



# Wind Energy Diversity in Southeast Wyoming - Initial Results

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# Introduction

- **Motivation**

- Large transmission projects proposed for transporting wind-generated electricity from SE Wyoming to West Coast and Desert Southwest
  - **In reponse to demand for renewables in energy portfolio of states**
- It is desirable to maximize energy from renewables on these lines
  - Addresses end users desire
  - Maximizes use of installed wind
  - Reduces backing power needs
- Wind in SE Wyoming is affected by several factors
  - **Provides diversity that could be used to maximize wind power production**
- From experience, integrating wind from large areas decreases the overall variability
  - Does SE Wyoming have sufficiently diverse wind resources to show similar effects over a smaller region?



## Objectives

- **Perform an analysis to determine the diversity of SE WY wind resources**
  - Determine if diversity exists
  - Characterize the diversity
  - Demonstrate how the diversity could be used to lower variability of wind-generated electricity

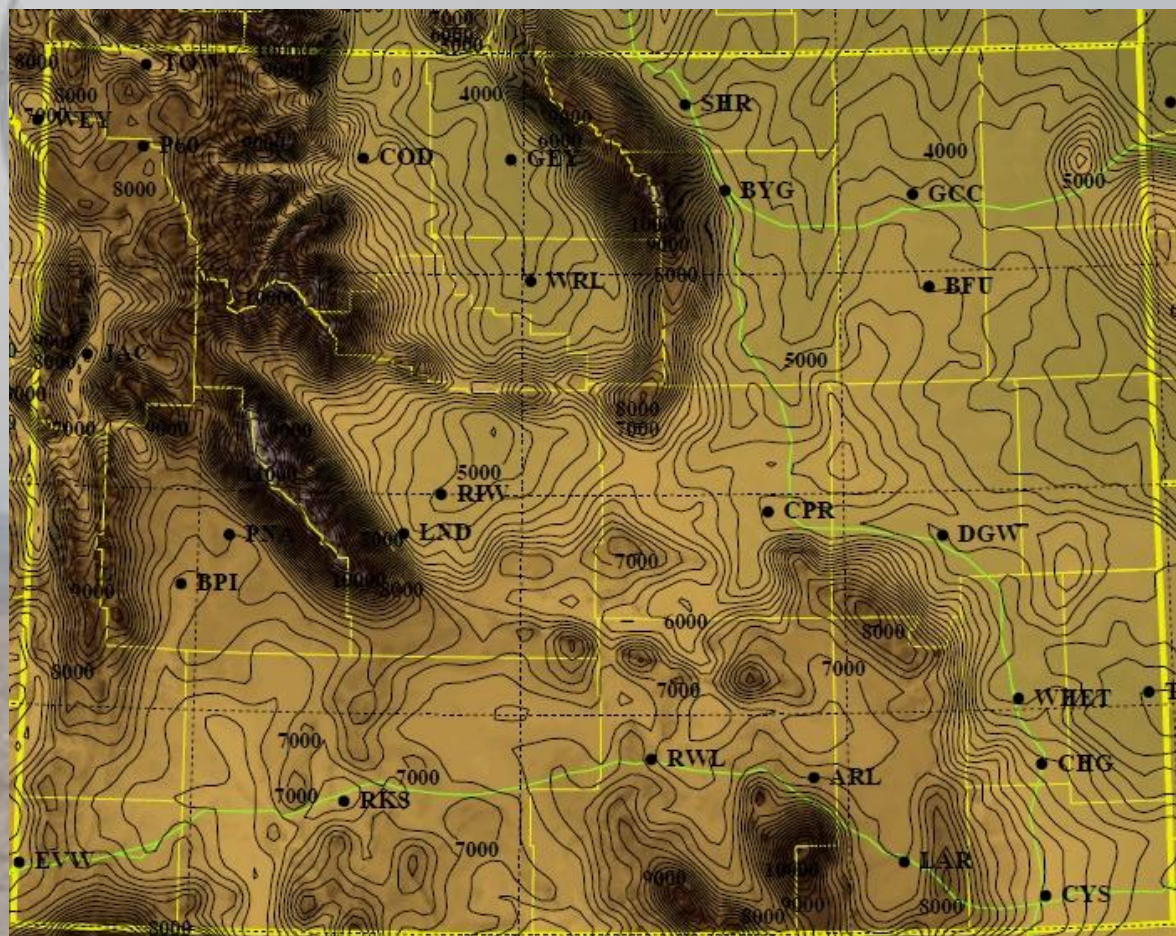
## Approach

- **Use existing weather simulation data for the study**
- **Characterize wind diversity and its effects**
  - Determine two-point spatial correlations to identify relationships between wind resources at different locations
  - Select wind plant “sites” and simulate wind power production



# Southeast Wyoming's Wind Resource

- **What drives Wyoming's Wind?**
  - Low spot in continental divide
  - Effect of high altitude on solar forcing increases wind speed
  - High pressure differences during the winter time
  - "Wind Corridor" in Southern Wyoming



# Southeast Wyoming's Wind Resource





## Estimating Wind Resource – NCEP Models

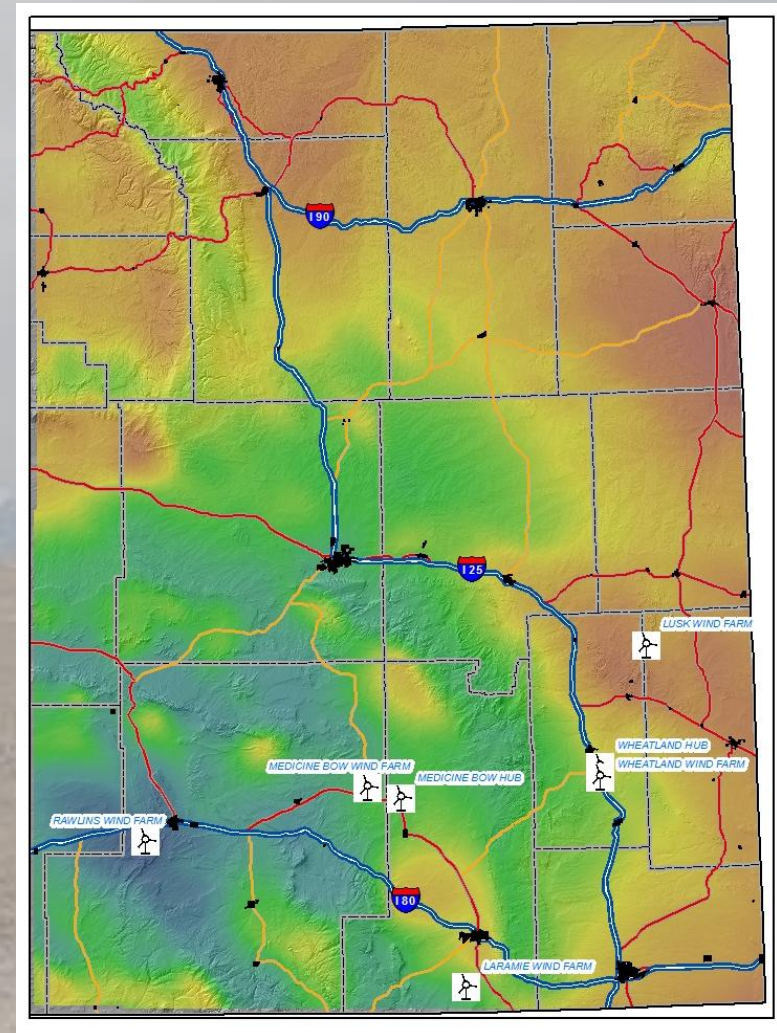
- Operational Models from National Centers for Environmental Prediction (NCEP)
  - **Weather Research and Forecasting Model (WRF)**
    - Weather prediction modeling system for both operations and research
    - Most widely used modeling system
    - Partnership between diverse university groups/governmental agencies
  - **12-km horizontal resolution North American Model (NAM)**
  - **Experimental 4-km horizontal resolution version**
    - Topographic resolution critical in west
    - Explicit resolution of convective motions
  - **10-m wind standard output variable**
  - **Wind forecasting remains a challenge**
    - Local topographic features
    - Proper depiction of turbulence in models
    - 10-m winds more difficult to forecast than upper level winds

# Correlation Determination

- **NCEP 4 kilometer grid, hourly data used over course of a year**
  - August 2009 – July 2010
- **Wind resource characterized by the wind power density at 80 m.**
- **Two-point correlation performed**
  - Wind power densities (WPD)
  - Wind velocity

$$\rho_{1,2} = \frac{\overline{u_1 u_2}}{\sigma_1 \sigma_2}$$

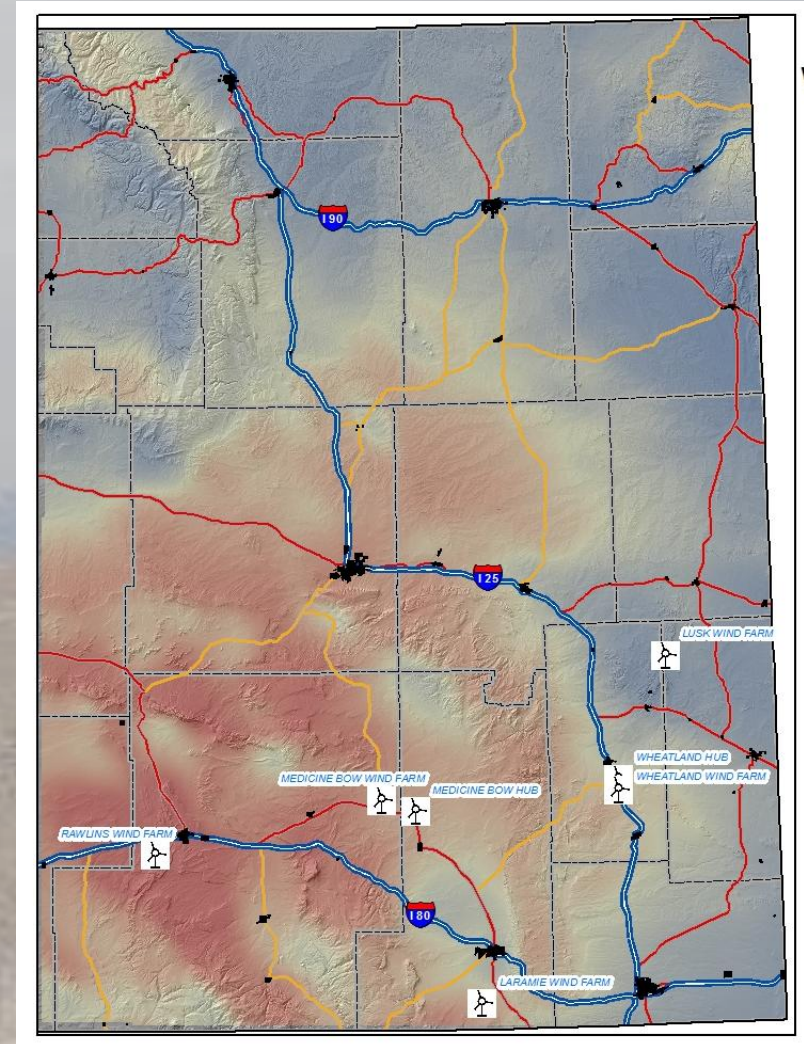
## Rawlins Velocity Correlation



# Correlation Coefficient Interpretation

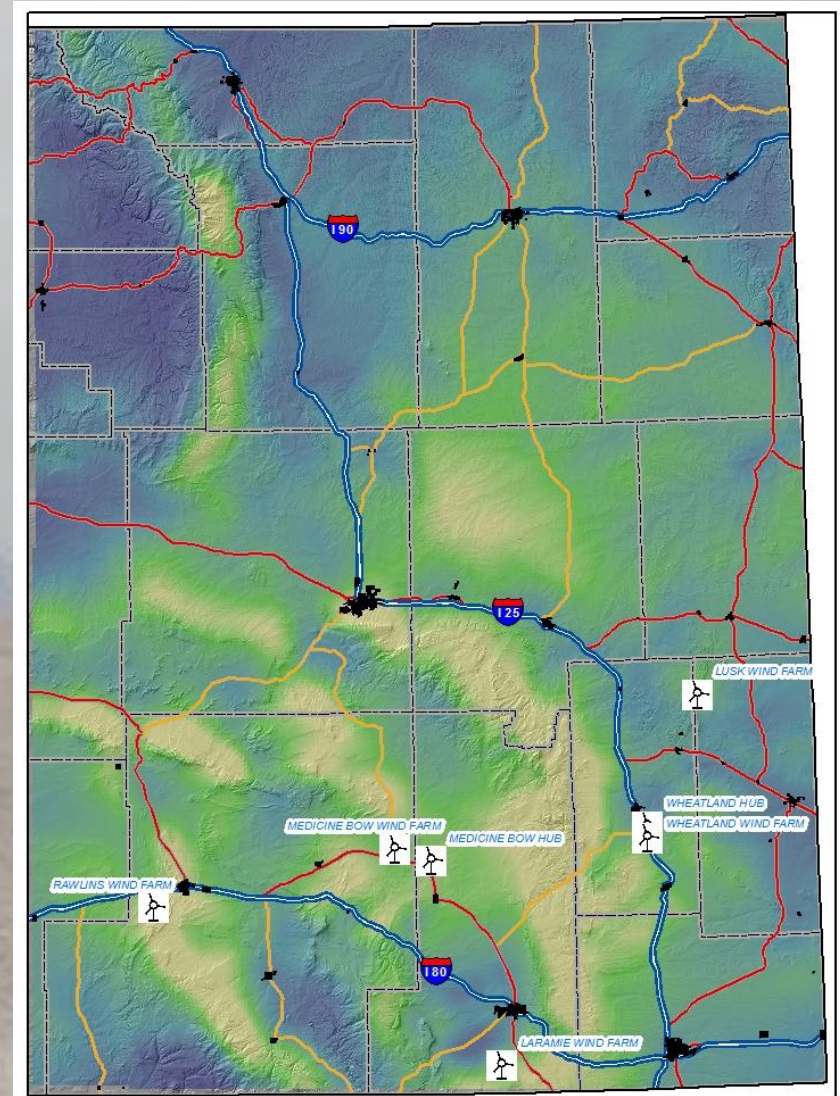
## Rawlins WPD Correlation

- **Values ~ 1 (Red)**
  - Highly correlated wind sites
  - Wind blows at both locations at the same time
- **Values ~ 0 (Blue)**
  - Low correlation wind sites
  - Wind blowing at 1 site has little relation to wind blowing at the other site



# Wind Power Density

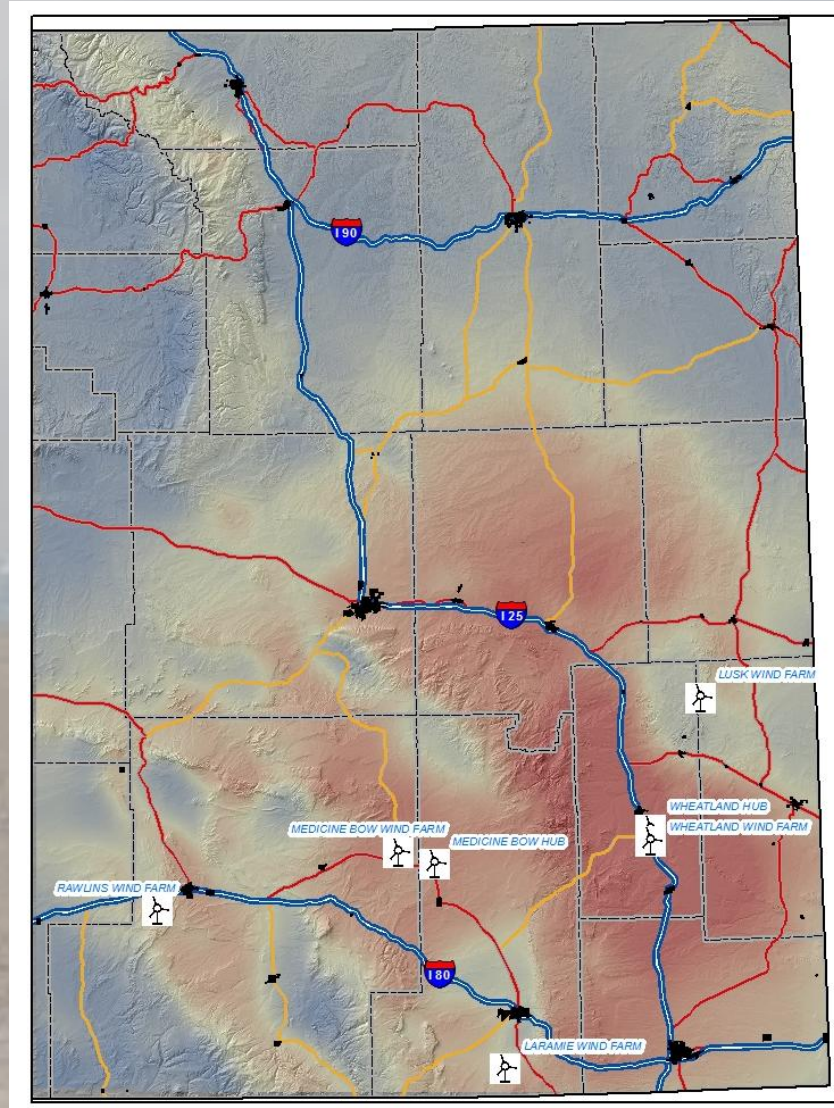
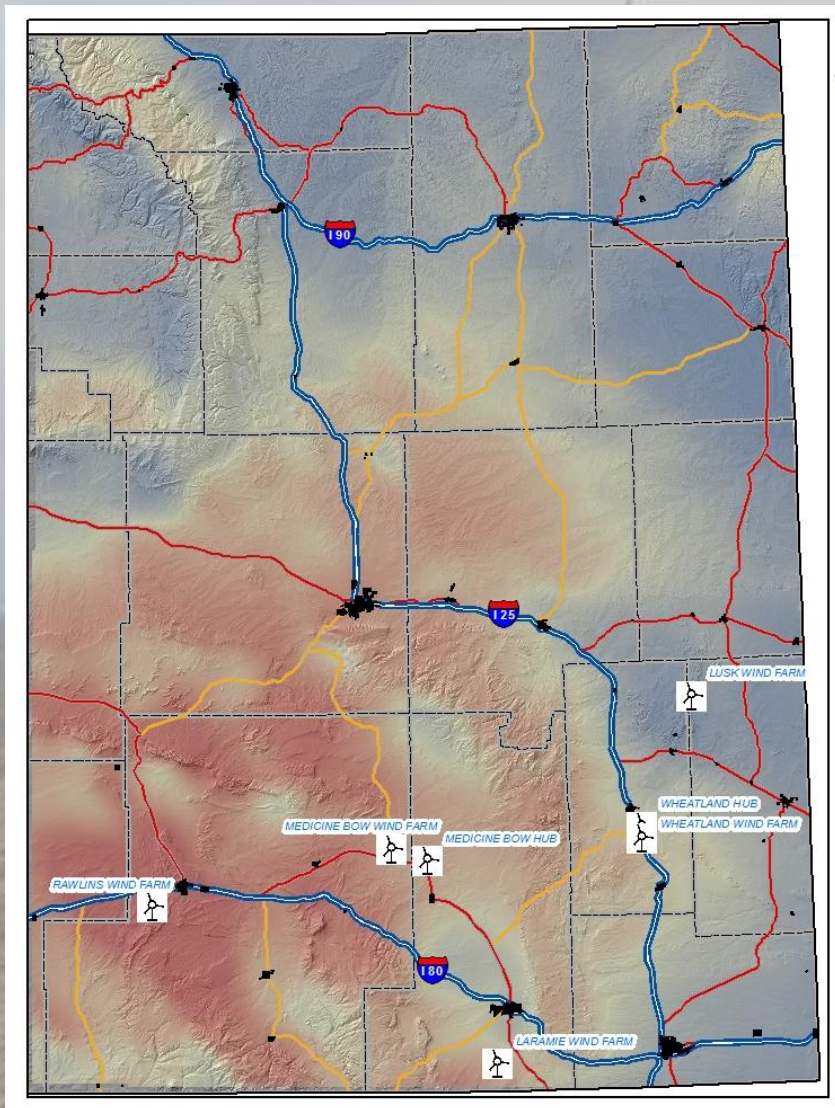
- **Low correlations indicate possibility of good wind diversity sites**
- **Wind must also be good**
  - Low wind speeds could still yield a low correlation, but this is not a place to locate a wind farm
  - Use regions of high wind power density to identify areas that also have good wind resource



## WPD Correlations for Different Sites

Rawlins

Wheatland

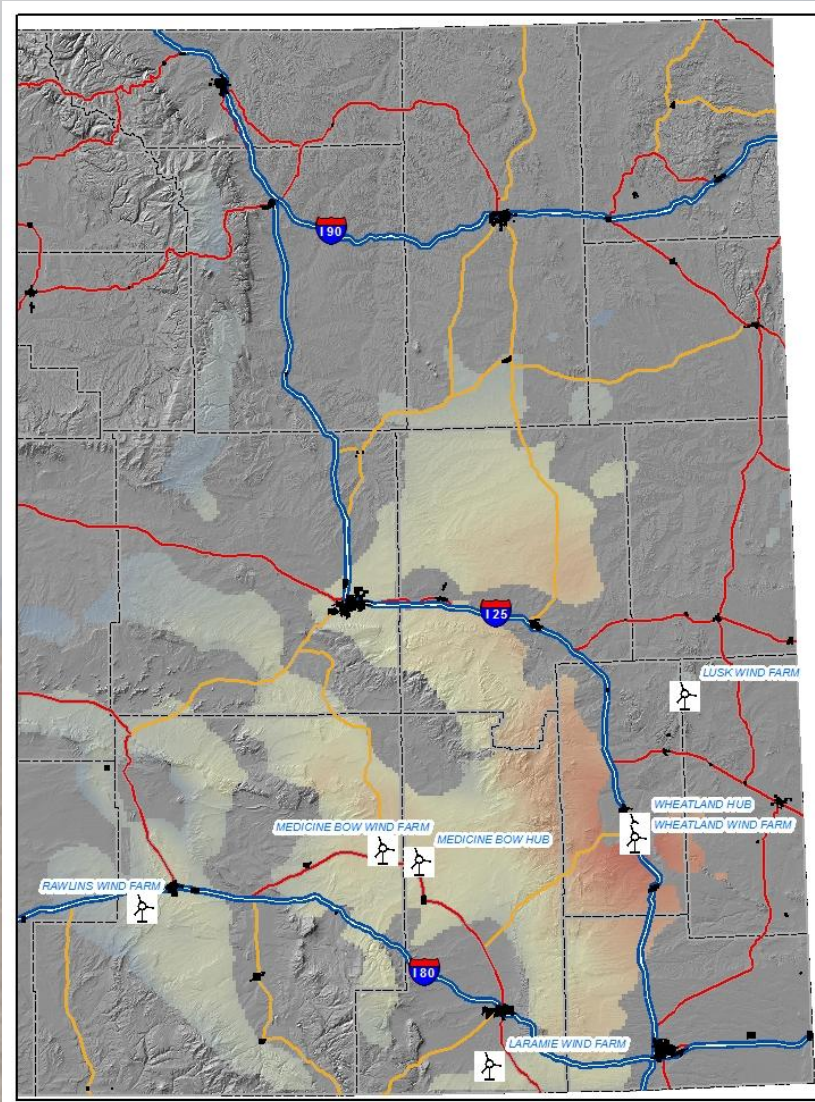
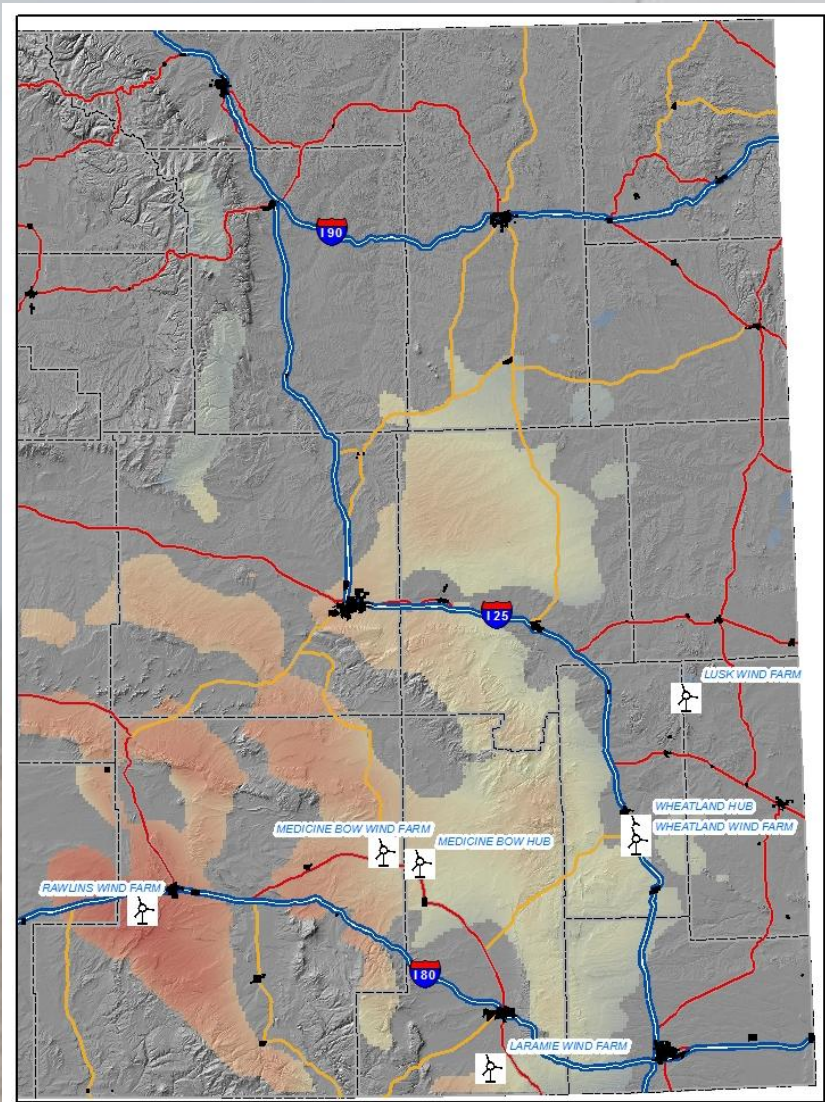


## WPD Correlations for Different Sites

Rawlins

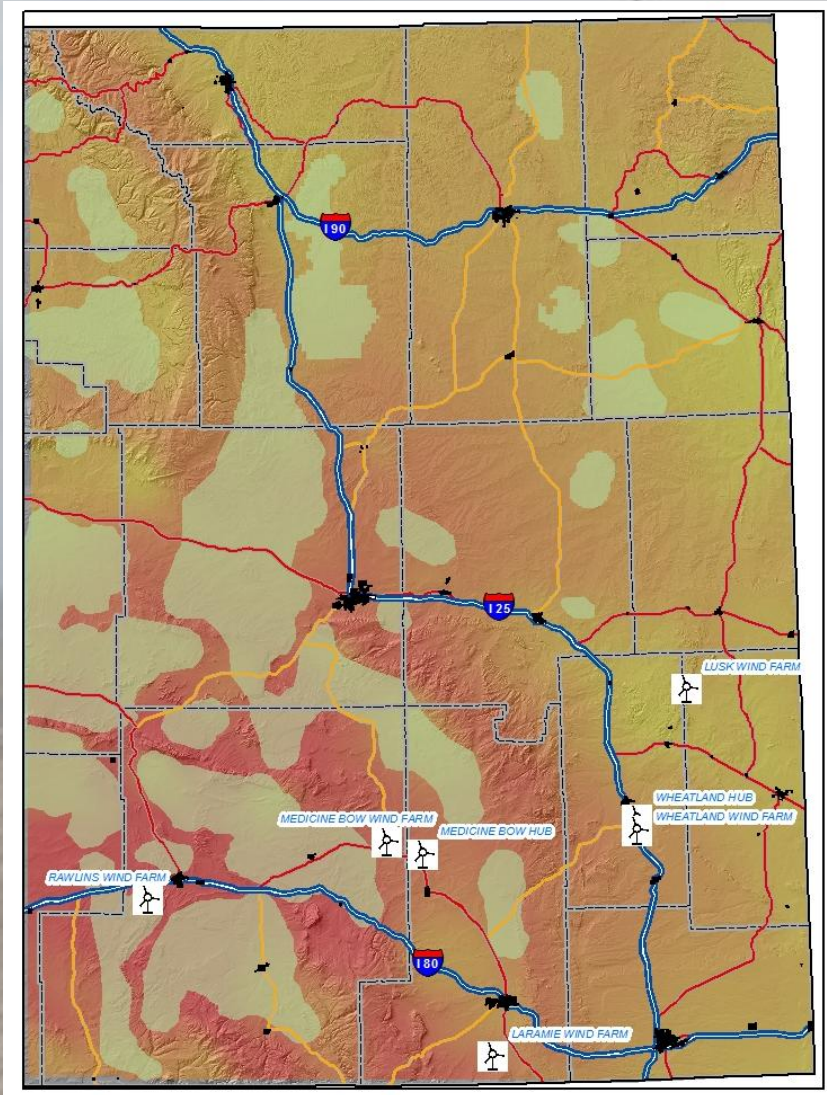
WPD > 400

Wheatland



## TPP Correlations for Different Sites

Rawlins



- **Other factors come into play besides good wind and low correlations between sites**
  - Wildlife
  - Archeological/Historical Sites
  - Municipality
- **Decision on wind farm placement dependent on all these factors**

# Results

## Site Selection and Evaluation

- **Selection**

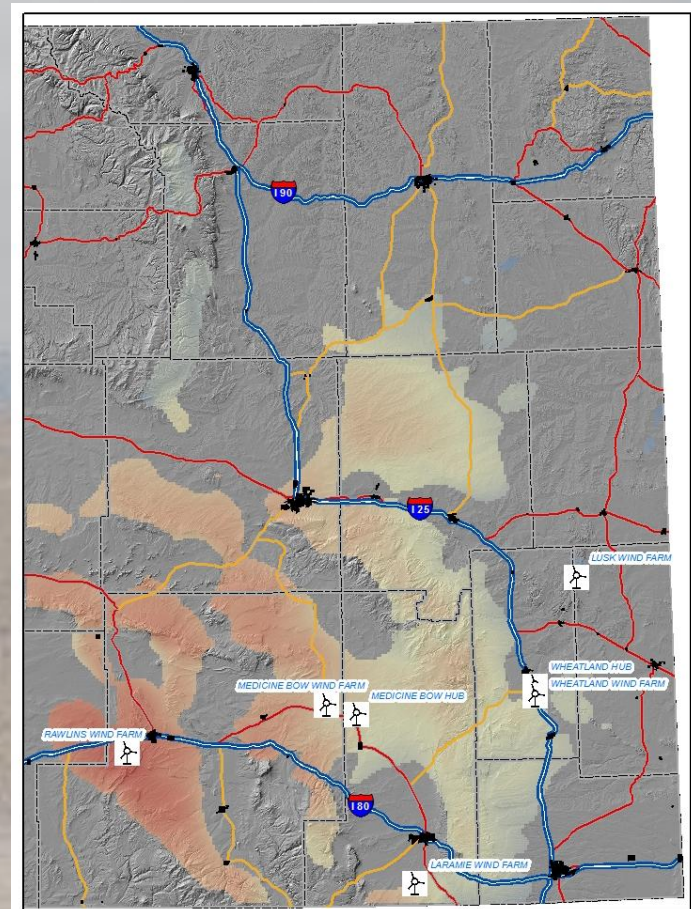
- Pick sites with complementary wind attributes
  - **Low correlation**
- Ensure other factors are positive
  - **Good to excellent wind resource**
  - **No restrictions on wind farm construction**

- **Evaluation**

- Place a number of turbines at each site selected.
- Assume same output from all turbines at the same site
- Estimate output

- **Transmission Line**

- Assume a 1 GW line connected to the sites



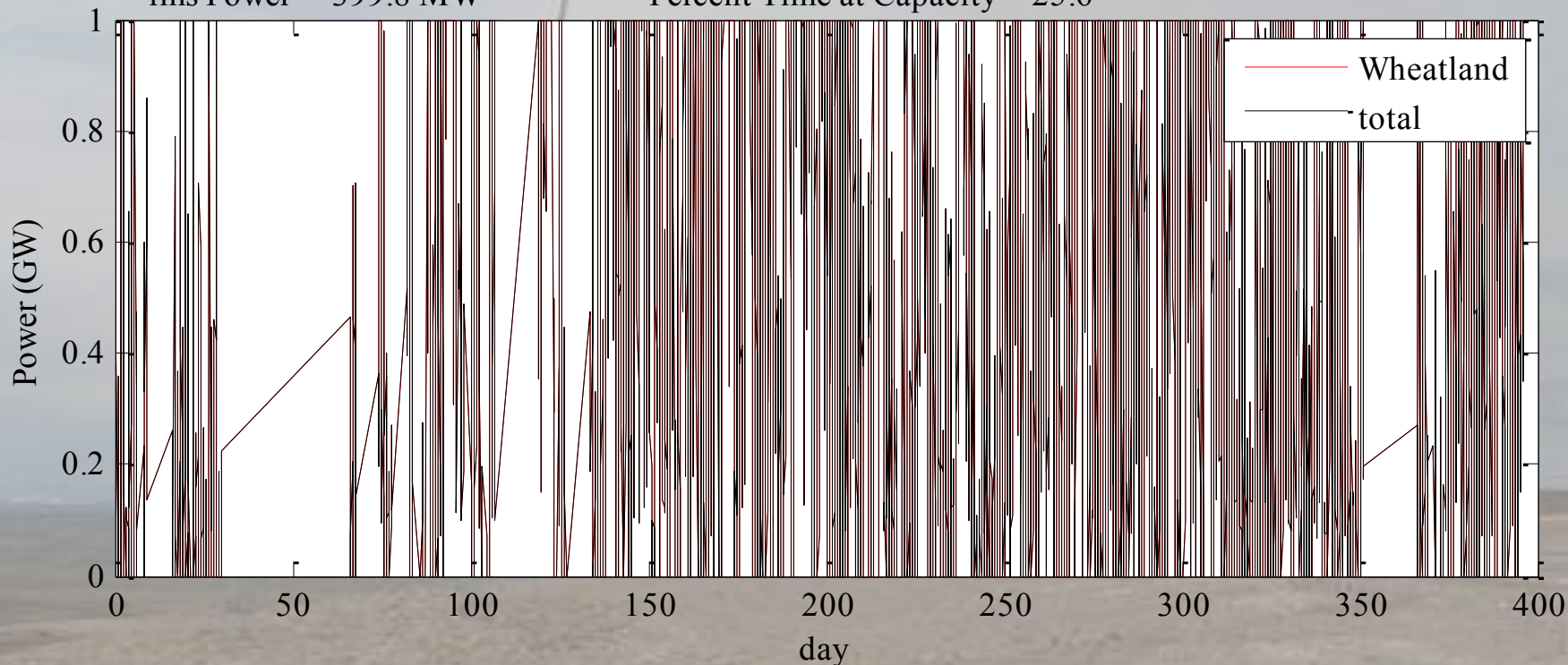
## 1 GW Capacity at a Single Site

Average Power = 446.3 MW

Total Energy = 78457.5 GW-hr

rms Power = 399.8 MW

Percent Time at Capacity = 25.6



Jul 1 09

Oct 1 09

Jan 1 10

Apr 1 10

Jul 1 10

- **Production is at full output a significant amount of time**
- **Any addition of wind turbines will result in significant curtailment**
- **Variability of output is high**

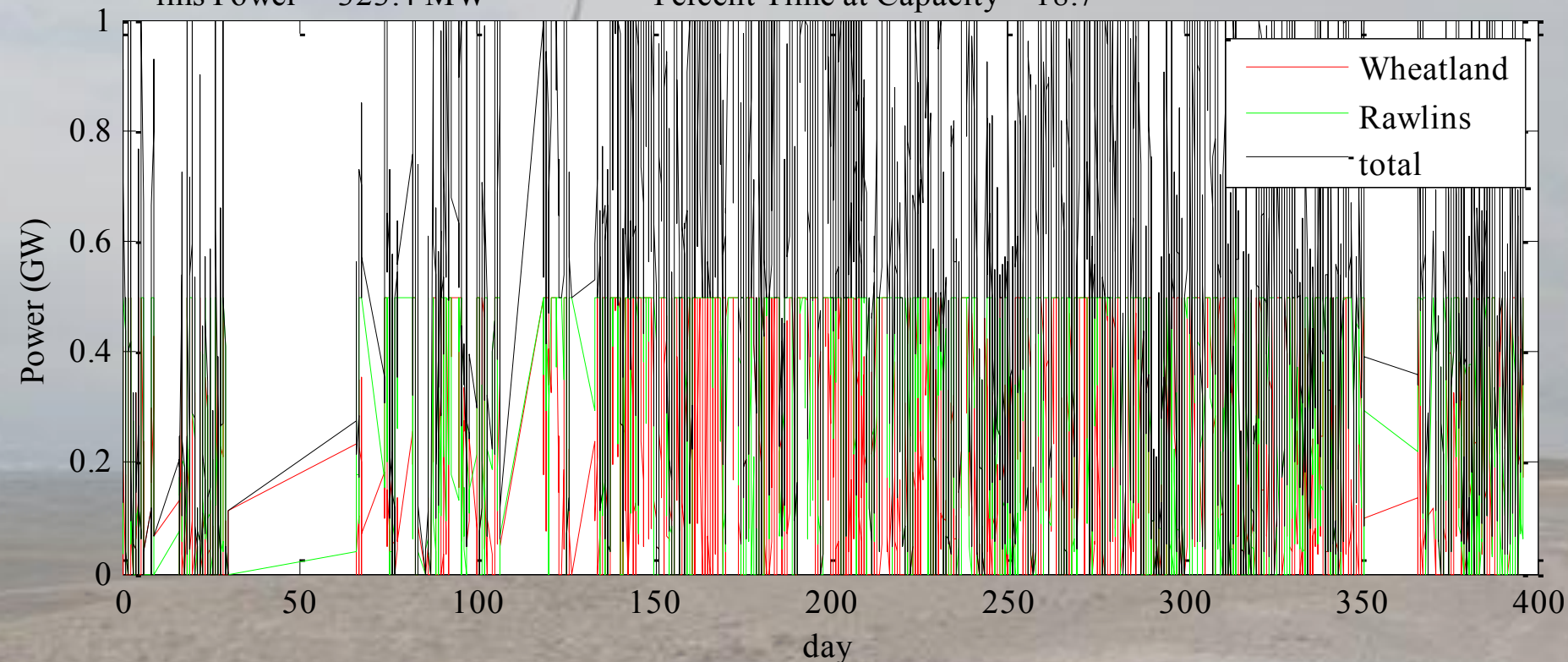
## 1 GW Capacity Split Between Two Sites

Average Power = 542.3 MW

Total Energy = 95332.6 GW-hr

rms Power = 323.4 MW

Percent Time at Capacity = 18.7



Jul 1 09

Oct 1 09

Jan 1 10

Apr 1 10

Jul 1 10

- **Production is at full output less of the time**
- **Any addition of wind turbines will result in less curtailment**
- **Variability of output is lower compared to single site case**

# Results

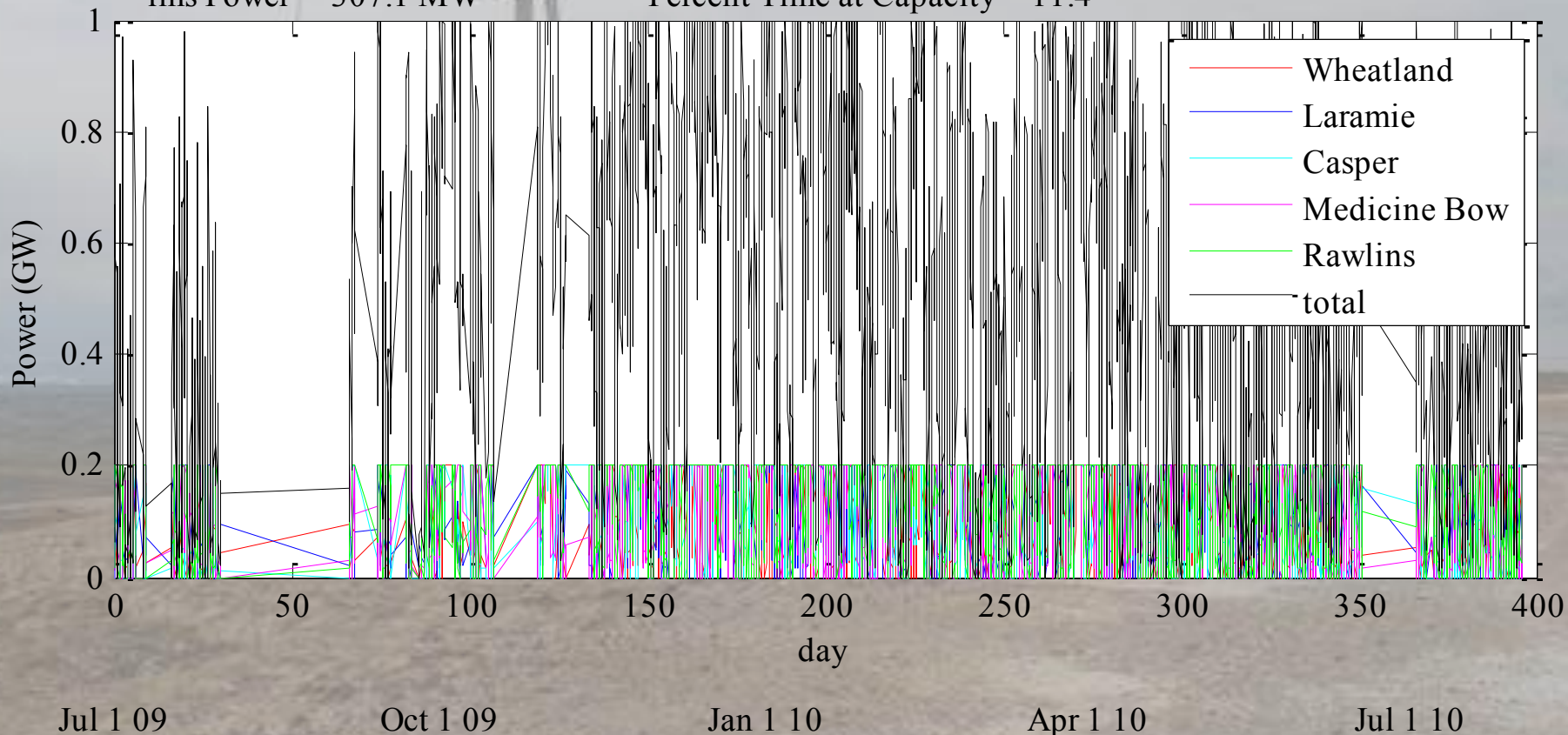
## 1 GW Capacity Split Between Five Sites

Average Power = 546.8 MW

Total Energy = 96119.3 GW-hr

rms Power = 307.1 MW

Percent Time at Capacity = 11.4

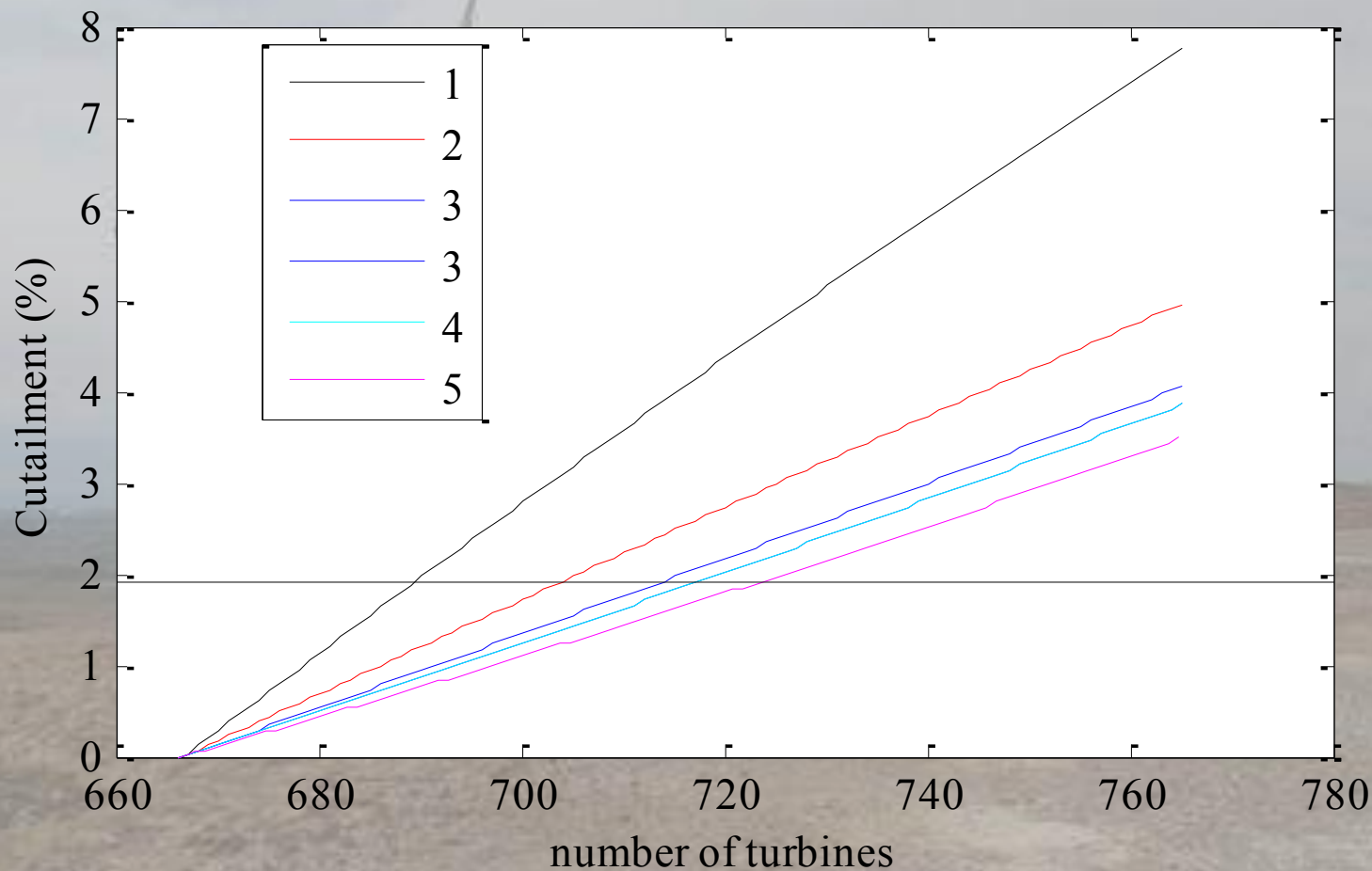


## Summary of Turbines Located at Combination of 5 Sites

Wind Farms	Average Power (MW)	rms Power (MW)	% time at capacity
Wheatland	446	400	25
Wheatland & Rawlins	542	323	19
Wheatland & Laramie	505	341	17
Wheatland ,Rawlins & Laramie	549	313	15
Wheatland ,Rawlins & Medicine Bow	550	317	15
Wheatland ,Rawlins, Laramie & Medicine Bow	554	315	13
Wheatland ,Rawlins, Laramie, Medicine Bow, Casper	547	307	11

# Results

## Curtailment at 2%





## Summary

- **Southeast Wyoming encompasses a diverse range of wind resources**
  - Correlations demonstrate this diversity
- **Careful integration of wind energy assets can improve delivery of wind-generated power**
  - Less variability in the power supplied
  - Increased power available for transmission for the same power curtailment

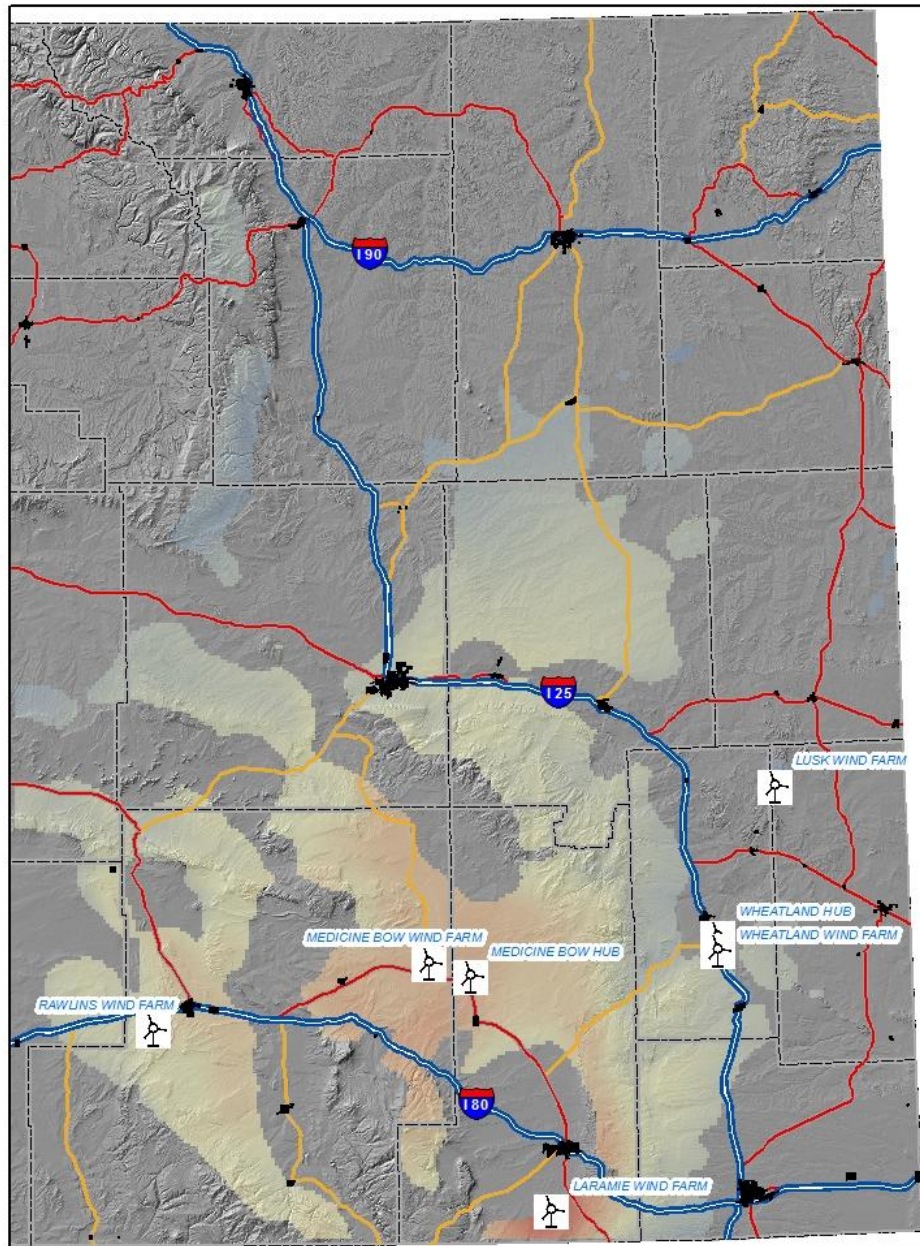
## Suggested Future Work

- **Verification of model data with field data**
- **Increase the geographical range included with the data**
- **Explore other scenarios**




# Acknowledgements

- **Wyoming Infrastructure Authority**
  - Support for this specific project
- **BP Gift Fund**
  - Ongoing support for various wind resource projects
- **School for Energy Resources**
  - Support for the Center's activities



## Laramie Wind Farm Wind Power Density Correlations where $WPD \geq 400 \text{ W/m}^2$

### Legend

 Sites

 Interstate Highways

 US Highways

 WY Highways

 County Boundaries

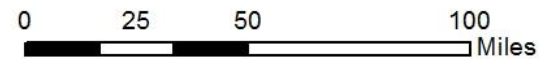
 Municipal Boundaries

**WPD Correlations Nat. Neighbor**

**Value**

High : 0.998581

Low : 0.0560563





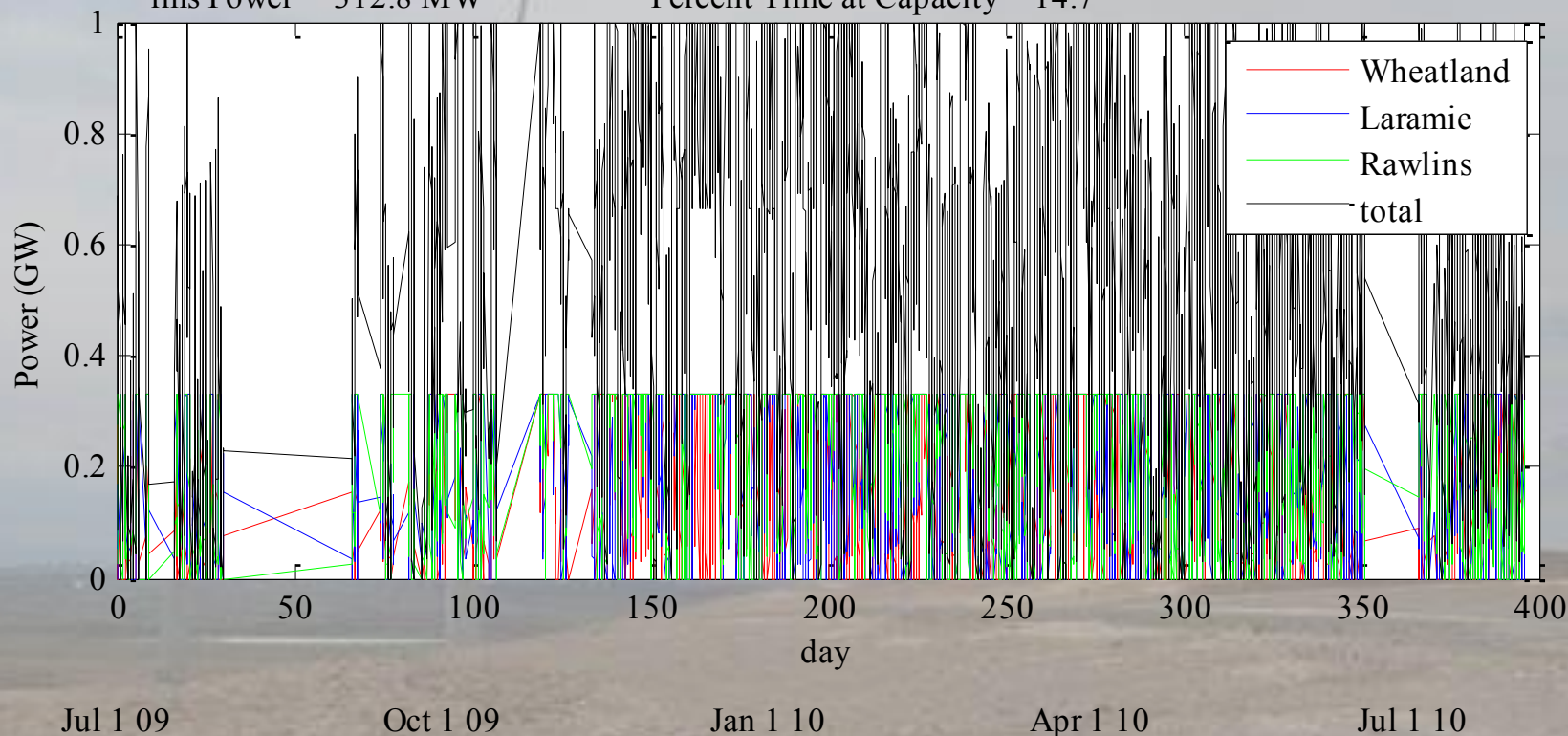
## 1 GW Turbines Split Between Three Sites

Average Power = 549.3 MW

Total Energy = 96568.1 GW-hr

rms Power = 312.8 MW

Percent Time at Capacity = 14.7



- **Production is at full output less of the time than either single or dual site**
- **Any addition of wind turbines will result in less curtailment**
- **Variability of output is lower compared to single and dual site case**