Center for Land Use Education
College of Natural Resources
University of Wisconsin-Stevens Point

Extension
UNIVERSITY OF WISCONSIN–MADISON

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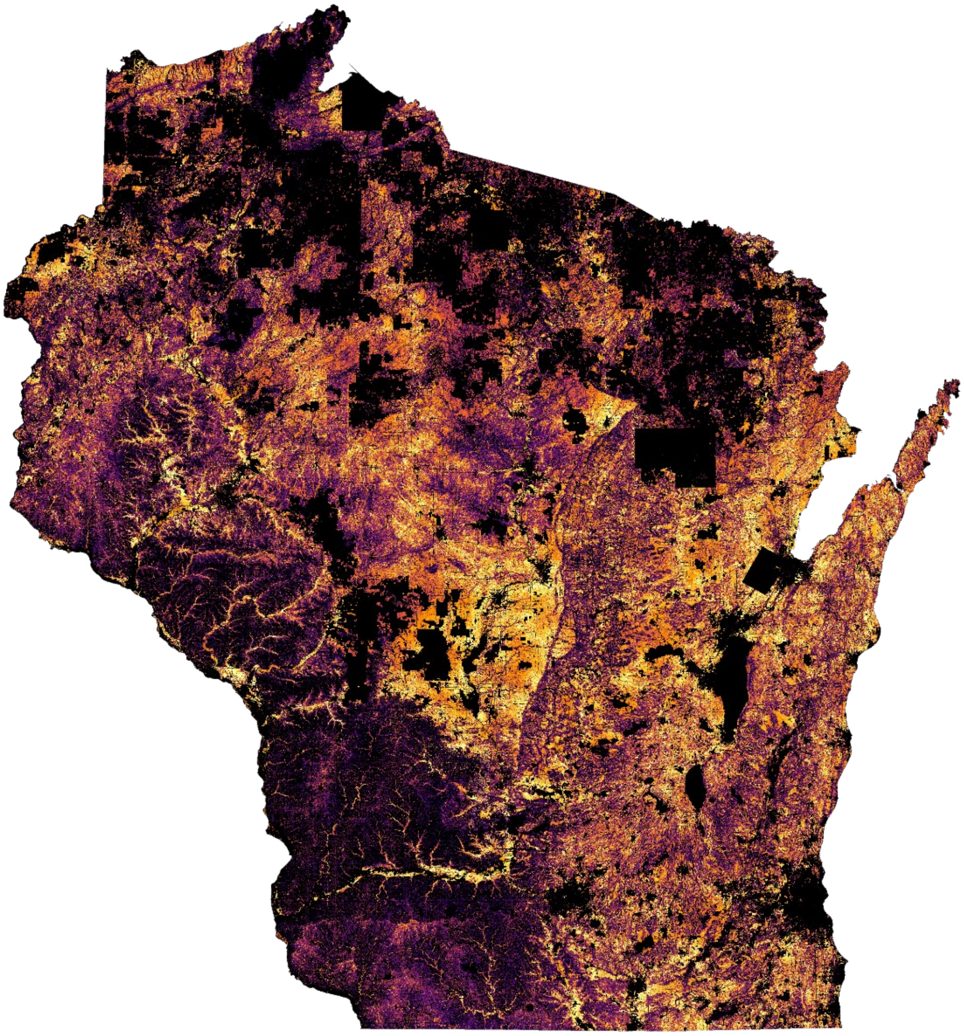

Solar Suitability at Universities of Wisconsin: Technical Report

Suitability for Solar Energy Siting on Universities of Wisconsin Properties using Geographic Information Systems

Acknowledgments

This project was funded by the University of Wisconsin-Madison Office of Sustainability. We would like to specifically thank Josh Arnold, Campus Energy Advisor. Josh provided ongoing support and meaningful, constructive feedback throughout the study's duration. Josh also served as a reviewer for the final report. Finally, the authors would like to thank Lynn Markham and Karen Blaha for their review of this technical report.

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MODEL PROCESS

1. **Introduction**

As anthropogenic climate change continues to alter our environment, the need for supplementing fossil fuel consumption with sources of renewable energy such as solar increases. The objective of this study was to identify suitable sites for utility-scale solar across Wisconsin using Multi-Criteria Decision Making (MCDM) techniques. Previous studies have separated decision-making factors into three evaluation and constraint criteria categories: environmental, economic, and social[3]. Both Geographic Information Systems (GIS) and Analytical Hierarchy Process (AHP) were used to assess seven factors of the three criteria. AHP is a method developed by Saaty, T.L. and is widely used within MCDM processes to assign criterion weights by way of a pairwise comparison matrix and Saaty's scale of relative importance[4][1]. Sassi et al. identified slopes greater than 10% to absolutely prevent the development of utility solar, while slopes less than 5% are optimal[4]. Therefore, USGS protected areas, NLCD open water and developed areas, and slopes greater than 10% were combined into a constraint layer[2]. Evaluation factors were compared to one another using the AHP method and separated into five suitability categories[5]. Finally, a Weighted Sum of each evaluation factor and the constraint layer was performed to produce a suitability map with a spatial resolution of 30x30 meters for Wisconsin. Final raster values range from 0 to 10, with 10 being most suitable for utility-scale solar development (at least one megawatt (1 MW).

This work identifies areas in Wisconsin that are most or least suitable for utility-scale solar energy from a landscape and modeling perspective, which should be treated as a starting point for energy planning. The Universities of Wisconsin properties or other areas that are identified as highly suitable in our analysis still require additional research, stakeholder input, and decision-making for solar development. Decisions about the implementation of solar projects on Universities of Wisconsin properties or elsewhere are beyond the scope of this technical report.

2. **Materials and Methods**

All procedures were conducted using ArcGIS Pro and Microsoft Excel. The full method is depicted through in Figure 6.

2.2 Evaluation Criteria

Evaluation criteria are divided by social, environmental, and economic factors. These criteria include factors that influence the decision making process. Within our model, slope, and land cover are our environmental criteria. Distance from transmission lines and substations are consdiered economic criteria as solar farm placements further from transmission lines and substations increases costs. Landcover is also considered social criteria and accounted for within the constraint layer. Each layer required a series of geoprocessing steps to prepare the data for analysis, which is described in detail in the following section. Afterward, a suitability ranking for each raster value depends on its impact on solar installations (Table 1).

Tab. 1.	**Suitability Ranking Raster Value**				
	High suitability	Suitable	Moderately Suitable	Less Suitable	Not Suitable
Factor	5	4	3	2	1
Slope	0-2%	2.1-4%	4.1-6%	6.1-8%	8.1-10%
Distance to Transmission Lines (miles)	0 - 1	1.1 - 3.81	3.82 - 6.68	6.69 - 10.65	10.66 - 18.73
Distance to Substations (miles)	0 - 2	2.1 - 4.8	4.81 - 7.69	7.7 - 11.97	11.98 - 22.27
Land Cover	Barren/ag	Hay/pasture	Short veg/shrubs	Herbaceous	Forests/wetlands

The importance values were determined from previous solar models developed by students through the Center for Land Use Education, literature on solar energy siting[2-5], and the consultation of project advisors. Our model considered cost savings and impact on natural vegetation as the two main considerations for our suitability rankings.

a) Utility Substations

Data was acquired from the U.S. Department of Security Foundation-Level Data (HIFLD) as a point shapefile. This layer was processed within the distance accumulation tool to create a 30 by 30 meter resolution raster denoting distance from the points. The distance raster was reclassified into 5 suitability categories (Table 1).

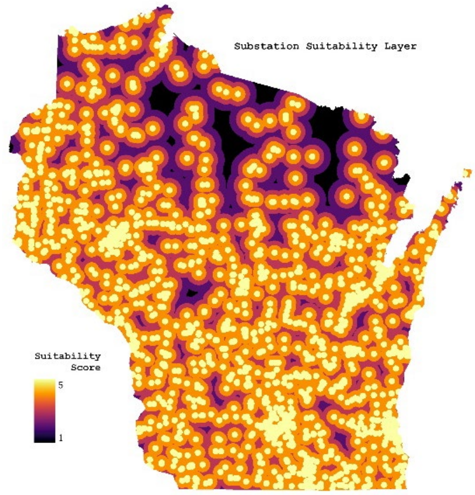


Fig. 1. Distance to substations suitability layer.

b) Utility Transmission Lines

Data was acquired from the U.S. Department of Security Foundation-Level Data (HIFLD) as a line shapefile. This layer was processed within the distance accumulation tool to create a 30 by 30 meter resolution raster denoting distance from the lines. The distance raster was reclassified into 5 suitability categories (Table 1).

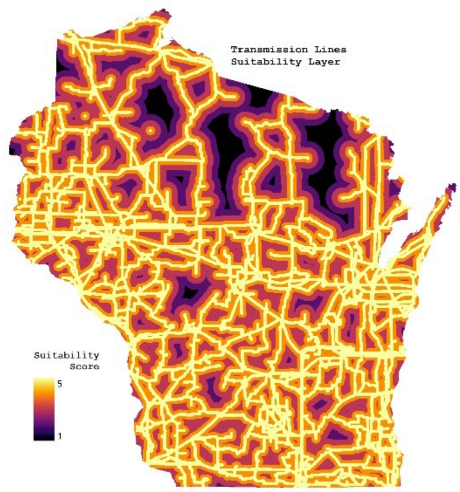


Fig. 2. Distance to transmission lines suitability layer.

c) Slope

d) A slope DEM with 10 meter resolution was downloaded from the WI DNR. It was converted to percent rise using the Slope geoprocessing tool and then reclassified into 5 suitability categories (Table 1).

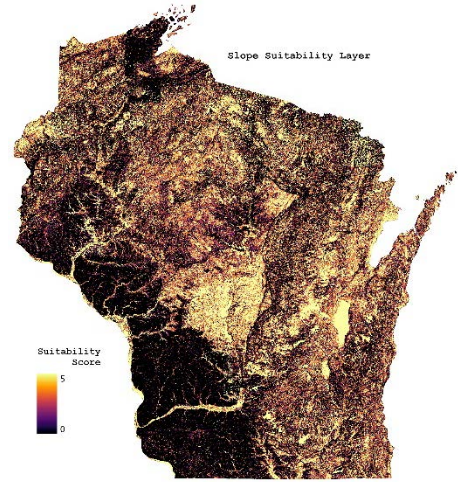


Fig. 3. Percent rise in slope suitability layer.

e) NLCD Land Cover

Data was downloaded from the National Land Cover Database from 2021. As this layer is already a raster, it was recalssified into 5 suitability categories (Table 1).

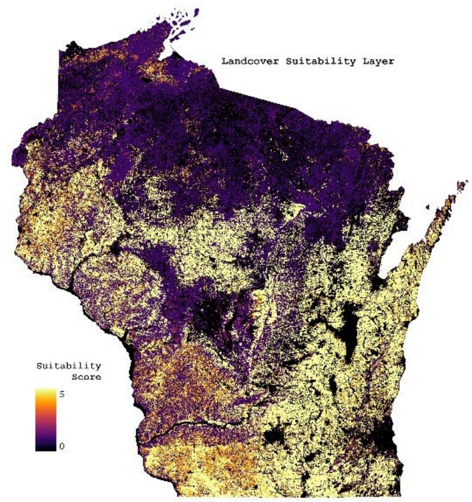


Fig. 4. Landcover suitability layer.

2.3 <u>**Constraint Criteria**</u>

Within this suitability assessment, there are some factors that needed to be completely excluded for a varitey of reasons. This included slopes greater than 10 percent, open water and developed land cover classes, and all tribal, federal, state, and local protected areas (Table 2). These three factors were each reclassified into binary raster layers and then combined with Raster Calculator to produce a single constraint layer.

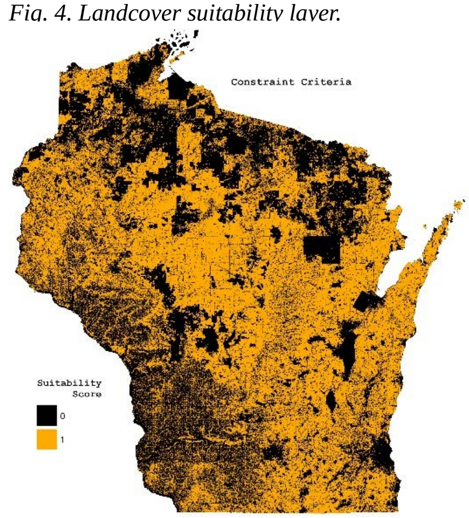


Fig. 5. Constraint suitability layer.

a) *Slope*

A slope DEM with 10 meter resolution was downloaded from the WI DNR. It was converted to percent rise using the Slope geoprocessing tool and then reclassified into a binary raster. Slopes greater than 10% were given a raster value of zero and all other values given a raster value of 1.

b) *NLCD Land Cover*

NLCD landcover data was reclassified into a binary raster layer wherein all landcover classes but open water, and developed areas were given a raster value of 1. Open water and developed landcover was given a raster value of zero.

c) *USGS Protected Areas – WI*

USGS Protected areas include tribal, federal, state, and local protected areas. A complete list and explanation of what is included in this data can be found in the PAD-US Data manual (USGS).

Tab. 2. Constraint Criteria

Factor	**Raster Value**	
	0	1
Slope	> 10%	all other values
USGS Protected Areas	All protected areas in WI, including Federal, State, Local Government and Private designations and Easements.	
NLCD Land Cover	Open water, developed areas	

2.4 Calculating Weights Using the Analytical Heirarchy Process

The analytical Hierarchy Process, developed by Saaty, is a Multi Criteria Decision Making tool for calculating weights of factors within evaluation criteria. Each criterion is rated against other criterion using Saaty's Scale of Relative Importance (Table 3) within a pariwise matrix (Table 4)

Tab. 3. Saaty's Scale of Relative Importance

1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience or judgement strongly favor one activity over another
7	Very strong importance	An activity is favored very strongly over another, its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible affirmation
2,4,6,8	Intermediate values	Sometimes one needs to interpolate a compromise judgment numerically because there is no good word to describe it
1/3, 1/5, 1/7, 1/9	Values for inverse comparison	A comparison mandated by choosing the smaller element as the unit to estimate the larger one as a multiple of that unit

Tab. 4. Pairwise Matrix of Relative Importance

Factor	Slope	Landcover	Distance from Substations	Distance From Transmission Lines
Slope	1	5	5	3
Landcover	1/5	1	1/3	1/3
Distance from Substations	1/5	3	1	1/3
Distance From Transmission Lines	1/3	3	3	1

After normalizing the assigned values, weights can be determined by averaging the row (Table 5).

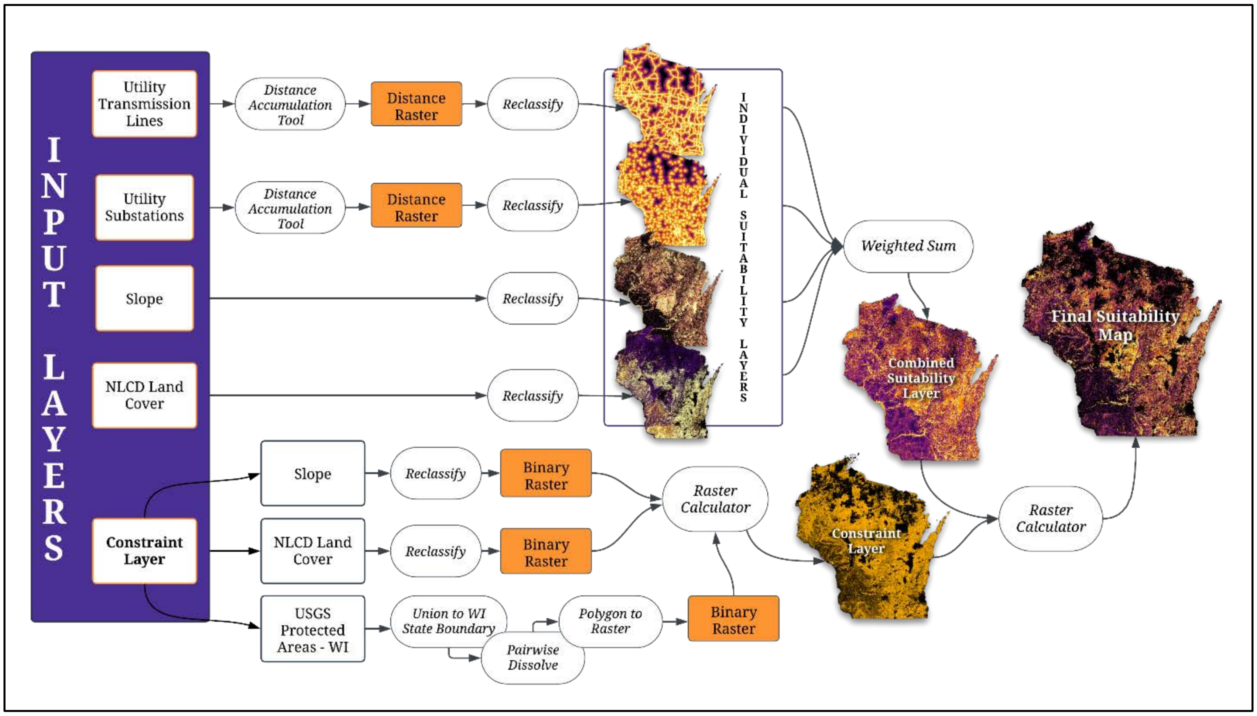
Tab. 5. Normalized values. Each relative importance value is divided by the column sum. The weight is determined by averaging the row.

	Slope	Landcover	Distance from Substations	Distance From Transmission Lines	Weights
Slope	0.58	0.42	0.54	0.64	0.54
Landcover	0.12	0.08	0.04	0.07	0.08
Distance from Substations	0.12	0.25	0.11	0.07	0.14
Distance From Transmission Lines	0.19	0.25	0.32	0.21	0.24

2.5 Suitability Mapping

After the weights were identified, each layer was combined using a weighted sum analysis. This combined suitability map was then multiplied by our constraint layer to classify any area as unsuitable for solar. Below is a generalized visual of the suitability mapping steps to create our final suitability map.

Fig. 6. Flow chart outlining methods for determining solar suitability.



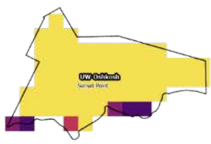
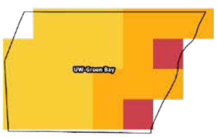
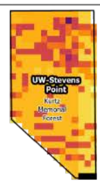
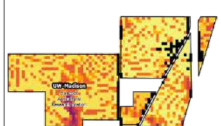
3. Results

The final suitability map can be viewed in Figure 7. Zonal statistics were completed for all Universities of Wisconsin properties to find the average suitability score within the boundaries of each BOR property polygon. Top 5 highest, moderate and low suitable BOR properties are examined in Tables 6-8. Included are the average suitability scores for each input layer (evaluation criterion factor).

The top-rated scores were associated with properties that were close to vital infrastructure, had flat surfaces, and had moderate or favorable land cover. In Table 6, you can view the top-rated BOR Properties and their scores based on each individual suitability layer.

Tab. 6. *Top 5 highest suitability BOR properties. Included is the mean suitability score for each evaluation criteria factor.*

Top Five High Suitability

IMAGE	INSTITUTE NAME	AREA NAME	ACRES	MEAN WEIGHTED SOLAR SCORE	Mean Landcover Score	Mean Slope Score	Mean Transmission Lines Score	Mean Substation Score
	UW-Oshkosh	Sunset Point	13.81	8.77	0.00	9.59	10.00	10.00
	UW-Green Bay		4.92	8.57	0.00	9.64	9.13	8.00
	UW-Stevens Point	Kurtz Memorial Forest	69.39	8.02	0.84	8.84	8.49	8.00
	UW-Madison	Hancock Agricultural Research Station	394.23	7.99	4.42	8.64	8.00	9.05
	UW-Stevens Point	Boston School Forest	20.25	7.88	1.18	8.41	10.00	10.00

Moderate properties tended to score high in one or more categories but often extremely low in others. These tended to be near vital infrastructure but either had unfavorable land cover or were on a steeper slope. In other cases, these properties were farther away from the infrastructure but were flatter and/or had favorable land cover.

Tab. 7. *Top 5 moderate suitability BOR properties. Included is the mean suitability score for each evaluation criteria factor.*

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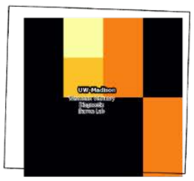
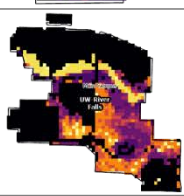
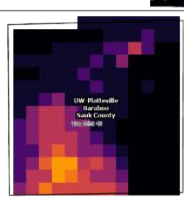
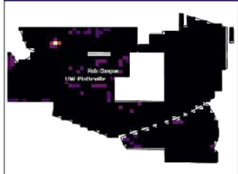
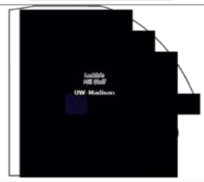
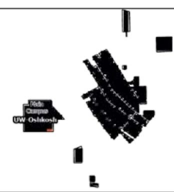
IMAGE	INSTITUTE NAME	AREA NAME	ACRES	MEAN WEIGHTED SOLAR SCORE	Mean Landcover Score	Mean Slope Score	Mean Transmission Lines Score	Mean Substation Score
	UW-Madison	Wisconsin Vetrinary Diagnostic Barron Lab	4.14	3.08	1.19	7.44	10	10
	UW-Superior	Dutchman's Creek	59.20	2.97	0.75	2.28	8	6
	UW-Milwaukee	Beech Woods	66.01	2.93	0.97	1.39	8	10
	UW-River Falls	Main Campus	362.59	2.87	1.34	4.22	10	10
	UW-Platteville Baraboo Sauk County	Van Zelst 40	40.62	2.74	1.23	1.63	6.36	8

BOR properties with the lowest rating either 1) have a low rating across all of the scores or 2) have a lower rating in multiple categories. These tended to be BOR properties that were high in impervious surface, far from infrastructure, and had steep slopes. These properties would likely require significant investment to develop solar.

Tab. 8. *Top 5 low suitability BOR properties. Included is the mean suitability score for each evaluation criteria factor.*

Top Five Low Suitability

IMAGE	INSTITUTE NAME	AREA NAME	ACRES	MEAN WEIGHTED SOLAR SCORE	Mean Landcover Score	Mean Slope Score	Mean Transmission Lines Score	Mean Substation Score
	UW-Platteville	Main Campus	317.16	0.21	1.23	0.46	10	10
	UW-Madison	Verona Storage Facility	10.42	0.18	0.16	3.29	10	10
	UW-Madison	Lodde's Mill Bluff	12.73	0.05	0.95	0	6	8
	UW-Madison	Charmany Farm	20.79	0.05	0.04	5.86	10	10
	UW-Oshkosh	Main Campus	170.04	0.02	0	7.15	10	10

Considering these values and the weights assigned by the model can inform developers as to why the model considers certain parcels as suitable for solar. As this is a generalized model that did not consider BOR property specific criteria, some properties might be more or less suitable for BOR energy development than this model predicts. Ground truthing is required for any project to determine actual suitability. This is because suitability analysis is a valuable tool as a beginning point of the planning process, but the output results remain course estimations based on large-scale data. Further in-depth social, economic, and environmental analysis is critical to determine true suitability on more local levels. For example, consideration of areas that hold cultural and natural significance may have a high score in our model but may not be appropriate to site solar for a variety of reasons that are not present in the data available.

4. Discussion

4.1 Legal authorities for permitting utility-scale solar

It takes 7-10 acres to produce 1 megawatt (MW) of energy from solar panels. This large amount of needed space warrants a conversation about who has jurisdiction to approve large solar developments. According to Wis. Stats. 196.491(1)(g) and 196.491(3)(a)1., legal authority for deciding on solar farms with a generating capacity of 100 MW or more is given to the Wisconsin Public Service Commission, not local governments. For projects less than 100 MW, which is around 700 acres, local governments may only restrict solar farms if their restrictions satisfy the conditions in Wis. Stat. 66.1001(1m) that relate to public health and safety, cost, and efficiency of the solar system.

4.2 Use of Data and Results

This technical report and its findings are intended to be a starting point to inform decision-makers about solar suitability. Additional site-specific information, research, and stakeholder input will need to be incorporated into the energy planning on each BOR Property or other area to determine if or when solar should be developed.

TABLES AND IMAGES

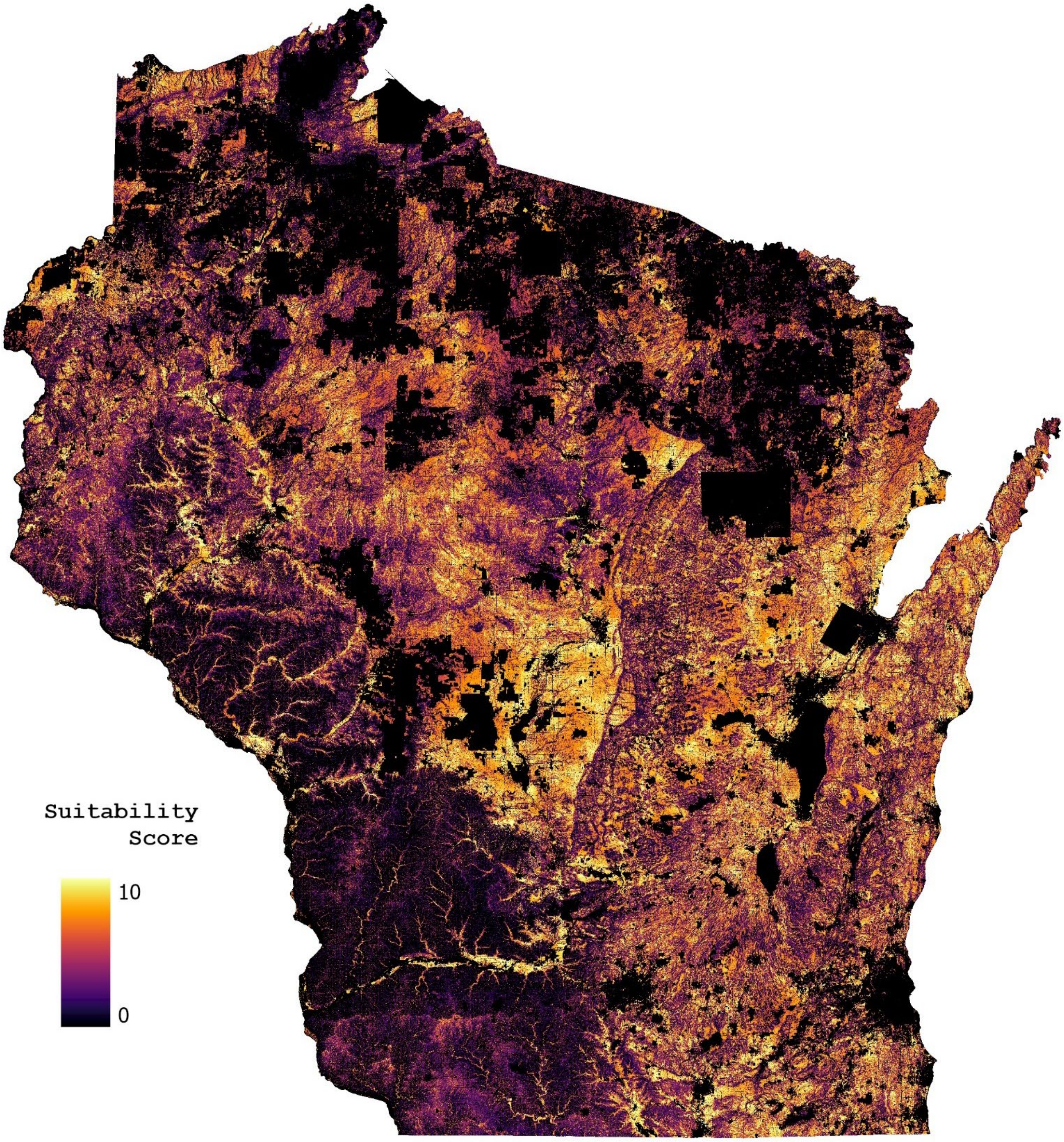
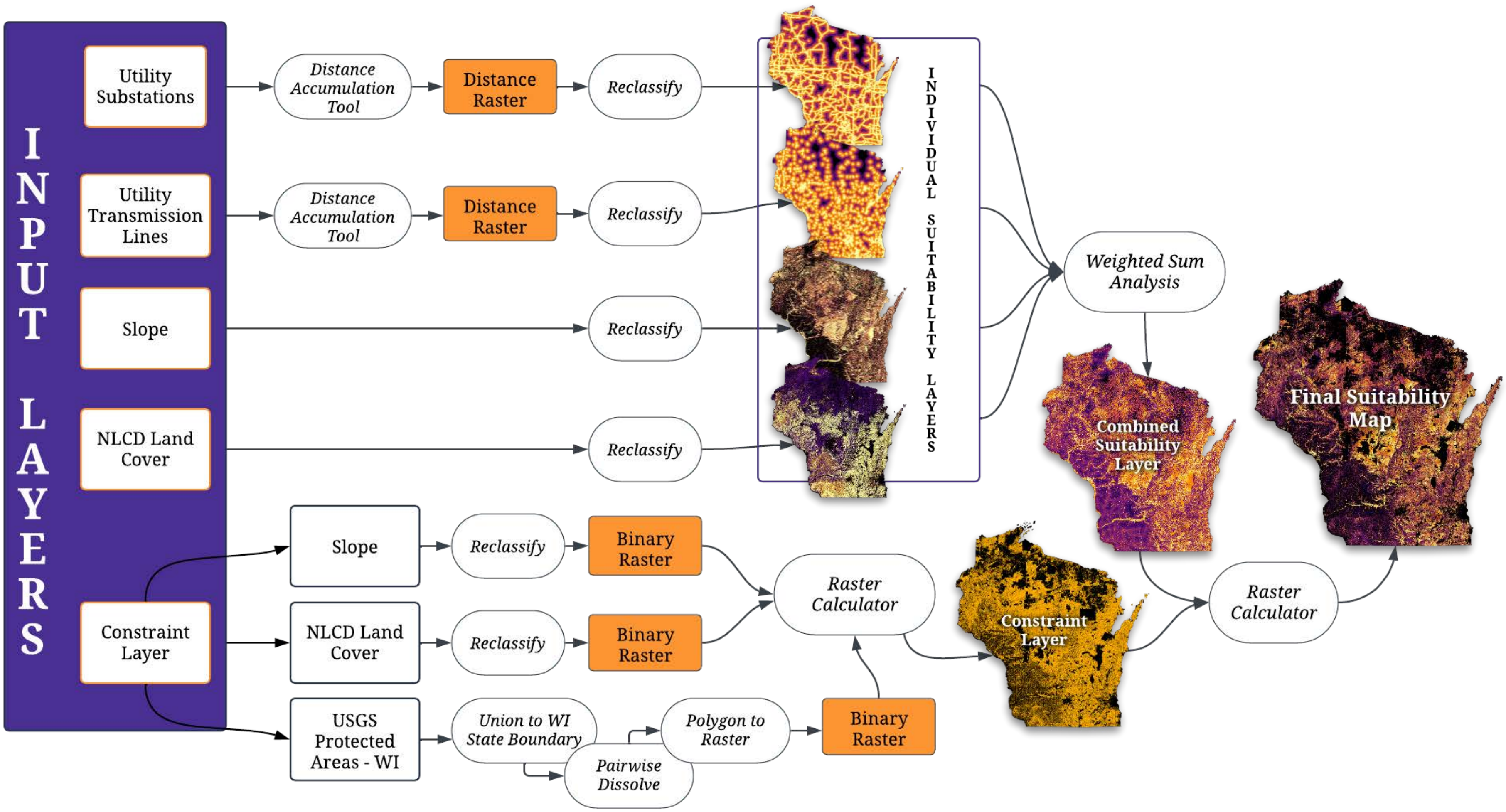


Fig. 7. *Final suitability map with scores ranging from zero to 10 with 10 being the most suitable for utility scale solar.*



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__Tab. 6__. Top 5 highest suitability BOR properties. Included is the mean suitability score for each evaluation criteria factor. This can inform us as to how the final suitability score was determined for the property.

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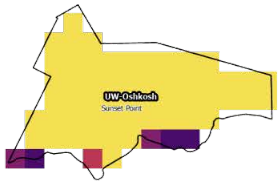
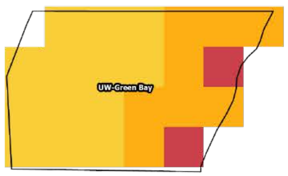
	UW-Oshkosh	Sunset Point	13.81	8.77	0.00	9.59	10.00	10.00
	UW-Green Bay		4.92	8.57	0.00	9.64	9.13	8.00
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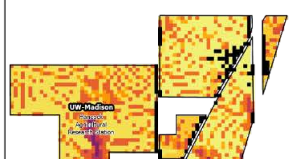
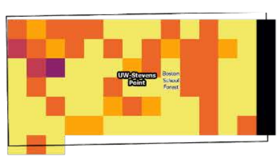
	UW-Madison	Hancock Agricultural Research Station	394.23	7.99	4.42	8.64	8.00	9.05
	UW-Stevens Point	Boston School Forest	20.25	7.88	1.18	8.41	10.00	10.00

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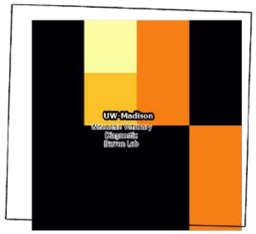
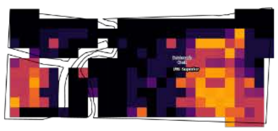
	UW-Madison	Wisconsin Vetrinary Diagnostic Barron Lab	4.14	3.08	1.19	7.44	10	10
	UW-Superior	Dutchman's Creek	59.20	2.97	0.75	2.28	8	6
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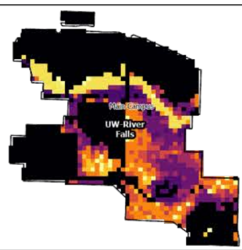
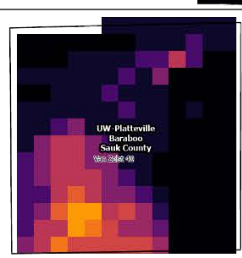
	UW-River Falls	Main Campus	362.59	2.87	1.34	4.22	10	10
	UW-Platteville Baraboo Sauk County	Van Zelst 40	40.62	2.74	1.23	1.63	6.36	8

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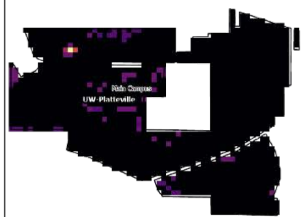
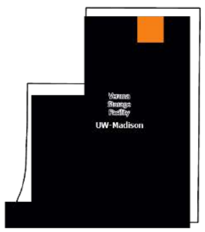
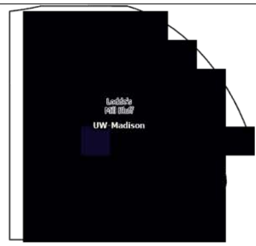
	UW-Platteville	Main Campus	317.16	0.21	1.23	0.46	10	10
	UW-Madison	Verona Storage Facility	10.42	0.18	0.16	3.29	10	10
	UW-Madison	Lodde's Mill Bluff	12.73	0.05	0.95	0	6	8
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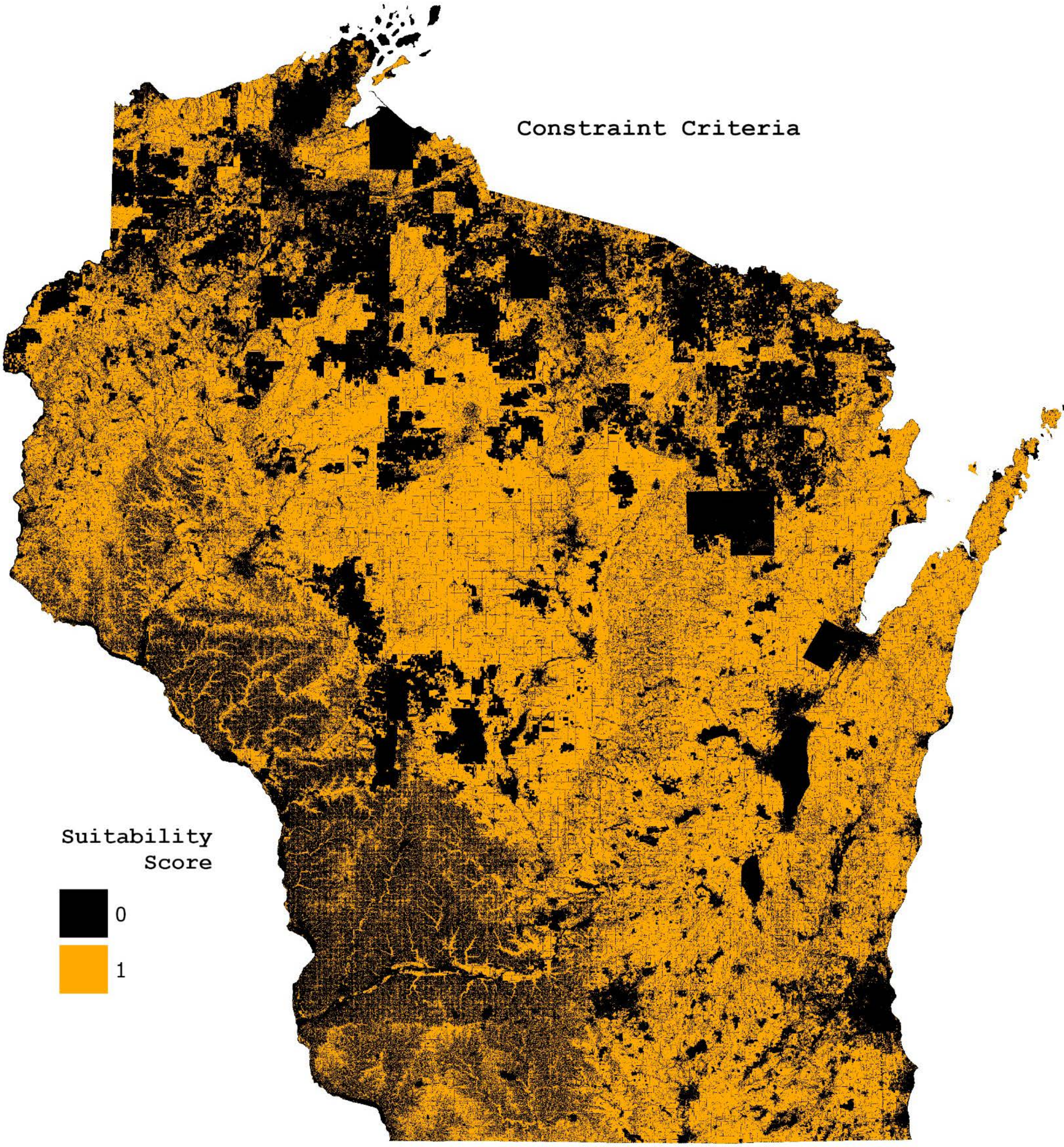
Constraint Criteria
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Score
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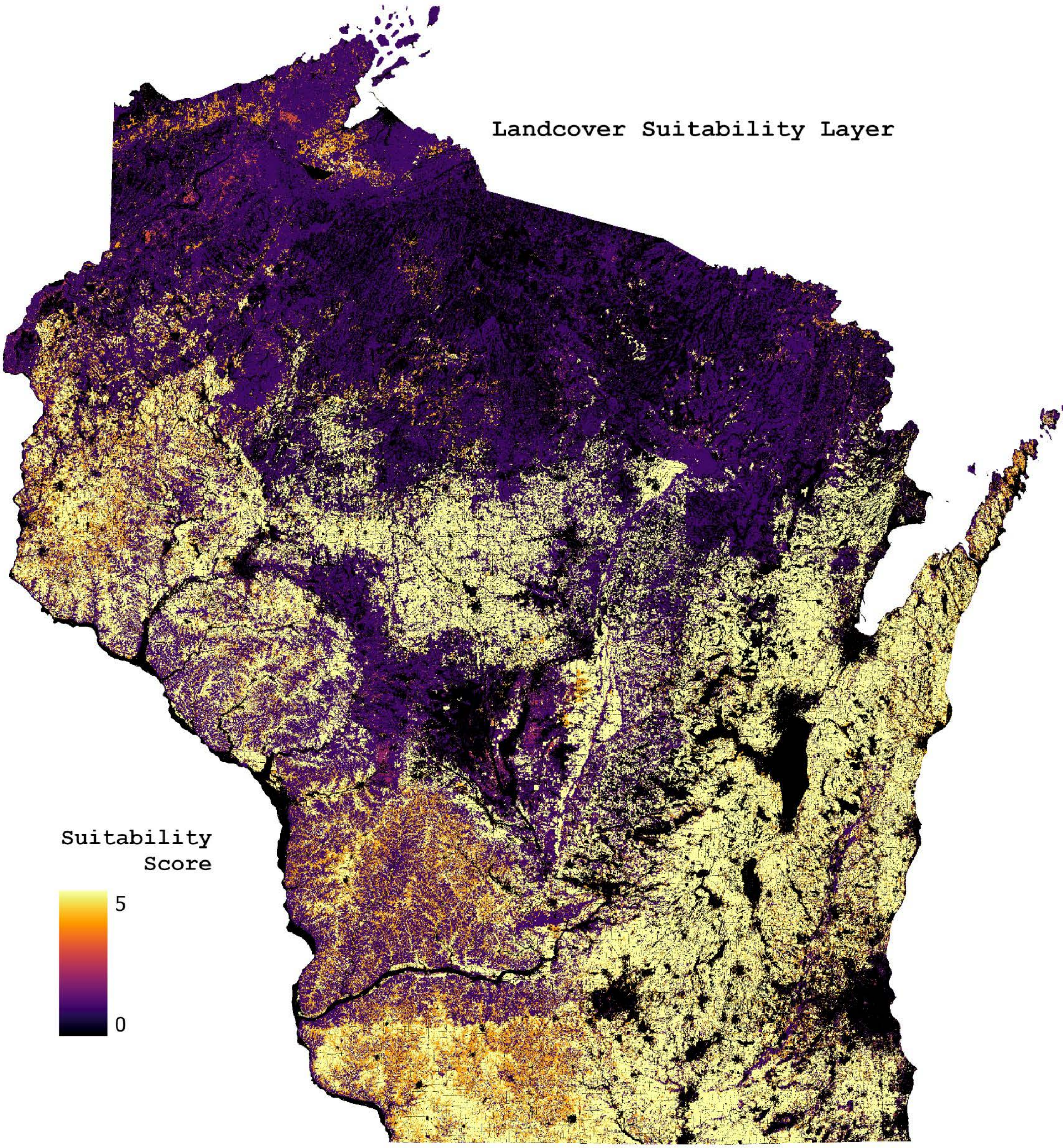
1


Landcover Suitability Layer
Suitability Score
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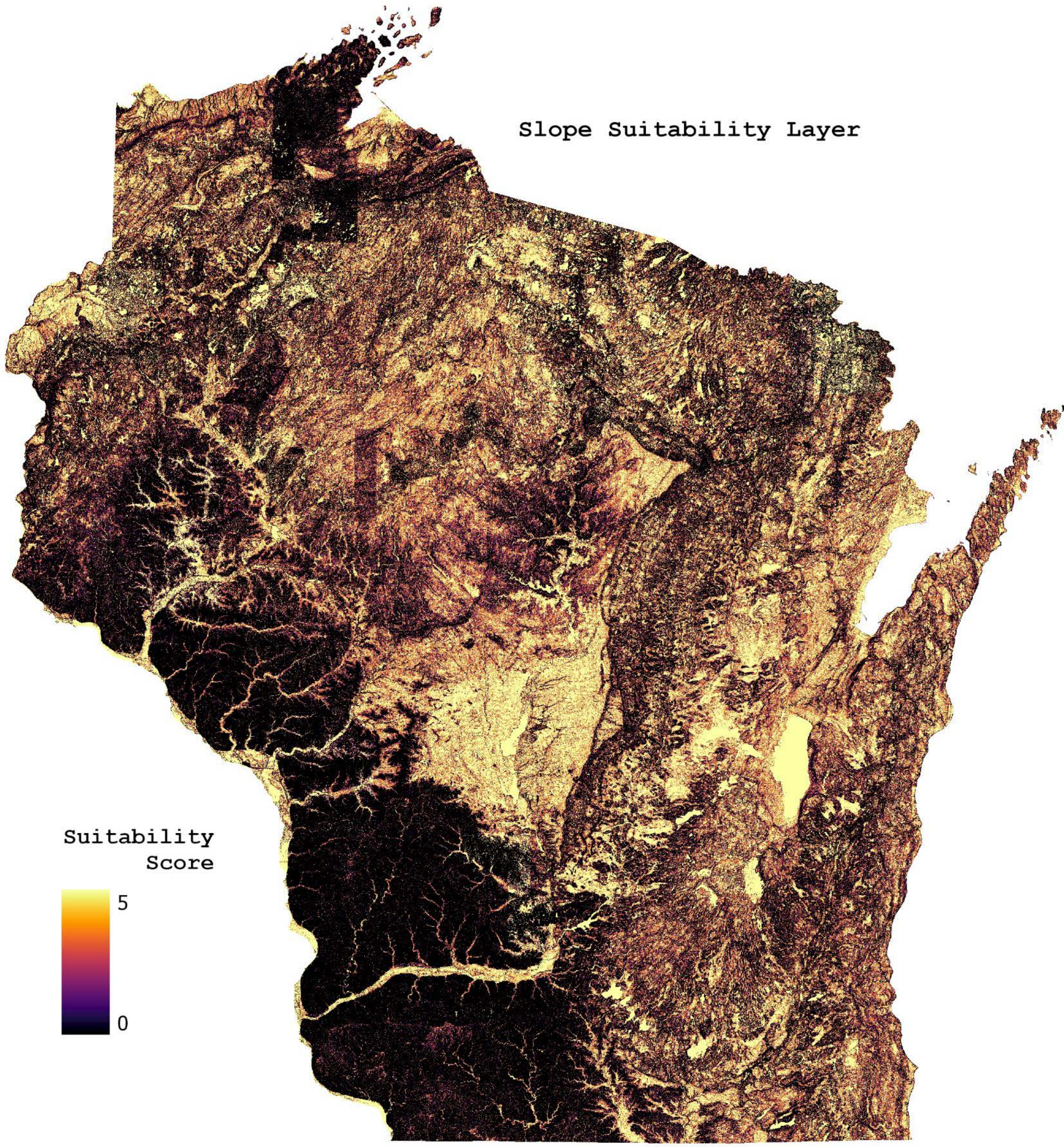
0


Slope Suitability Layer
Suitability Score
5
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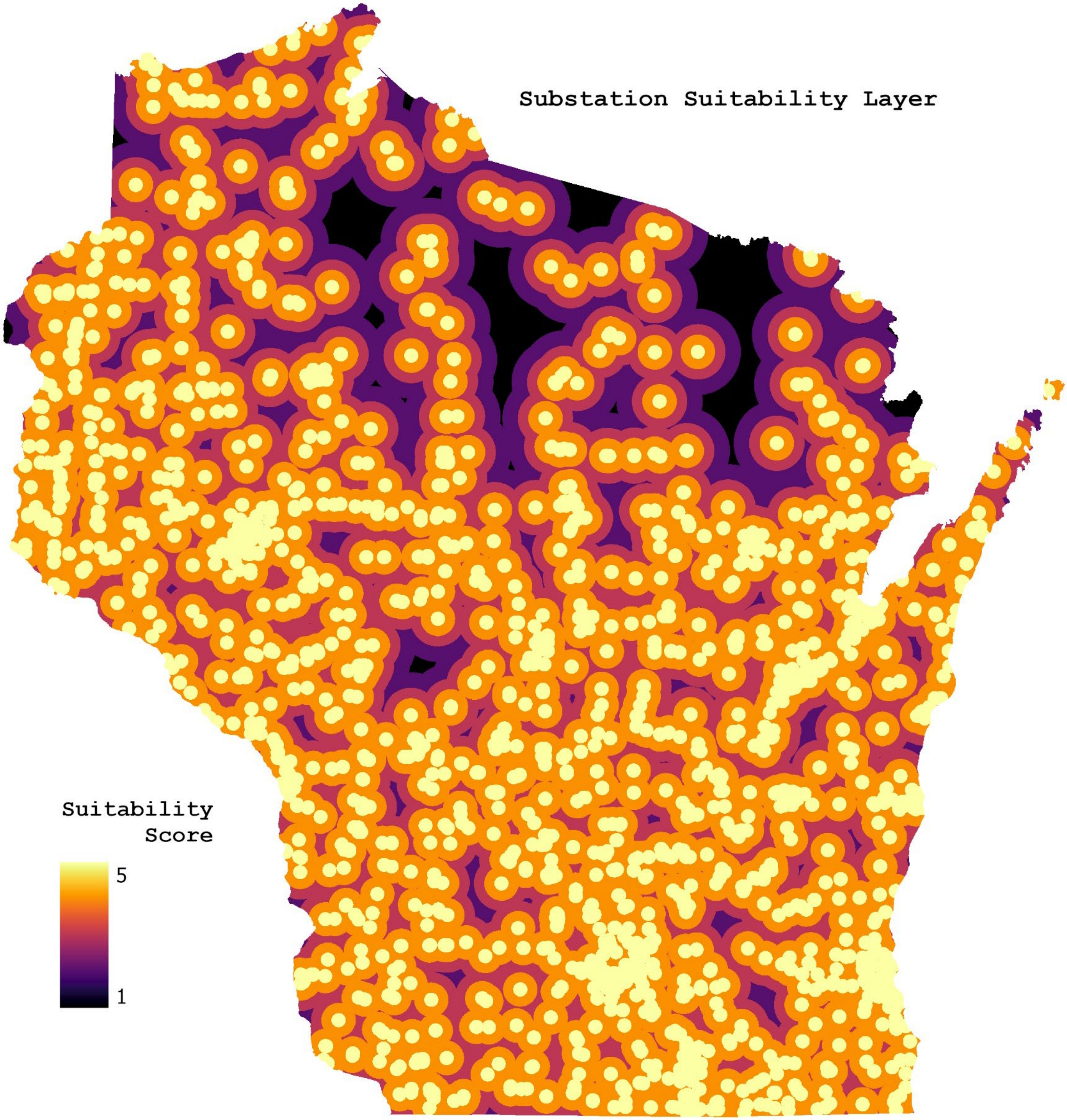
Substation Suitability Layer
Suitability
Score
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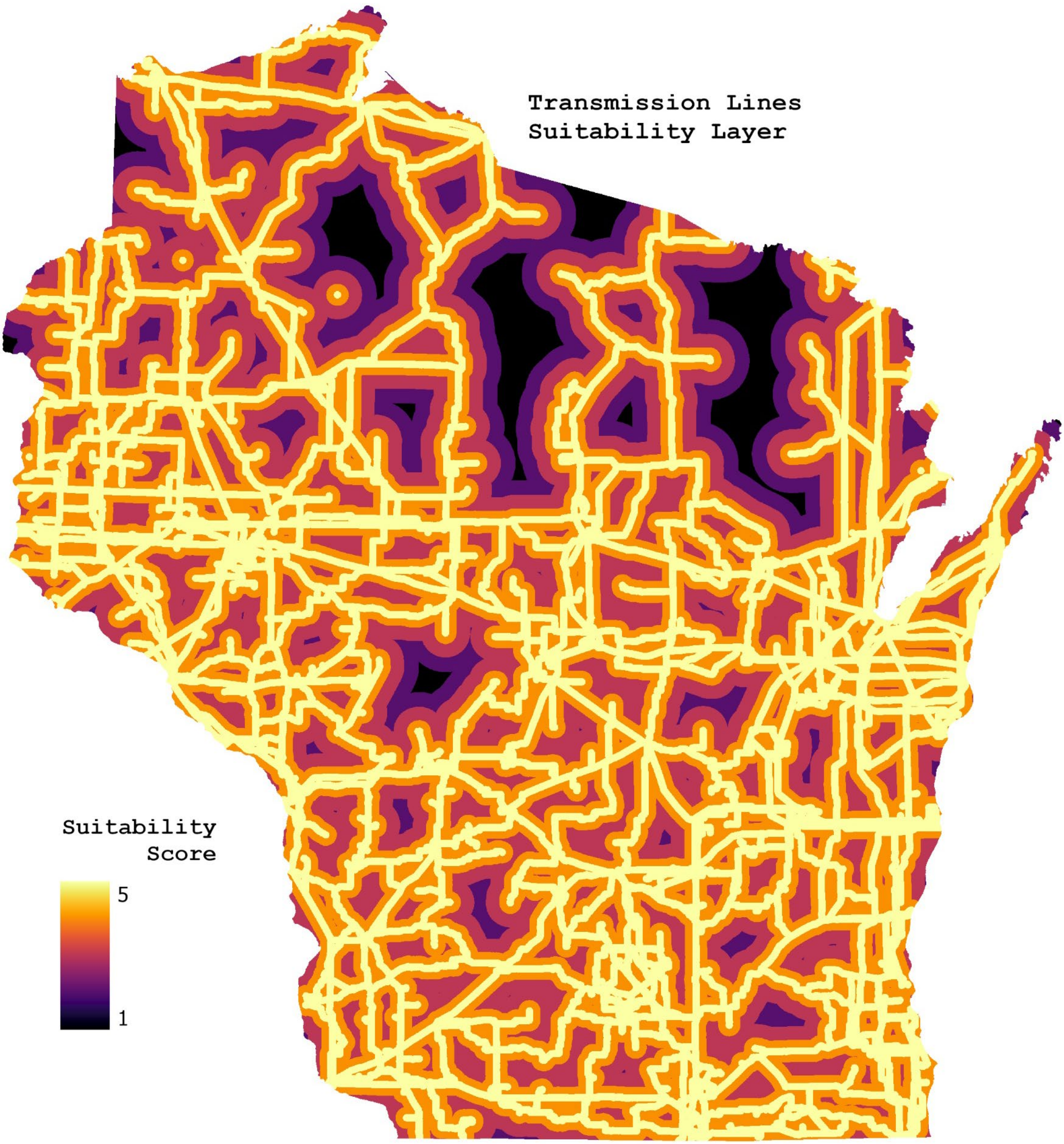
Transmission Lines
Suitability Layer
Suitability
Score
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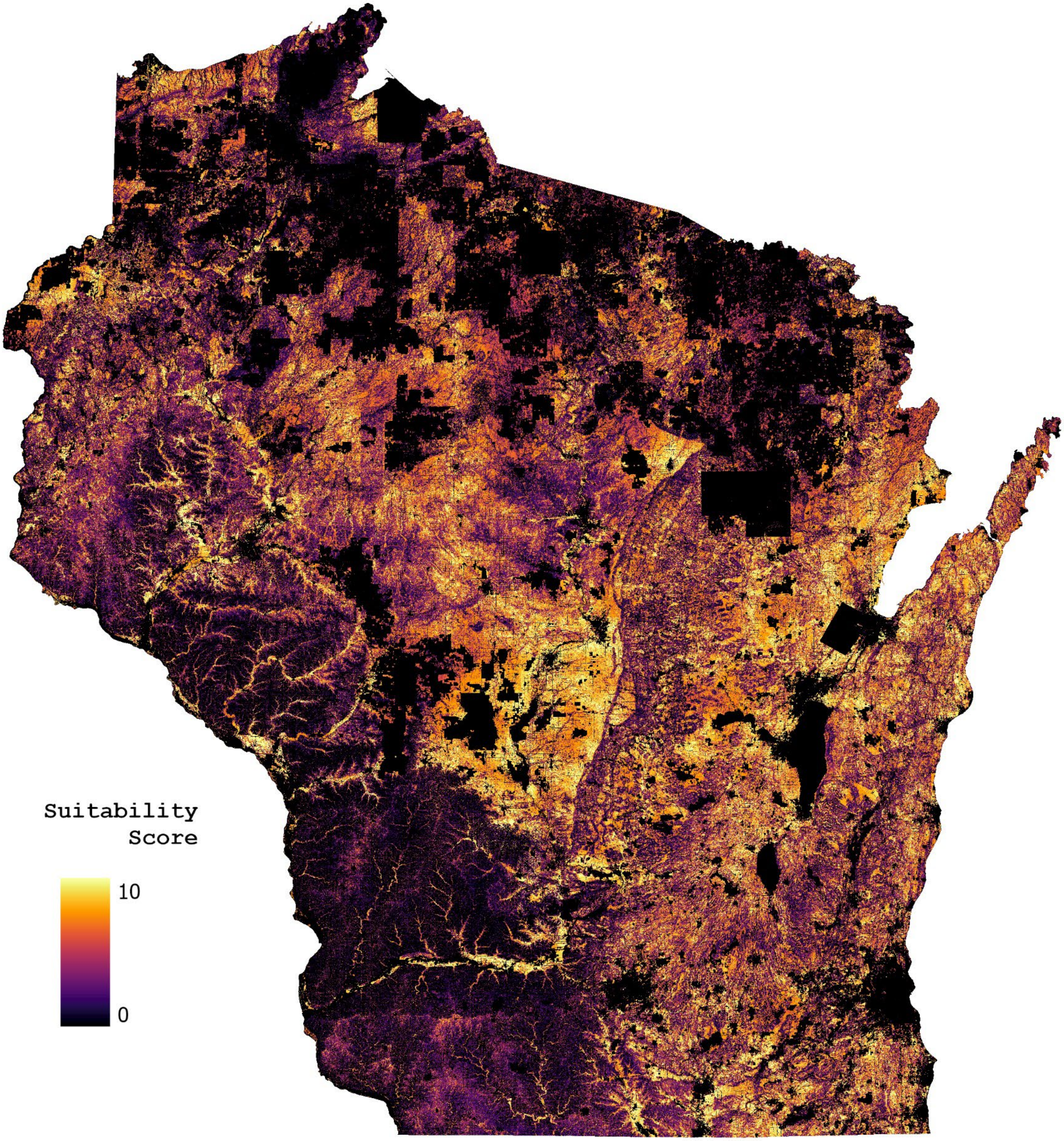
Suitability
Score
10
0

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