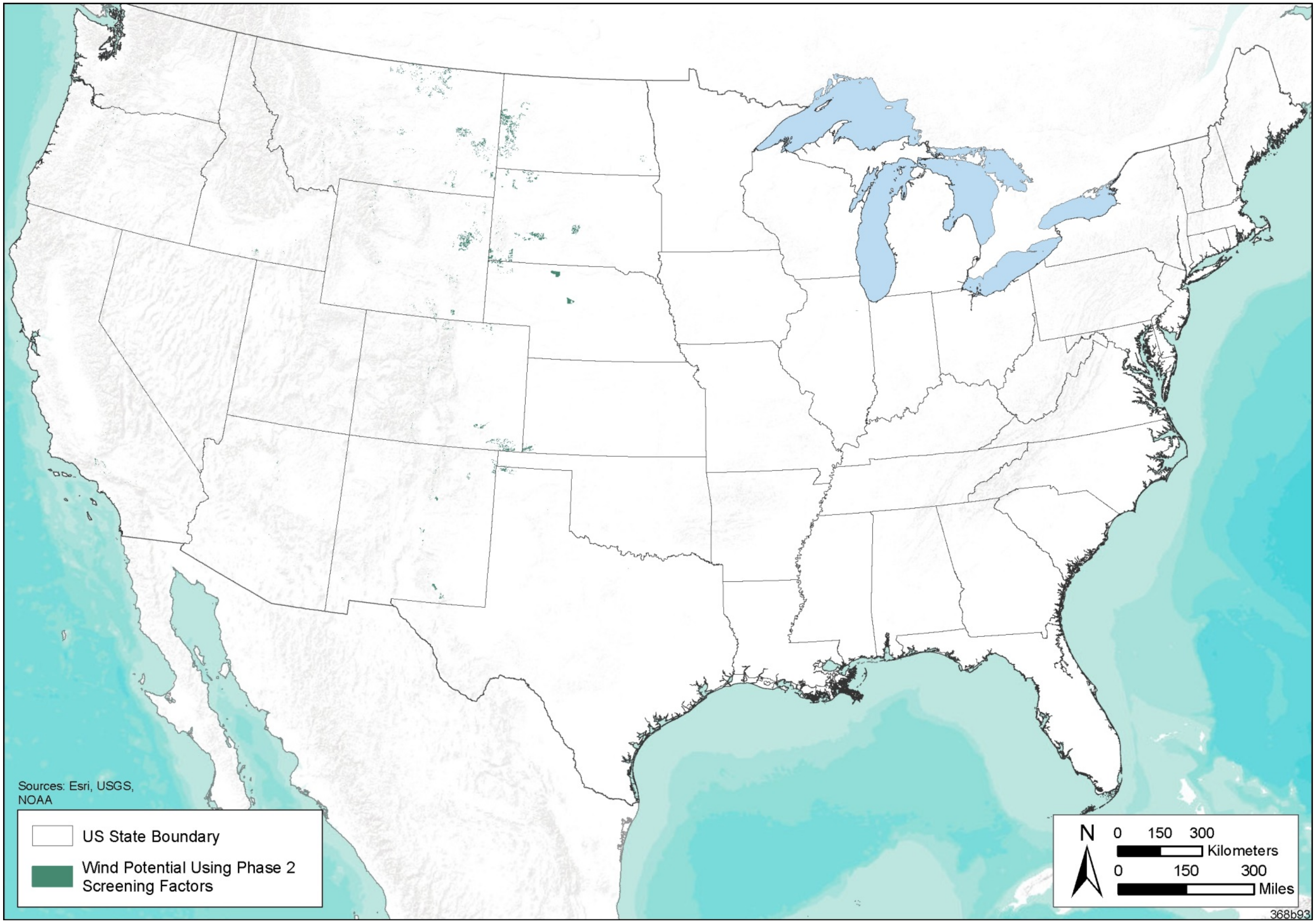


Figure 9. NFS land potentially suitable for wind energy development at a 100-m hub height, using Phase 2 screening factors.

4.3 Biomass

The results presented in Tables 8 and 9 and in Figures 10 and 11 represent the NFS lands that are potentially suitable for biomass development. Table 8 lists the 10 NFS units with the largest amount of potentially highly suitable land for biomass power, ordered by acreage. Table 9 lists all NFS units where suitable land for biomass power was found, each given a rank of potentially low, medium, or high. As Table 8 shows, biomass resources are not concentrated in one region. NFS units with highly suitable biomass resources are located from Idaho to Louisiana. Figure 10 shows Fremont-Winema National Forest, where the highest acreage occurred. Figure 11 displays locations of high, medium, and low potentially suitable land for biomass power across the United States.

Fremont-Winema National Forest has the most potentially highly suitable land for biomass power development out of the 133 NFS units where suitable land was found. In total, about 13,967,077 acres of NFS lands were found to be potentially highly suitable for biomass from logging and thinning residue development. Of that amount, 1,542,247 acres are located in Fremont-Winema National Forest in Oregon (Figure 10). On all NFS lands, 14,449,489 acres were found to have low suitability, and 14,773,320 acres were found to have medium suitability for biomass development.

Table 8. Top 10 NFS units with the most potentially highly suitable land for biomass development, listed by acreage.

Forest	State	High Suitability Acres
Fremont-Winema National Forest	Oregon	1,542,247
Chequamegon-Nicolet National Forest	Wisconsin	737,301
Malheur National Forest	Oregon	610,289
Ouachita National Forest	Arkansas and Oklahoma	539,122
Ottawa National Forest	Michigan	538,257
Lassen National Forest	California	526,026
Idaho Panhandle National Forests	Idaho	469,067
Plumas National Forest	California	436,265
Wallowa-Whitman National Forest	Oregon	426,442
Kisatchie National Forest	Louisiana	394,442

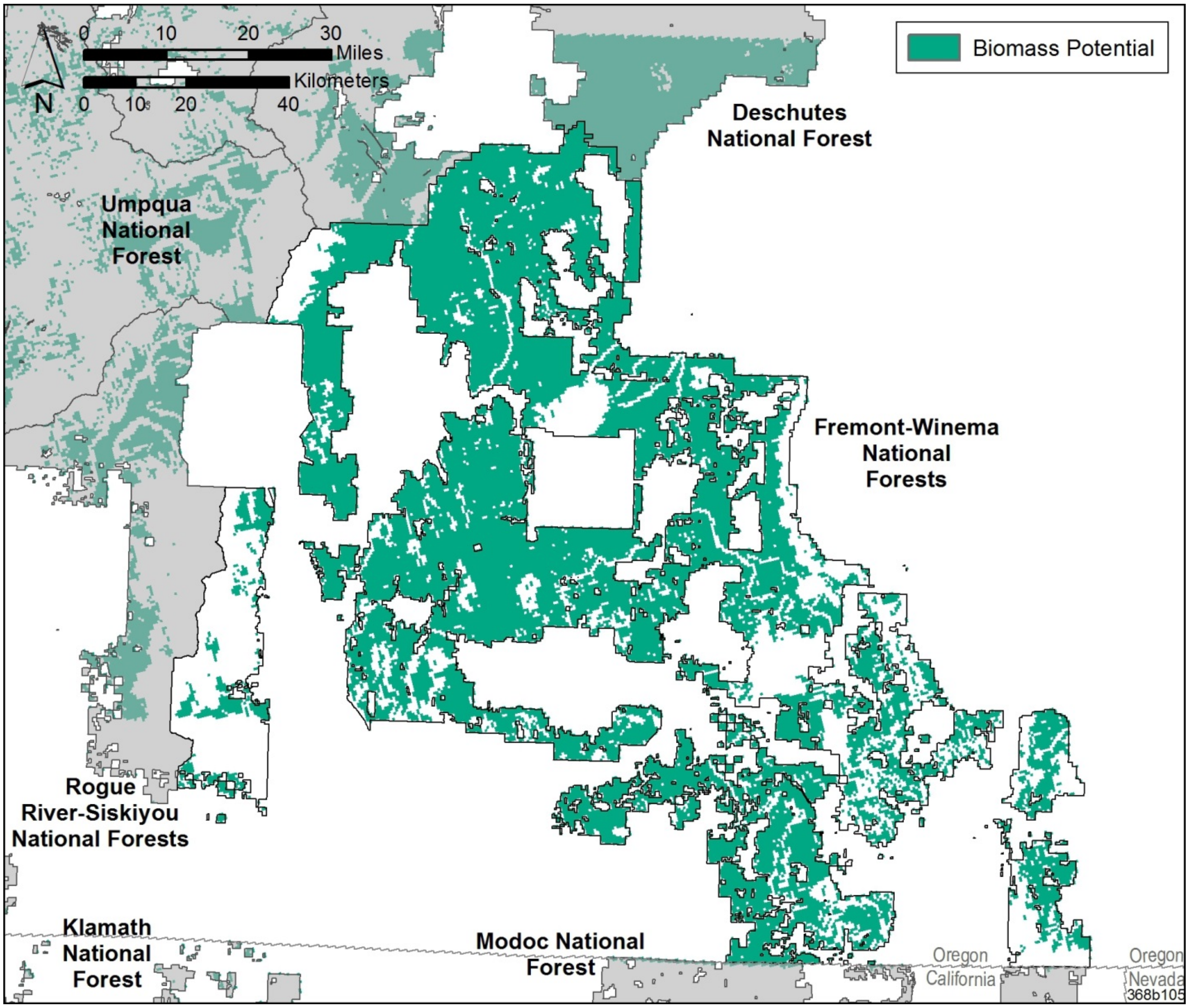


Figure 10. Location of land potentially suitable for biomass energy development within Fremont-Winema National Forest, Oregon.

Table 9. USFS units with largest total land area for biomass, ranked by suitability level.

Forest	State	Low Suitability Acres	Medium Suitability Acres	High Suitability Acres
Allegheny National Forest	Pennsylvania		99,336	288,434
Angeles National Forest	California	126,518		
Angelina National Forest	Texas			85,128
Apache-Sitgreaves National Forests	Arizona	476,481	238,395	
Apalachicola National Forest	Florida		65,915	51,460
Arapaho and Roosevelt National Forests	Colorado	374,859		
Ashley National Forest	Utah	138,132		
Bankhead-Jones Farm Tenant Act Land	Montana	464,188		
Beaverhead-Deerlodge National Forest	Montana	118,981	496,558	
Bienville National Forest	Mississippi		49,854	64,927
Bighorn National Forest	Wyoming	172,418		
Bitterroot National Forest	Montana		116,263	185
Black Hills National Forest	South Dakota	64,000	477,716	323,090
	Wyoming	2,780	133,746	
Boise National Forest	Idaho	115,584	91,800	119,846
Bridger-Teton National Forest	Wyoming	13,529		
Buffalo Gap National Grassland	South Dakota	307,955	25,823	151,537
Caribou-Targhee National Forest	Idaho	719,015	3,830	
	Montana	124		
	Wyoming	37,684		
Carson National Forest	New Mexico	249,144	616,404	
Chattahoochee-Oconee National Forest	Georgia	81,051	347,307	2,471
Chequamegon-Nicolet National Forest	Wisconsin		105,082	737,301
Cherokee National Forest	Tennessee	5,127	248,403	
Chippewa National Forest	Minnesota			162,348
Cibola National Forest	New Mexico	697,702		
Cleveland National Forest	California	6,178		
Coconino National Forest	Arizona	276,820	728,837	
Columbia River Gorge National Scenic Area	Washington			865
Colville National Forest	Washington			245,561

Forest	State	Low Suitability Acres	Medium Suitability Acres	High Suitability Acres
Comanche National Grassland	Colorado	41,205		
Conecuh National Forest	Alabama		247	60,232
Coronado National Forest	Arizona	48,371		
Croatan National Forest	North Carolina	10,749	7,104	11,490
Custer National Forest	Montana	151,476	294,735	
	South Dakota	68,634		
Dakota Prairie National Grasslands	North Dakota	18,286		
Daniel Boone National Forest	Kentucky	43,676	444,481	50,533
Davy Crockett National Forest	Texas			121,082
De Soto National Forest	Mississippi		113,545	213,746
Delta National Forest	Mississippi		247	432
Deschutes National Forest	Oregon		649,949	280,526
Dixie National Forest	Utah	590,520		
Eldorado National Forest	California	1,977	9,514	170,626
Fishlake National Forest	Utah	290,225		
Flathead National Forest	Montana		6,672	51,830
Fort Pierre National Grassland	South Dakota	55,660		
Francis Marion and Sumter National Forests	South Carolina		165,561	164,263
Fremont-Winema National Forest	Oregon			1,542,247
Gallatin National Forest	Montana	17,359	78,147	
George Washington and Jefferson National Forest	Kentucky		618	
	Virginia	49,792	453,130	6,054
	West Virginia		48,000	
Gifford Pinchot National Forest	Washington			170,873
Gila National Forest	New Mexico	853,749		
Grand Mesa, Uncompahgre and Gunnison National Forests	Colorado	751,571		
Green Mountain and Finger Lakes National Forests	Vermont	2,903	87,599	38,487
Helena National Forest	Montana	41,019	84,386	
Hiawatha National Forest	Michigan		348,419	185
Holly Springs National Forest	Mississippi		110,024	32,062

Forest	State	Low Suitability Acres	Medium Suitability Acres	High Suitability Acres
Homochitto National Forest	Mississippi			154,441
Hoosier National Forest	Indiana	927	143,815	
Humboldt-Toiyabe National Forest	California	38,857		14,209
	Nevada	4,819		988
Huron-Manistee National Forest	Michigan	172,294	514,659	
Idaho Panhandle National Forests	Idaho			438,118
	Montana			123
	Washington			30,826
Inyo National Forest	California	176,124	124	62
Kaibab National Forest	Arizona	16,185	662,366	
Kisatchie National Forest	Louisiana			394,442
Klamath National Forest	California			237,962
	Oregon			2,965
Kootenai National Forest	Idaho			1,730
	Montana			210,410
Lake Tahoe Basin Management Unit	California			17,236
Lassen National Forest	California		1,730	526,026
Lewis and Clark National Forest	Montana	83,151	125,406	
Lincoln National Forest	New Mexico	165,375	172,541	
Lolo National Forest	Montana		23,043	226,163
Los Padres National Forest	California	30,888		
Malheur National Forest	Oregon	247	232,650	610,289
Manti-La Sal National Forest	Colorado	7,290		
	Utah	242,472		
Mark Twain National Forest	Missouri	83,398	827,309	266,503
Medicine Bow-Routt National Forest	Colorado	188,603		
	Wyoming	223,074	207,630	
Mendocino National Forest	California	15,073	41,514	24,463
Midewin National Tallgrass Prairie	Illinois	11,985		
Modoc National Forest	California		909,595	186,935
Monongahela National Forest	West Virginia		53,251	295,723

Forest	State	Low Suitability Acres	Medium Suitability Acres	High Suitability Acres
Mt. Baker-Snoqualmie National Forest	Washington			17,792
Mt. Hood National Forest	Oregon		1,359	247,538
Nantahala National Forest	North Carolina	19,336	179,769	865
National Forests in Alabama			371	
Nebraska National Forest	Nebraska	28,911		
Nez Perce-Clearwater National Forests	Idaho		62	362,812
Ocala National Forest	Florida		246,735	
Ochoco National Forest	Oregon	143,939	281,762	741
Oglala National Forest	Nebraska	82,780		
Okanogan-Wenatchee National Forest	Washington		60,170	236,603
Olympic National Forest	Washington			37,436
Osceola National Forest	Florida		45,406	
Ottawa National Forest	Michigan			538,257
Ouachita National Forest	Arkansas	3,954	771,957	345,762
	Oklahoma			193,360
Ozark-St. Francis National Forests	Arkansas	494	641,300	67,830
Payette National Forest	Idaho	34,224	162,719	28,479
Pike and San Isabel National Forests	Colorado	505,701		
Pisgah National Forest	North Carolina		79,877	7,598
Plumas National Forest	California		7,290	436,265
Prescott National Forest	Arizona	507,802	24,834	
Rio Grande National Forest	Colorado	354,658		
Rogue River-Siskiyou National Forest	California			5,004
	Oregon			208,310
Sabine National Forest	Texas		56,216	45,344
Salmon-Challis National Forest	Idaho	201,762	2,780	432
Sam Houston National Forest	Texas		76,850	33,606
Samuel R. McKelvie National Forest	Nebraska	108,726		
San Bernardino National Forest	California	106,935		
San Juan National Forest	Colorado	407,786		
Santa Fe National Forest	New Mexico	398,952	218,318	

Forest	State	Low Suitability Acres	Medium Suitability Acres	High Suitability Acres
Sawtooth National Forest	Idaho	247,908		
Sequoia National Forest	California	29,529	54,054	
Shasta-Trinity National Forest	California			382,149
Shawnee National Forest	Illinois	145,792	24,834	
Shoshone National Forest	Wyoming	76,664		
Sierra National Forest	California		185,947	
Siuslaw National Forest	Oregon			59,305
Six Rivers National Forest	California			54,301
Stanislaus National Forest	California	7,598	40,155	185,453
Superior National Forest	Minnesota			38,610
Tahoe National Forest	California		12,232	247,600
Talladega National Forest	Alabama		213,932	85,251
Thunder Basin National Grassland	Wyoming	431,137	62	
Tombigbee National Forest	Mississippi			32,062
Tonto National Forest	Arizona	885,008	309	
Tuskegee National Forest	Alabama		8,154	
Uinta-Wasatch-Cache National Forest	Utah	301,839		
Umatilla National Forest	Washington	59,614		
	Oregon		305,855	201,267
Umpqua National Forest	Oregon			217,144
Uwharrie National Forest	North Carolina		1,297	34,224
Wallowa-Whitman National Forest	Oregon	432	260,449	426,442
Wayne National Forest	Ohio	127,877	42,996	
White Mountain National Forest	Maine			17,792
	New Hampshire		46,518	106,873
White River National Forest	Colorado	283,924		
Willamette National Forest	Oregon		124	209,792
William B. Bankhead National Forest	Alabama		55,352	67,336
Total		**14,449,489**	**14,773,320**	**13,967,077**

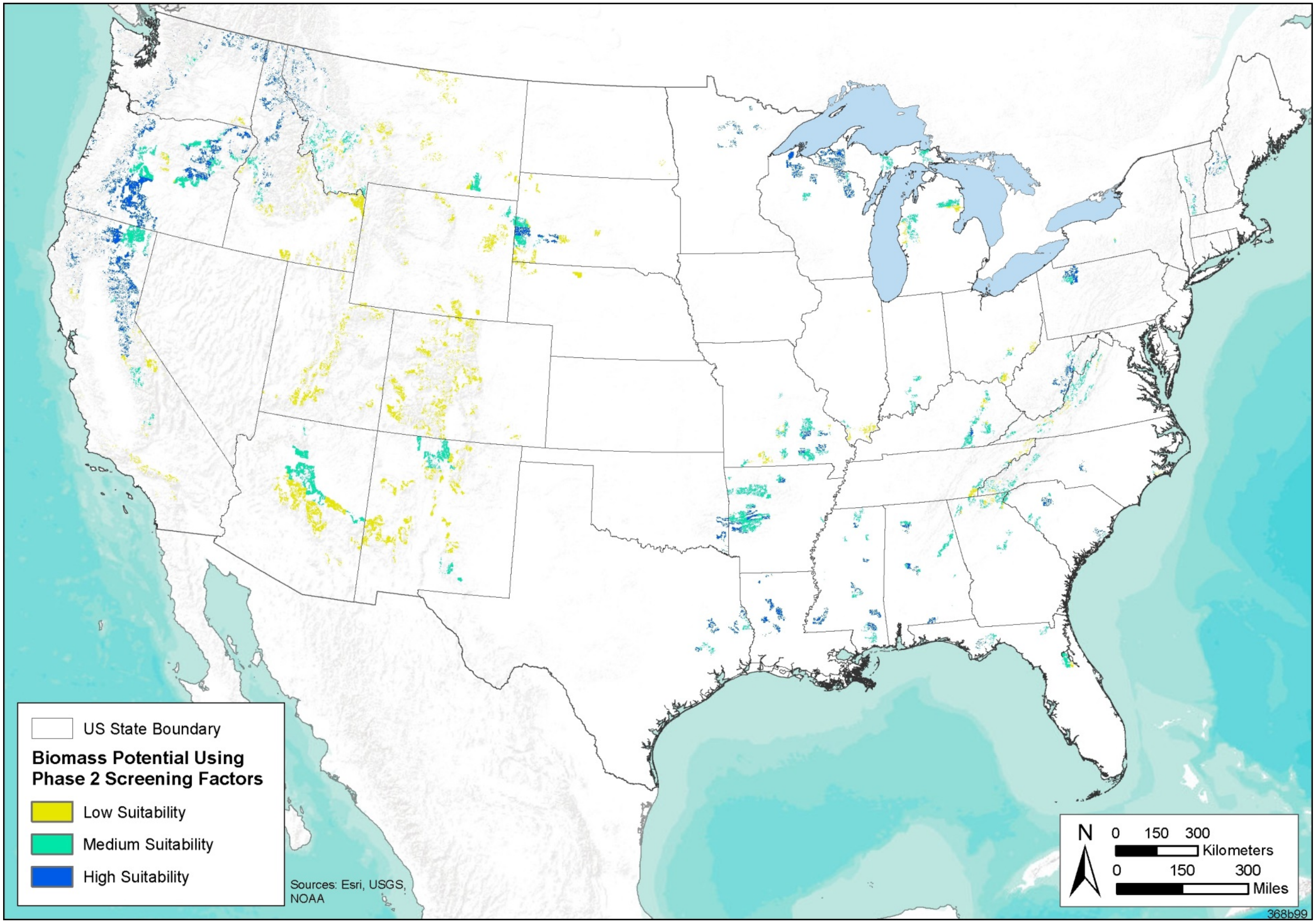


Figure 11. NFS land that is potentially suitable for biomass energy development, based on Phase 2 screening factors.

4.4 Enhanced Geothermal Systems

The results presented in Tables 10 and 11 and in Figures 12 and 13 represent the NFS lands that are potentially suitable for enhanced geothermal system (EGS) development. Table 10 lists the 10 NFS units with the largest amount of potentially highly suitable land for EGS, ordered by acreage. Table 11 lists all NFS units where land of any suitability level for EGS development was found. Figure 12 shows Mark Twain National Forest, where the highest acreage occurred. Figure 13 displays locations of all categories of suitability for EGS development across the United States.

In total, about 6,475,459 acres were found potentially highly suitable for EGS development. Of that area, 900,637 acres are located in Mark Twain National Forest in Missouri (Figure 12), which has the most potentially highly suitable land for EGS out of the 127 USFS units where suitable land was found. For the other levels of potential suitability: 5,063,869 acres have low suitability; 5,712,768 acres have medium-low suitability; 10,808,576 acres have medium suitability; and 3,525,515 acres have medium-high suitability for EGS.

Table 10. Top 10 NFS units with the most potentially highly suitable land for EGS development, listed by acreage.

Forest	State	High Suitability
Mark Twain National Forest	Missouri	900,637
Ouachita National Forest	Arkansas and Oklahoma	888,220
Chequamegon-Nicolet National Forest	Wisconsin	671,818
Daniel Boone National Forest	Kentucky	543,076
Ottawa National Forest	Michigan	488,095
Huron-Manistee National Forest	Michigan	347,924
Chattahoochee-Oconee National Forest	Georgia	256,557
George Washington and Jefferson National Forest	Kentucky, Virginia, and West Virginia	218,565
Shasta-Trinity National Forest	California	147,893
Coconino National Forest	Arizona	146,657

Figure 12. Location of potentially highly suitable land for EGS development within Mark Twain National Forest, Missouri.

Table 11. NFS units with largest total land area for Enhanced Geothermal Systems (EGS), ranked by suitability level and listed alphabetically.

Forest	State	Low Suitability Acres	Medium-Low Suitability Acres	Medium Suitability Acres	Medium-High Suitability Acres	High Suitability Acres
Allegheny National Forest	Pennsylvania			111,074	278,797	
Angeles National Forest	California			1,544		
Angelina National Forest	Texas		4,139	83,398		
Apache-Sitgreaves National Forests	Arizona		66,410	46,209		
Apalachicola National Forest	Florida			28,108	15,382	79,383
Arapaho and Roosevelt National Forests	Colorado	11,182	294,364	80,680		
Ashley National Forest	Utah		1,483	127,939		
	Wyoming			124		
Bankhead-Jones Farm Tenant Act Land	Montana		2,409	681,084	26,873	22,301
Beaverhead-Deerlodge National Forest	Montana		50,286	501,068		
Bienville National Forest	Mississippi			101,746	14,950	
Bighorn National Forest	Wyoming			62	34,965	
Bitterroot National Forest	Montana		10,440	106,008		
Black Hills National Forest	South Dakota			78,456	32,062	11,676
Boise National Forest	Idaho	12,911	176,371	138,688		
Bridger-Teton National Forest	Wyoming	618	680	10,378		
Buffalo Gap National Grassland	South Dakota			204,171	81,730	99,336
Caddo-Lyndon B. Johnson National Grasslands	Texas			10,873	5,313	927
Caribou-Targhee National Forest	Idaho	407,786	196,758	121,452		
	Montana	124				
	Utah		62			
	Wyoming	6,919	7,537	23,228		
Carson National Forest	New Mexico	346,071	326,488			
Chattahoochee-Oconee National Forest	Georgia				16,927	256,557
Chequamegon-Nicolet National Forest	Wisconsin					671,818
Cherokee National Forest	Tennessee					71,846
Cibola National Forest	New Mexico	35,460	35,707	103,599	10,070	
Cleveland National Forest	California		2,965	2,162		
Coconino National Forest	Arizona			220,974	69,869	146,657

Forest	State	Low Suitability Acres	Medium-Low Suitability Acres	Medium Suitability Acres	Medium-High Suitability Acres	High Suitability Acres
Columbia River Gorge National Scenic Area	Oregon				62	
	Washington			865		
Colville National Forest	Washington		11,058	209,792		
Comanche National Grassland	Colorado			78,950		
Conecuh National Forest	Alabama			1,112	44,170	17,544
Coronado National Forest	Arizona		13,900	124		
Croatan National Forest	North Carolina					27,305
Custer National Forest	Montana			354,596	11,985	9,946
Dakota Prairie National Grasslands	North Dakota		119,846	586,690		15,815
Daniel Boone National Forest	Kentucky					543,076
Davy Crockett National Forest	Texas		7,351	116,325		
De Soto National Forest	Mississippi		8,525	322,967		
Delta National Forest	Mississippi		680			
Deschutes National Forest	Oregon	724,451				
Dixie National Forest	Utah		86,672	3,151		
Eldorado National Forest	California					28,664
Fishlake National Forest	Utah	18,162	22,734	74,193		
Flathead National Forest	Montana			58,502		
Fort Pierre National Grassland	South Dakota		2,100	93,529		
Francis Marion and Sumter National Forests	South Carolina			39,352	191,260	111,630
Fremont-Winema National Forest	Oregon	899,464	240,001			
Gallatin National Forest	Montana	33,236	18,471	30,888	1,174	
George Washington and Jefferson National Forest	Kentucky					618
	Virginia				128,433	217,020
	West Virginia				3,274	927
Gifford Pinchot National Forest	Washington		19,954	144,433	3,336	2,780
Gila National Forest	New Mexico	14,209	200,032			
Grand Mesa, Uncompahgre and Gunnison National Forests	Colorado	302,642	197,623	219,738	1,730	
Green Mountain and Finger Lakes National	Vermont			12,108		78,765

Forest	**State**	**Low Suitability Acres**	**Medium-Low Suitability Acres**	**Medium Suitability Acres**	**Medium-High Suitability Acres**	**High Suitability Acres**
Forests						
Helena National Forest	Montana		988	112,618		
Hiawatha National Forest	Michigan					105,452
Holly Springs National Forest	Mississippi			16,803		124,912
Homochitto National Forest	Mississippi			160,495		
Hoosier National Forest	Indiana				135,352	9,514
Humboldt-Toiyabe National Forest	California		432	39,352	3,459	6,734
	Nevada		74,008	42,440	124	
Huron-Manistee National Forest	Michigan					347,924
Idaho Panhandle National Forests	Idaho		115,584	322,967		
	Montana		62	62		
	Washington			30,826		
Inyo National Forest	California		105,699	64,247	2,965	
Kaibab National Forest	Arizona			2,162	300,666	618
Kisatchie National Forest	Louisiana		80,803	280,465	33,668	
Klamath National Forest	California	36,695	13,282	6,301	556	13,035
	Oregon					2,965
Kootenai National Forest	Idaho			1,730		
	Montana		13,158	196,202		
Lake Tahoe Basin Management Unit	California			680	4,510	12,170
	Nevada			1,112	1,359	
Lassen National Forest	California	157,221	290,905	65,421	6,239	371
Lewis and Clark National Forest	Montana			64,371		
Lolo National Forest	Montana		78,950	169,514		
Los Padres National Forest	California		3,027	14,023		
Malheur National Forest	Oregon		221,654	1,297		
Manti-La Sal National Forest	Colorado			7,537		
	Utah		10,811	76,294		
Mark Twain National Forest	Missouri				286,210	900,637
Medicine Bow-Routt National Forest	Colorado	122,255	50,286	16,124		

Forest	State	Low Suitability Acres	Medium-Low Suitability Acres	Medium Suitability Acres	Medium-High Suitability Acres	High Suitability Acres
	Wyoming		432	202,565	78,580	84,139
Mendocino National Forest	California		8,402	61,282	10,440	1,606
Midewin National Tallgrass Prairie	Illinois				11,985	
Modoc National Forest	California	145,051	286,333	56,278		
Monongahela National Forest	West Virginia			163,769	185,761	1,977
Mt. Baker-Snoqualmie National Forest	Washington			14,888	1,544	1,359
Mt. Hood National Forest	Oregon	86,302	67,522	95,136		
Nantahala National Forest	North Carolina					129,607
National Forests in Alabama						371
Nebraska National Forest	Nebraska			88,093		
Nez Perce-Clearwater National Forests	Idaho		106,070	256,804		
Ocala National Forest	Florida					24,525
Ochoco National Forest	Oregon	66,904	151,970			
Oglala National Forest	Nebraska			5,931		
Okanogan-Wenatchee National Forest	Washington		21,066	262,179		
Ottawa National Forest	Michigan					488,095
Ouachita National Forest	Arkansas				192,433	868,390
	Oklahoma			18,595	67,460	19,830
Ozark-St. Francis National Forests	Arkansas			139,367	548,080	26,255
Pawnee National Grassland	Colorado		16,433	8,093		
Payette National Forest	Idaho		17,544	207,877		
Pike and San Isabel National Forests	Colorado	42,749	320,002	72,711		
Pisgah National Forest	North Carolina					30,147
Plumas National Forest	California		12,602	251,924	46,641	66,533
Prescott National Forest	Arizona		47,259	173,715		
Rio Grande National Forest	Colorado	259,831				
Rogue River-Siskiyou National Forest	California					309
	Oregon	75,552	44,232	1,668	4,819	22,487
Sabine National Forest	Texas		100,634	927		
Salmon-Challis National Forest	Idaho	6,487	58,317	125,530		

Forest	State	Low Suitability Acres	Medium-Low Suitability Acres	Medium Suitability Acres	Medium-High Suitability Acres	High Suitability Acres
Sam Houston National Forest	Texas			113,916		
Samuel R. McKelvie National Forest	Nebraska			108,726		
San Juan National Forest	Colorado	405,685	8,834			
Santa Fe National Forest	New Mexico	172,974	169,700	23,413		
Sawtooth National Forest	Idaho	38,981	64,433	21,683		
Sequoia National Forest	California			15,197	39,537	27,182
Shasta-Trinity National Forest	California	163,893	29,591	24,649	7,351	147,893
Shawnee National Forest	Illinois				173,962	
Shoshone National Forest	Wyoming			22,919	12,911	27,120
Sierra National Forest	California			1,606	26,996	69,190
Six Rivers National Forest	California					54,240
Stanislaus National Forest	California			62	371	29,344
Tahoe National Forest	California			46,209	57,699	56,525
Talladega National Forest	Alabama					136,279
Tombigbee National Forest	Mississippi					32,371
Tonto National Forest	Arizona		432,682	533,068		
Tuskegee National Forest	Alabama					7,413
Uinta-Wasatch-Cache National Forest	Utah	7,043	47,630	41,019		
Umatilla National Forest	Oregon		320,557	184,279		
	Washington			59,552		
Umpqua National Forest	Oregon	86,919	19,521	78,332	17,050	15,197
Uwharrie National Forest	North Carolina					35,769
Wallowa-Whitman National Forest	Oregon		99,583	406,427		
Wayne National Forest	Ohio				109,221	63,321
White Mountain National Forest	Maine			62	17,544	247
	New Hampshire			57,637	56,031	40,031
White River National Forest	Colorado	268,727	30,394			
Willamette National Forest	Oregon	107,367	46,332	39,104	14,085	3,212
William B. Bankhead National Forest	Alabama				97,545	25,575
Total		**5,063,869**	**5,712,768**	**10,808,576**	**3,525,515**	**6,475,459**

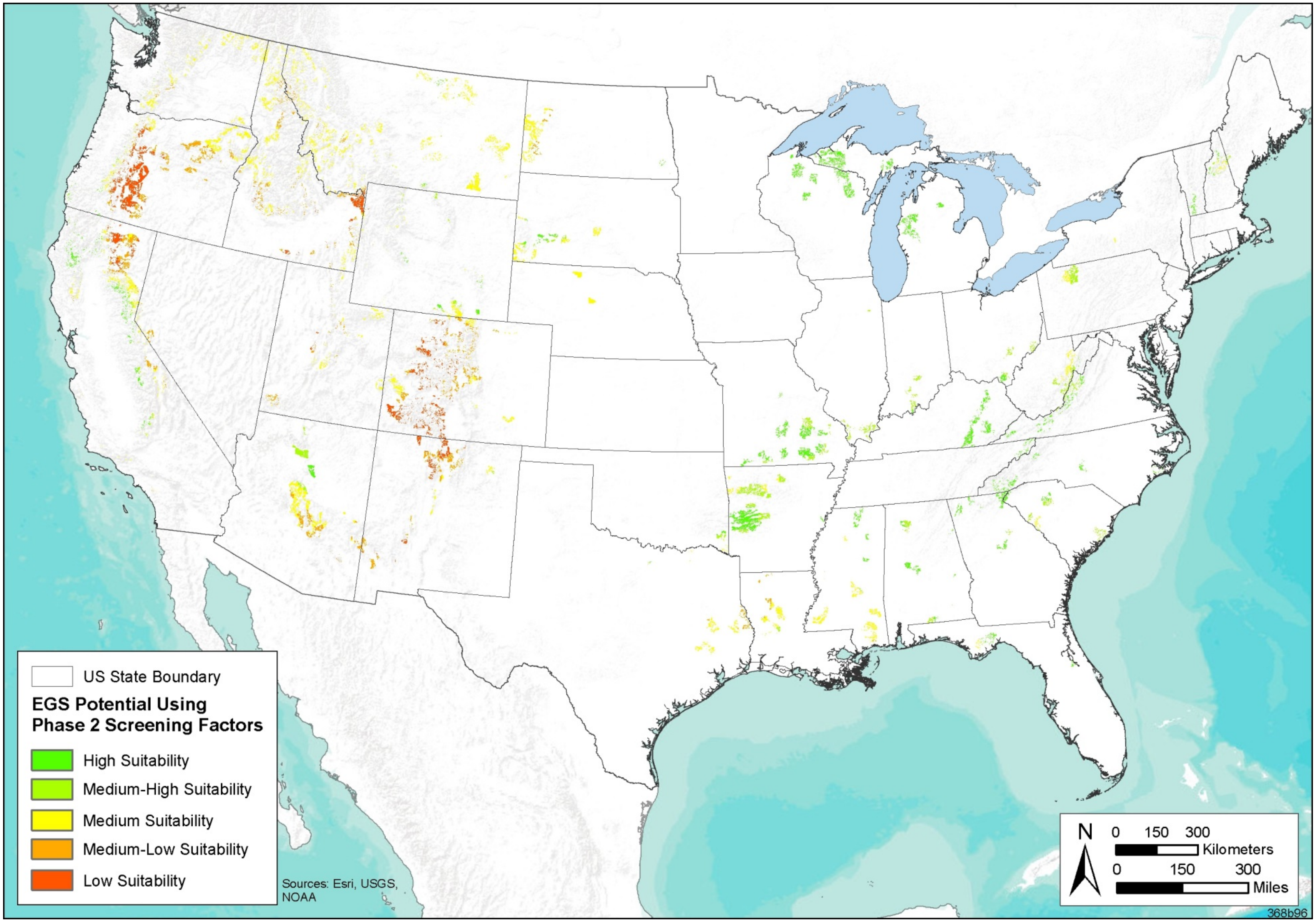


Figure 13. NFS land that is potentially suitable for EGS energy development.

4.5 Comparison of 2005 NREL Results with This Study

The first phase of analysis for solar and wind resources sought to replicate the 2005 NREL methodology using updated source data. Some differences in the analysis were unavoidable, such as the discontinued availability of single-axis tracking data for PV analysis. The source data for CSP and wind were also updated based on continuing data collection and meteorology, although based on similar methods as the previous data sources. Other differences were intentional to enhance the analysis, such as using actual NFS land jurisdictions from the surface management administration data, as opposed to the administrative boundaries used in the 2005 study, which included private and non-NFS inholdings (USFS 2009b). Table 12 lists the results of the original 2005 NREL assessment (2005 Assessment); the results of using the original assessment screening factors with updated data (Updated Data); and the new assessment using additional screening factors (Refined Screening Factors).

For the CSP updated assessment and refined screening factors assessment, insolation data with a minimum of 7 kWh/m2/day were used, consistent with the 2005 NREL methodology. For the PV analysis, the 2005 NREL methodology used tilted-plane insolation data with a minimum insolation of 7 kWh/m2/day, as compared to the updated assessment which used stationary panel insolation data and a minimum of 5.8 kWh/m2/day. This was as consistent with the NREL analysis as possible. For wind, the updated assessment used 100 m hub height data rather than 50 m hub height due to trends in the size of turbines being installed and newly available data. The results of the CSP, PV, and wind data analysis updates are shown in Figures 14, 15, and 16, respectively.

The United States-wide acreage for every technology listed in Table 12 was lower for the updated assessment compared to the 2005 NREL analysis. This difference was due primarily to a reduction in parameters from administrative boundaries applied in the earlier NREL report to actual land areas managed by the USFS. The acreages were again lower when the refined screening factors were added, as would be expected. These remaining areas are of greater interest because they adhere more closely to the newer, broader criteria.

For CSP, exceptions to the trend of lower acreages in the updated assessment include Carson NF (NM), Humboldt-Toiyabe NF (NV), Lincoln NF (NM), Sequoia NF (CA), and Sierra NF (CA). This result occurs primarily because the 7 kWh/m2/day or higher insolation values in the updated solar energy resource data were applicable further north in California, Nevada, and New Mexico, than they were at the time of the 2005 NREL study. Some units, such as Angeles NF (CA), Fishlake NF (UT), Lake Tahoe Basin Management Unit (CA), Los Padres NF (CA), Manti-La Sal NF, San Juan NF (CO), and Tahoe NF (CA) have areas potentially suitable for CSP that were not identified in the 2005 NREL analysis. While the acreages are comparatively small, they are large enough for siting a CSP plant. This result also occurs primarily because of changes in the solar resource data since the 2005 NREL assessment. (These areas did not meet the minimum 7 kWh/m2/day criteria in the 2005 data, but did in the updated data.)

In the PV analysis, exceptions to the trend of lower acreages in the updated assessment include Eldorado NF (CA), Grand Mesa, Uncompahgre and Gunnison NF (CO), Plumas NF (CA), and particularly Lassen NF (CA), where the acreage increased from 692 to 26,008. Similar to the CSP analysis, this is due primarily to differences in the solar energy resource data. Some units, such as Cimarron NG (KS), Comanche NG (CO), McClellan Creek NG (TX), Mendocino NF (CA), Modoc NF (CA), and Rita Blanca NG (OK, TX) have areas potentially suitable for PV that were not identified in the 2005 NREL analysis. Of these, the California NFS units have some suitable solar energy resource areas in the updated analysis that were not suitable in the 2005 assessment. The others are all national grasslands that were not listed in the 2005 assessment; however, GIS layers provided with the 2005 assessment show potentially suitable PV results overlapping these grasslands.

In the wind analysis, exceptions to the trend of lower acreages in the updated assessment include Apache-Sitgreaves NF (AZ), Ashley NF (UT), Bankhead-Jones Farm Tenant Act Land (MT), Bighorn NF (WY), Black Hills NF (WY), Bridger-Teton NF (WY), Caribou-Targhee NF (ID), Carson NF (NM), Cibola NF (NM), Custer NF (MT, SD), Deschutes NF (OR), Kaibab NF (AZ), Lewis and Clark NF (MT), Lincoln NF (NM), Mt. Hood NF (OR), Nebraska NF (NE), Ochoco NF (OR), Payette NF (ID), Santa Fe NF (NM), Sawtooth NF (ID), Shoshone NF (WY), Siuslaw NF (OR), and Umatilla NF (OR). The industry trend toward higher and larger wind turbines, and the corresponding change from 50-m to 100-m hub heights at which winds are generally stronger, accounts for many of these cases, while the reduced acreages occur because of the use of surface management agency data rather than administrative boundaries.

In Montana, Bankhead-Jones Farm Tenant Act lands may have been omitted from the 2005 assessment because of their management category. Some units have areas potentially suitable for PV that were not identified in the 2005 assessment. These include Buffalo Gap NG (SD), Caddo-Lyndon B. Johnson NG (TX), Cimarron NG (KS), Columbia River Gorge NSA (WA), Comanche NG (CO) Fort Pierre NG (SD), Grand River NG (SD), Hiawatha NF (MI), McClellan Creek NG (TX), Midewin National Tallgrass Prairie (IL), Nantahala NF (NC), Oglala NF (NE), Pawnee NG (CO), Pisgah NF (NC), Rita Blanca NG (OK, TX), Samuel R. McKelvie NF (NE), and Thunder Basin NG (WY). Many of these units are grasslands and show suitability for wind resources in the 2005 assessment, though it is unclear why they were not listed in the assessment results.

5 Conclusions

This study updates and expands on the 2005 NREL assessment of the potential for solar and wind energy development on NFS lands, providing new insights about areas that could potentially be used for siting CSP, PV, or wind power, and new analysis for biomass and geothermal energy. The first phase of this study concentrated on performing an analysis similar to the 2005 NREL assessment, with updated data. The most significant updates in the data were in the energy resource layers, which have been refined since 2005 based on continuing data collection and modeling, and the use of surface management agency data rather than administrative boundaries to identify NFS lands. Although a comparison of the overall NFS-wide 2005 assessment and current results found less potentially suitable area for each technology, a significant number of individual NFS units had an opposite trend.

The overall reduction in suitable area was due primarily to the elimination of non-NFS inclusions within administrative boundaries. The increase or decrease in suitable area of some NFS units increasing or decreasing was due primarily to the variability in the energy resource data which, in turn, was due in large part to variations in the weather data on which it was based. While updated data did contribute to improved estimates, the authors caution against using the areas reported in the results as a final and definitive estimate of suitability for these technologies. This analysis is most useful for determining locations that should be examined more fully, and for identifying regional and national trends.

Phase 2 of the analysis introduced more screening factors and added biomass and geothermal technologies to the scope. Tables and figures in the Results and Discussion section highlight both the NFS units with the highest acreages found potentially suitable for each technology, and locations on the maps where the most acres are concentrated. Consistent with trends in the solar power industry, NFS units in the Southwest were found to be most favorable for CSP and PV technologies, with the notable addition of national grasslands in Kansas, Oklahoma, and Texas. For wind power, the top NFS units were concentrated in the northern Plains states, with 7 NFS units having at least 100,000 acres meeting the full set of siting criteria.

Analysis of biomass resources focused on logging residues and forest thinning sources. NFS units with the highest suitability for these biomass resources were widely distributed throughout the United States. Fremont-Winema National Forest in Oregon capped the list with over 1.5 million acres. Not surprisingly, most NFS units have at least some level of potentially suitable biomass resources. In general, these resources could significantly offset consumption of coal and petroleum-based fuels.

Energy resource data for geothermal technologies is less refined than that for other resources in this study, with large regions coded with similar suitability levels (Figure B.4). Typically, the geothermal potential level is uniform for regions at least the size of most NFS units, therefore, additional siting criteria primarily determined a given level of geothermal resource suitability. The analysis found that Mark Twain National Forest in Missouri has the largest area of highly suitable geothermal resources that also meets the other siting criteria. In addition, 15 widely distributed NFS units had more than 100,000 acres with similarly favorable characteristics. More rigorous siting studies are needed for siting geothermal plants, especially the geological characteristics of specific sites, but the results suggest that there is significant potential for geothermal power generation within many NFS units.

As this study illustrates, the availability of GIS data for renewable energy resources and major screening factors now allows national screening level studies to effectively assess the levels and spatial distribution for potential renewable energy technology development. More detailed siting studies, land use planning, and environmental compliance are essential before individual projects can be permitted and built. However, this study can serve to inform resource managers and planners of where these technologies are most likely to be investigated and proposed; help prioritize efforts to continue informed and sustainable development of renewable power generation within the United States; and help characterize the role of the USFS in this arena.

Table 12. Comparison of 2005 NREL, updated, and refined screening factors assessments (all NFS units, listed alphabetically).

Forest	State	CSP Acres			PV Acres			Wind Acres		
		2005 Assessment	Updated Data	Refined Screening Factors	2005 Assessment	Updated Data	Refined Screening Factors	2005 Assessment	Updated Data	Refined Screening Factors
Angeles NF[a]	California		618	185	2,115	1,112	927	71,560	50,965	33,421
Apache-Sitgreaves NF	Arizona	180,086	84,572	14,950	184,208	90,070	38,363	3,341	14,147	865
Arapaho and Roosevelt NF	Colorado							407,464	284,604	40,155
Ashley NF	Utah							316	1,297	865
	Wyoming							10		
Bankhead-Jones Farm Tenant Act Land	Montana								598,551	571,431
Beaverhead-Deerlodge NF	Montana							84,854	81,359	20,077
Bighorn NF	Wyoming							33,447	64,742	22,487
Bitterroot NF	Montana							2,580	1,421	309
Black Hills NF	S. Dakota							657,711	247,291	22,989
	Wyoming							9,350	42,996	5,189
Boise NF	Idaho							4,211	1,112	618
Bridger-Teton NF	Wyoming							5,061	15,444	247
Buffalo Gap NG[b]	S. Dakota								345,577	339,090
Caddo-Lyndon B. Johnson NG	Texas								2,286	1,112
Caribou-Targhee NF	Idaho							8,926	13,035	5,189
	Wyoming							504	371	
Carson NF	Colorado				10					
	New Mexico	2,323	15,691	9,637	37,589	18,471	12,108	46,178	58,502	11,552
Chattahoochee-Oconee NF	Georgia							33,075	556	
Chequamegon-Nicolet NF	Wisconsin							3,398		
Cherokee NF	Tennessee							42,321	1,483	

Forest	State	CSP Acres			PV Acres			Wind Acres		
		2005 Assessment	Updated Data	Refined Screening Factors	2005 Assessment	Updated Data	Refined Screening Factors	2005 Assessment	Updated Data	Refined Screening Factors
Cibola NF	New Mexico	93,157	42,873	23,166	189,150	81,236	71,166	12,750	90,997	78,888
	Oklahoma							138,887		
	Texas				203,195			88,252		
Cimarron NG	Kansas					71,352	65,298		87,228	75,800
Cleveland NF	California	1,236	865	62	3,954	1,236	741	14,727	2,903	62
Coconino NF	Arizona	222,509	126,394	34,471	230,900	126,394	52,819	6,543	4,695	1,730
Columbia River Gorge NSA[c]	Washington								124	
Colville NF	Washington							8,303	803	124
Comanche NG	Colorado					154,441	150,920		227,213	223,198
Coronado NF	Arizona	15,666	6,239	124	17,337	6,239	3,830	9,479	247	247
Custer NF	Montana							38,557	148,634	92,108
	S. Dakota							31,372	62,827	47,135
Dakota Prairie NG	N. Dakota							836,453	606,520	538,319
	S. Dakota							292,804		
Deschutes NF	Oregon							17,811	22,301	3,398
Dixie NF	Utah	6,523	5,622	247	38,063	9,266	4,695	7,591	556	124
Eldorado NF	California				425	1,853	309	1,443	247	124
Fishlake NF	Utah		124	124	2,224	680	432	13,077	247	247
Flathead NF	Montana							16,813	4,139	62
Fort Pierre NG	S. Dakota								93,097	89,637
Francis Marion and Sumter NF	S. Carolina							4,520		
Fremont-Winema NF	Oregon							31,204	23,228	5,992
Gallatin NF	Montana							49,410	22,425	3,768
George Washington and Jefferson NF	Kentucky							1,275		
	Virginia							52,534	6,116	
	W. Virginia							7,720	1,668	62
Gifford Pinchot NF	Washington							52,059	17,544	2,842
Gila NF	New Mexico	74,585	27,182	2,718	89,401	27,182	12,355	7,136	5,622	2,842

Forest	State	CSP Acres			PV Acres			Wind Acres		
		2005 Assessment	Updated Data	Refined Screening Factors	2005 Assessment	Updated Data	Refined Screening Factors	2005 Assessment	Updated Data	Refined Screening Factors
Grand Mesa, Uncompahgre and Gunnison NF	Colorado				494	927	432	11,297	6,795	2,039
Grand River NG	S. Dakota								86,549	83,831
Green Mountain and Finger Lakes NF	New York							259		
	Vermont							53,344	39,166	618
Helena NF	Montana							57,792	52,077	3,954
Hiawatha NF	Michigan								1,544	
Humboldt-Toiyabe NF	California	69	185	185	2,372	432	309	8,767	1,915	1,483
	Nevada	4,092	6,981	2,100	61,686	8,093	6,487	24,987	4,942	2,595
Huron-Manistee NF	Michigan							5,645	1,297	62
Idaho Panhandle NF	Idaho							47,582	16,680	2,286
	Montana							1,690		
	Washington							99		
Inyo NF	California	12,474	6,239	4,695	67,854	6,425	4,757	7,621	1,544	124
	Nevada	1,236	494		1,483	494	309			
Kaibab NF	Arizona	78,944	72,464	19,830	109,248	72,464	37,004	929	3,707	3,583
Klamath NF	California							11,614	865	62
	Oregon							1,255	1,050	185
Kootenai NF	Idaho							613	432	62
	Montana							27,636	3,521	247
Lake Tahoe Basin Management Unit	California		618	62	909	618	62	1,483	371	309
	Nevada				208			3,568	432	309
Lassen NF	California				692	26,008	7,475	7,818	1,421	432
Lewis and Clark NF	Montana							80,189	126,518	23,351
Lincoln NF	New Mexico	2,224	7,475		24,038	7,846	3,830	91,101	99,460	67,151
Lolo NF	Montana							49,548	26,564	3,398
Los Padres NF	California		618	62	11,040	1,112	432	13,699	5,498	2,100
Malheur NF	Oregon							1,661	1,174	
Manti-La Sal NF	Colorado		371					49		
	Utah				1,483	741		19,471		

Forest	State	CSP Acres			PV Acres			Wind Acres		
		2005 Assessment	Updated Data	Refined Screening Factors	2005 Assessment	Updated Data	Refined Screening Factors	2005 Assessment	Updated Data	Refined Screening Factors
McClellan Creek NG	Texas					247	62		988	494
Medicine Bow-Routt NF	Colorado							15,696	14,950	1,483
	Wyoming							870,859	362,751	85,622
Mendocino NF	California					618	309	1,878		
Midewin National Tallgrass Prairie	Illinois								4,139	3,336
Modoc NF	California					865	494	19,155	2,595	680
Monongahela NF	W. Virginia							63,159	7,969	
Mt Baker-Snoqualmie NF	Washington							28,911	5,127	680
Mt. Hood NF	Oregon							47,621	60,541	10,008
Nantahala NF	N. Carolina								1,977	185
National Forests in North Carolina								34,707		
Nebraska NF	Nebraska							72,108	99,645	82,286
	S. Dakota							889,303		
Nez Perce-Clearwater NF	Idaho							5,080	2,039	124
Ochoco NF	Oregon							929	2,903	1,174
Oglala NF	Nebraska								78,147	75,182
Okanogan-Wenatchee NF	Washington							42,788	27,552	6,487
Olympic NF	Washington							14,470	12,293	432
Ottawa NF	Michigan							57,175		
Ouachita NF	Arkansas							40,086	20,819	309
	Oklahoma							2,828		
Ozark-St. Francis NF	Arkansas							50,844	2,100	62
Pawnee NG	Colorado								35,089	34,533
Payette NF	Idaho							2,738	3,027	1,421
Pike and San Isabel NF	Colorado	247	309	309	448,832	3,212		418,202	57,020	14,765
	Kansas				107,815		927	13,042		

Forest	State	CSP Acres			PV Acres			Wind Acres		
		2005 Assessment	Updated Data	Refined Screening Factors	2005 Assessment	Updated Data	Refined Screening Factors	2005 Assessment	Updated Data	Refined Screening Factors
Pisgah NF	N. Carolina								3,274	
Plumas NF	California				8,510	11,614	3,521	15,261	3,089	1,668
Prescott NF	Arizona	75,583	9,761	5,622	79,942	9,761	7,537	455		
Rio Grande NF	Colorado	3,064	927	556	10,042	1,421	680	34,663	25,205	8,278
Rita Blanca NG	Oklahoma					1,606	1,606		1,421	1,421
	Texas					52,819	52,201		59,367	58,873
Rogue River-Siskiyou NF	California							2,886		
	Oregon							69,455	52,942	4,695
Salmon-Challis NF	Idaho							7,324	4,695	3,336
Samuel R. McKelvie NF	Nebraska								111,506	108,726
San Bernardino NF	California	3,647	1,050		4,557	1,112	247	23,059	11,490	6,178
San Juan NF	Colorado		3,398	1,853	24,413	9,575	3,459	3,519		
Santa Fe NF	New Mexico	14,490	11,120	5,498	34,979	14,703	7,598	36,630	54,981	25,081
Sawtooth NF	Idaho							27,873	28,850	26,378
	Utah							6,029	185	124
Sequoia NF	California	979	1,297	247	5,347	1,359	309	3,657	1,668	618
Shasta-Trinity NF	California							16,931	1,174	
Shoshone NF	Wyoming							55,014	80,000	31,259
Sierra NF	California	237	2,039	185	7,116	2,533	309			
Siuslaw NF	Oregon							20,262	28,911	741
Six Rivers NF	California							1,759		
Stanislaus NF	California				1,700	2,162	494	40		
Tahoe NF	California		309	247	7,334	2,718	988	11,307	1,050	680
Thunder Basin NG	Wyoming								310,364	304,125
Tonto NF	Arizona	51,456	16,741	8,896	57,021	16,741	8,896	12,869	741	741
Uinta-Wasatch-Cache NF	Utah							8,352	8,031	1,050
Umatilla NF	Oregon							21,330	39,660	5,251
	Washington							9,330	8,093	1,915
Umpqua NF	Oregon							14,777	5,683	1,112

Forest	State	CSP Acres			PV Acres			Wind Acres		
		2005 Assessment	Updated Data	Refined Screening Factors	2005 Assessment	Updated Data	Refined Screening Factors	2005 Assessment	Updated Data	Refined Screening Factors
Wallowa-Whitman NF	Oregon							8,095	7,784	1,544
White Mountain NF	Maine							1,522		
	New Hampshire							36,185	3,583	62
White River NF	Colorado							15,735	2,965	2,533
Willamette NF	Oregon							17,396	6,178	1,668
Total		**844,826**	**452,574**	**136,032**	**2,077,686**	**847,757**	**564,698**	**6,858,036**	**5,403,207**	**3,357,792**

[a] NF = National Forest

[b] NG = National Grassland

[c] NSA = National Scenic Area

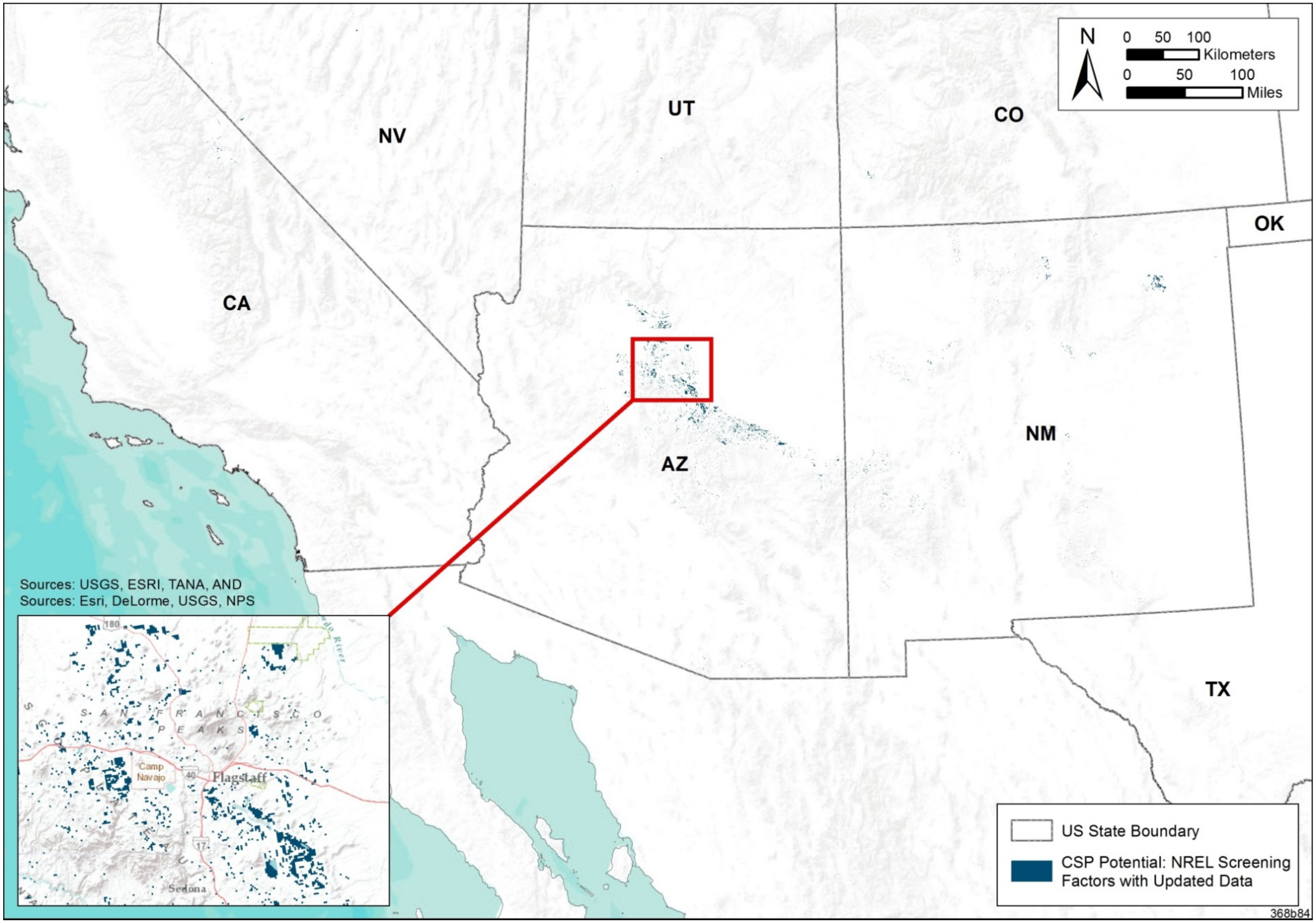


Figure 14. NFS land that is potentially suitable for concentrating solar power energy development, based on screening factors from the 2005 NREL report, using updated data.

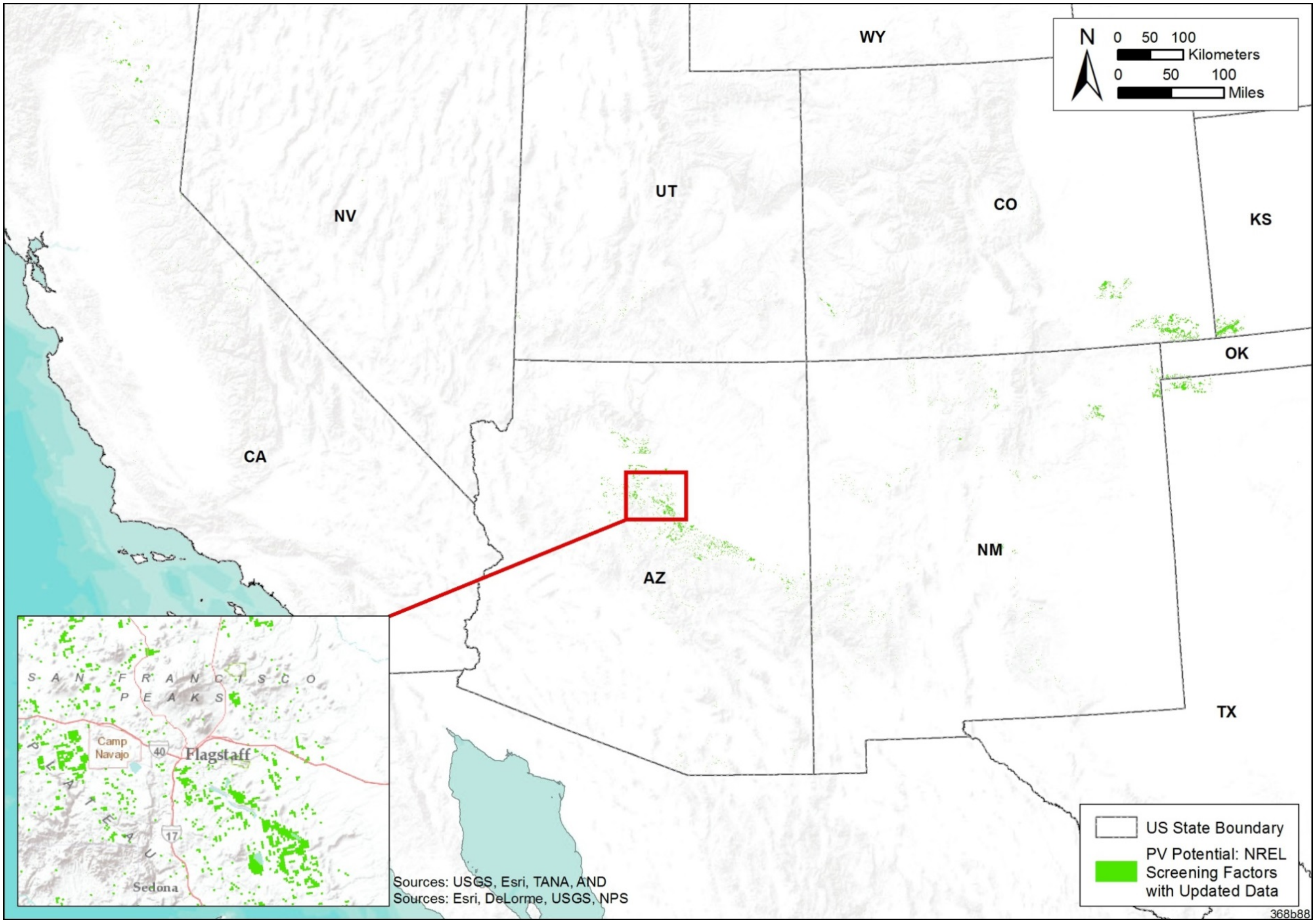


Figure 15. NFS land that is potentially suitable for photovoltaic power energy development, based on screening factors from the 2005 NREL report, using updated data.

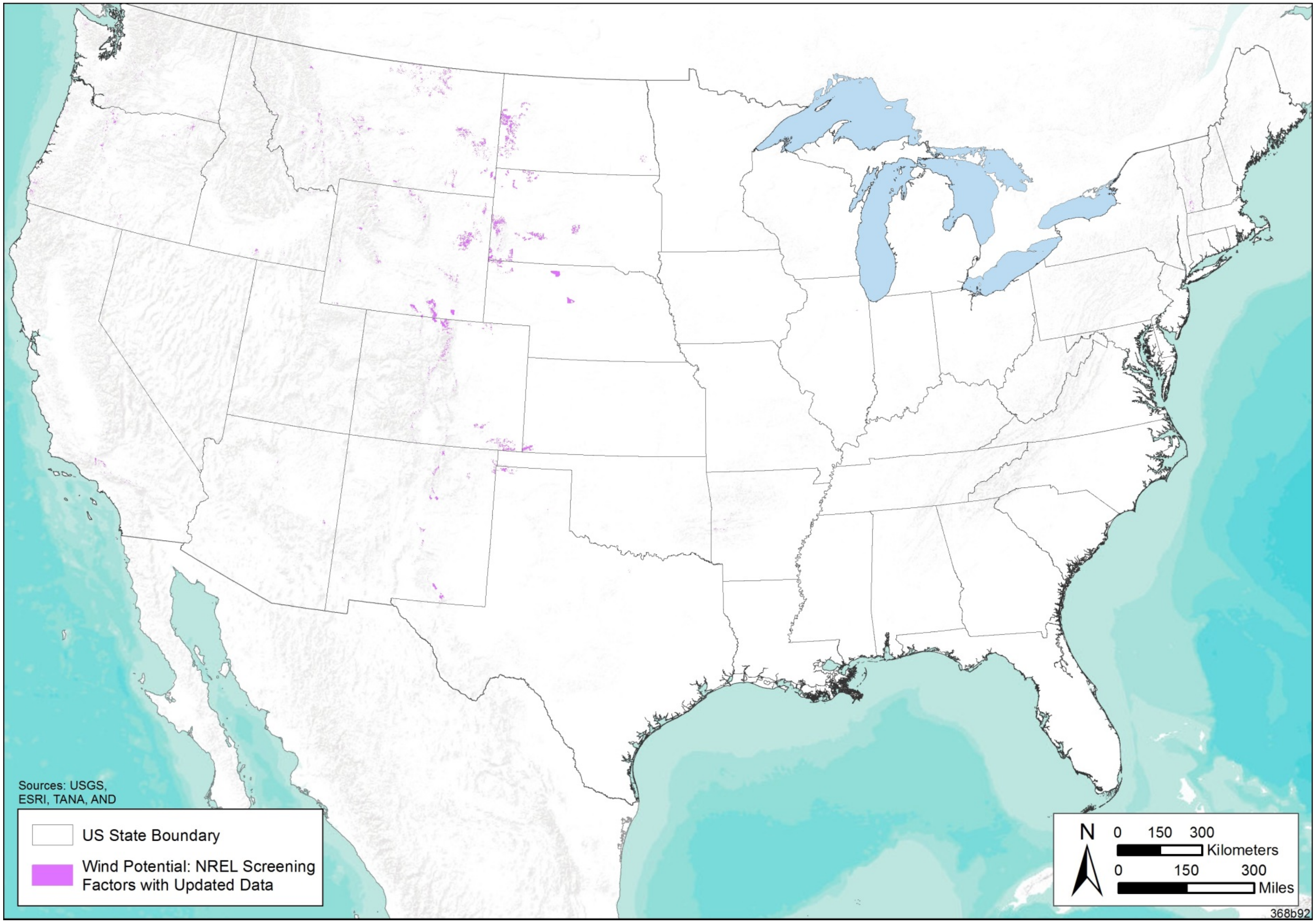


Figure 16. NFS land that is potentially suitable for wind energy development, based on screening factors from the 2005 NREL report, using updated data.

This page intentionally left blank.

6 References

Argonne (Argonne National Laboratory). 2008. *land_restriction_area_wsa_anl2* [computer file]. Environmental Science Division. Accessed internal file August 1, 2012.

Argonne. 2009. *EVS_Common_DBO_land_restriction_area_national_monument* [computer file]. Environmental Science Division. Accessed internal file August 1, 2012.

Argonne. 2011. *land_restriction_area_fws_topeka_shiner* [computer file]. Environmental Science Division. Accessed internal file August 1, 2012.

Argonne. 2011b. *recreation_trail_centerline* [computer file]. Environmental Science Division. Accessed internal file August 1, 2012.

Argonne. 2012. *Airport_Surveillance_Radar_Site* [computer file]. Environmental Science Division. Accessed internal file September 4, 2012.

Argonne. 2012b. *NEXRAD_Radar_Site* [computer file]. Environmental Science Division. Accessed internal file September 4, 2012.

Argonne. 2012c. *Renewable Energy Atlas of the United States.* ANL/EVS/RP-73128, April.

Argonne. 2012d. *TARS_Radar_*Site [computer file]. Environmental Science Division. Accessed internal file September 4, 2012.

Argonne. 2012e. *TDWR_Radar_Site* [computer file]. Environmental Science Division. Accessed internal file September 4, 2012.

Argonne. 2013. *Energy Zones Study: A Comprehensive Web-Based Mapping Tool to Identify and Analyze Clean Energy Zones in the Eastern Interconnection, ANL/DIS-13/09, Argonne National Laboratory, prepared for the U.S. Department of Energy,* Office of Electricity Delivery and Energy Reliability, Washington, D.C., 242 pp., September. Available at https://eispctools.anl.gov/document/21/file. Accessed November 26, 2013.

Arthaud, G. 2012. *all_ef_swr.shp* [computer file]. G. Arthaud (U.S. Forest Service) and E. Zvolanek (Argonne), personal communication, October 5.

AWS TruePower. 2012. *lwr48_pwr50m* [computer file]. J. Frank (AWS TruePower) and J. Kuiper (Argonne), personal communication, December 19.

AWS TruePower. 2012b. *lwr48_pwr80m* [computer file]. J. Frank (AWS TruePower) and J. Kuiper (Argonne), personal communication, December 19.

AWS TruePower. 2012c. *lwr48_pwr100m* [computer file]. J. Frank (AWS TruePower) and J. Kuiper (Argonne), personal communication, December 19.

Bentek. 2012. *trans_ln.shp* in: *POWERmap* [CD-ROM]. Platts, A Division of The McGraw-Hill Companies.

BLM (Bureau of Land Management). 2010. *Conservation_Areas.shp* [computer file]. U.S. Department of the Interior. Received from BLM on April 16, 2010.

BLM. 2012. "Approved Resource Management Plan Amendments/Record of Decision (ROD) for Solar Energy Development in Six Southwestern States." October. Accessed August 22, 2013. http://www.solareis.anl.gov/documents/docs/Solar_PEIS_ROD.pdf.

BLM and DOE (U.S. Department of Energy). 2012. "Final Programmatic Environmental Impact Statement for Solar Energy Development in Six Southwestern States." DOE/EIS-0403, July. Available at http://www.solareis.anl.gov/documents/fpeis/index.cfm. Accessed August 22, 2013.

BLM et al. (BLM, U.S. Forest Service, and Great Basin Unified Air Pollution Control District). 2013. *Casa Diablo IV Geothermal Development Project, Final Joint Environmental Impact Statement and Environmental Impact Report*, BLM/CA/ES-2013/021+3200+1793, June. Accessed November 15, 2013. http://www.blm.gov/ca/st/en/fo/bishop/casadiabloIV.html.

Defne, Z., K.A. Haas, H.M. Fritz, L. Jiang, X. Shi, S.P. French, B.T. Smith, V.S. Neary, and K.M. Stewart. 2012. "National Geodatabase of Tidal Stream Power Resource in the USA." *Renewable and Sustainable Energy Reviews 16(5),* 3326–3338. Available at http://dx.doi.org/10.1016/j.rser.2012.02.061. Accessed November 18, 2013.

DOE (U.S. Department of Energy), 2011, *2010 Renewable Energy Data Book, Energy Efficiency and Renewable Energy*. Available at http://www.nrel.gov/analysis/pdfs/51680.pdf. Accessed September 12, 2013.

DOE and ORNL (Oak Ridge National Laboratory), 2011a. *BillionTonUpdateForestResidueSupplement.mdb* [computer file]. Available at https://bioenergykdf.net/content/billiontonupdate. Accessed December 12, 2011.

DOE and ORNL. 2011b. *BillionTonUpdateForestThinningsSupplement.mdb* [computer file]. Available at https://bioenergykdf.net/content/billiontonupdate. Accessed December 12, 2011.

DOE EERE (Energy Efficiency & Renewable Energy). 2010. *Biopower Technical Strategy Workshop Summary Report*. DOE/EE-0376, December.

DOE EERE. 2012. *SunShot Vision Study Executive Summary.* DOE/GO-102012-3037, February.

DOE EERE. 2012b. *Replacing the Whole Barrel to Reduce U.S. Dependence on Oil.* DOE/EE-0762, July.

DOE EERE. 2012c. *Wind Program Accomplishments.* DOE/EE-0726, September.

DOE EERE. 2012d. *What is an Enhanced Geothermal System (EGS)?.* DOE/EE-0785, September.

DOE EERE. 2012e. *An Assessment of Energy Potential at Non-Powered Dams in the United States*. Available at http://www1.eere.energy.gov/water/pdfs/npd_report.pdf. Accessed November 18, 2013.

DOI (U.S. Department of the Interior) et al. 2007. Potential Hydroelectric Development at Existing Federal Facilities, for Section 1834 of the Energy Policy Act of 2005. Available at http://www.usbr.gov/power/data/1834/Sec1834_EPA.pdf. Accessed November 18, 2013.

EISPC (Eastern Interconnection States' Planning Council). 2012. "EISPC Energy Zone Workgroup Identified Goals and Objectives, Desired Deliverables and Definition of Terms, FINAL – EISPC APPROVED JULY 27, 2011, Inclusion of Natural Gas – August 2012, Attachment A, Energy Resources and Resource Criteria." Available at http://communities.nrri.org/web/eispc/discuss-solutions-members?p_auth=K19duMuL&p_p_id=19&p_p_lifecycle=1&p_p_state=exclusive&p_p_mode=view&p_p_col_id=column-2&p_p_col_count=1&_19_struts_action=%2Fmessage_boards%2Fget_message_attachment&_19_messageId=381081&_19_attachment=EZWG.20120921+AL+EZ_Goals_AttachmentA_Resource_Criteria+EISPC_NatGas+section_Rev+3.doc. Accessed August 30, 2012.

EISPC. 2012b. "Methodology and Process for Identifying Clean Energy Zones, Draft, January 24, 2012." Available at http://communities.nrri.org/documents/68668/9a5cb7c7-ed34-43af-8ff4-ff8ef9b0a9fc. Accessed August 30, 2013.

EPA (Environmental Protection Agency) and USGS (U.S. Geological Survey). 2012. *NHDPlus Version 2* [computer file]. Available at http://www.horizon-systems.com/NHDPlus/NHDPlusV2_data.php. Accessed October 23, 2012.

ESRI (Environmental Systems Research Institute). 2010a. *airportp.sdc* in: *ESRI Data & Maps* [CD-ROM].

ESRI. 2010b. *dtl_st.sdc* in: *ESRI Data & Maps* [CD-ROM].

ESRI. 2010c. *hydroln.sdc* in: *ESRI Data & Maps* [CD-ROM].

ESRI. 2010d. *hydroply.sdc* in: *ESRI Data & Maps* [CD-ROM].

ESRI. 2013. "Download ArcReader." Available at http://www.esri.com/software/arcgis/arcreader/download. Accessed August 19, 2013.

FEMA (Federal Emergency Management Agency). 2011. *FEMA_Floodplain_20111128* [computer file]. Available at http://www.msc.fema.gov. Accessed November 28, 2011.

FERC (Federal Energy Regulatory Commission). 2013a. *FERC: Hydropower - Hydrokinetic Projects*. Available at http://www.ferc.gov/industries/hydropower/gen-info/licensing/ hydrokinetics.asp. Accessed November 18, 2013.

FERC. 2013b. *FERC: Hydropower - Pumped Storage Projects*. Available at http://www.ferc.gov/industries/hydropower/gen-info/licensing/pump-storage.asp. Accessed November 18, 2013.

Fry, J., C. Barnes, J. Dewitz, N. Herold, C. Homer, S. Jin, J. Wickham, G. Xian, and L. Yang. 2011. *Completion of the 2006 National Land Cover Database for the Conterminous United States*. PE&RS, Vol. 77(9):858–864.

FWS (U.S. Fish and Wildlife Service). 2009. *FWS_Tran_Trails.shp* [computer file]. Available at http://www.fws.gov/GIS/data/roads_trails/. Accessed November 11, 2010.

FWS. 2010. *CRITHAB_POLY* [computer file]. Available at http://criticalhabitat.fws.gov. Accessed March 22, 2012.

FWS. 2011. *National Wetland Inventory* [computer file]. Available at http://www.fws.gov/wetlands. Accessed March 22, 2012.

GEA (Geothermal Energy Association). 2013. *Geothermal Energy Association Power Plant Details*, Available at http://geo-energy.org/plantdetails.aspx?id=125 and http://geo-energy.org/plantdetails.aspx?id=126. Accessed November 15, 2013.

Hall, D.G., S.J. Cherry, K.S. Reeves, R.D. Lee, G.R. Carroll, G.L. Sommers, and K.L. Verdin. 2004. *Water Energy Resources of the United States with Emphasis on Low Head/Low Power Resources*, U.S. Department of Energy Report DOE/ID-11111. Available at http://www1.eere.energy.gov/water/pdfs/doewater-11111.pdf. Accessed November 18, 2013.

MIT (Massachusetts Institute of Technology). 2006. *The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century*, INL/EXT-06-11746.

NREL (National Renewable Energy Laboratory). 2005. *Assessing the Potential for Renewable Energy on National Forest System Lands,* NREL/BK-710-36759, January.

NREL. 2009. *GeothermalLCOE_NoExclusions.shp* [computer file]. Available at http://www.nrel.gov/gis/data_geothermal.html. Accessed March 7, 2012.

NREL. 2012. *us9809_dni_updated.shp* [computer file]. Available at http://www.nrel.gov/gis/data_solar.html. Accessed December 20, 2012.

NREL. 2012b. *us9809_latilt_updated.shp* [computer file]. Available at http://www.nrel.gov/gis/data_solar.html. Accessed December 20, 2012.

NREL. 2012c. *U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis*. NREL/TP-6A20-51946, July.

NREL. 2013. "Land-Use Requirements for Solar Power Plants in the United States." NREL/TP-6A20-56290, June. http://www.nrel.gov/docs/fy13osti/56290.pdf. Accessed September 16, 2013.

Ormat (Ormat Technologies, Inc.). 2013. *Ormat Technologies Inc. | Map*. Available at http://www.ormat.com/global-project. Accessed November 15, 2013.

Reitsma, J., 2010. *sma_20090914* [computer file], J. Reitsma (BLM) and B. Cantwell (Argonne), personal communication, Jan. 27.

RITA BTS (Research and Innovative Technology Administration, Bureau of Transportation Statistics). 2011. *county.shp* in: *NTAD (National Transportation Atlas Database) 2012* [CD-ROM].

RITA BTS. 2011b. *nhpn.shp* in: *NTAD 2012* [CD-ROM].

RITA BTS. 2011c. *rail_lines.shp* in: *NTAD 2012* [CD-ROM].

USACE (U.S. Army Corps of Engineers). 2013. *CorpsMap National Inventory of Dams*. Available at http://geo.usace.army.mil/pgis/f?p=397:1:0::NO:::. Accessed November 18, 2013.

USBR (U.S. Bureau of Reclamation). 2009. *Dam details - Shasta Dam - Bureau of Reclamation*. Available at http://www.usbr.gov/projects/Facility.jsp?fac_Name=Shasta+Dam&groupName=General. Accessed November 18, 2013.

USBR. 2011. *Hydropower Resource Assessment at Existing Reclamation Facilities*. Denver, Colo. March. Available at http://www.usbr.gov/power/AssessmentReport/USBRHydroAssessment FinalReportMarch2011.pdf. Accessed November 18, 2013.

U.S. Census Bureau. 2010. *Census_Tract.shp* [computer file]. Available at http://www.census.gov/geo/ maps-data/data/tiger-data.html. Accessed May 7, 2012.

USDA (U.S. Department of Agriculture). 2012. *US Forest Service Harnesses Hydropower without Having to Build a Dam*. Available at http://blogs.usda.gov/2012/03/30/us-forest-service-harnesses-hydropower-without-having-to-build-a-dam. Accessed November 18, 2013.

USFS. 2007. "USDA Forest Service Strategic Plan, FY 2007–1012." United States Department of Agriculture, Forest Service, FS-880, July. Available at http://www.fs.fed.us/publications/strategic/fs-sp-fy07-12.pdf. Accessed April 4, 2013.

USFS (U.S. Forest Service). 2007b. *Washington Office Engineering at the USDA Forest Service: Dams.* Available at http://www.fs.fed.us/eng/dams. Accessed November 18, 2013.

USFS. 2009a. *Master_Conus_WSR2009_Oct20.shp* [computer file]. Available at http://www.rivers.gov/ rivers/mapping-gis.php. Accessed January 29, 2010.

USFS. 2009b. *S_USA_AdministrativeForest.shp* [computer file]. Available at http://fsgeodata.fs.fed.us/ vector/lsrs.php. Accessed February 11, 2013.

USFS. 2012. *irasda_us_dd_nad83.gdb* [computer file]. Available at http://www.fs.usda.gov/detail/ roadless/2001roadlessrule/maps/?cid=stelprdb5382437. Accessed January 16, 2013.

USFS. 2012a. *Final Environmental Impact Statement for Geothermal Leasing on the Humboldt-Toiyabe National Forest*, September. Available at http://a123.g.akamai.net/7/123/11558/abc123/ forestservic.download.akamai.com/11558/www/nepa/77509_FSPLT2_287462.pdf. Accessed November 15, 2013.

USFS. 2012b. "Future of America's Forests and Rangelands, Forest Service, 2010 Resources Planning Act Assessment." United States Department of Agriculture, Forest Service, Gen. Tech. Rep. WO-87, August. Accessed April 4, 2013. http://www.fs.fed.us/research/publications/gtr/gtr_wo87.pdf.

USGS (U.S. Geological Survey). 2001. *ws_river_na.shp* [computer file]. Available at http://nationalatlas.gov/atlasftp.html. Accessed 2008.

Walkes, J. 2011. *DEM_US_500m* [computer file]. J. Walkes (USGS) and A. Orr (Argonne), personal communication, August 24.

Wilderness Institute. 2012. *Wilderness_areas_3.12.12.shp* [computer file]. Available at http://www.wilderness.net/NWPS/geography. Accessed March 27, 2012.

This page intentionally left blank.

Appendix A: Further Analysis of Renewable Energy Technologies in Proximity to Transmission Infrastructure

While the 2005 NREL study used 25 miles as the maximum distance from existing transmission infrastructure, it is likely that development would occur nearer to existing infrastructure if at all possible because of the high cost of siting and building new transmission lines. This appendix presents the quantity of potentially suitable land for concentrating solar power (CSP), photovoltaic (PV), wind, biomass, and enhanced geothermal system (EGS) energy development within 3 miles of existing transmission lines and substations. Tables A.1 – A.5 list the 5 NFS units with the most potentially suitable land that meet this criterion for each renewable energy type. The "Percent of Land Retained" field of Tables A.1 – A.5 shows what percentage of an area found to be both suitable and within 25 miles of existing transmission infrastructure is also within 3 miles for that NFS unit. The spreadsheet named "transmission_comparison.xlxs" that accompanies this report lists similar results for all NFS units. Table A.6 compares the available acreage of all potentially suitable NFS land at 25 and 3 miles from existing transmission infrastructure, cross-tabulated by NFS unit and energy technology. For geothermal and biomass technologies, only the highest category of suitability is reported here, as those lands likely would be developed before lands with lower quality resources. Figures A.1 –A.5 display the results of the CSP, PV, wind, biomass, and EGS results within 3 miles of existing transmission infrastructure.

Table A.1 NFS units with the most potentially suitable land for CSP development within 3 miles of existing transmission infrastructure.

Forest	State	Within 25 Miles of Transmission (Acres)	Within 3 Miles of Transmission (Acres)	Percent of Land Retained
Cibola National Forest	New Mexico	23,166	12,973	56.0%
Coconino National Forest	Arizona	34,471	12,479	36.2%
Kaibab National Forest	Arizona	19,830	4,757	24.0%
Apache-Sitgreaves National Forests	Arizona	14,950	4,757	31.8%
Tonto National Forest	Arizona	8,896	3,830	43.1%

Table A.2 NFS units with the most potentially suitable land for PV development within 3 miles of existing transmission infrastructure.

Forest	State	Within 25 Miles of Transmission (Acres)	Within 3 Miles of Transmission (Acres)	Percent of Land Retained
Comanche National Grassland	Colorado	150,920	37,066	24.6%
Coconino National Forest	Arizona	52,819	22,919	43.4%
Cibola National Forest	New Mexico	71,166	20,386	28.6%
Apache-Sitgreaves National Forests	Arizona	38,363	18,224	47.5%
Rita Blanca National Grassland	Texas	52,201	10,440	20.0%

Table A.3 NFS units with the most potentially suitable land for wind energy development within 3 miles of existing transmission infrastructure.

Forest	State	Within 25 Miles of Transmission (Acres)	Within 3 Miles of Transmission (Acres)	Percent of Land Retained
Dakota Prairie National Grasslands	North Dakota	538,319	199,970	37.1%
Bankhead-Jones Farm Tenant Act Land	Montana	571,431	54,178	9.5%
Buffalo Gap National Grassland	South Dakota	339,090	52,386	15.4%
Thunder Basin National Grassland	Wyoming	304,125	51,892	17.1%
Nebraska National Forest	Nebraska	82,286	32,803	39.9%

Table A.4 NFS units with the most potentially suitable land for biomass development within 3 miles of existing transmission infrastructure.

Forest	State	Within 25 Miles of Transmission (Acres)	Within 3 Miles of Transmission (Acres)	Percent of Land Retained
Fremont-Winema National Forest	Oregon	1,542,247	560,312	36.3%
Shasta-Trinity National Forest	California	382,149	186,873	48.9%
Lassen National Forest	California	526,026	162,286	30.9%
Idaho Panhandle National Forests	Idaho	438,118	159,136	36.3%
Black Hills National Forest	South Dakota	323,090	153,638	47.6%

Table A.5 NFS units with the most potentially suitable land for EGS development within 3 miles of existing transmission infrastructure.

Forest	State	Within 25 Miles of Transmission (Acres)	Within 3 Miles of Transmission (Acres)	Percent of Land Retained
Daniel Boone National Forest	Kentucky	543,076	258,040	47.5%
Mark Twain National Forest	Missouri	900,637	164,696	18.3%
Huron-Manistee National Forest	Michigan	347,924	145,051	41.7%
Ottawa National Forest	Michigan	488,095	119,290	24.4%
Chattahoochee-Oconee National Forest	Georgia	256,557	117,622	45.8%

Table A.6 Quantity (acreage) of potentially suitable land within 25 and 3 miles of existing transmission infrastructure for each resource.

		CSP		*PV*		*Wind*		*Biomass*		*Geothermal*	
Forest	**State**	**Within 25 Miles of Transmission (Acres)**	**Within 3 Miles of Transmission (Acres)**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**
Allegheny NF[a]	Pennsylvania							288,434	121,143		
Angeles NF	California	185	185	927	865	33,421	30,085				
Angelina NF	Texas							85,128	13,529		
Apache-Sitgreaves NF	Arizona	14,950	4,757	38,363	18,224	865					
Apalachicola NF	Florida							51,460	3,459	79,383	57,823
Arapaho and Roosevelt NF	Colorado					40,155	10,378				
Ashley NF	Utah					865					
Bankhead-Jones Farm Tenant Act Land	Montana					571,431	54,178			22,301	2,965
Beaverhead-Deerlodge NF	Montana					20,077	4,695				
Bienville NF	Mississippi							64,927	44,294		
Bighorn NF	Wyoming					22,487					
Bitterroot NF	Montana					309		185	62		
Black Hills NF	S. Dakota					22,989	13,529	323,090	153,638	11,676	9,884
	Wyoming					5,189	865				
Boise NF	Idaho					618		119,846	14,147		
Bridger-Teton NF	Wyoming					247	62				
Buffalo Gap NG[b]	S. Dakota					339,090	52,386	151,537	16,494	99,336	22,487
Caddo-Lyndon B. Johnson NG	Texas					1,112	1,050			927	927

		CSP		PV		Wind		Biomass		Geothermal	
Forest	**State**	**Within 25 Miles of Transmission (Acres)**	**Within 3 Miles of Transmission (Acres)**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**
Caribou-Targhee NF	Idaho					4,880	988				
	Wyoming					309					
Carson NF	New Mexico	9,637	3,459	12,108	3,459	11,552	124				
Chattahoochee-Oconee NF	Georgia							2,471	371	256,557	117,622
Chequamegon-Nicolet NF	Wisconsin							737,301	133,190	671,818	100,695
Cherokee NF	Tennessee									71,846	39,043
Chippewa NF	Minnesota							162,348	59,923		
Cibola NF	New Mexico	23,166	12,973	71,166	20,386	78,888	27,614				
Cimarron NG	Kansas			65,298	5,622	75,800	5,745				
Cleveland NF	California	62	62	741	680	62	62				
Coconino NF	Arizona	34,471	12,479	52,819	22,919	1,730	680			146,657	115,089
Columbia River Gorge NSA[c]	Washington							865	865		
Colville NF	Washington					124	62	245,561	97,607		
Comanche NG	Colorado			150,920	37,066	223,198	30,394				
Conecuh NF	Alabama							60,232	13,467	17,544	13,714
Coronado NF	Arizona	124		3,830	618	247	247				
Croatan NF	N. Carolina							11,490	10,626	27,305	16,124
Custer NF	Montana					92,108	6,734			9,946	9,266
	S. Dakota					47,135	15,877				
Dakota Prairie NG	N. Dakota					538,319	199,970			15,815	1,236
Daniel Boone NF	Kentucky							50,533	30,023	543,076	258,040

		CSP		*PV*		*Wind*		*Biomass*		*Geothermal*	
Forest	**State**	**Within 25 Miles of Transmission (Acres)**	**Within 3 Miles of Transmission (Acres)**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**
Davy Crockett NF	Texas							121,082	28,973		
De Soto NF	Mississippi							213,746	60,726		
Delta NF	Mississippi							432			
Deschutes NF	Oregon					3,398	124	280,526	114,842		
Dixie NF	Utah	247		4,695	1,174	124					
Eldorado NF	California			309	62	124		170,626	17,606	28,664	4,139
Fishlake NF	Utah	124		432	185	247					
Flathead NF	Montana					62		51,830	17,544		
Fort Pierre NG	S. Dakota					89,637	62				
Francis Marion & Sumter NF	S. Carolina							164,263	88,958	111,630	26,440
Fremont-Winema NF	Oregon					5,992	1,544	1,542,247	560,312		
Gallatin NF	Montana					3,768	309				
George Washington & Jefferson NF	Kentucky									618	309
	Virginia							6,054	2,718	217,020	91,614
	W. Virginia					62				927	
Gifford Pinchot NF	Washington					2,842		170,873	6,919	2,780	124
Gila NF	New Mexico	2,718	1,297	12,355	4,448	2,842	2,842				
Grand Mesa, Uncompahgre & Gunnison NF	Colorado			432		2,039	618				
Grand River NG	S. Dakota					83,831	6,672				
Green Mountain & Finger Lakes NF	Vermont					618	371	38,487	4,880	78,765	39,043

		CSP		*PV*		*Wind*		*Biomass*		*Geothermal*	
Forest	**State**	**Within 25 Miles of Transmission (Acres)**	**Within 3 Miles of Transmission (Acres)**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**
Helena NF	Montana					3,954	618				
Hiawatha NF	Michigan							185	62	105,452	17,112
Holly Springs NF	Mississippi							32,062	9,452	124,912	55,475
Homochitto NF	Mississippi							154,441	71,290		
Hoosier NF	Indiana									9,514	432
Humboldt-Toiyabe NF	California	185		309		1,483	62	14,209	9,946	6,734	
	Nevada	2,100	1,668	6,487	2,656	2,595	618	988	865		
Huron-Manistee NF	Michigan					62				347,924	145,051
Idaho Panhandle NF	Idaho					2,286	865	438,118	159,074		
	Montana							123	62		
	Washington							30,826			
Inyo NF	California	4,695	3,212	4,757	3,274	124		62			
	Nevada			309							
Kaibab NF	Arizona	19,830	4,757	37,004	10,317	3,583	1,730			618	
Kisatchie NF	Louisiana							394,442	71,228		
Klamath NF	California					62		237,962	36,572	13,035	803
	Oregon					185		2,965	124	2,965	124
Kootenai NF	Idaho					62		1,730	494		
	Montana					247		210,410	53,437		
Lake Tahoe Basin Management Unit	California	62	62	62	62	309	309	17,236	9,761	12,170	4,819
	Nevada					309	309				
Lassen NF	California			7,475	1,606	432	185	526,026	162,286	371	185

		CSP		*PV*		*Wind*		*Biomass*		*Geothermal*	
Forest	**State**	**Within 25 Miles of Transmission (Acres)**	**Within 3 Miles of Transmission (Acres)**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**
Lewis and Clark NF	Montana					23,351	4,263				
Lincoln NF	New Mexico			3,830	371	67,151	3,274				
Lolo NF	Montana					3,398	741	226,163	87,043		
Los Padres NF	California	62	62	432	124	2,100	927				
Malheur NF	Oregon							610,289	104,773		
Mark Twain NF	Missouri							266,503	93,777	900,637	164,696
McClellan Creek NG	Texas			62	62	494	494				
Medicine Bow-Routt NF	Colorado					1,483	432				
	Wyoming					85,622	10,749			84,139	9,143
Mendocino NF	California			309				24,463		1,606	
Midewin National Tallgrass Prairie	Illinois					3,336	3,336				
Modoc NF	California			494		680	309	186,935	37,931		
Monongahela NF	W. Virginia							295,723	67,769	1,977	618
Mt. Baker-Snoqualmie NF	Washington					680	432	17,792	9,822	1,359	556
Mt. Hood NF	Oregon					10,008	3,830	247,538	86,487		
Nantahala NF	N. Carolina					185		865	124	129,607	32,741
National Forests in Alabama	Alabama									371	
Nebraska NF	Nebraska					82,286	32,803				
Nez Perce-Clearwater NF	Idaho					124		362,812	16,680		
Ocala NF	Florida									24,525	14,270

		CSP		PV		Wind		Biomass		Geothermal	
Forest	**State**	**Within 25 Miles of Transmission (Acres)**	**Within 3 Miles of Transmission (Acres)**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**
Ochoco NF	Oregon					1,174	741	741			
Oglala NF	Nebraska					75,182	1,297				
Okanogan-Wenatchee NF	Washington					6,487	1,112	236,603	12,849		
Olympic NF	Washington					432	247	37,436	18,348		
Ottawa NF	Michigan							538,257	128,433	488,095	119,290
Ouachita NF	Arkansas					309	62	345,762	52,201	868,390	87,908
	Oklahoma							193,360	30,518	19,830	124
Ozark-St. Francis NF	Arkansas					62	62	67,830	2,162	26,255	10,626
Pawnee NG	Colorado					34,533	5,683				
Payette NF	Idaho					1,421	865	28,479	62		
Pike and San Isabel NF	Colorado	309	62	927	309	14,765	6,981				
Pisgah NF	N. Carolina							7,598	4,942	30,147	2,286
Plumas NF	California			3,521	741	1,668	309	436,265	118,858	66,533	10,687
Prescott NF	Arizona	5,622	1,792	7,537	2,348						
Rio Grande NF	Colorado	556		680		8,278					
Rita Blanca NG	Oklahoma			1,606		1,421					
	Texas			52,201	10,440	58,873	13,591				
Rogue River-Siskiyou NF	California							5,004	1,421	309	309
	Oregon					4,695		208,310	16,309	22,487	494
Sabine NF	Texas							45,344	17,236		
Salmon-Challis NF	Idaho					3,336	371	432			
Sam Houston NF	Texas							33,606	2,224		

		CSP		*PV*		*Wind*		*Biomass*		*Geothermal*	
Forest	**State**	**Within 25 Miles of Transmission (Acres)**	**Within 3 Miles of Transmission (Acres)**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**
Samuel R. McKelvie NF	Nebraska					108,726					
San Bernardino NF	California			247	62	6,178	5,066				
San Juan NF	Colorado	1,853	124	3,459	803						
Santa Fe NF	New Mexico	5,498	1,730	7,598	1,792	25,081	247				
Sawtooth NF	Idaho					26,378	1,483				
	Utah					124					
Sequoia NF	California	247	62	309	62	618	124			27,182	5,622
Shasta-Trinity NF	California							382,149	186,873	147,893	57,390
Shoshone NF	Wyoming					31,259	7,598			27,120	11,182
Sierra NF	California	185		309	124					69,190	23,846
Siuslaw NF	Oregon					741	124	59,305	30,085		
Six Rivers NF	California							54,301	5,004	54,240	4,942
Stanislaus NF	California			494				185,453	45,591	29,344	309
Superior NF	Minnesota							38,610	9,390		
Tahoe NF	California	247	62	988	680	680	124	247,600	100,943	56,525	10,564
Talladega NF	Alabama							85,251	13,591	136,279	30,456
Thunder Basin NG	Wyoming					304,125	51,892				
Tombigbee NF	Mississippi							32,062	16,618	32,371	16,680
Tonto NF	Arizona	8,896	3,830	8,896	3,830	741	741				
Tuskegee NF	Alabama									7,413	6,363
Uinta-Wasatch-Cache NF	Utah					1,050					
Umatilla NF	Oregon					5,251	1,236	201,267	35,398		
	Washington					1,915					

		CSP		*PV*		*Wind*		*Biomass*		*Geothermal*	
Forest	**State**	**Within 25 Miles of Transmission (Acres)**	**Within 3 Miles of Transmission (Acres)**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**	**Within 25 Miles**	**Within 3 Miles**
Umpqua NF	Oregon					1,112		217,144	44,726	15,197	2,100
Uwharrie NF	N. Carolina							34,224	15,815	35,769	16,741
Wallowa-Whitman NF	Oregon					1,544	432	426,442	56,278		
Wayne NF	Ohio									63,321	36,201
White Mountain NF	Maine							17,792	185	247	185
	New Hampshire					62		106,873	63,568	40,031	18,842
White River NF	Colorado					2,533	1,174				
Willamette NF	Oregon					1,668	124	209,792	37,375	3,212	247
William B. Bankhead NF	Alabama							67,336	5,992	25,575	988
Total		**136,032**	**52,633**	**564,698**	**155,368**	**3,357,792**	**636,235**	**13,967,077**	**3,778,365**	**6,475,459**	**1,846,989**

[a] NF = National Forest

[b] NG = National Grassland

[c] NSA = National Scenic Area

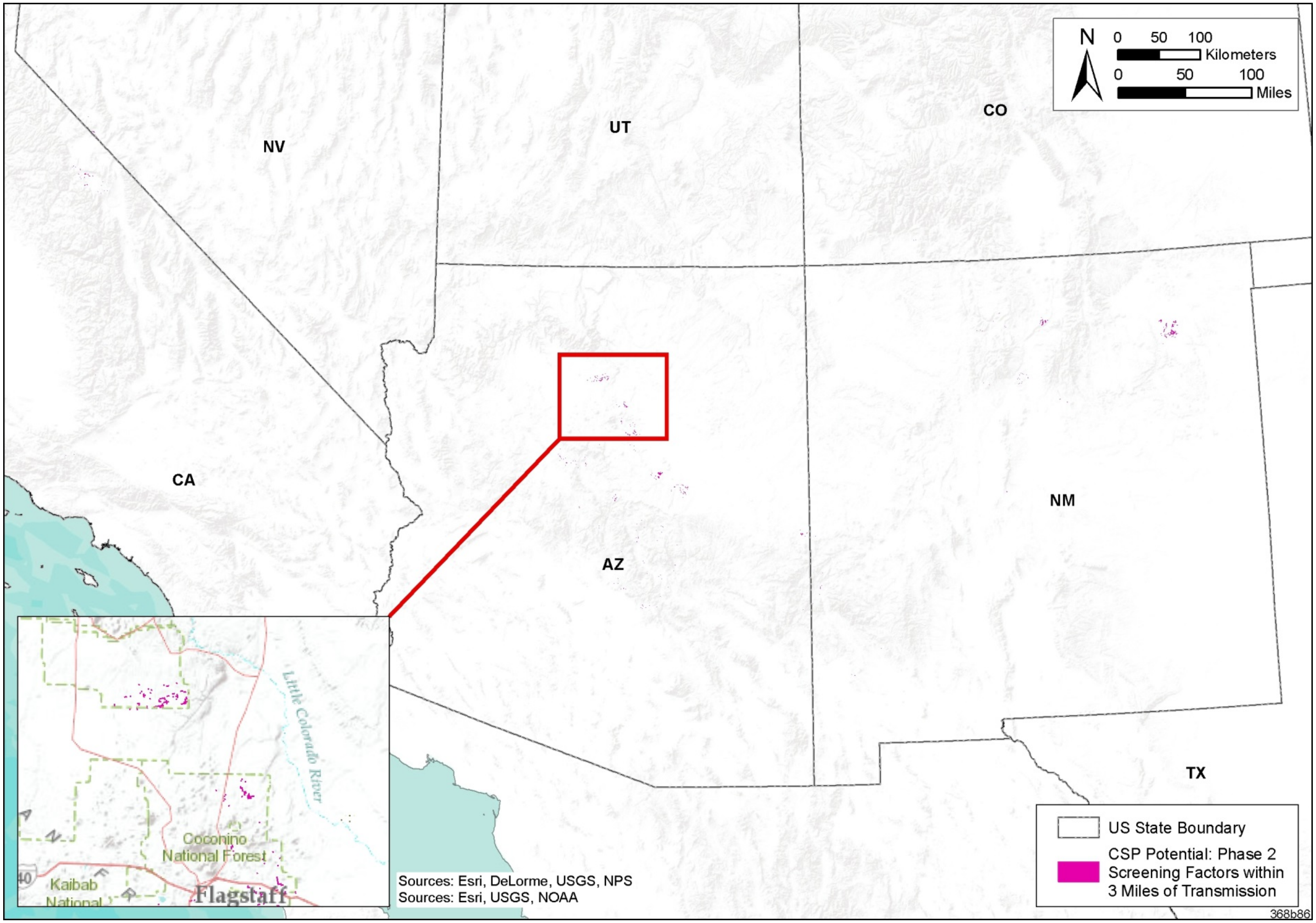


Figure A.1 NFS land that is potentially suitable for concentrating solar power energy development within 3 miles of existing transmission infrastructure.

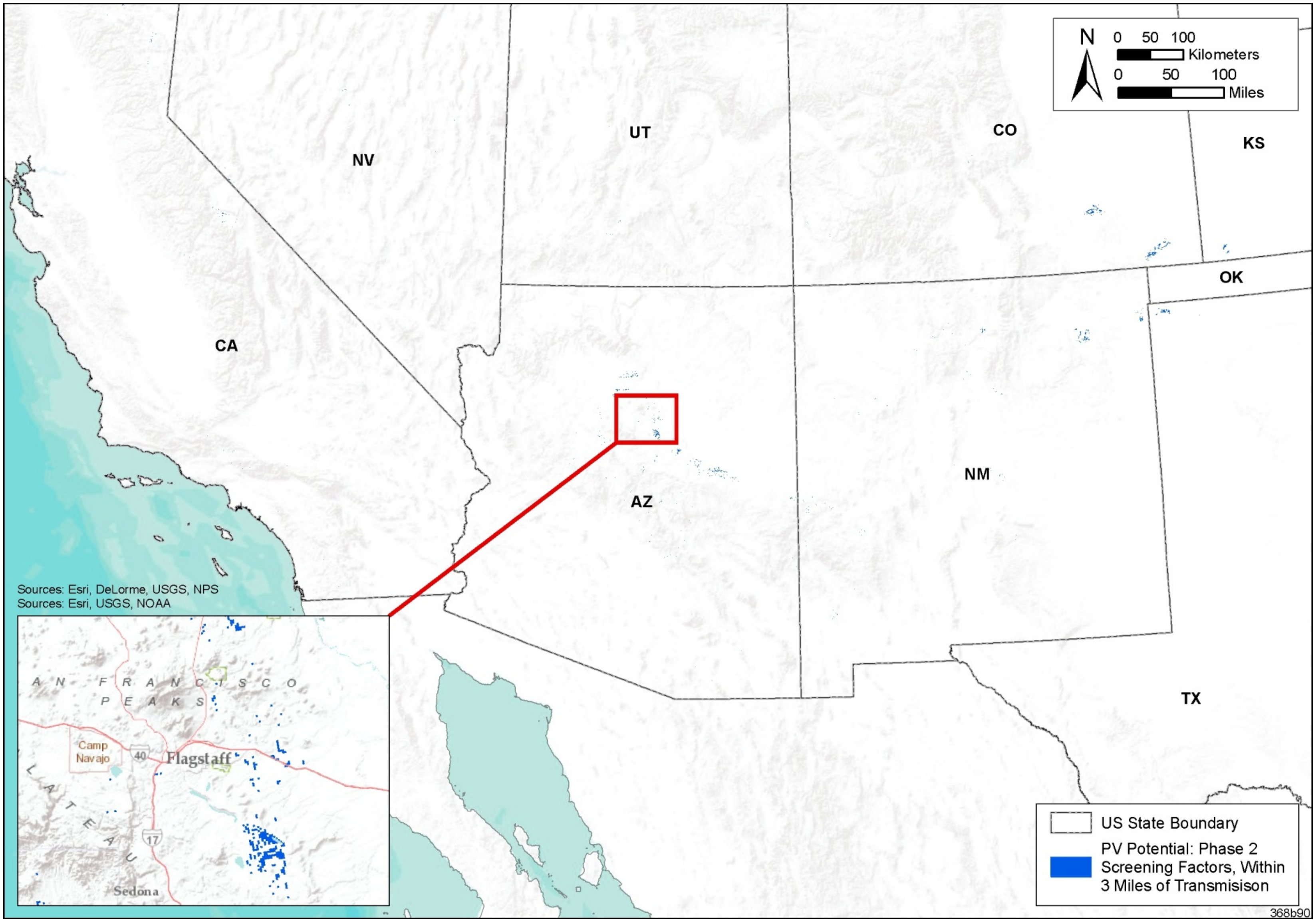


Figure A.2 NFS land that is potentially suitable for photovoltaic solar energy development within 3 miles of existing transmission infrastructure.

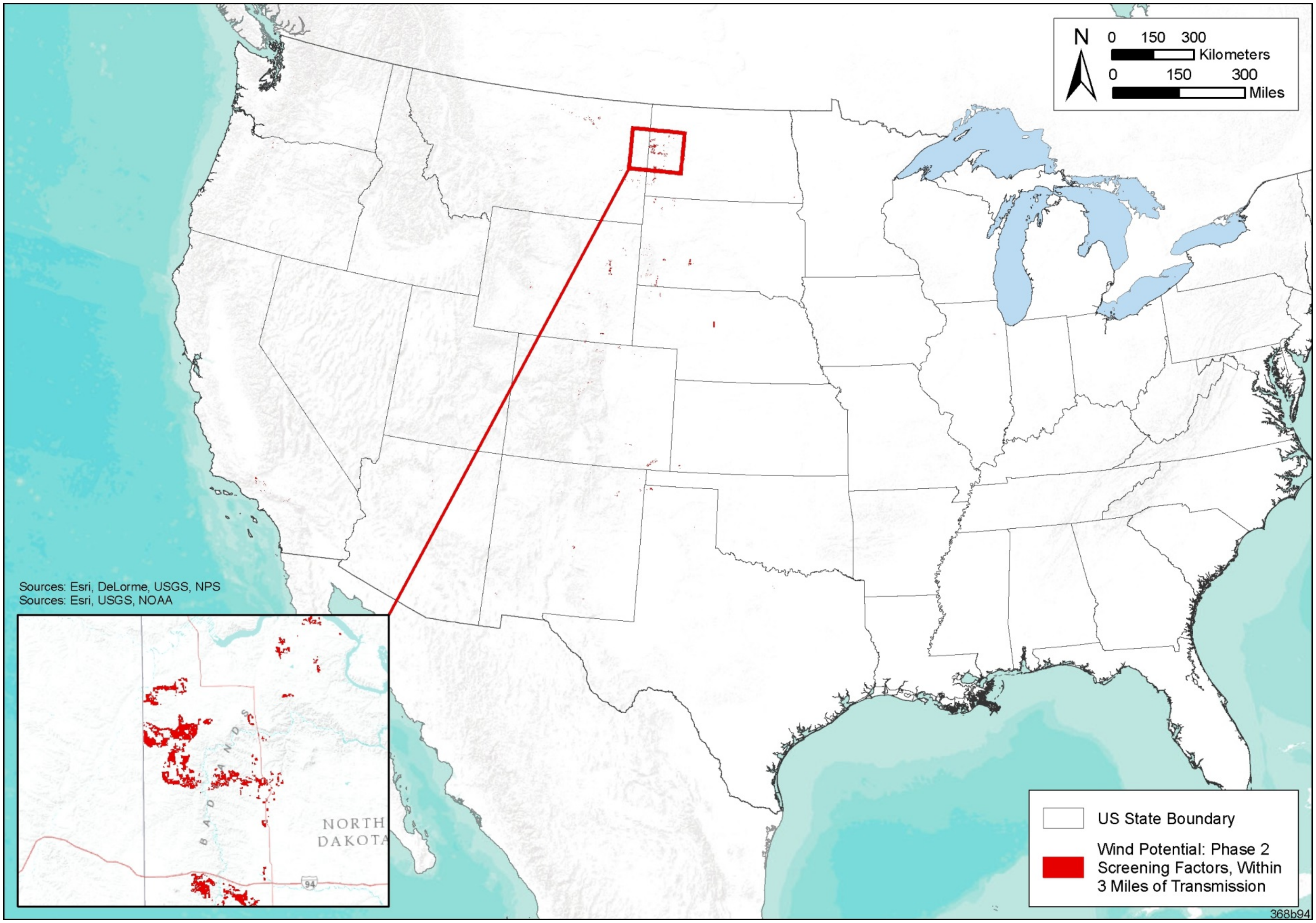


Figure A.3 NFS land that is potentially suitable for wind energy development within 3 miles of existing transmission infrastructure.

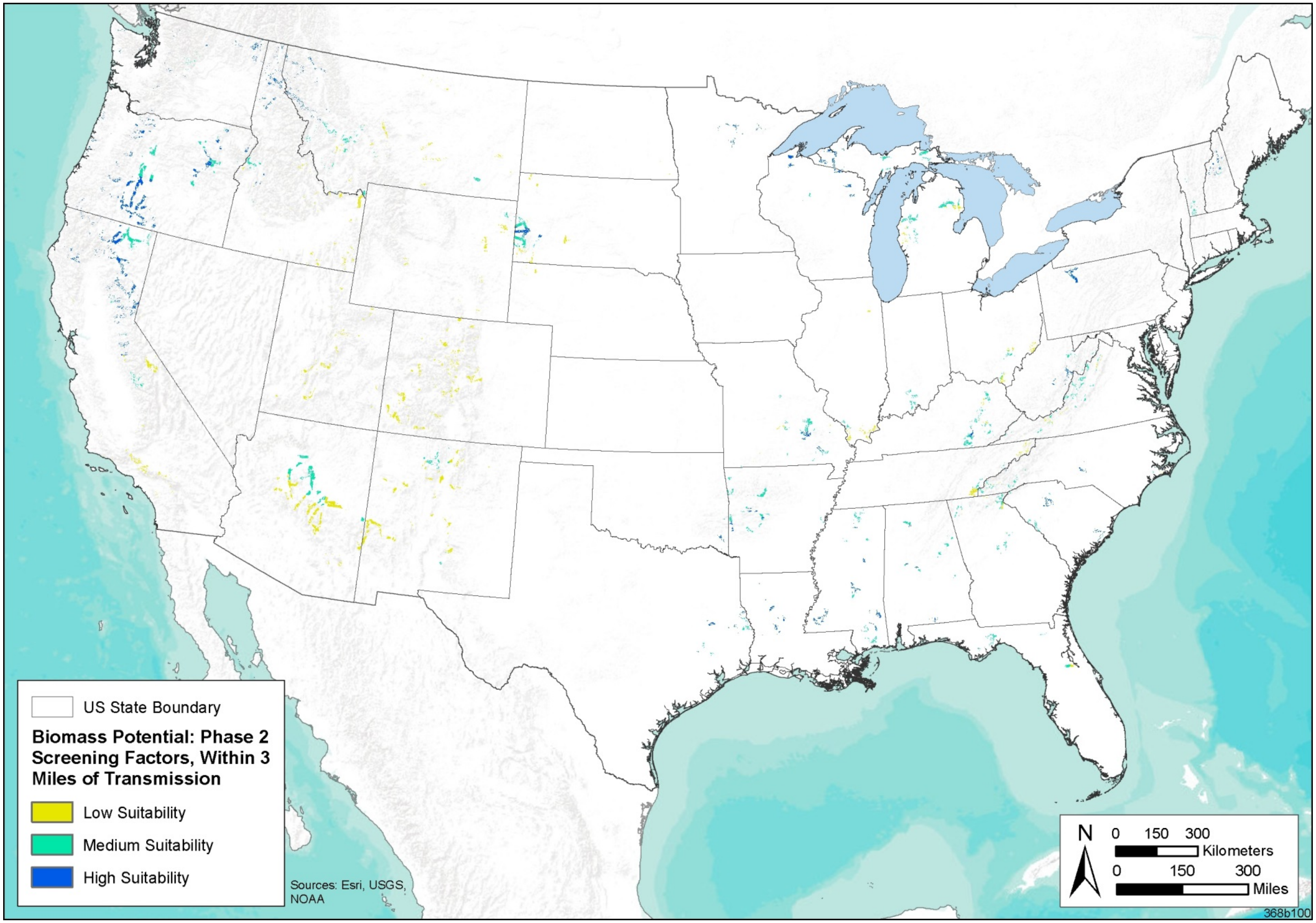


Figure A.4 NFS land that is potentially suitable for biomass energy development within 3 miles of existing transmission infrastructure.

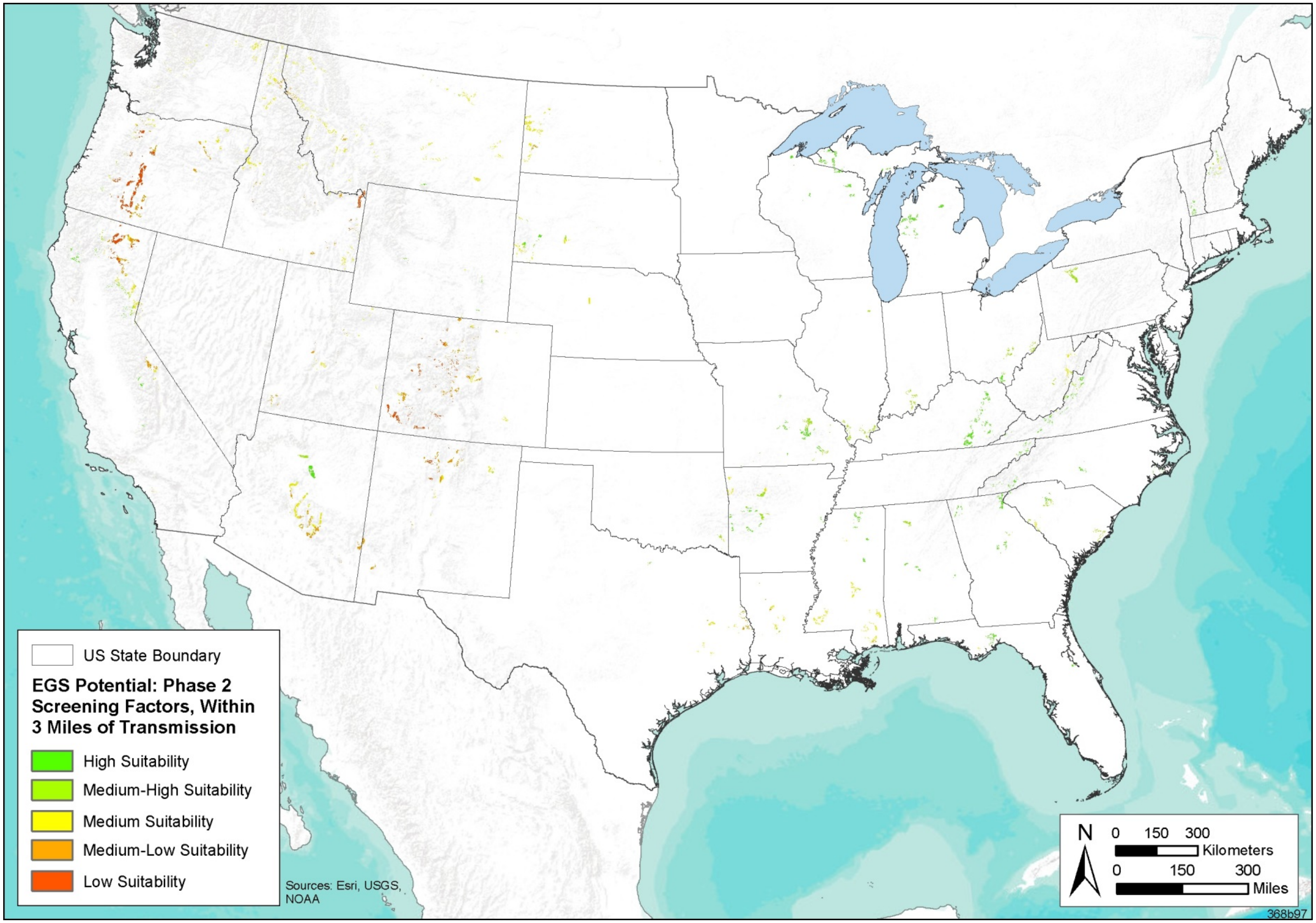


Figure A.5 NFS land that is potentially suitable for enhanced geothermal systems energy development within 3 miles of existing transmission infrastructure.

This page intentionally left blank.

Appendix B: Maps of Energy Resources and Screening Factors

The figures in this appendix (Figures B.1–B.X) display the input layers used in the renewable energy technology suitability analyses, including energy resource data and screening factors. The figures show the data after they were converted to 500-m raster format, except in cases of line or point data where the raster version would be barely visible at the scale of the figures.

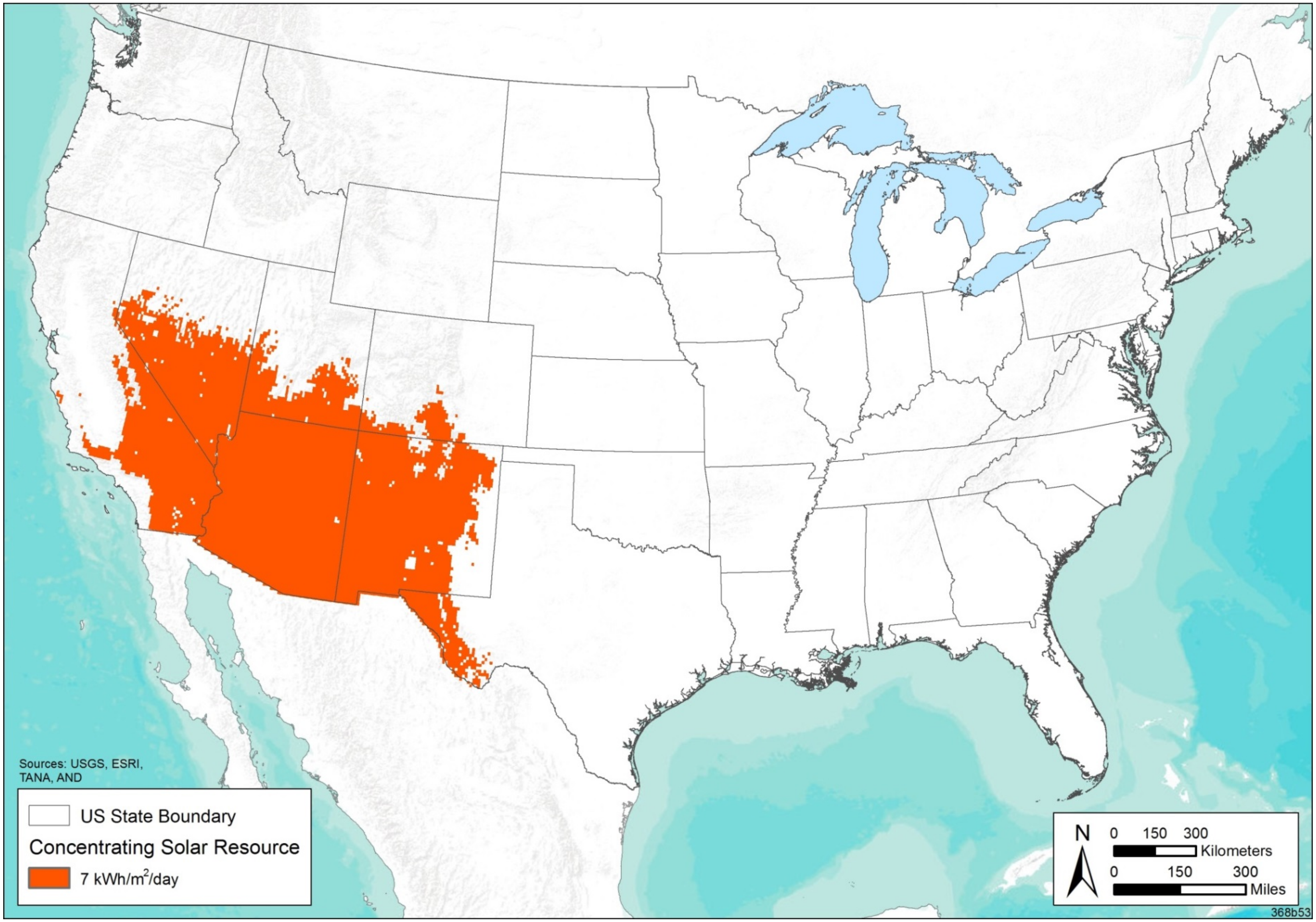


Figure B.1 Location of CSP resource with insolation greater than or equal to 7 kWh/m²/day.

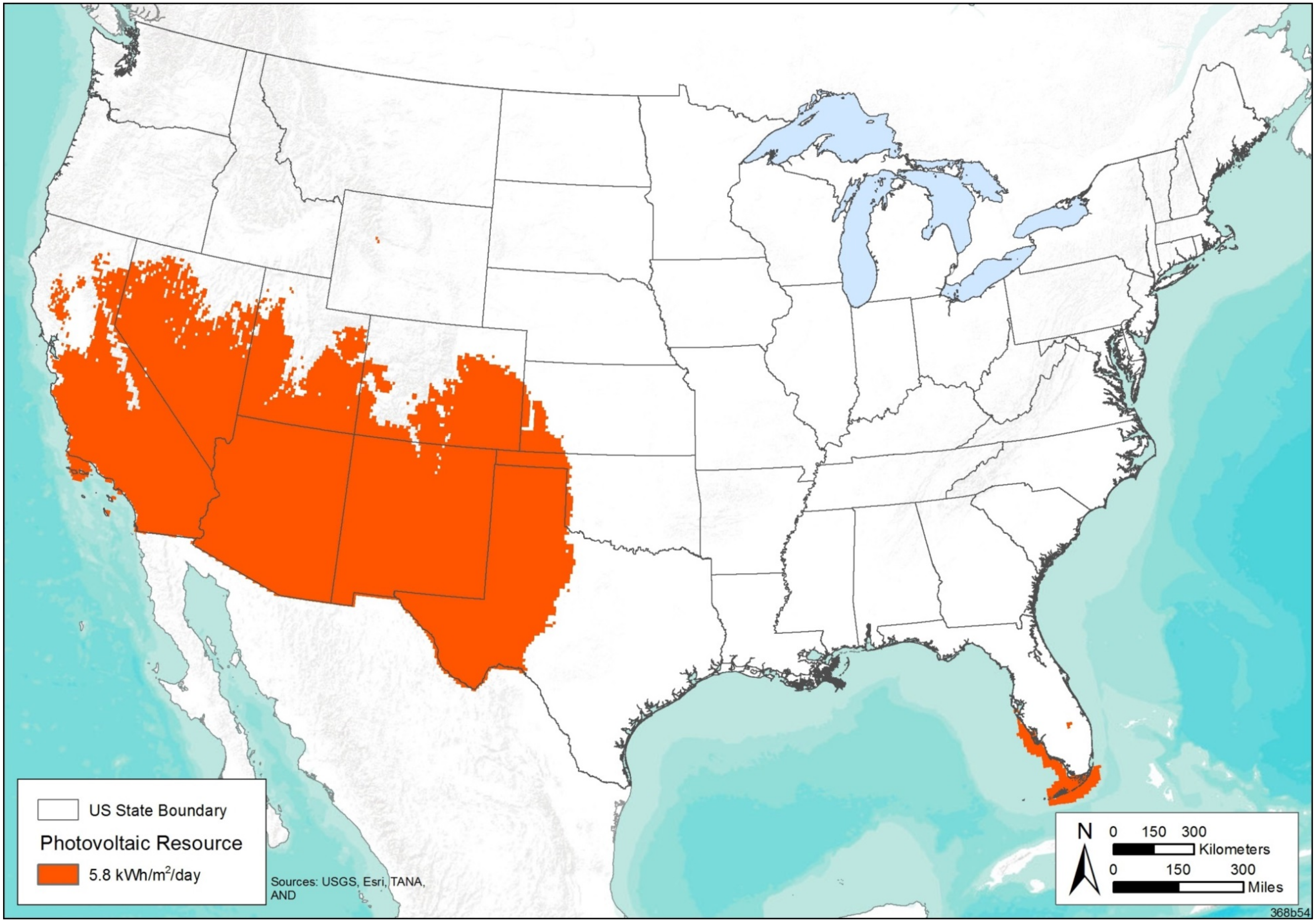


Figure B.2 Location of PV resource with insolation greater than or equal to 5.8 kWh/m^2/day.

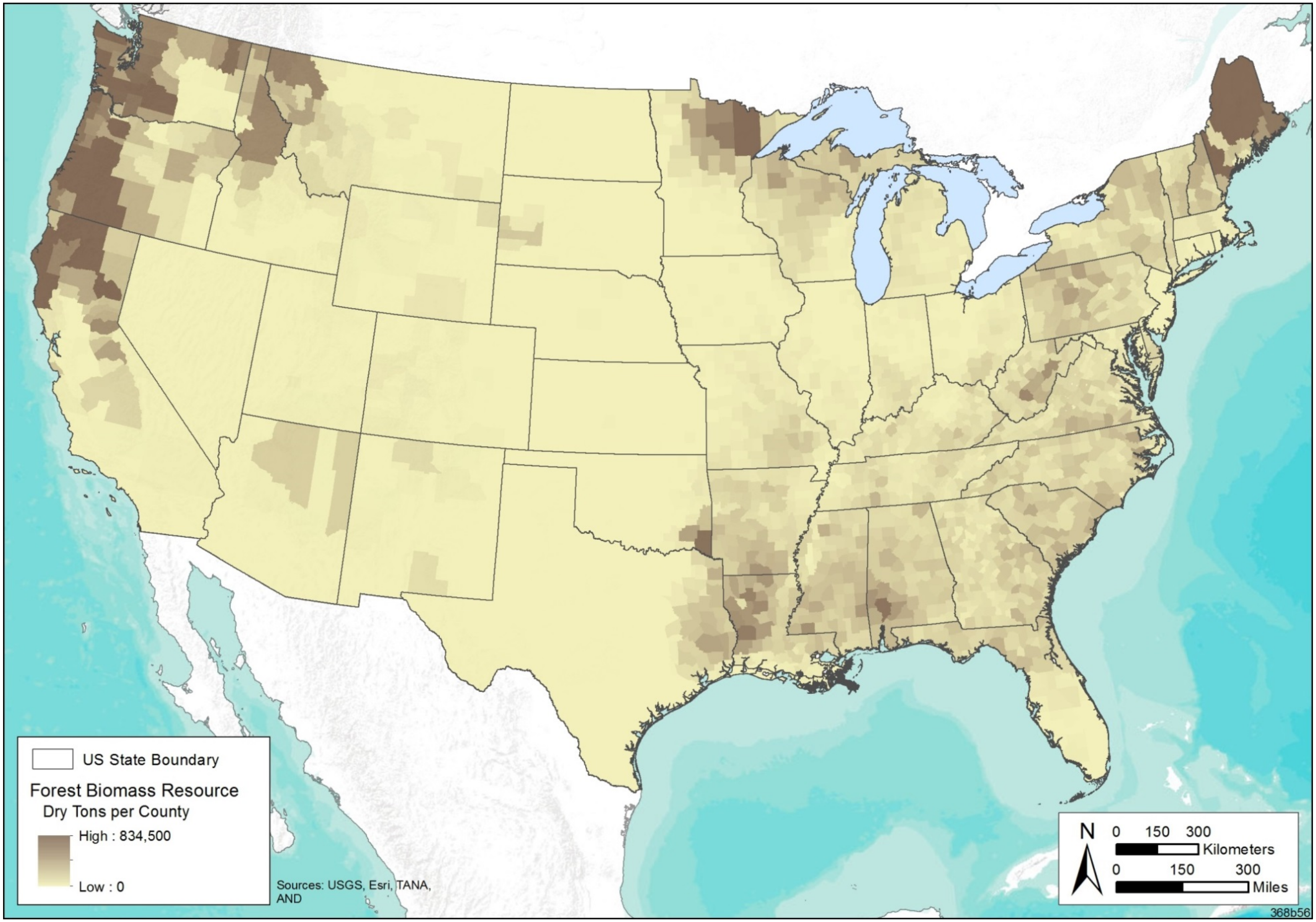


Figure B.3 Biomass resource; sourced from forest logging and thinning residues, in dry tons per county.

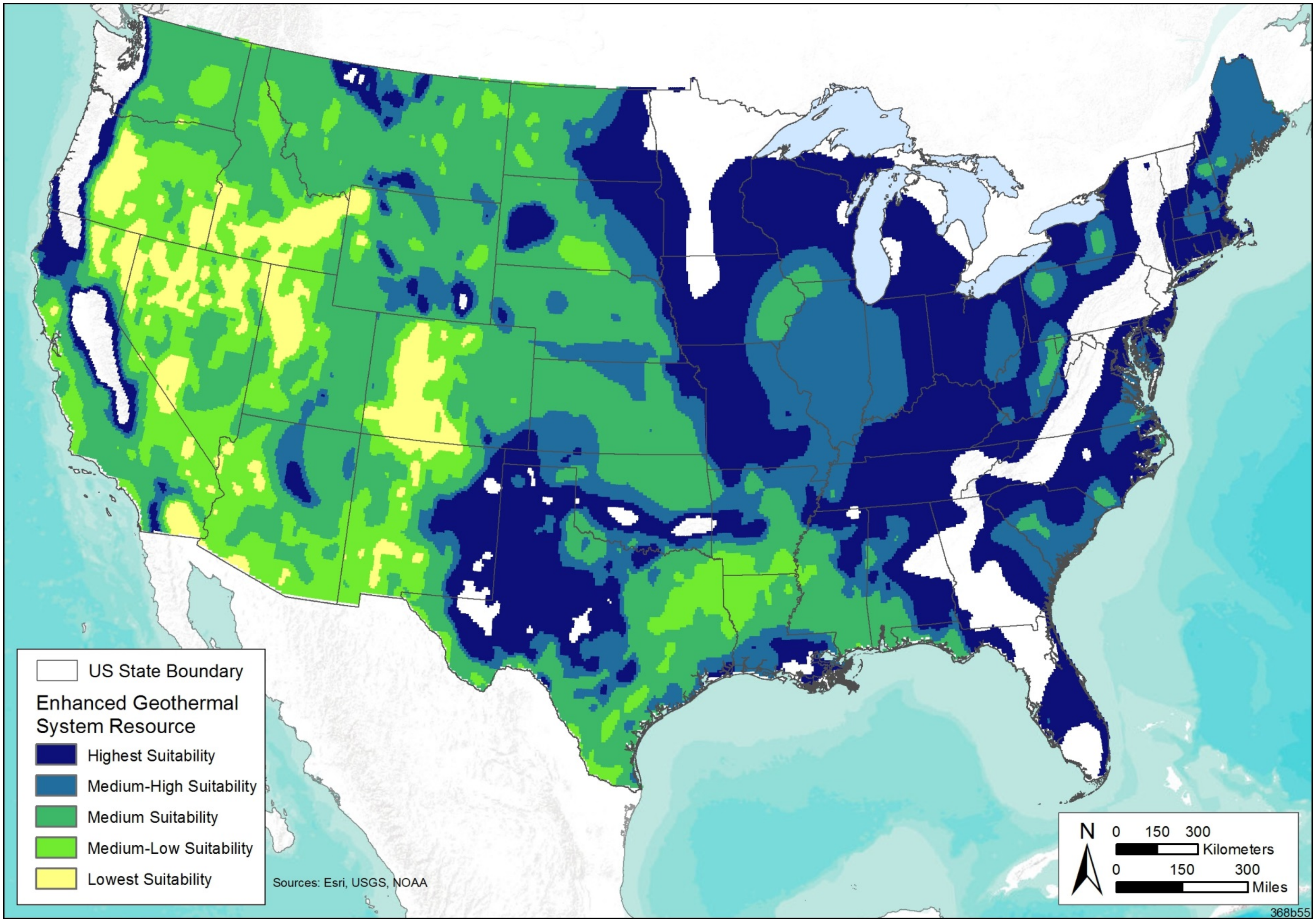


Figure B.4 Enhanced Geothermal System (EGS) resource; groupings based on Levelized Cost of Electricity.

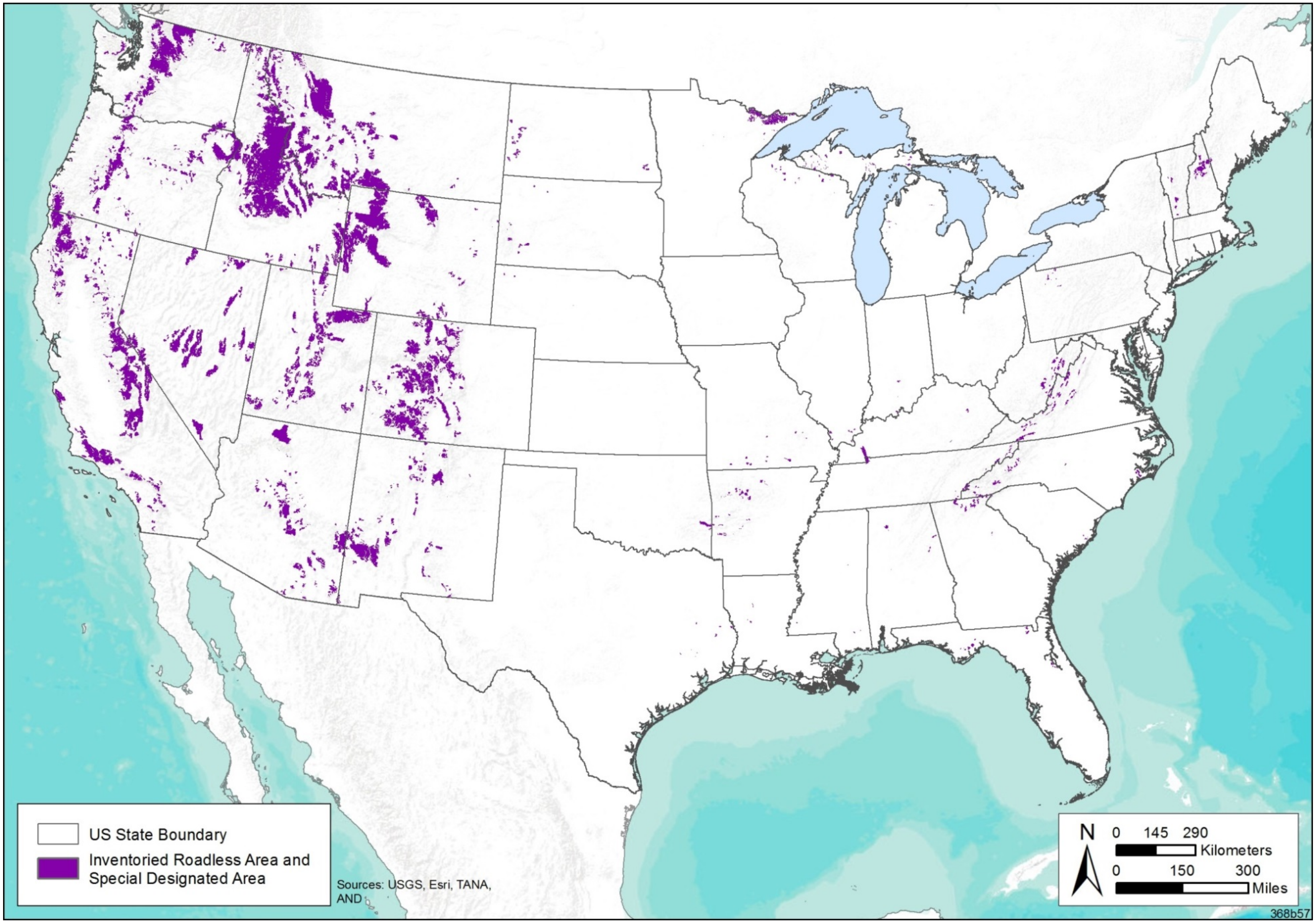


Figure B.5 NFS Inventoried Roadless Areas and Special Designated Areas, as excluded from potential development analyses.

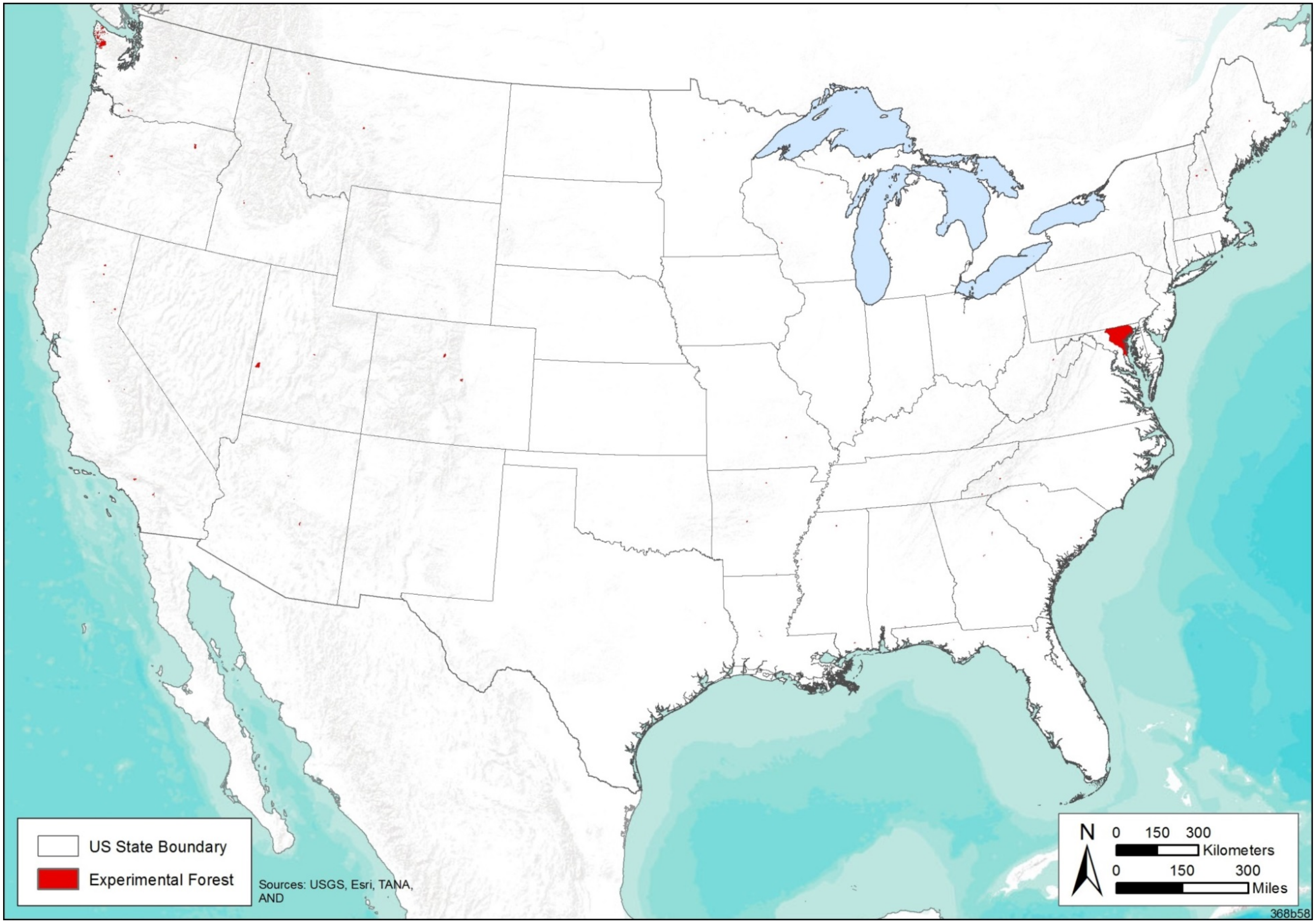


Figure B.6 NFS experimental forests, as excluded from potential development analyses.

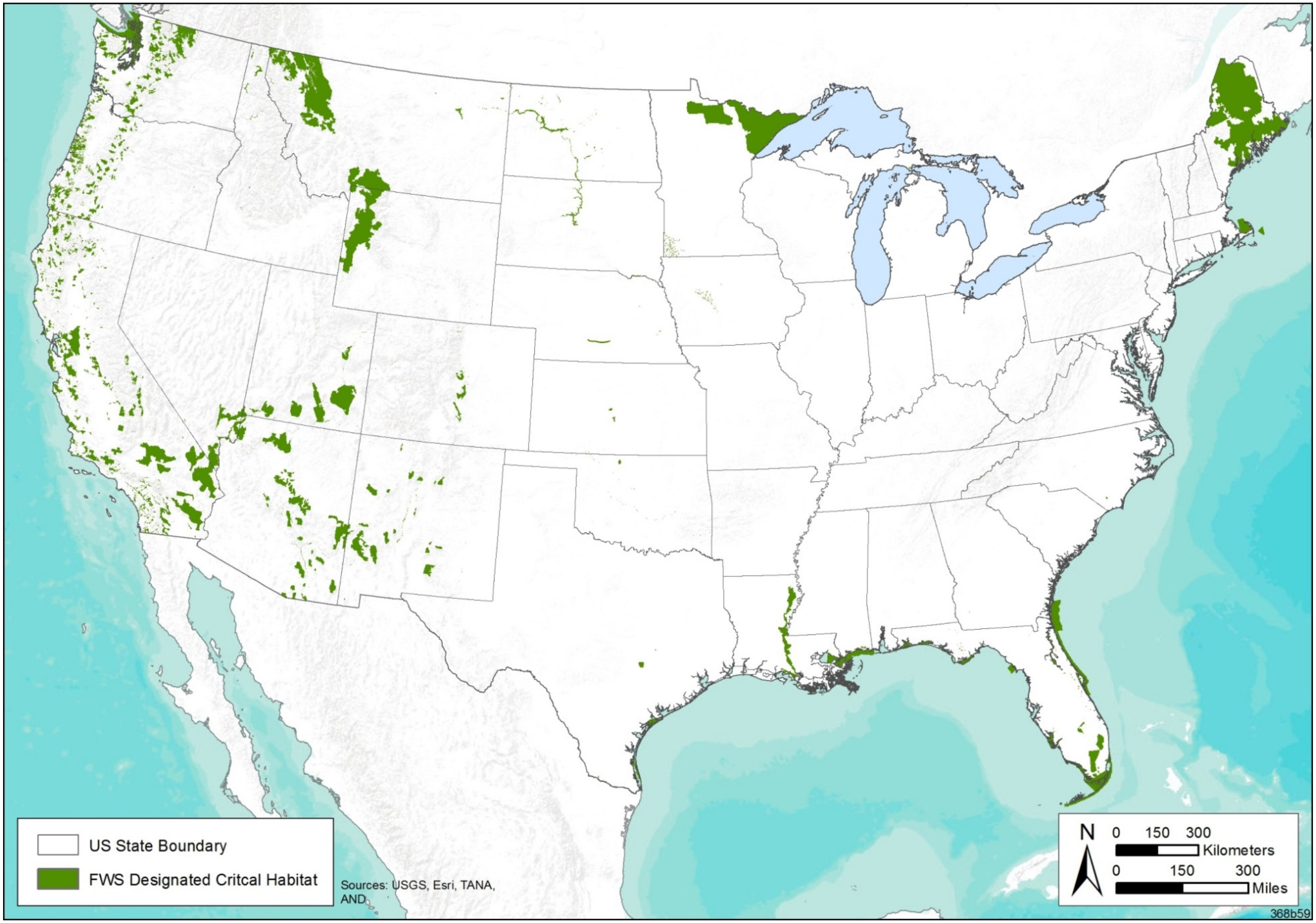


Figure B.7 Critical habitat areas designated by the U.S. Fish and Wildlife Service, as excluded from potential development analyses.

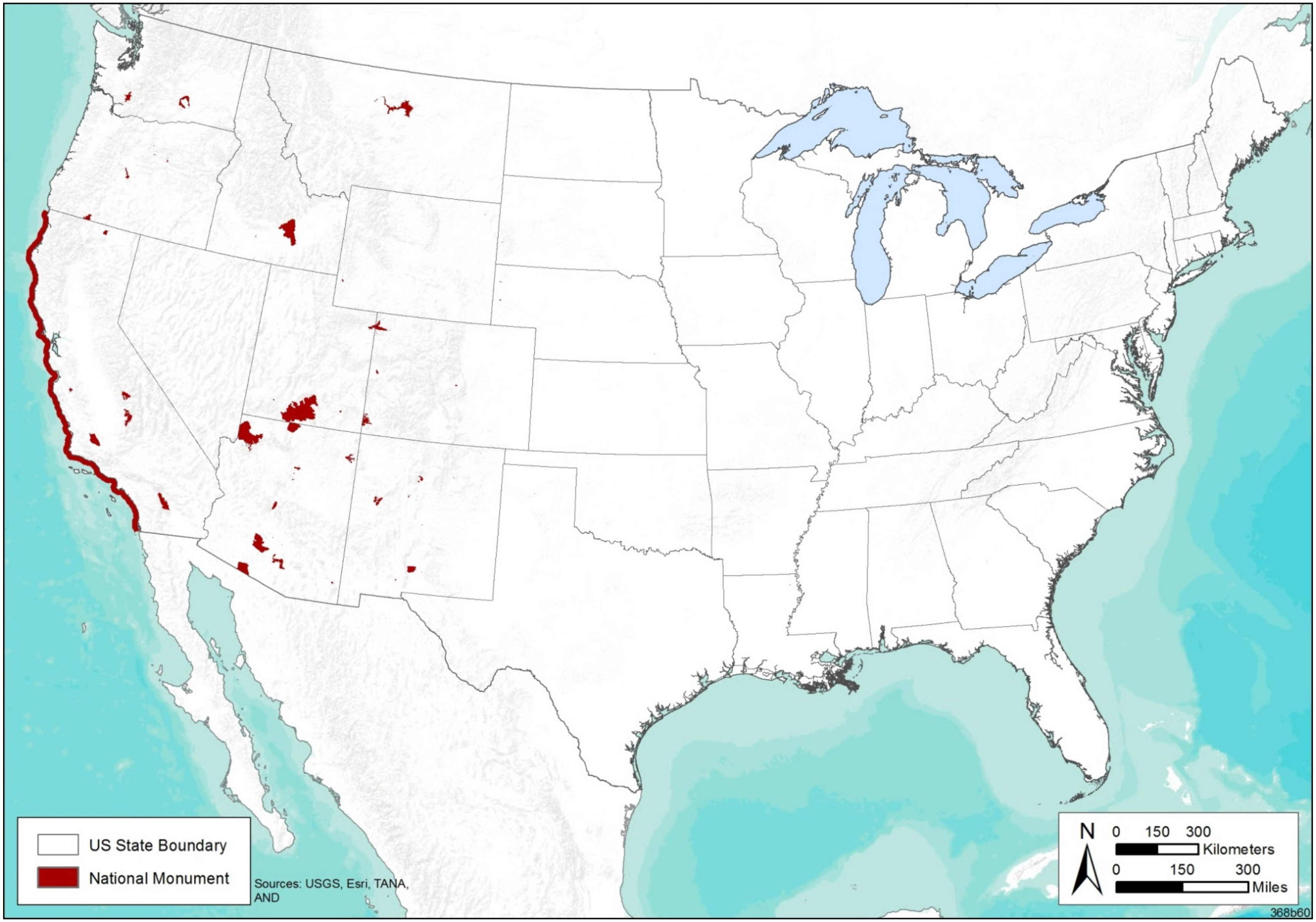


Figure B.8 National monuments, as excluded from potential development analyses.

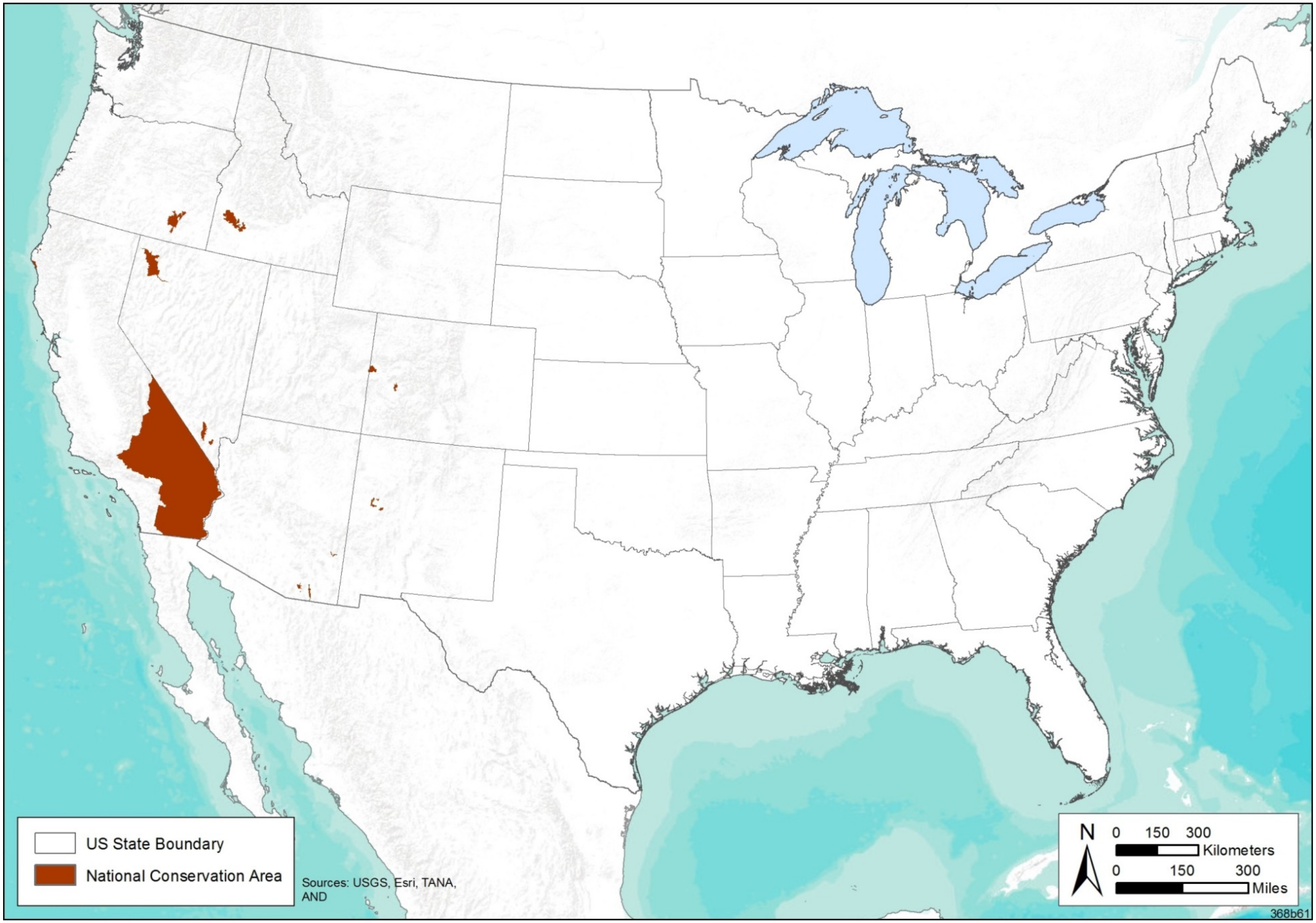


Figure B.9 National Conservation Areas, as excluded from potential development analyses.

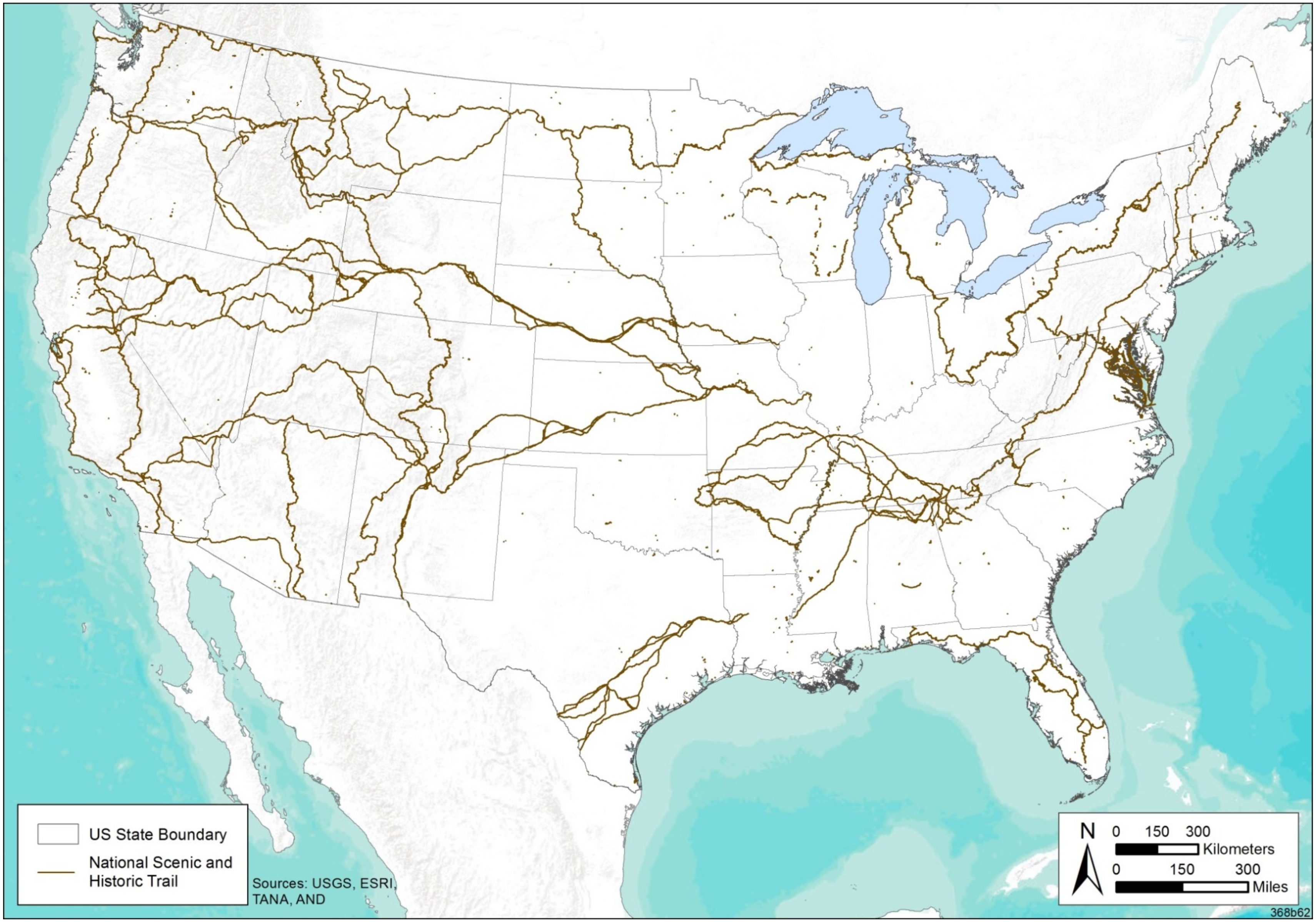


Figure B.10 National Scenic and National Historic Trails, as excluded from potential development analyses.

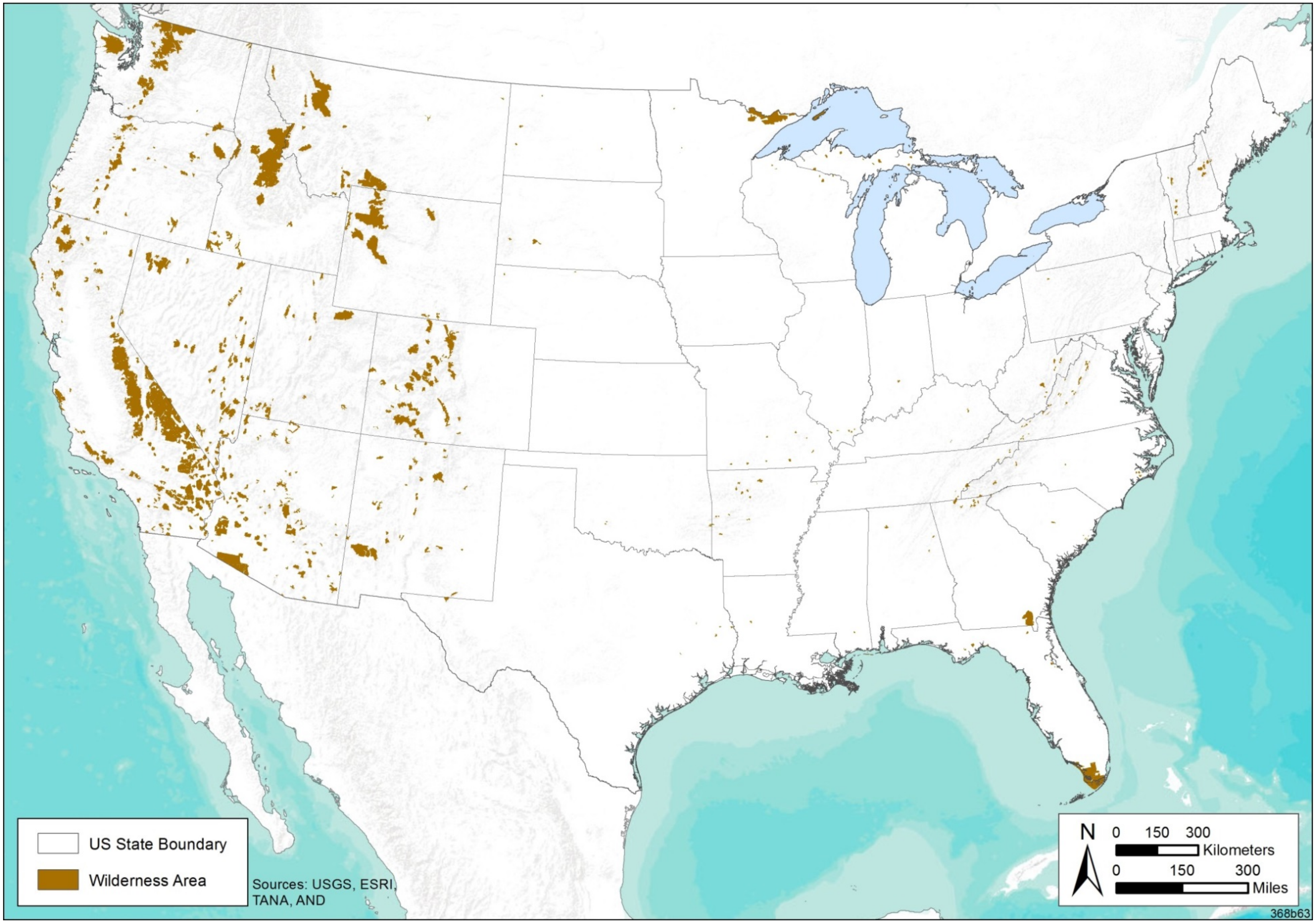


Figure B.11 Wilderness areas, as excluded from potential development analyses.

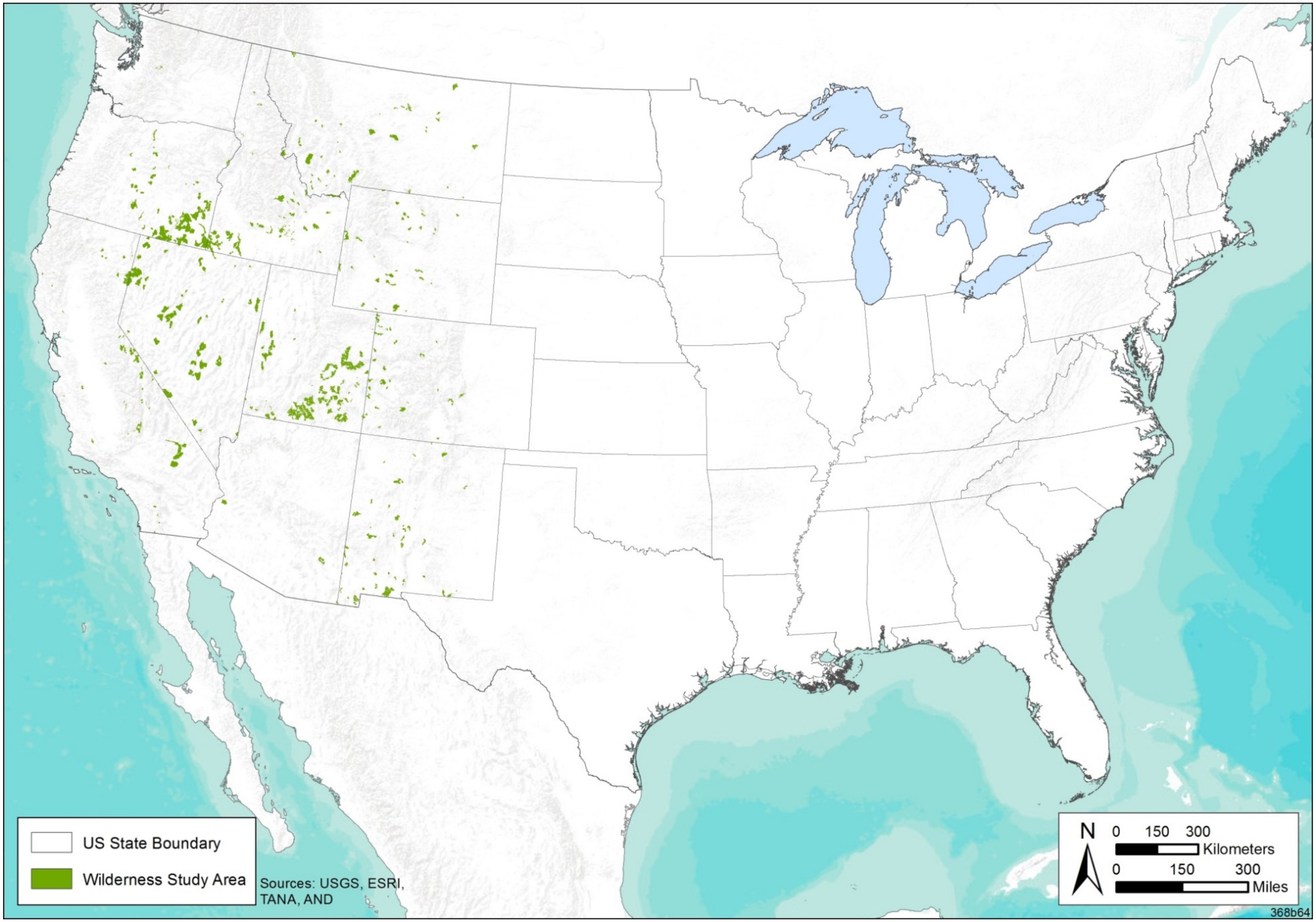


Figure B.12 Wilderness study areas, as excluded from potential development analyses.

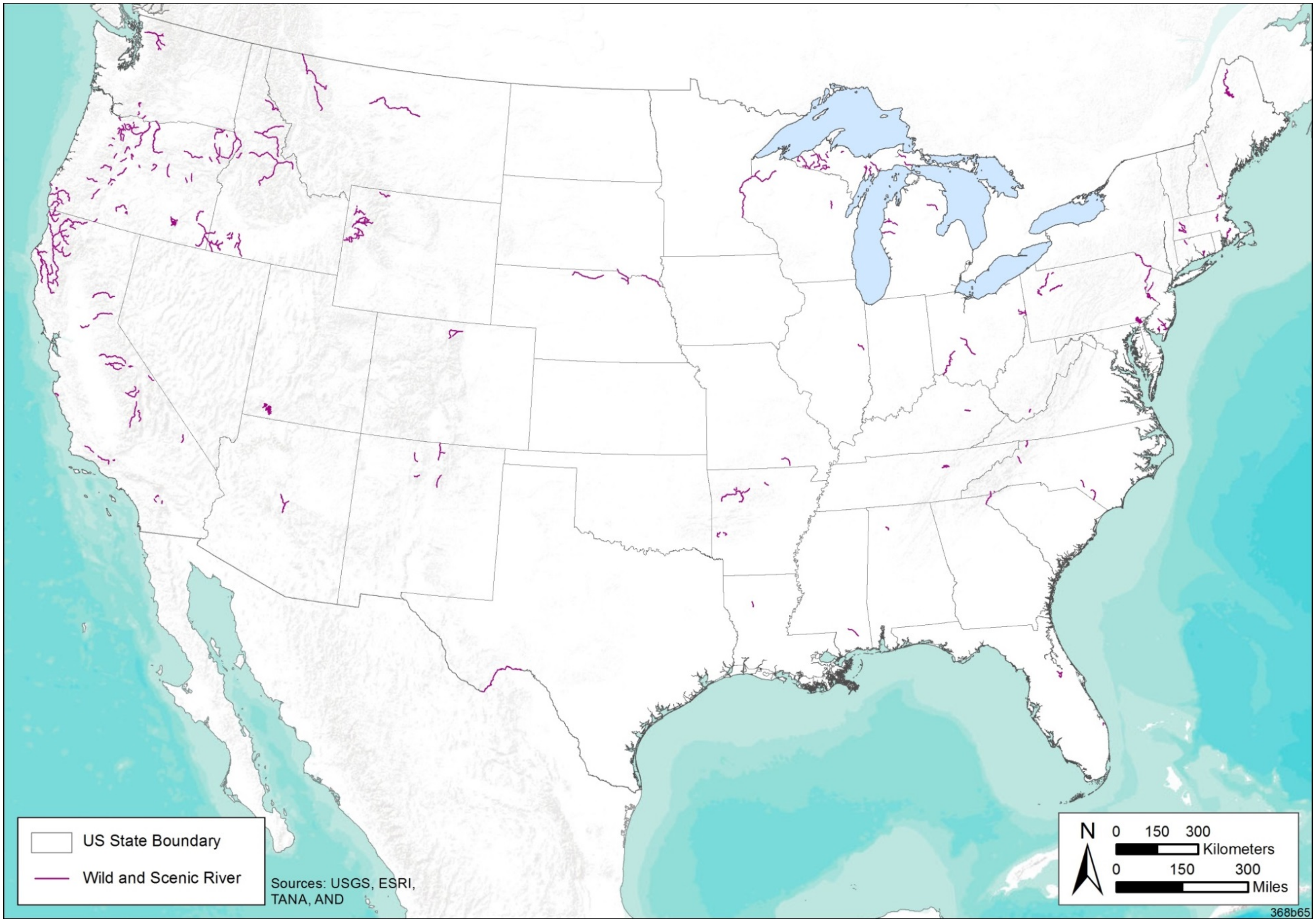


Figure B.13 Wild and scenic rivers, as excluded from potential development analyses.

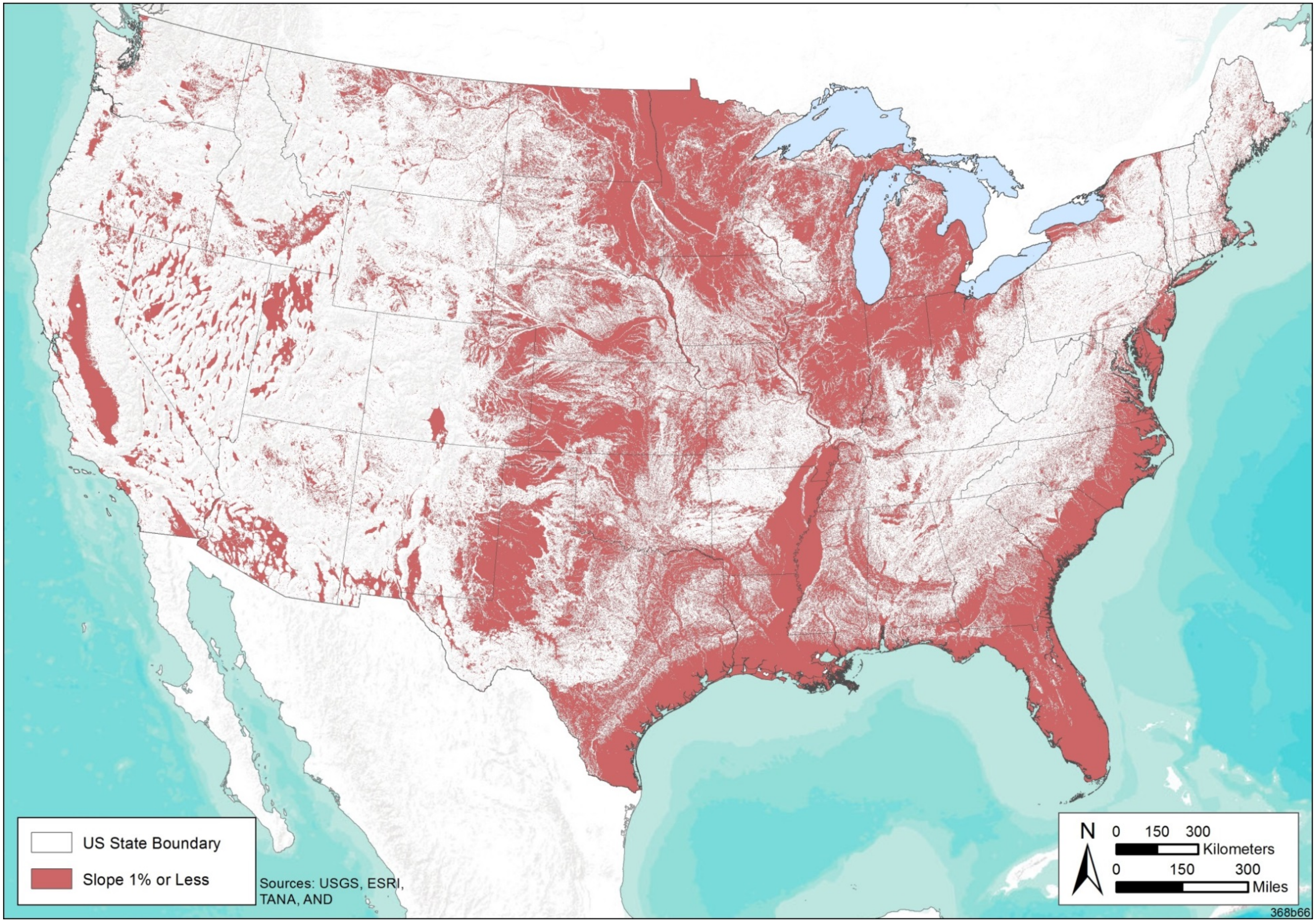


Figure B.14 Areas where topographic slope is less than or equal to 1%, as used in CSP and PV refining analyses.

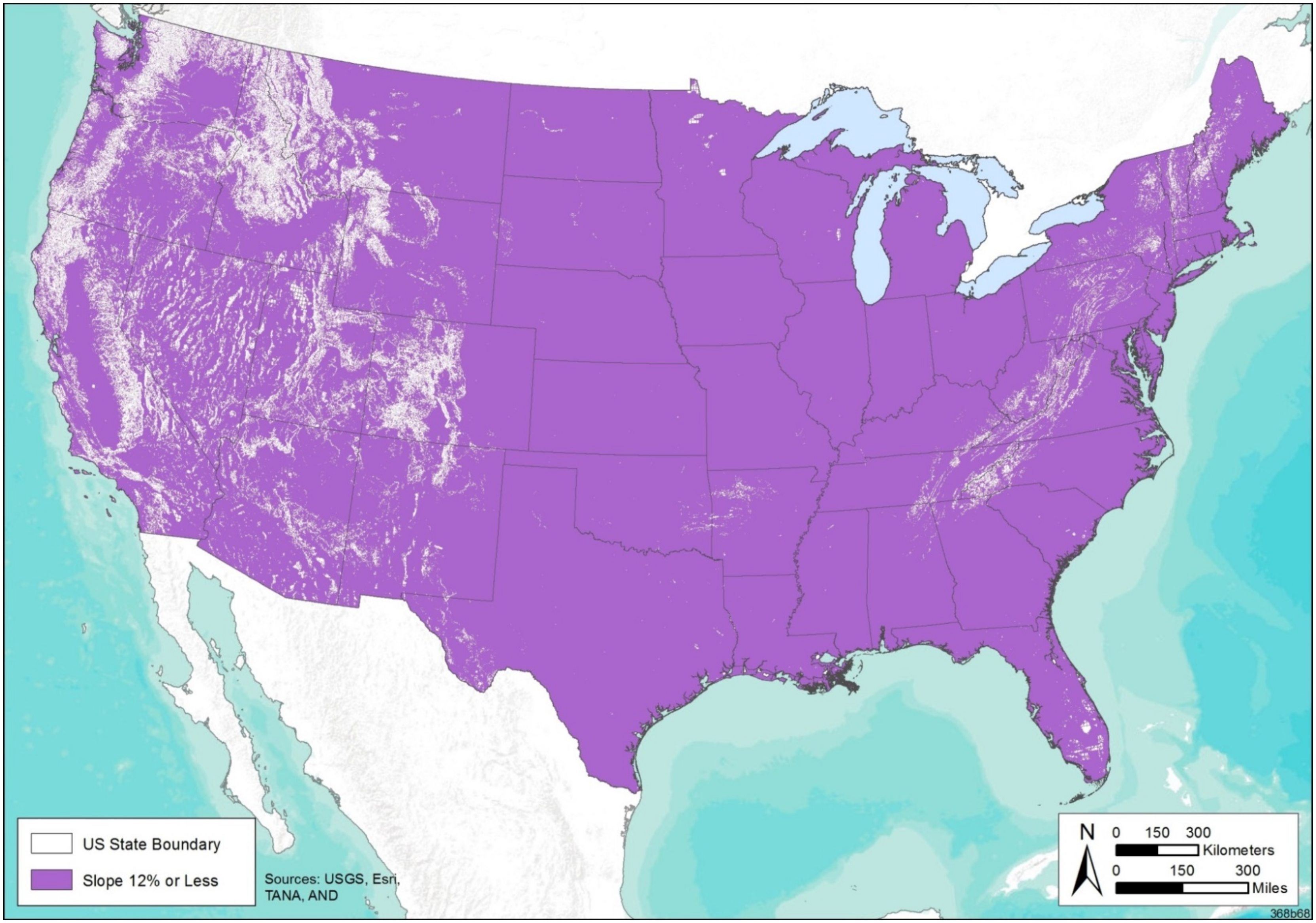


Figure B.15 Areas where topographic slope is less than or equal to 12%, as used in the biomass and EGS analyses.

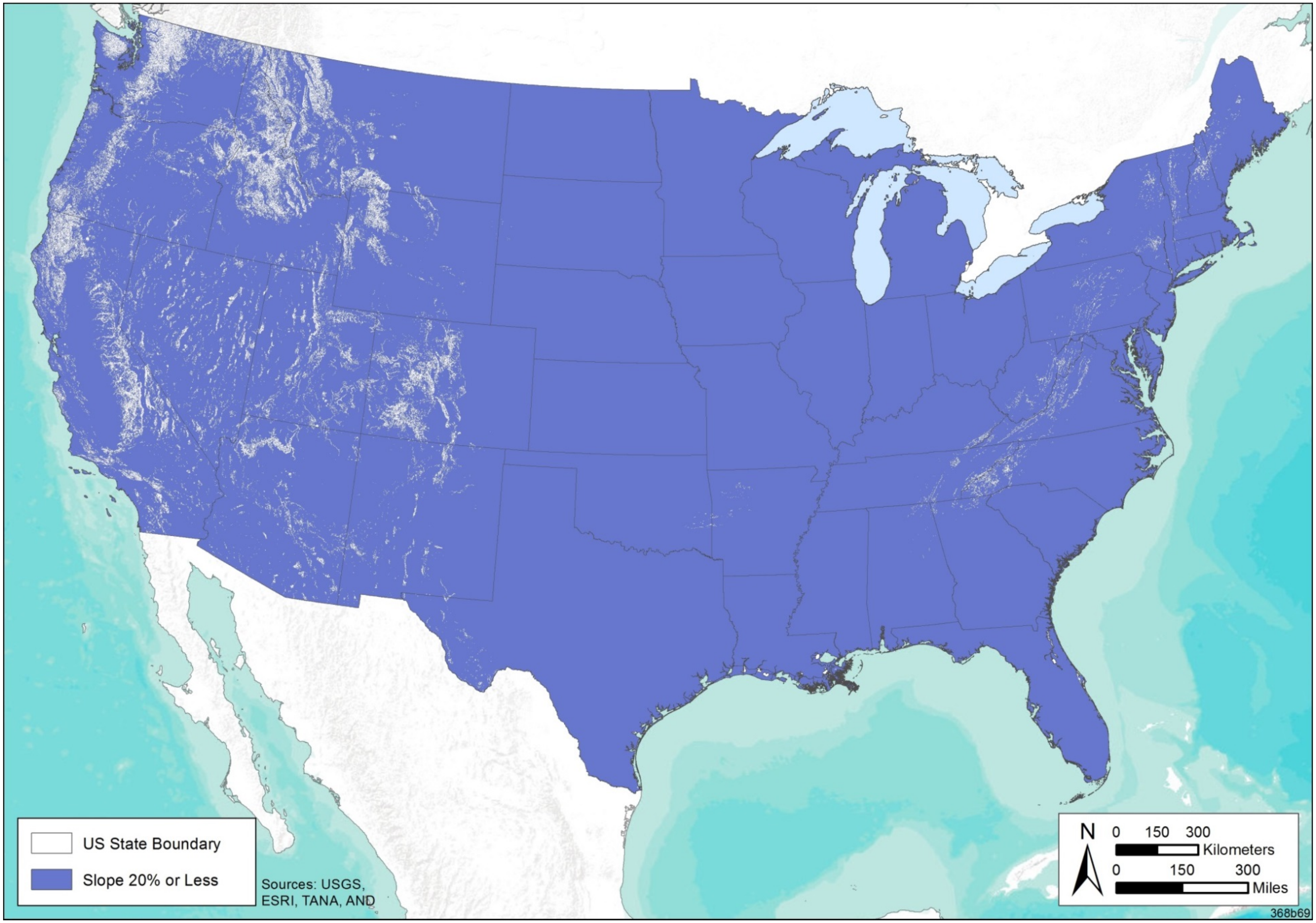


Figure B.16 Areas where topographic slope is less than or equal to 20%, as used in the wind energy analysis.

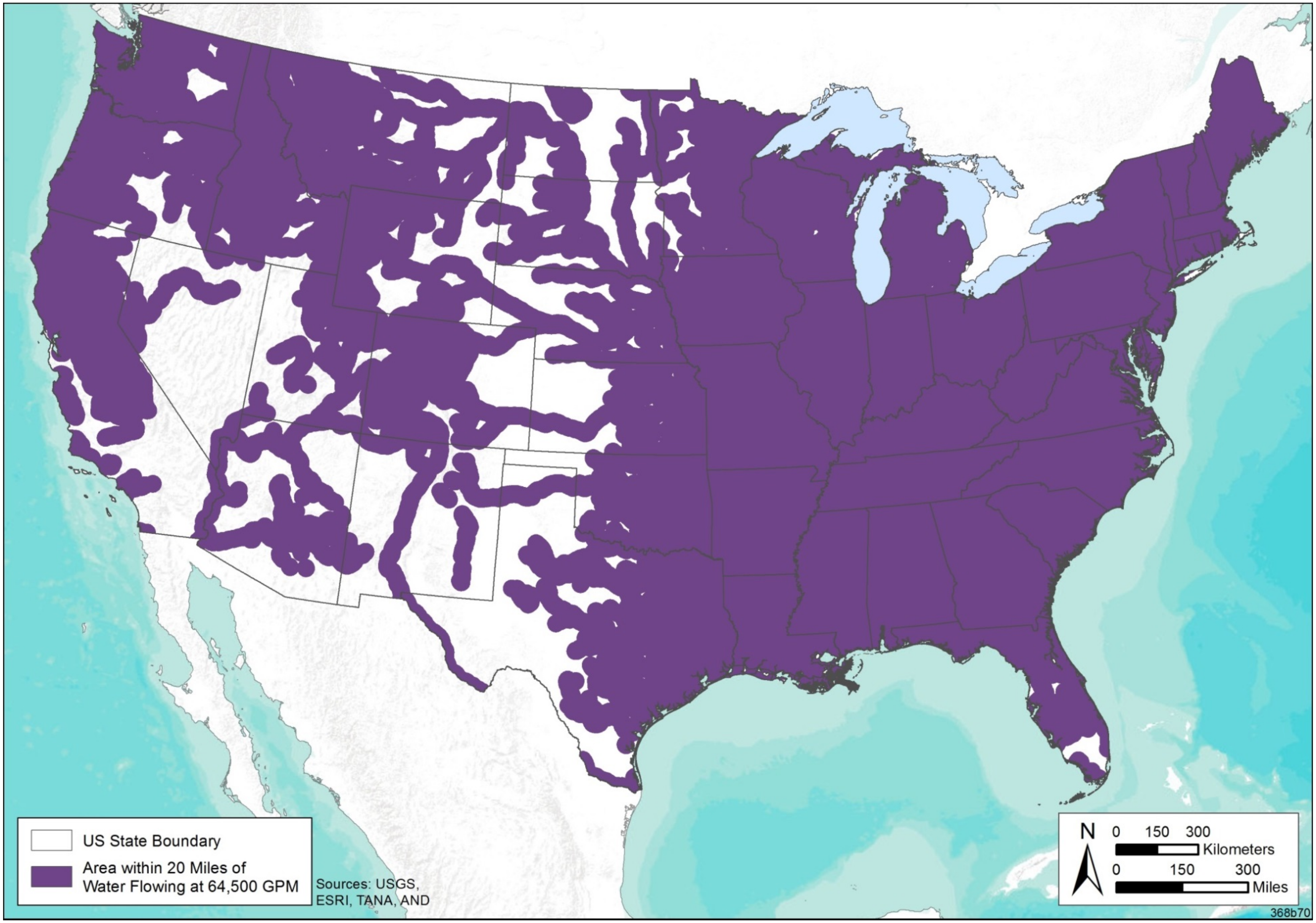


Figure B.17 Areas within 20 miles of a water source having at least 64,500 gallons per minute flow, as used in the CSP analysis.

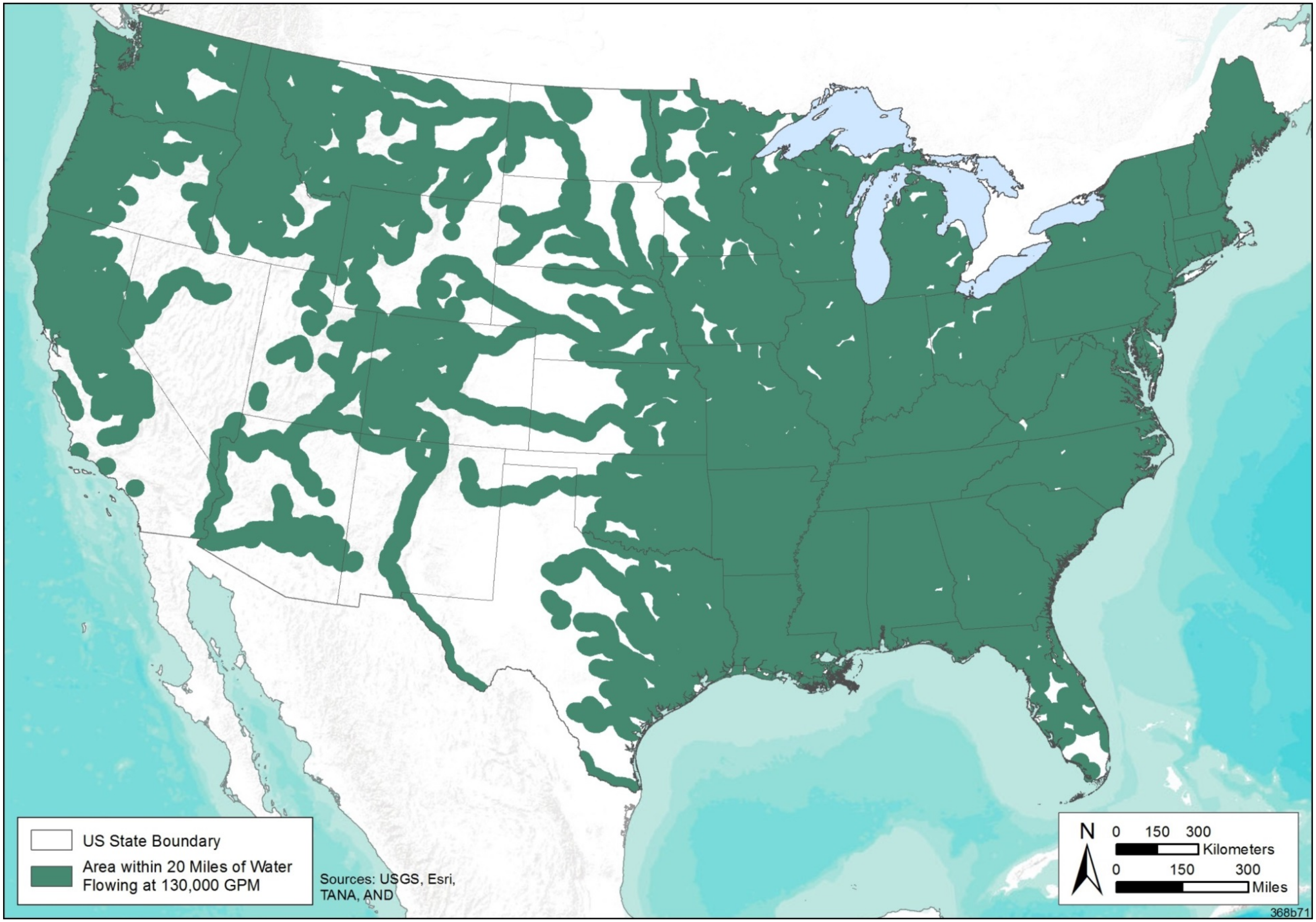


Figure B.18 Areas within 20 miles of a water source having at least 130,000 gallons per minute flow, as used in the EGS analysis.

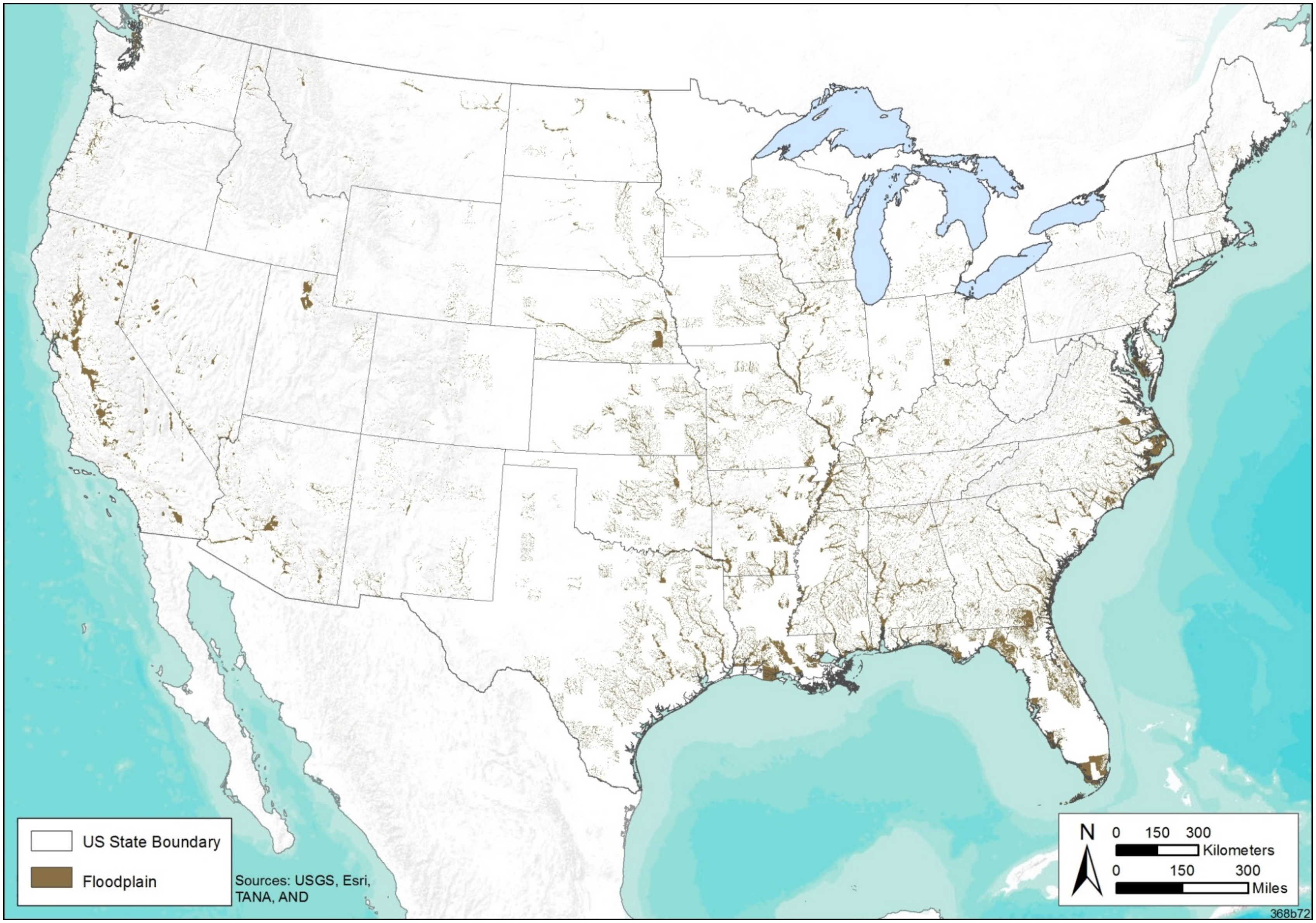


Figure B.19 FEMA 100-year floodplains, as excluded from potential development analyses.

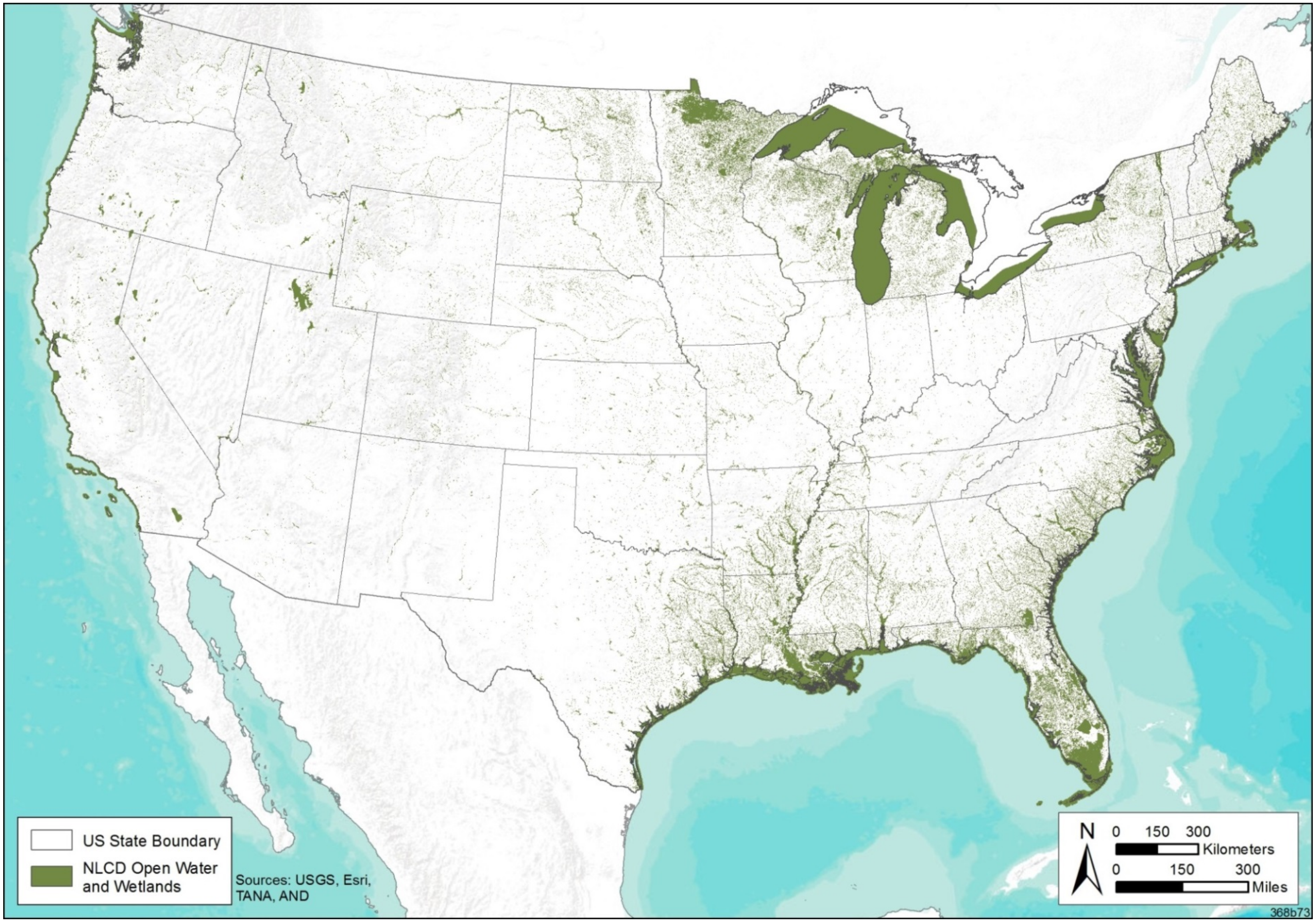


Figure B.20 Open water, woody wetlands, and herbaceous wetlands from the National Land Cover Dataset, as excluded from the biomass and EGS analyses.

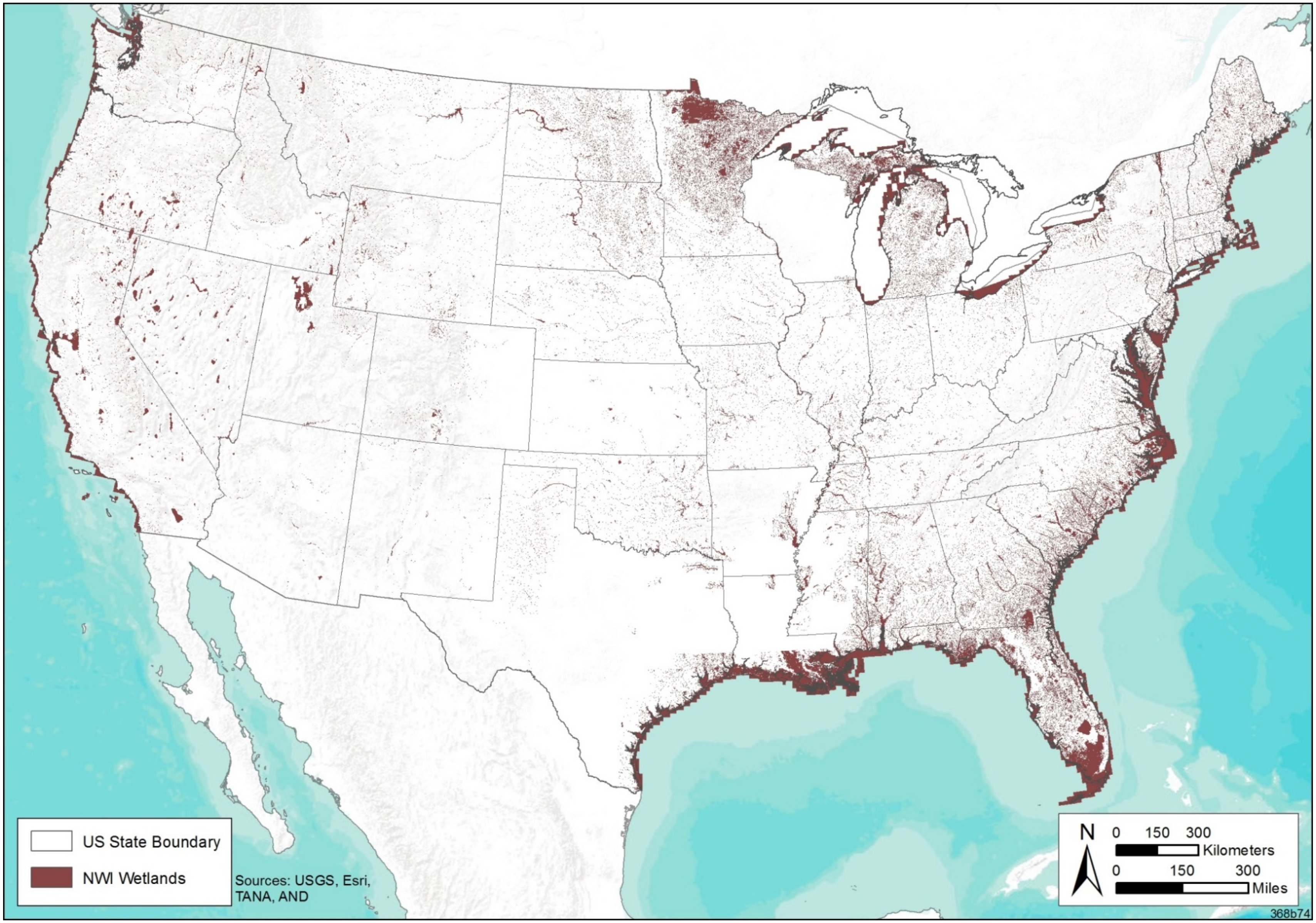


Figure B.21 Wetlands from the National Wetlands Inventory, as excluded from the CSP, PV, and wind analyses.

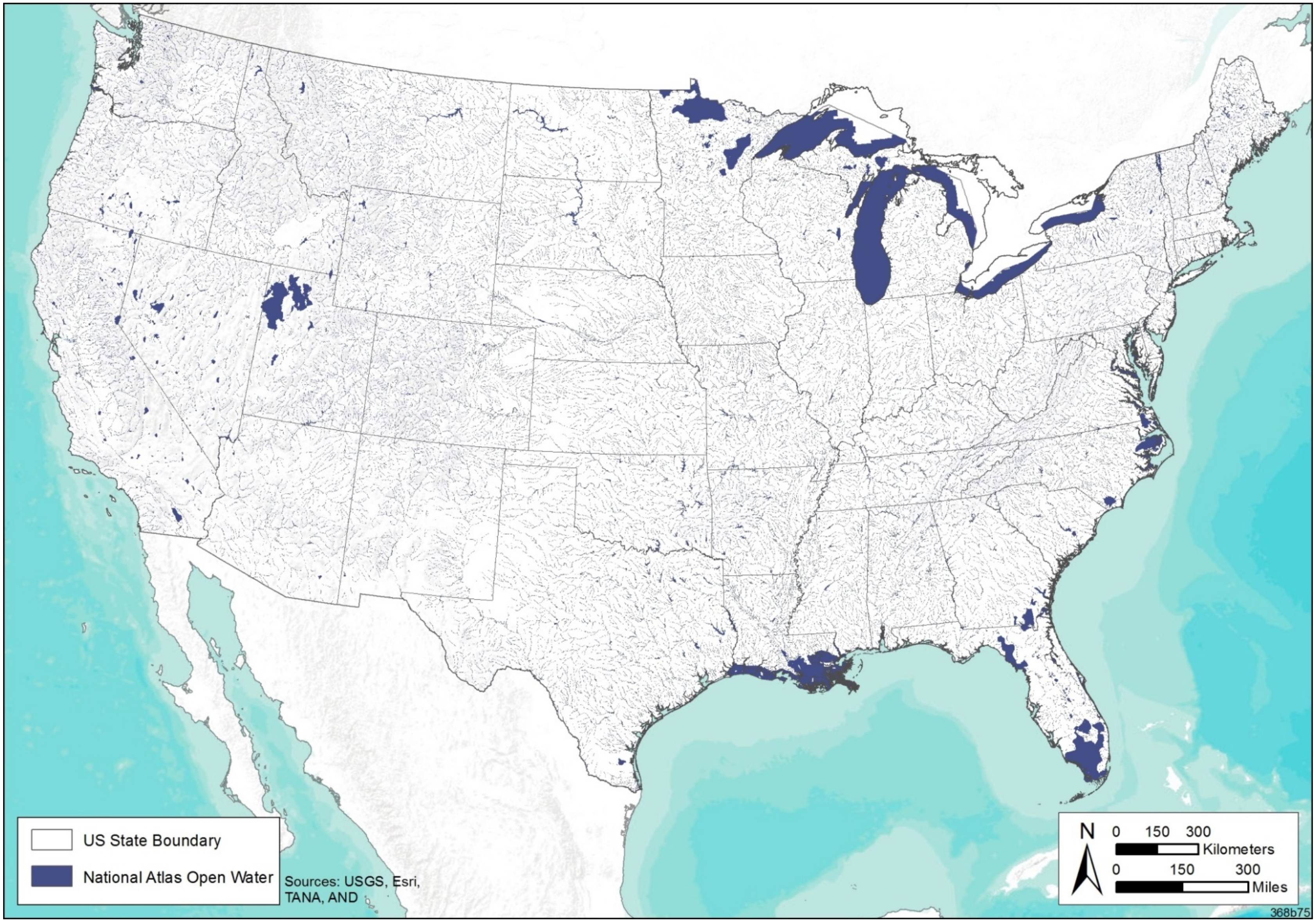


Figure B.22 Surface water from the National Atlas, as excluded from the biomass and EGS analyses.

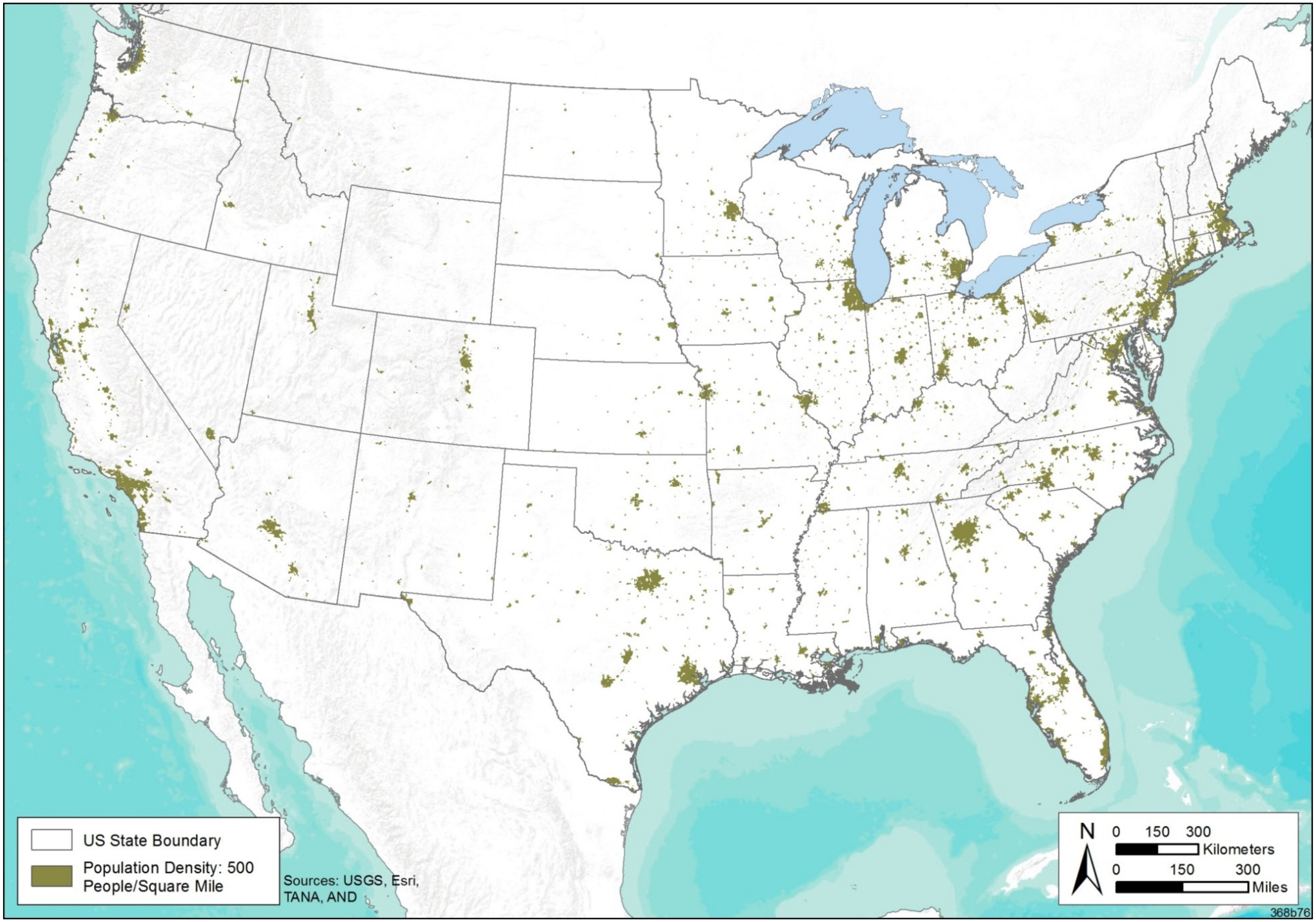


Figure B.23 Areas with a population density of 500 people per square mile or greater, as excluded from the EGS analysis.

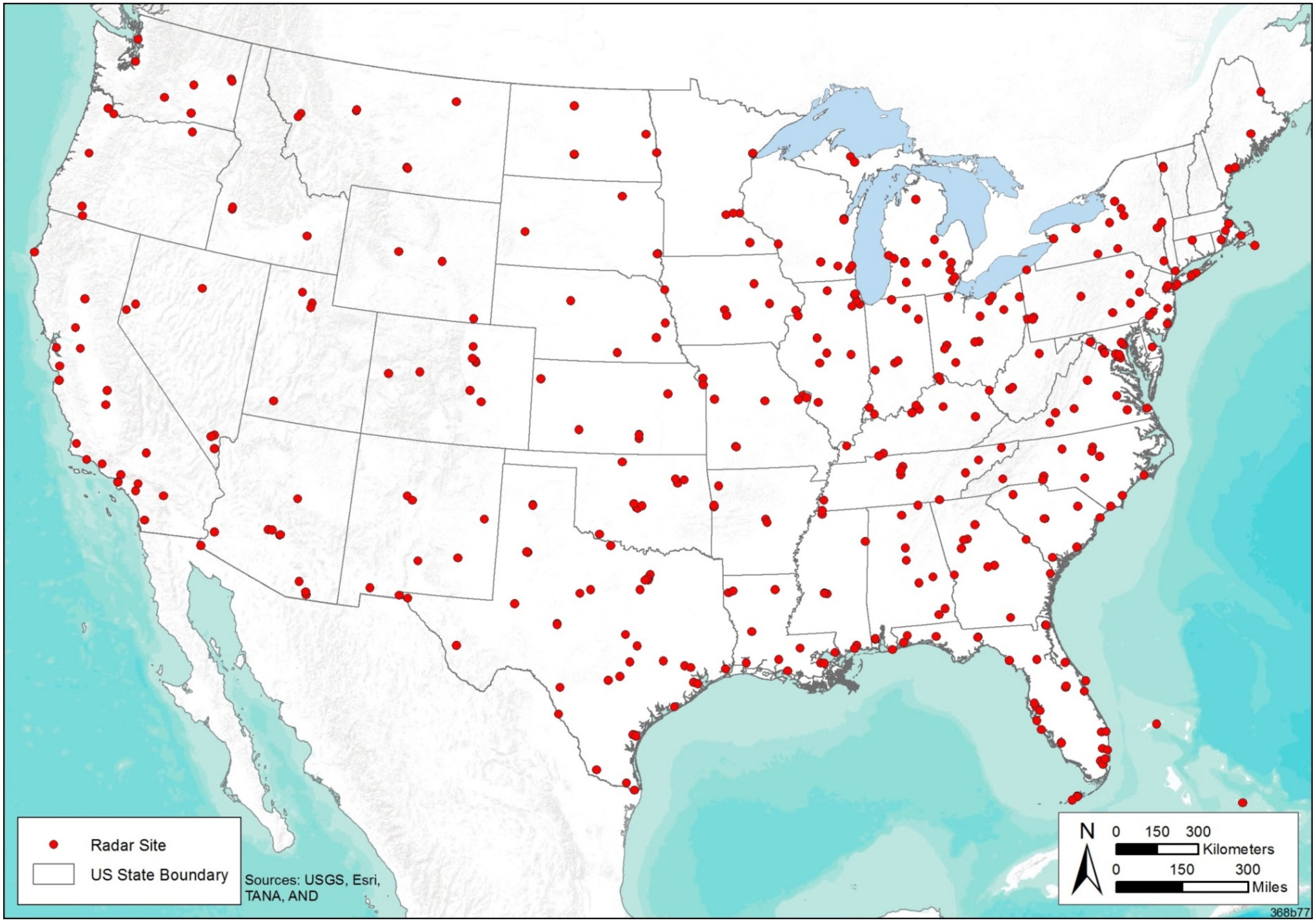


Figure B.24 Radar site locations, including Airport Surveillance Radar Sites, Next Generation Weather Radar Systems, Terminal Doppler Weather Radar Systems, and Tethered Aerostat Radar Systems, as excluded from the wind analysis.

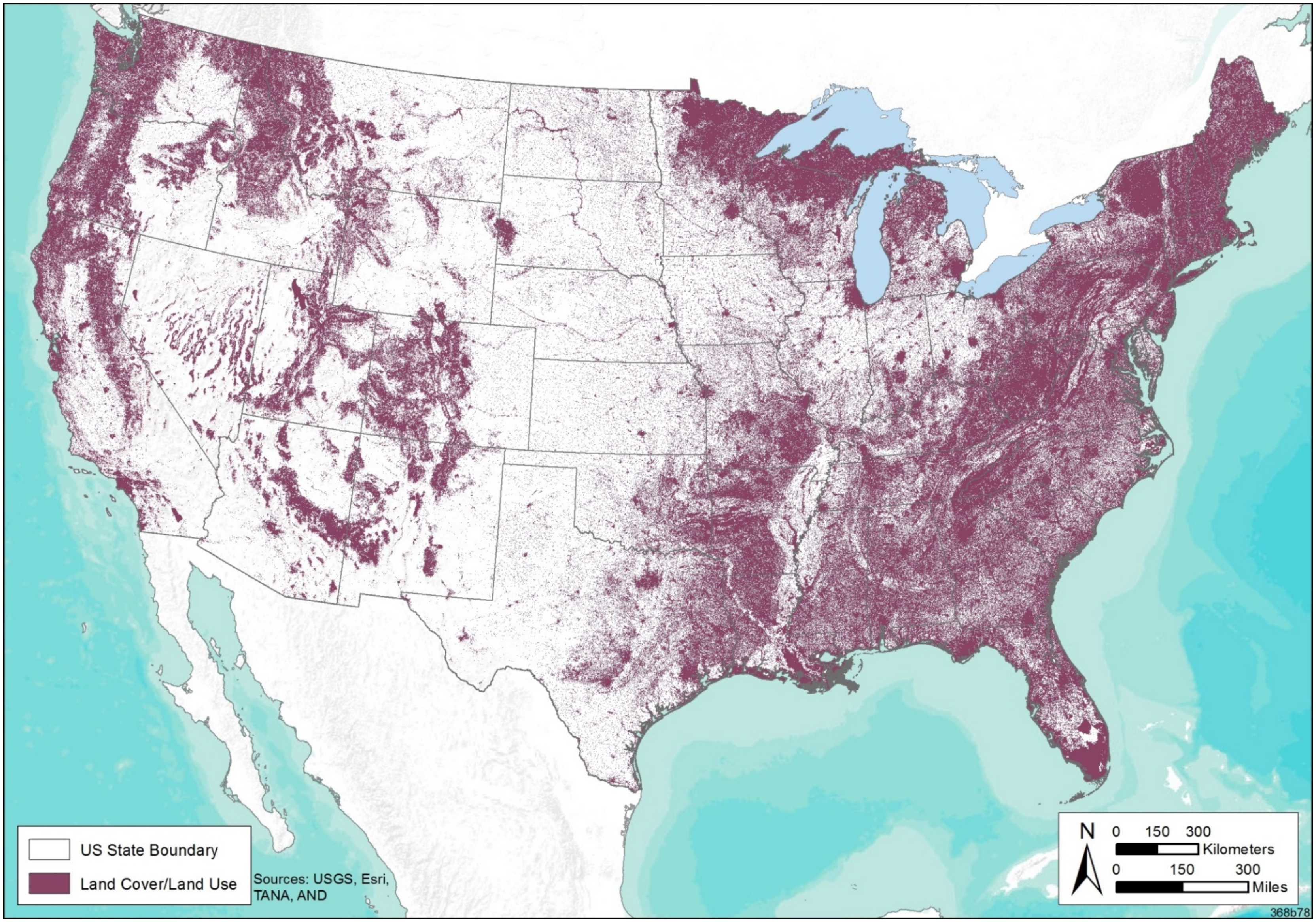


Figure B.25 National Land Cover Dataset categories excluded from CSP, PV, and wind analyses, including open land, vegetation, forest, urban, and developed land cover types.

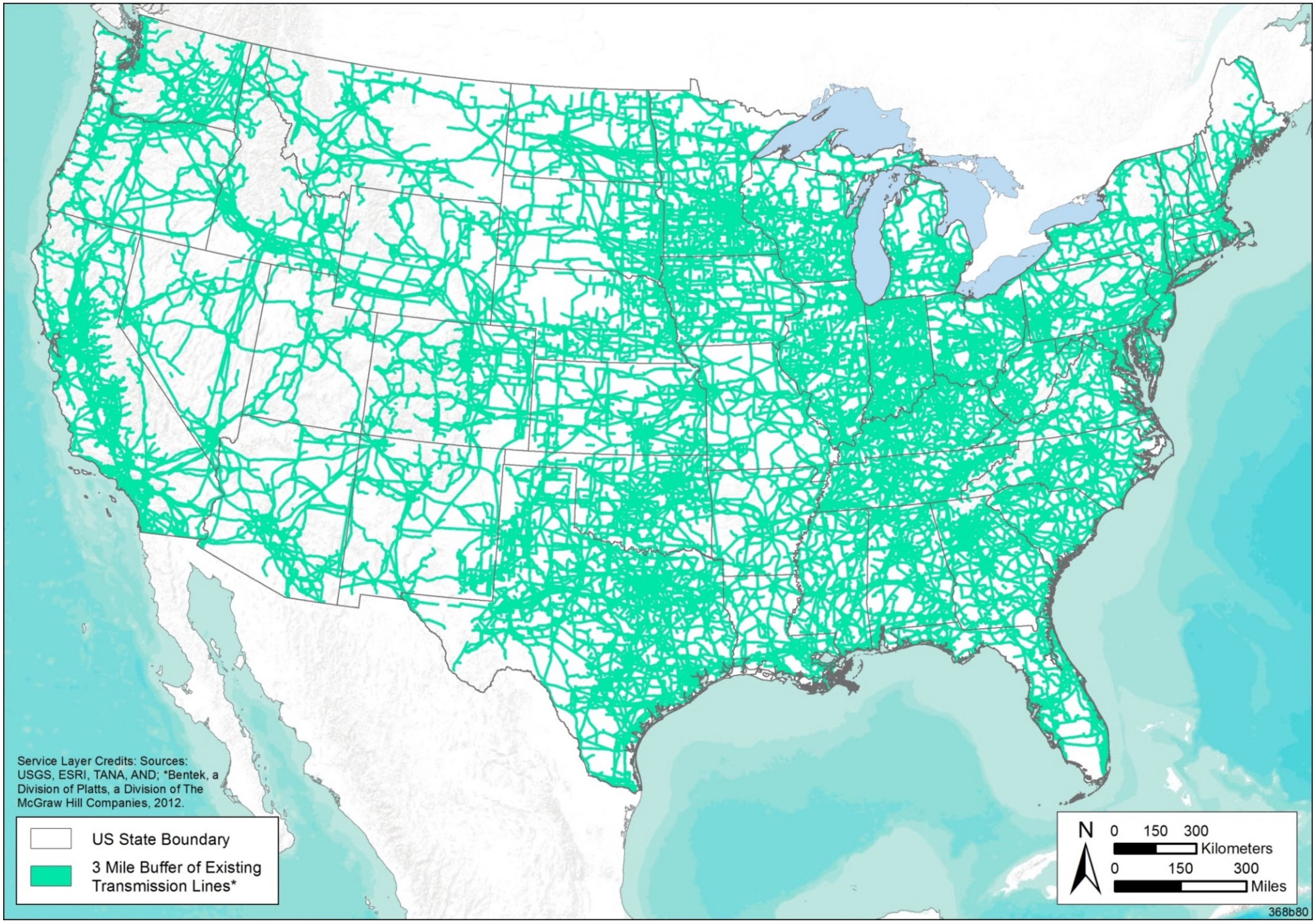


Figure B.26 Areas within 3 miles of existing transmission lines 69 kV or greater, used in transmission refinement analyses for the 5 renewable energy technologies.

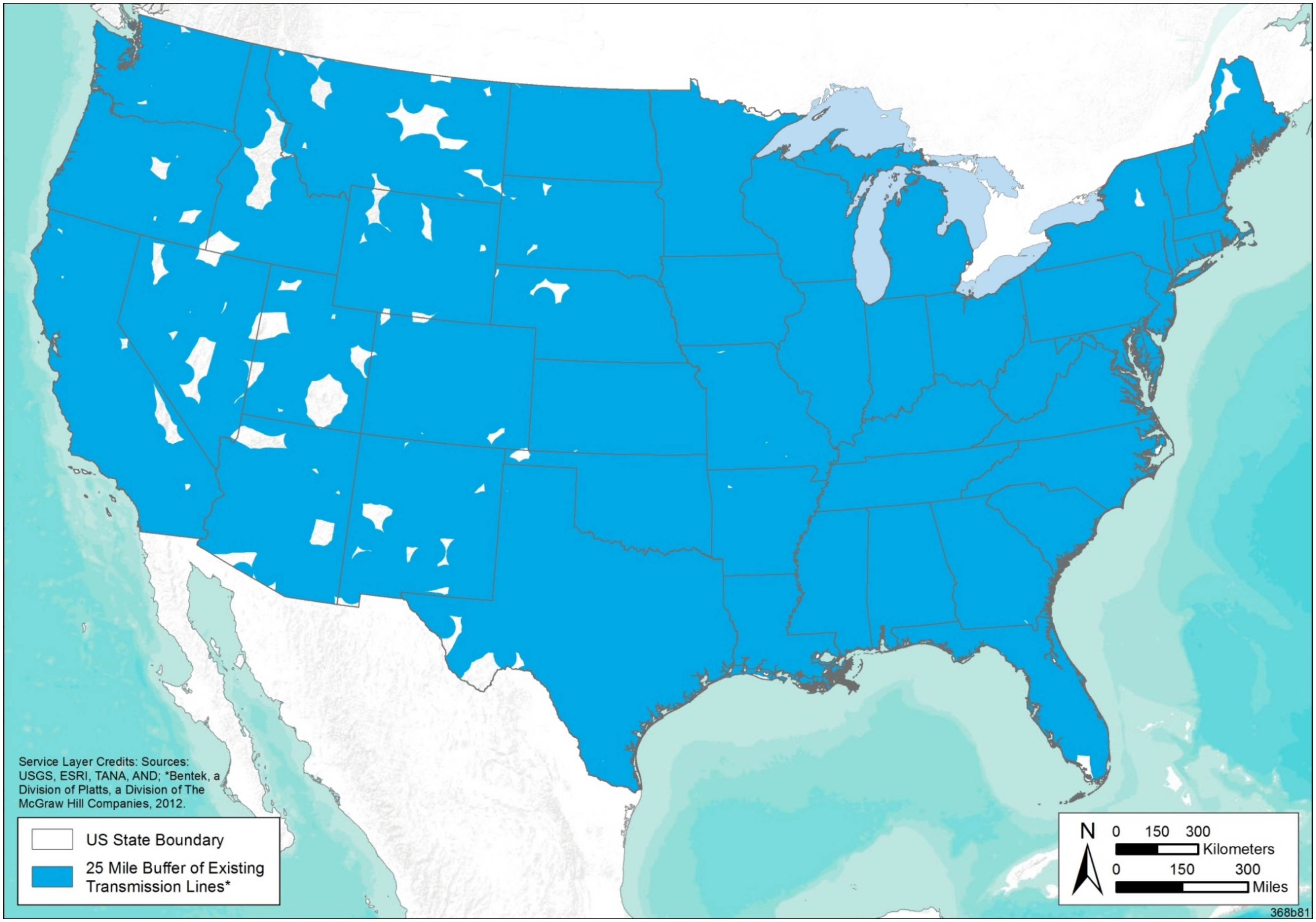


Figure B.27 Areas within 25 miles of existing transmission lines 69 kV or greater, used in the potential development analyses.

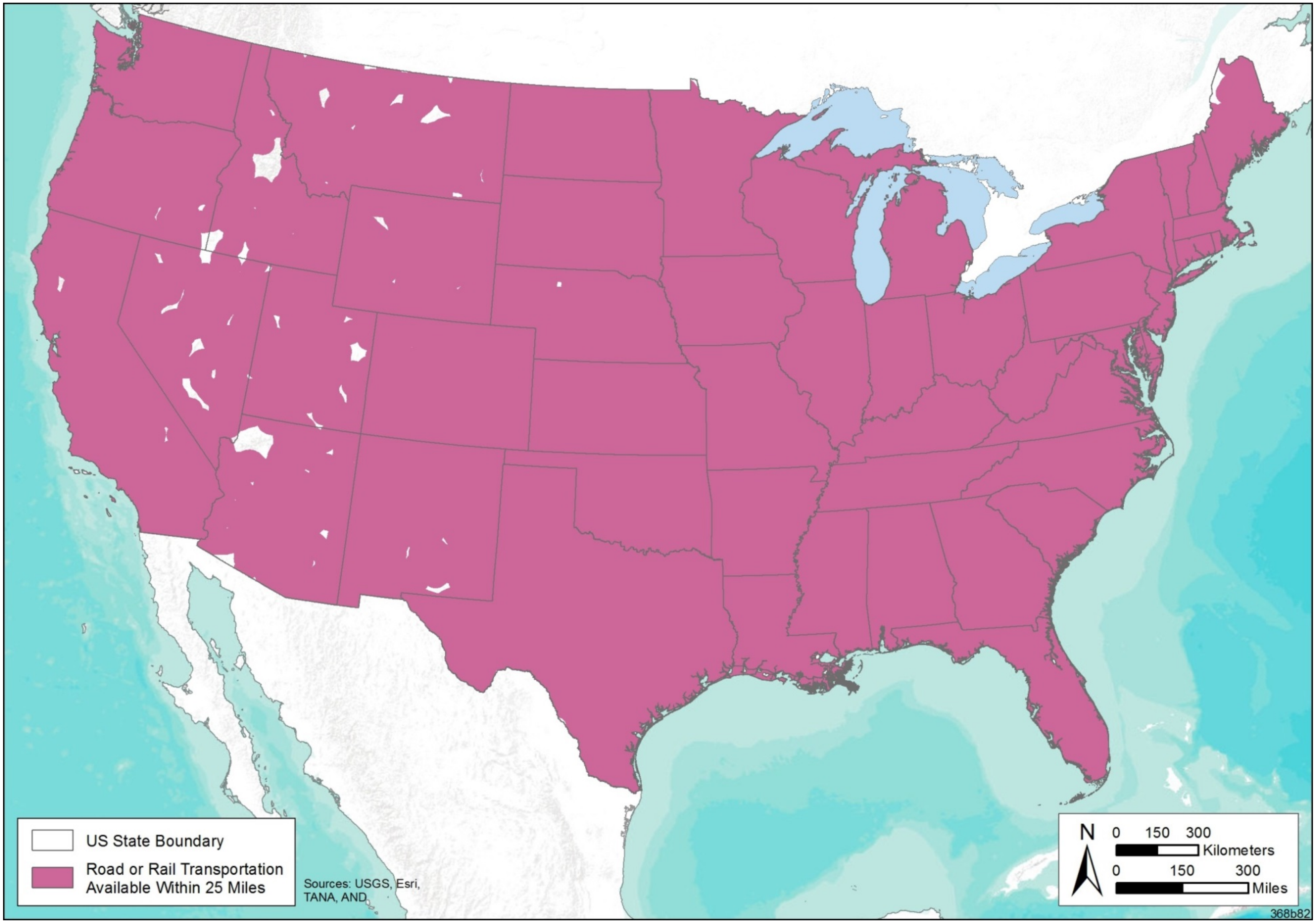


Figure B.28 Areas within 25 miles of roads or railroads, as used in the CSP, PV, wind, and EGS analyses.

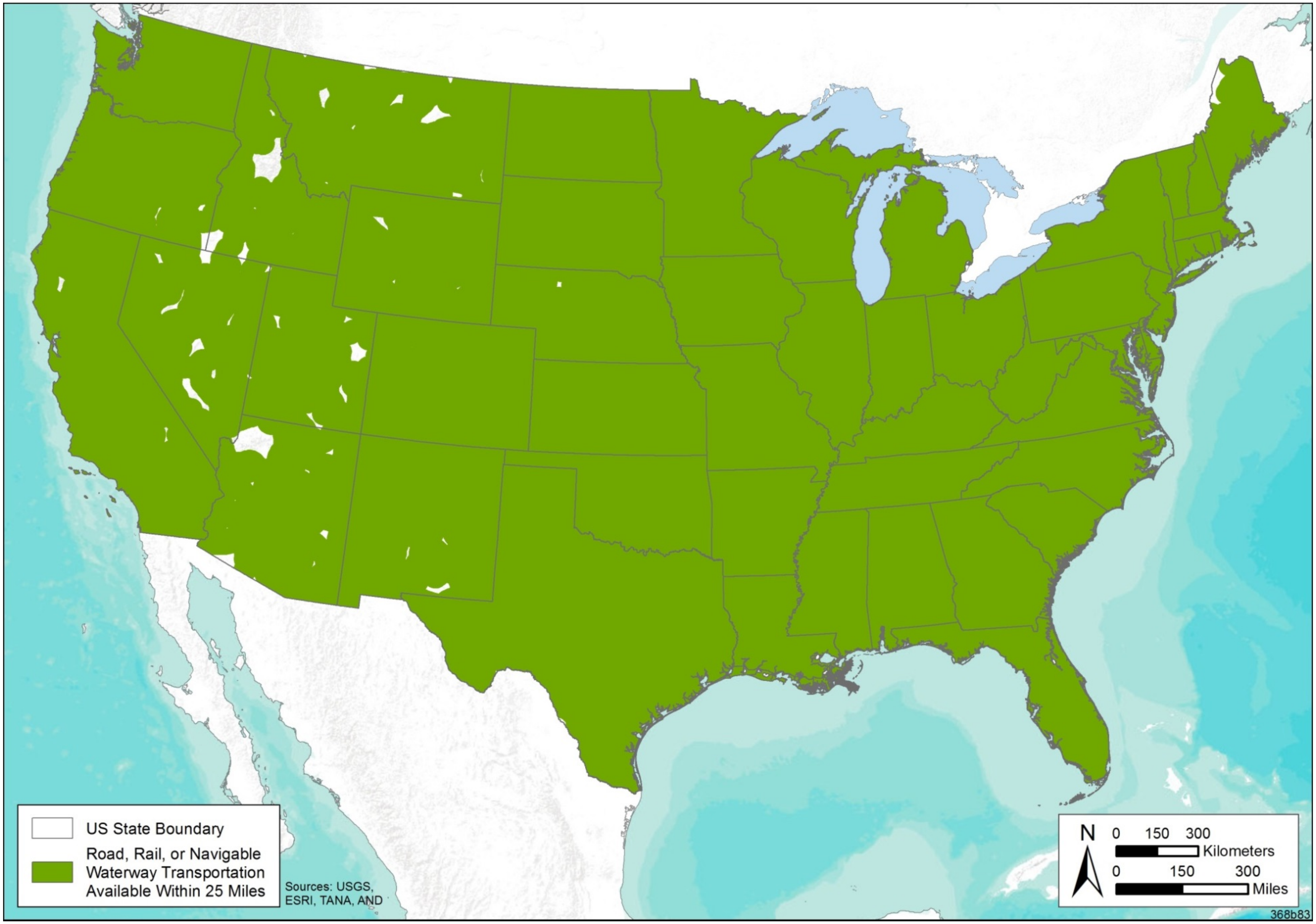


Figure B.29 Areas within 25 miles of roads, railroads, or navigable waterways, as used in the biomass analysis.

Appendix C: Installing and Using the Accompanying GIS Database, ArcReader Project, and Spreadsheets

Accompanying this report are the following files:

- GIS database with the layers used for the analysis, except for the proprietary wind resource data.
- ESRI ArcReader project (and ArcMap project for users having ArcGIS Desktop).
- Spreadsheet versions of the tables used in this report.
- Copies of figures included in this report, in PDF format.

C.1 Installing ArcReader and Navigating the Project File(s)

ESRI ArcReader 10.1, ArcGIS ArcMap 10.1, or a more current version of either product is required to open the interactive map project files. ArcReader is a free application distributed by ESRI, and ArcMap is a commercial product with more extensive capabilities. The instructions below assume ArcReader is being used. (When using ArcMap, open the .mxd files rather than the .pmf files.) Because of the size and complexity of the database, ArcReader or ArcMap may take a few minutes to open the interactive map project file on some computers.

1) Download ArcReader 10.1 (or a more current version) from http://www.esri.com/software/arcgis/arcreader/download.html.

2) Extract the contents of the downloaded zip file, run the ESRI.exe installation program with administrator-level privileges, and install the software.

3) For better performance, copy the files from the Renewable_Energy_Potential folder to a local hard disk on your system. This folder contains two subfolders: GIS and Report. Report contains the Microsoft Excel tables and PDF copies of figures used in the report, as well as the report itself. GIS contains ArcReader and ArcMap project files for Alaska and the lower 48 states, and associated data.

4) Double-click the GIS folder and then double-click on the Lower48.pmf file to open the ArcReader project (or the Lower48.mxd file if using ArcMap). The same strategy applies to the Alaska ArcReader, as well. Figure C.1 shows a view of the Lower48 ArcReader.

5) If you are not familiar with ArcReader, start by choosing the **Help → ArcReader Help** menu item for a guide on getting started with the software.

Below are some important considerations that will help improve your use of the Alaska and Lower 48 ArcReader projects:

- Because of the many map layers in the ArcReader projects, there will be cases when one map layer obscures another one of interest. Layers in the map are drawn in reverse of the order in which they appear in the table of contents. In ArcMap, drag a layer in the table of contents higher than a layer obscuring it to make it draw above the other one. ArcReader does not provide this capability; however, the **Transparency** and **Swipe Layer** tools provide ways to view layers that might otherwise be obscured.

- Some layers have detailed information that takes a long time to display when the map is zoomed out. Scale dependency (a property where layers are only displayed at specified scale ranges) was avoided in ArcReader because the dependency cannot be changed by users. If a map display is taking too long to draw, press the **Escape (Esc)** key to stop the drawing process, then turn the layer off in the **Table of Contents** or **Zoom** the map into a smaller area.

- The World Terrain and Image Base Map layers at the bottom of the table of contents are Internet-based map services provided by ESRI. They require an adequate Internet connection to work properly, and provide high-quality base maps at both general and detailed scales.

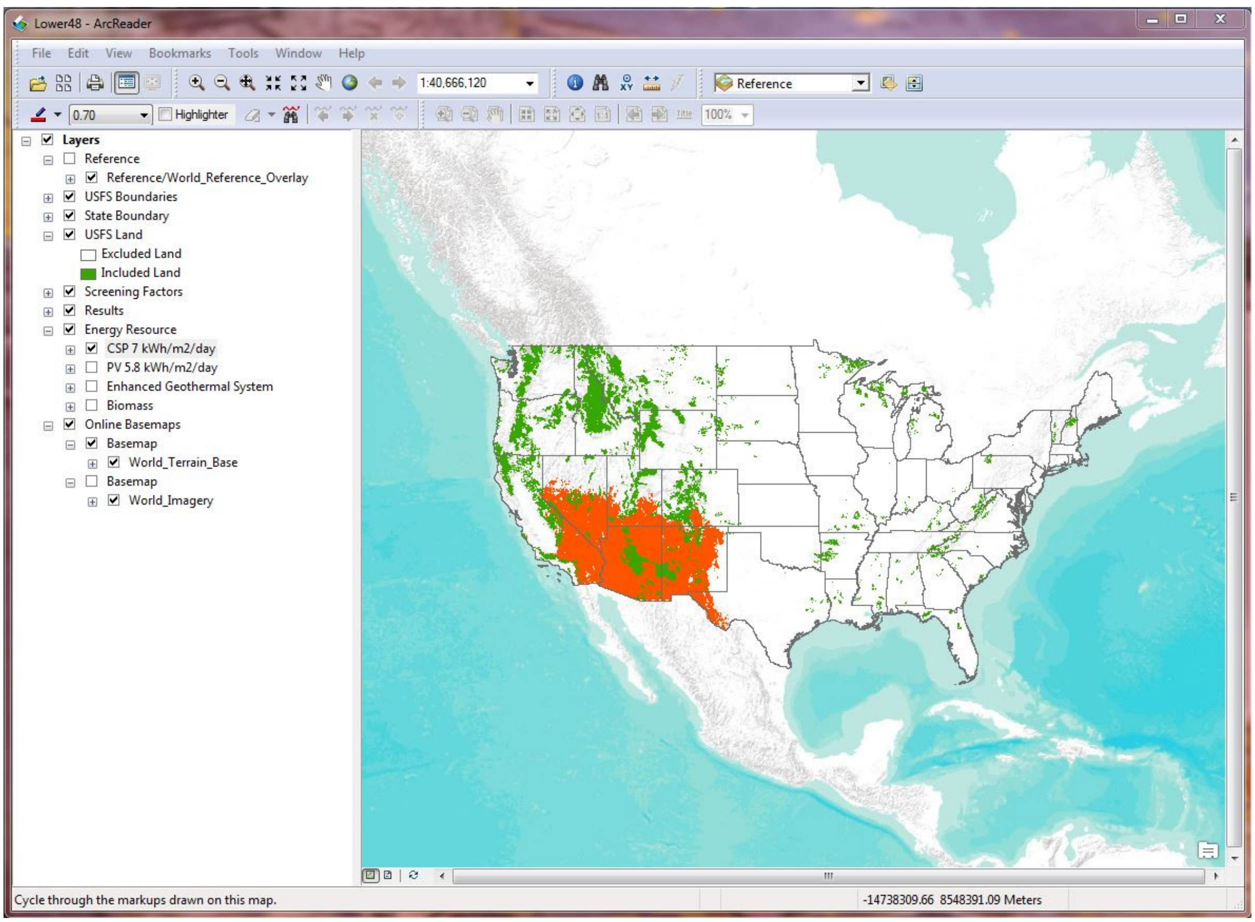


Figure C.1 View of the Renewable Energy Potential for Concentrating Solar Power, and USFS Land, in ArcReader.

U.S. Department of Agriculture
Forest Service