GLOBAL SOLUTIONS
IN ENGINEERING

GENIVAR

NorthWestern Energy Wind Integration Study

Lessons Learned and Other Opportunities

Utility Variable-Generation Integration Group
Operating Impacts and Integration Studies Users Group Meeting

Tuesday, October 23, 2012

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GENIVAR

Presentation Overview

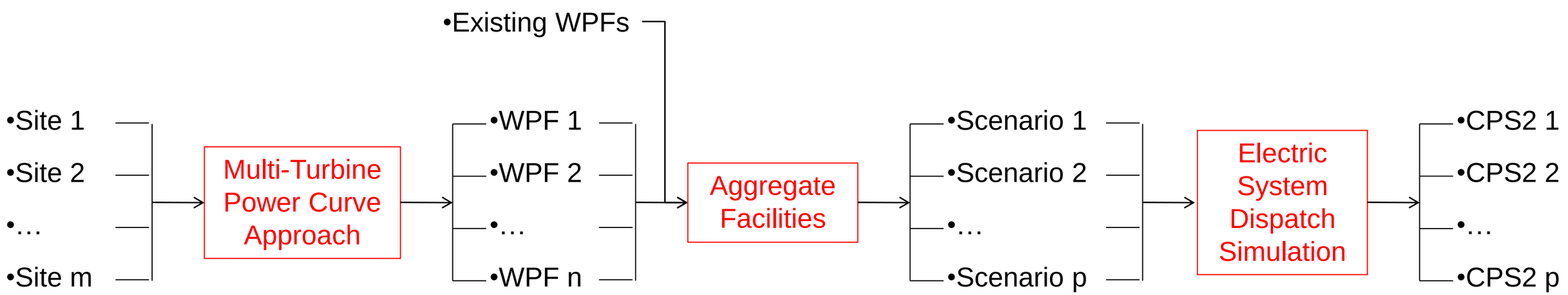
- Project Background
- GENIVAR's Integration Study Approach
- Scope of NWE Wind Integration Study
- Scenario Descriptions
- Dispatch Simulation Overview
- Dispatch Simulation Results
- Lessons Learned
- Other Possibilities

Project Background

- 2004 - 2005: Participated in AESO Wind Integration Study
- 2008: Completed 1st wind integration study for NWE
- 2010 - 2011: Worked on and completed 2nd wind integration study for NWE

GENIVAR's Integration Study Approach

→ Overview of study approach



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Scope of NWE Wind Integration Study

- Prove fidelity of dispatch simulator (again)
- Devise wind development scenarios that:
  - Investigate effect of geographical diversity while controlling capacity
  - Investigate effect of added capacity while controlling geographical diversity
- In all scenarios, determine regulating reserves required to meet performance standards
- Investigate merits of alternative operational strategies:
  - Different wind forecasting methods
  - Wind curtailment schemes
  - Intra-hour supply adjustment

Scenario Descriptions

- Study Period: July 1, 2008 to December 31, 2009, inclusive
- 16 Scenarios were run through the dispatch simulator
- 2 trivial scenarios were identified
  - Scenario A: Existing wind - 135 MW Judith Gap & 9 MW Horseshoe Bend ≈ 10% load
  - Scenario B: All wind resources removed
- 14 “Development Scenarios” identified by modeling subgroup
  - Based on wind data collected by developers

Scenario Descriptions

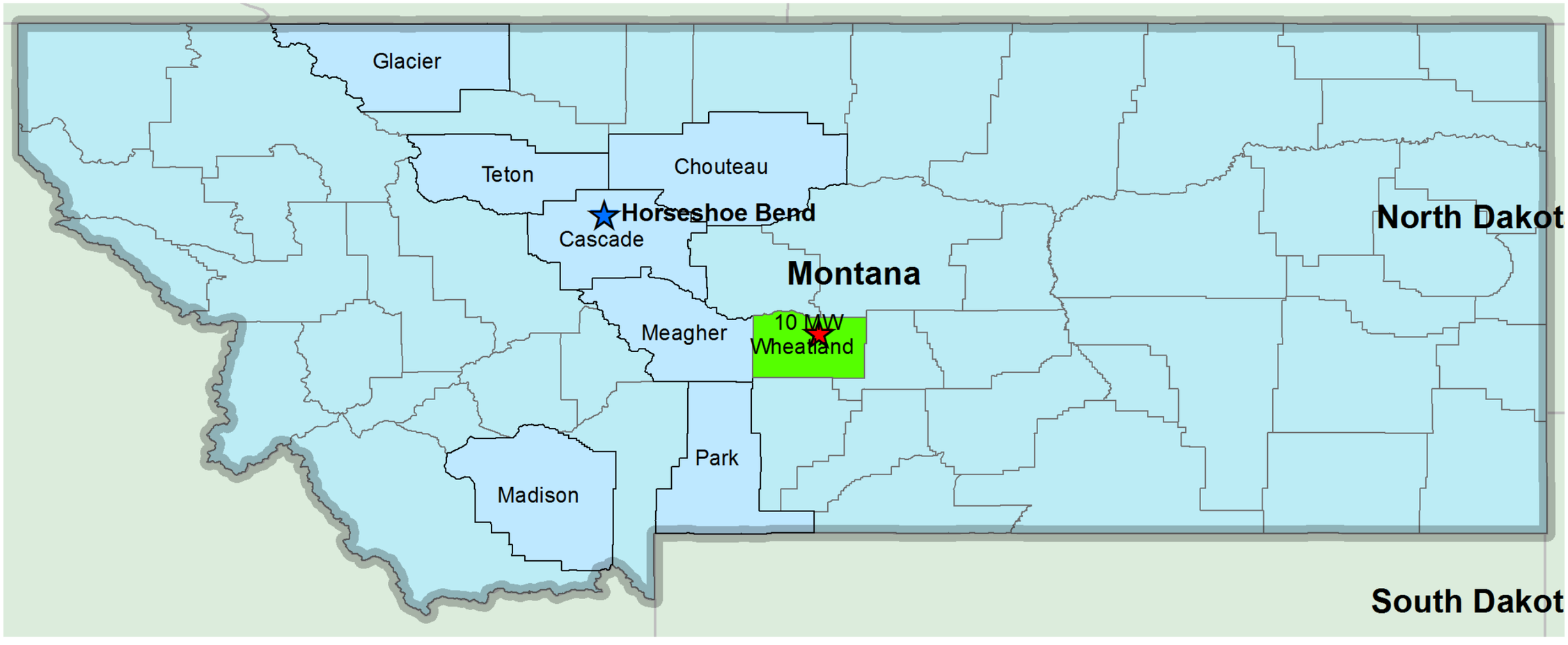
→ Pros and Cons of scenario based approach

Cons	Pros
• Specific in nature	•Designed to address immediate concerns
•Difficult to generalize	•As quickly as concerns change, the simulated scenarios can be changed

Scenario Descriptions

→ Scenario C1: Add 10 MW

- One 10 MW project added near Judith Gap in Wheatland County
- Nameplate Wind Capacity: 154 MW



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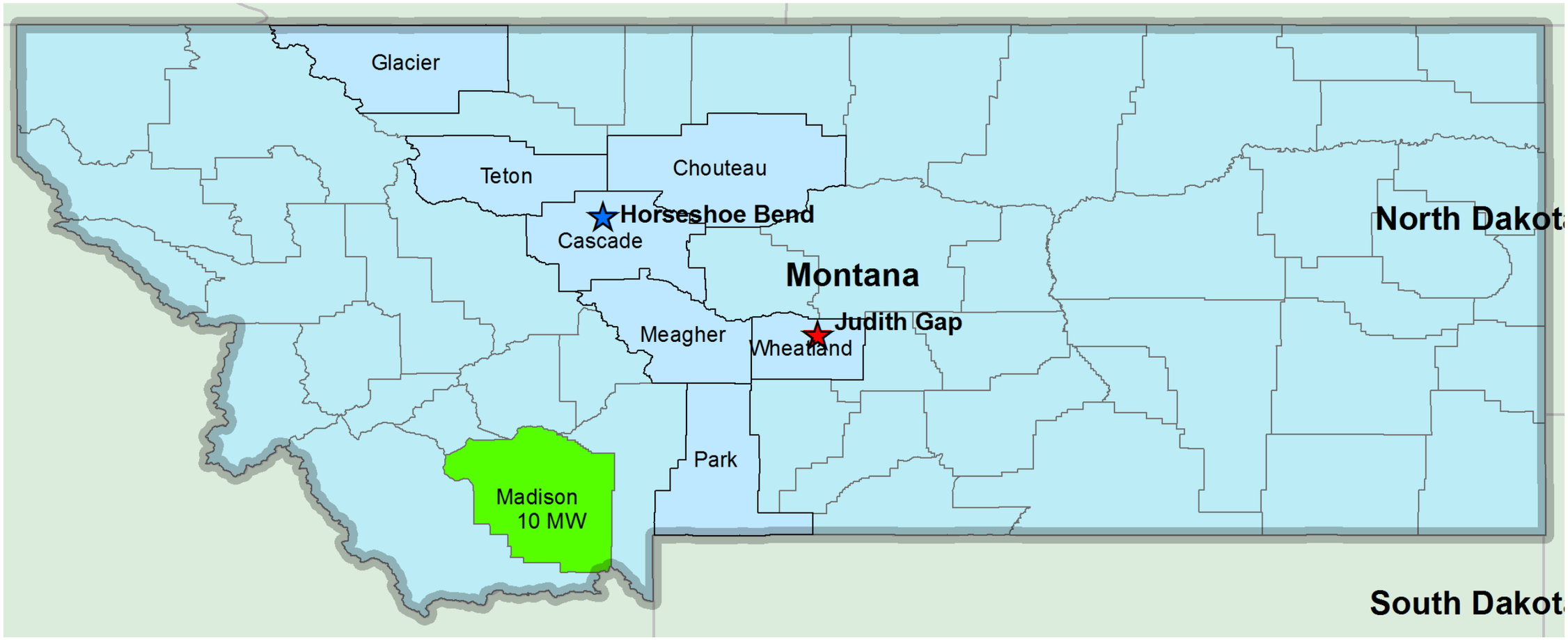
Scenario Descriptions

→ Scenario C2: Add 10 MW

- One 10 MW project added distant from Judith Gap in Madison County
- Nameplate Wind Capacity: 154 MW



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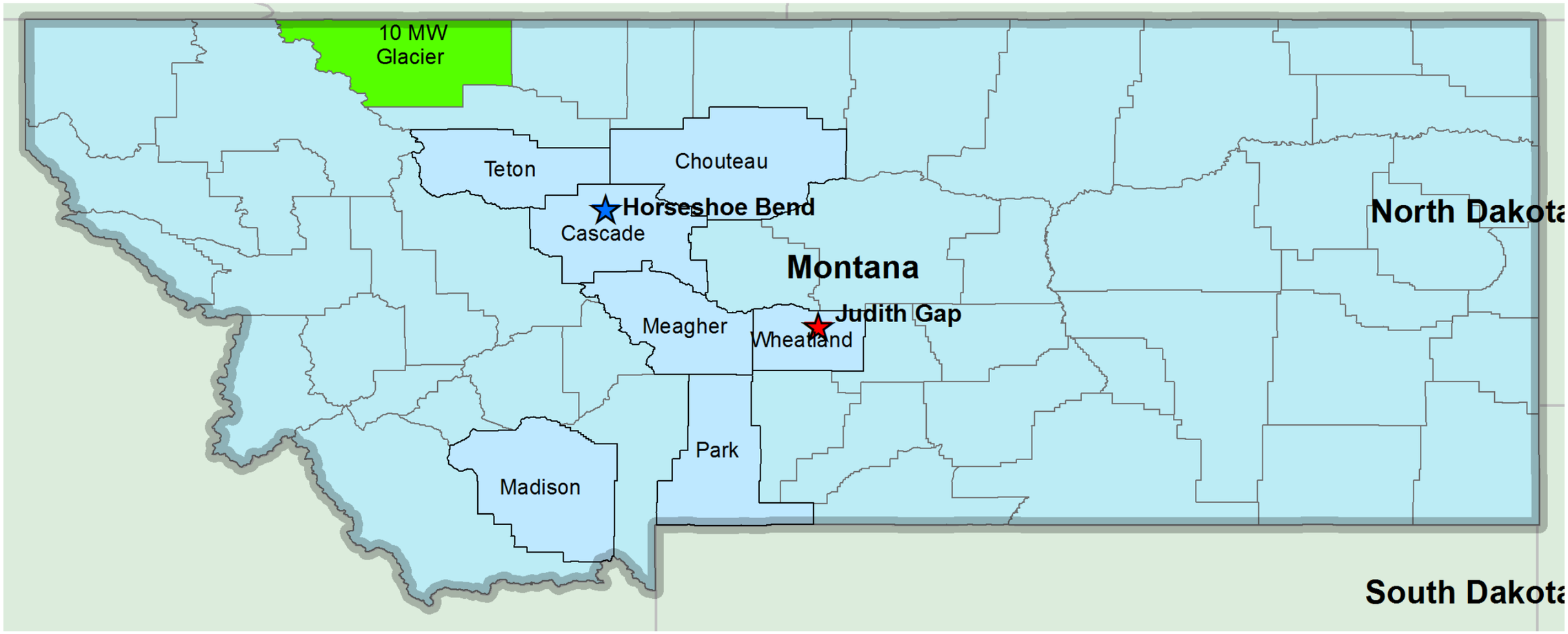
Scenario Descriptions

→ Scenario C3: Add 10 MW

- One 10 MW project added distant from Judith Gap in Glacier County
- Nameplate Wind Capacity: 154 MW



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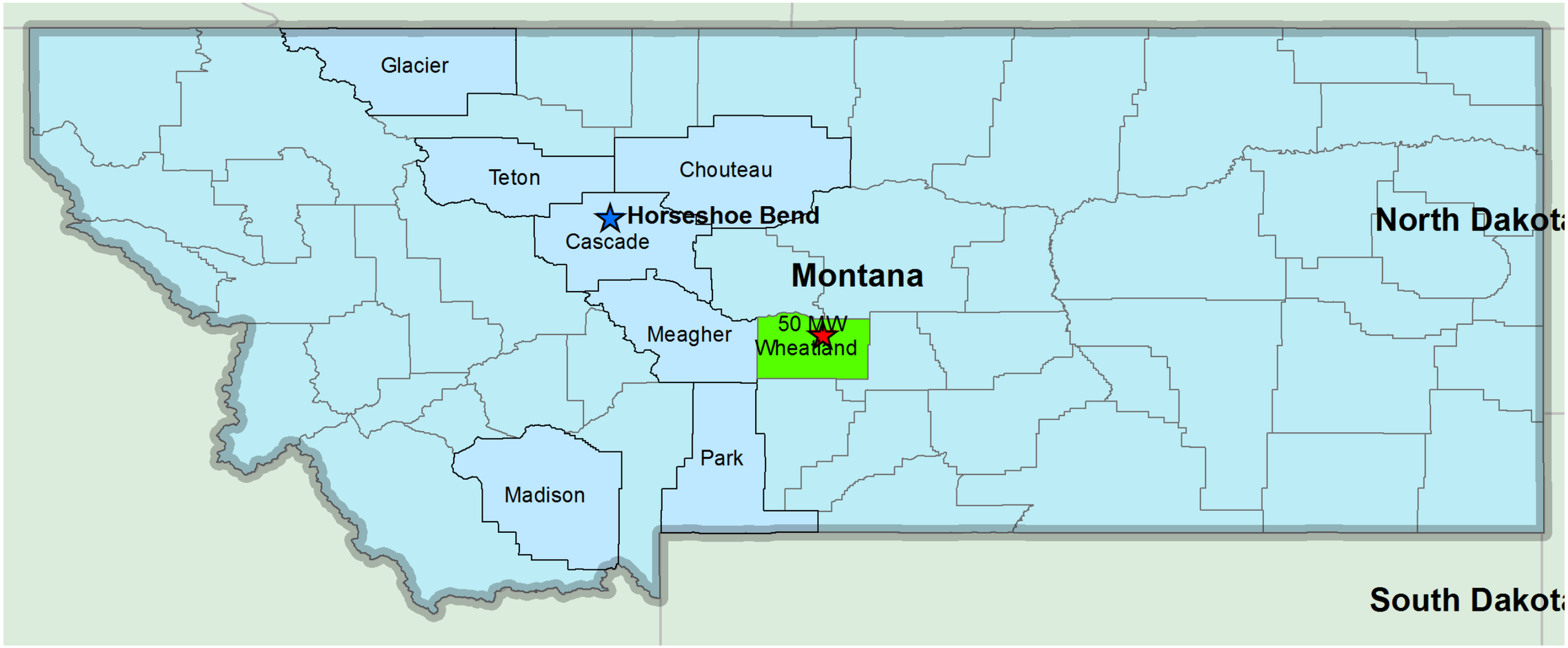
Scenario Descriptions

→ Scenario D1: Add 50 MW

- One 50 MW project added near Judith Gap in Wheatland County
- Nameplate Wind Capacity: 194 MW



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Scenario Descriptions

→ Scenario D2: Add 50 MW

- One 50 MW project distant from Judith Gap in Madison County
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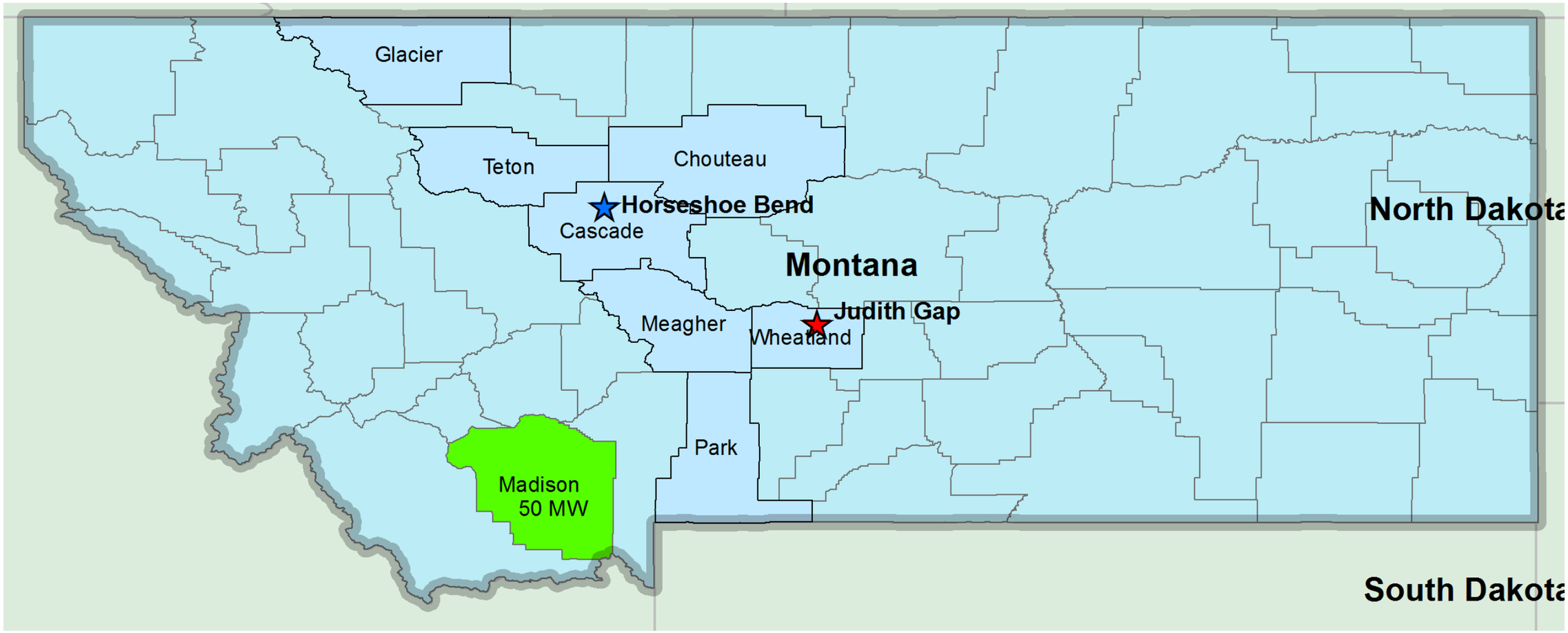

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Scenario Descriptions

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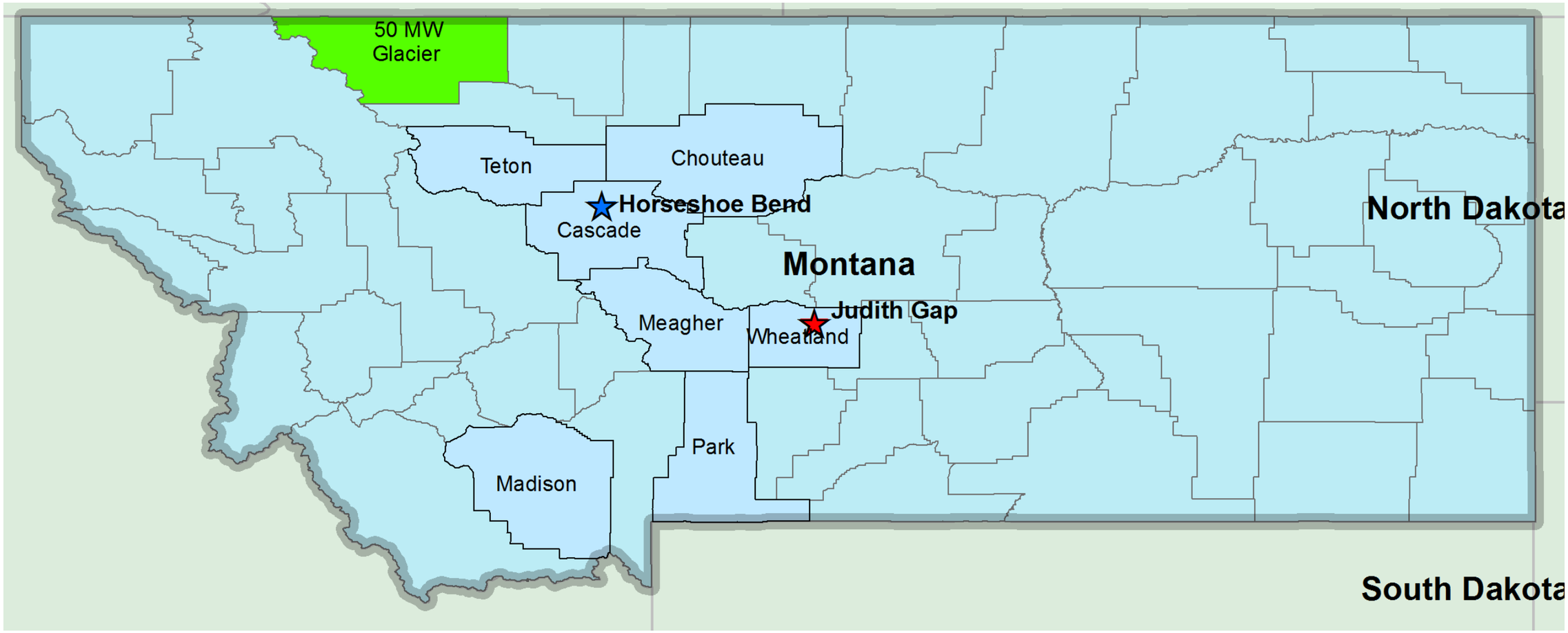

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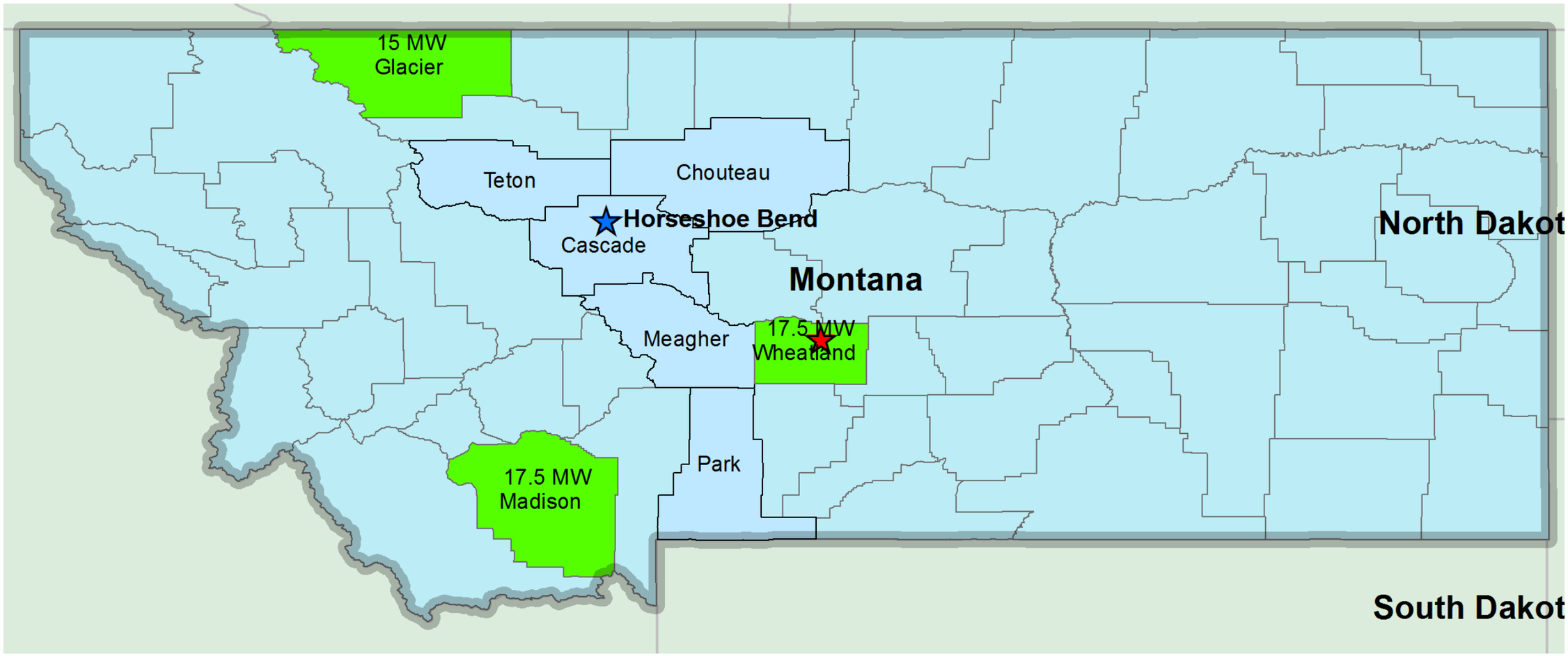
Scenario Descriptions

→ Scenario D4: Add 50 MW

- Two 17.5 MW projects and one 15 MW project added
- Nameplate Wind Capacity: 194 MW



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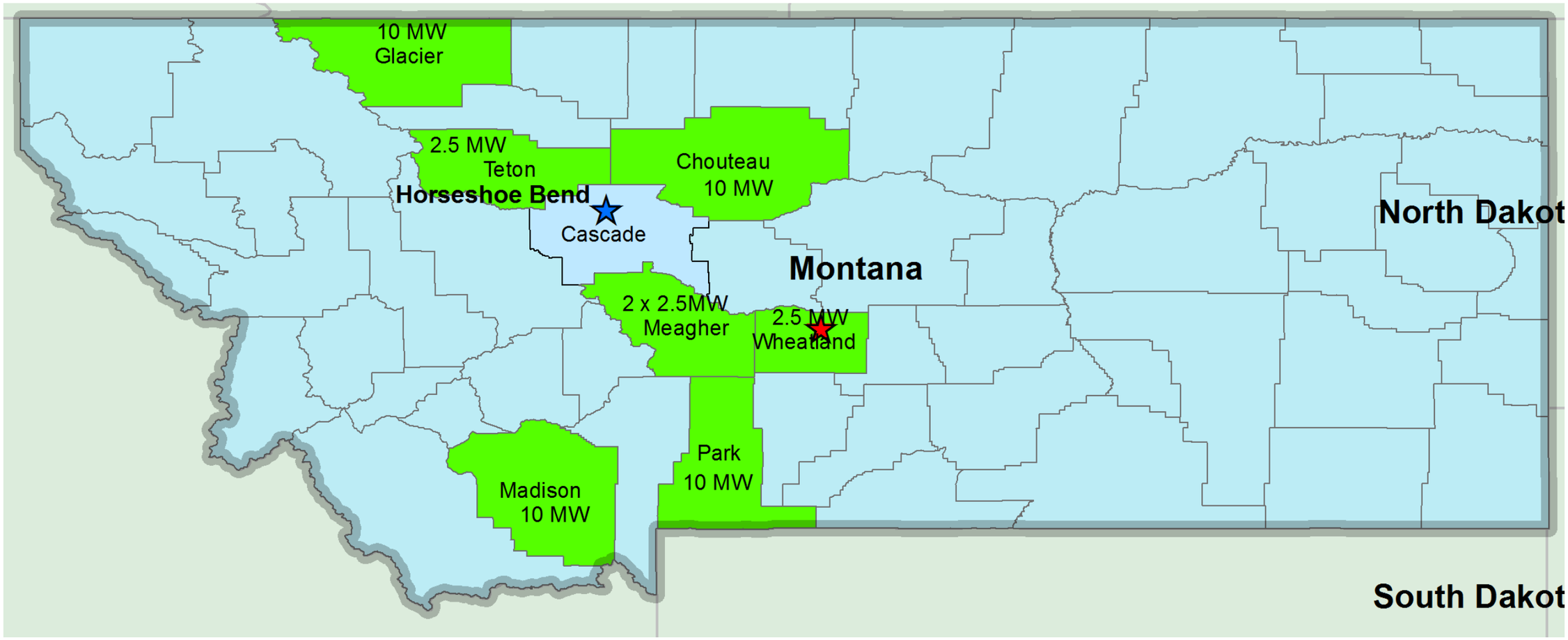
Scenario Descriptions

→ Scenario D5: Add 50 MW

- Four 10 MW projects and four 2.5 MW projects added
- Nameplate Wind Capacity: 194 MW



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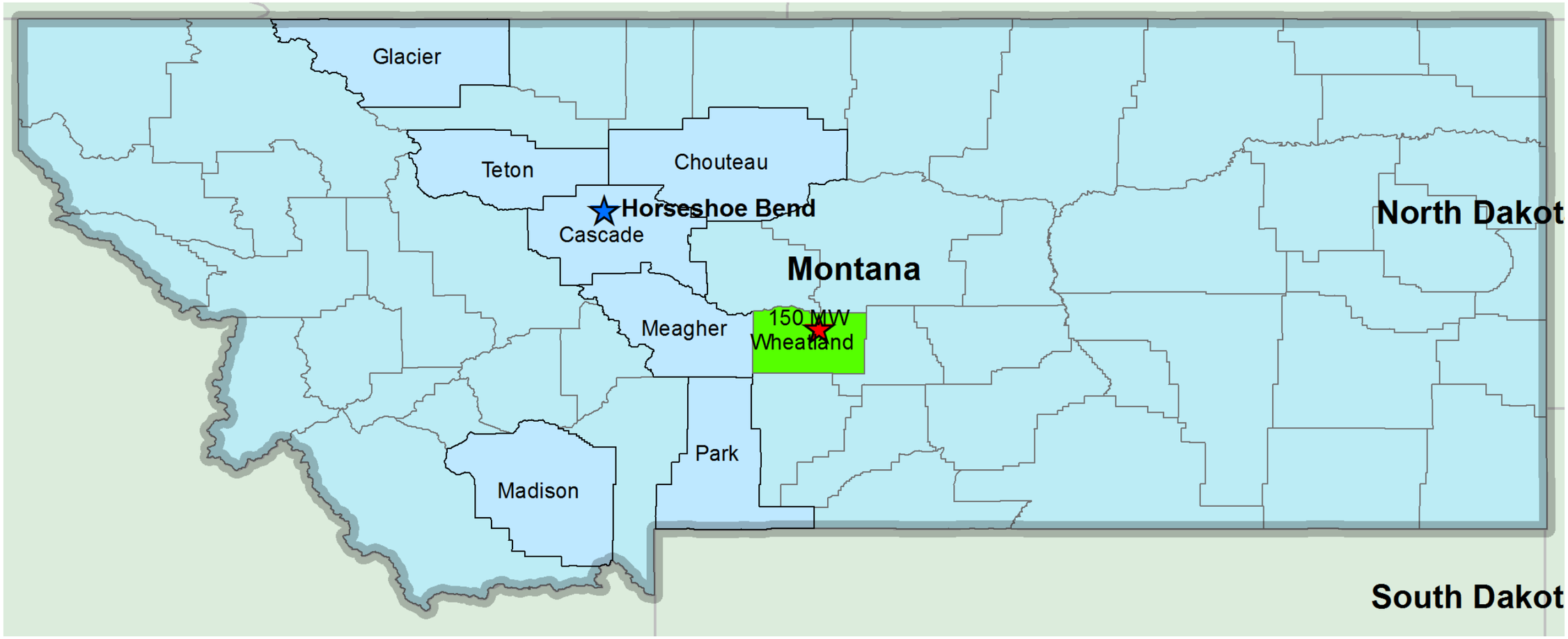
Scenario Descriptions

→ Scenario E1: Add 150 MW

- One 150 MW project added near Judith Gap in Wheatland County
- Nameplate Wind Capacity: 294 MW



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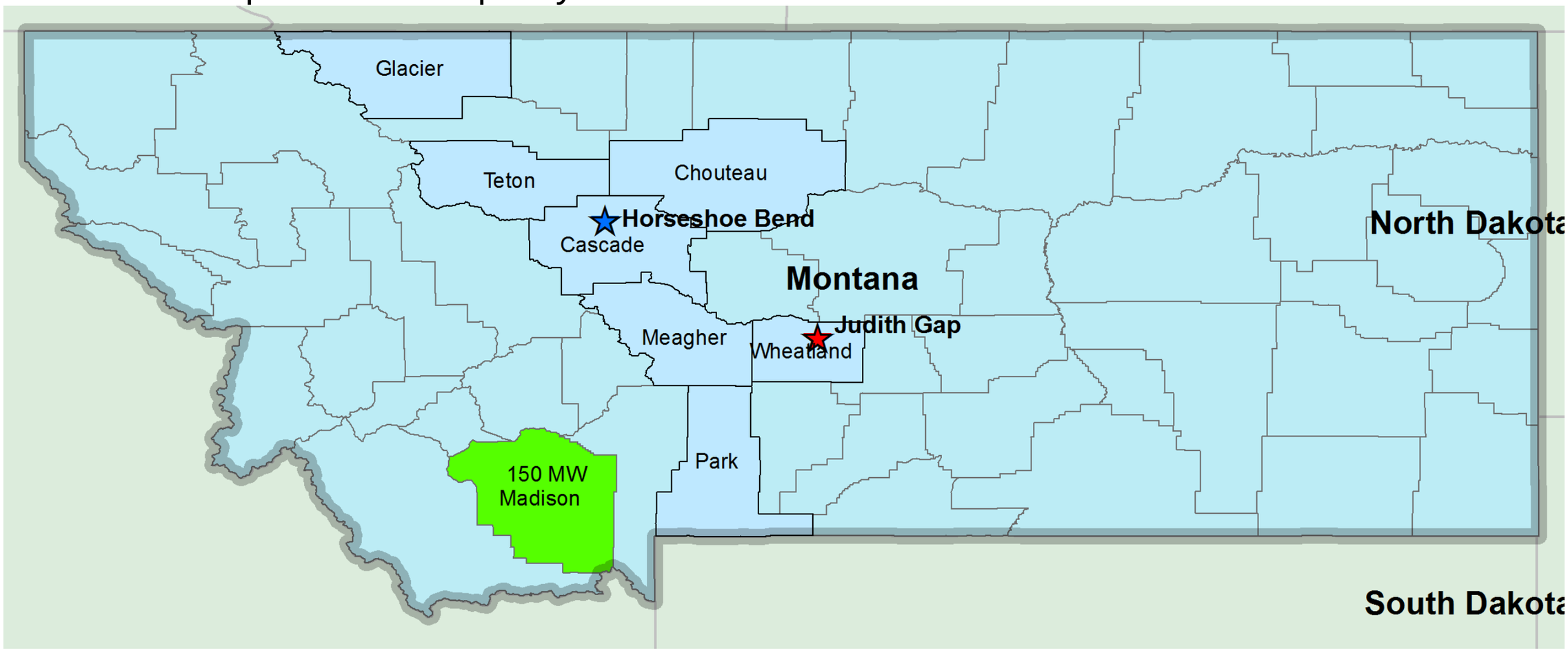
Scenario Descriptions

→ Scenario E2: Add 150 MW

- One 150 MW project added distant from Judith Gap in Madison County
- Nameplate Wind Capacity: 294 MW



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Scenario Descriptions

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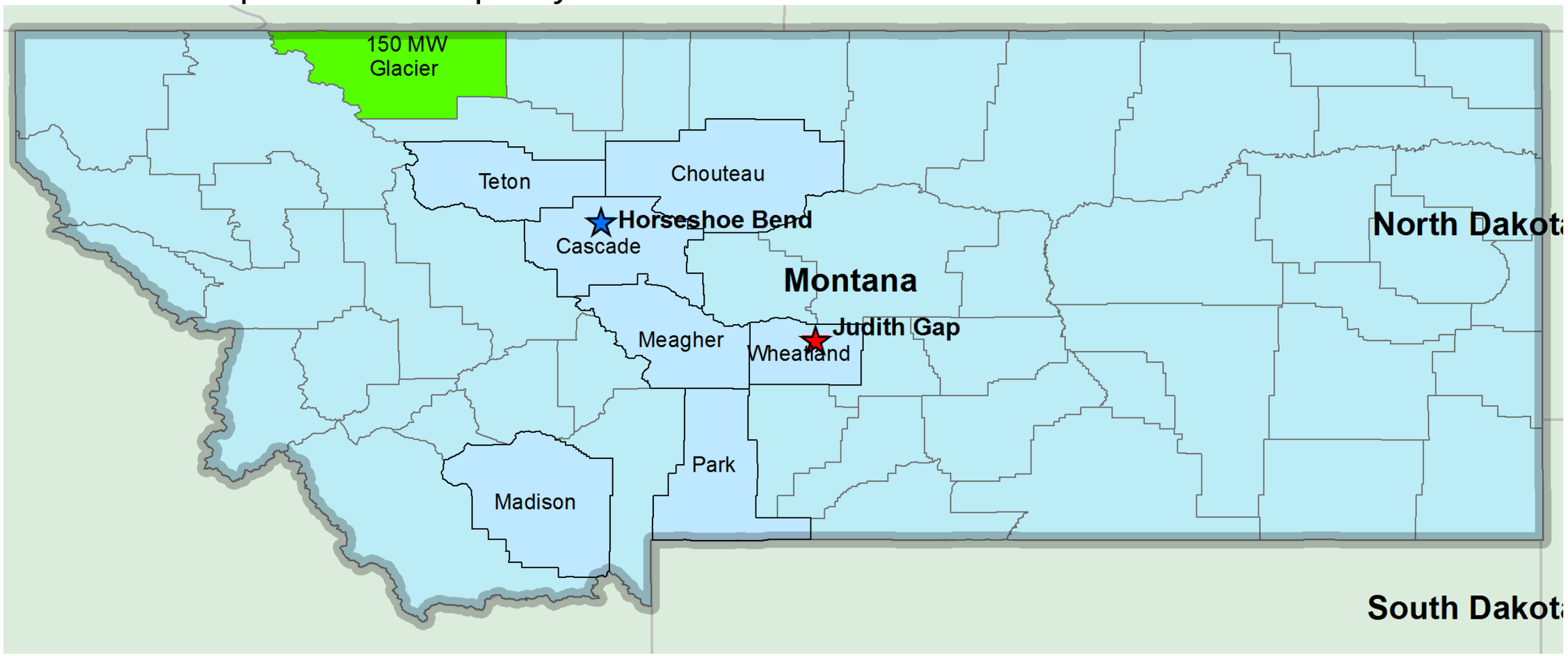

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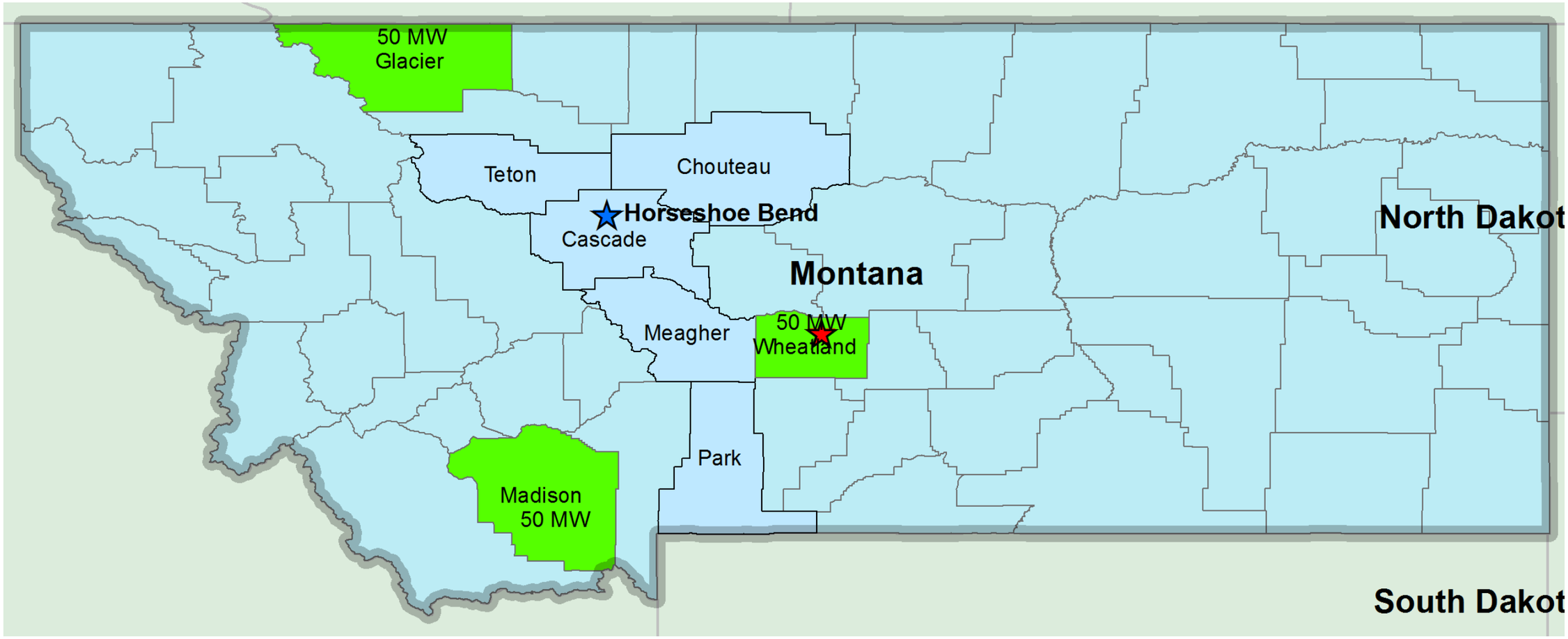
Scenario Descriptions

→ Scenario E4: Add 150 MW

- One 50 MW project added in each of Madison, Wheatland, and Glacier counties
- Nameplate Wind Capacity: 294 MW



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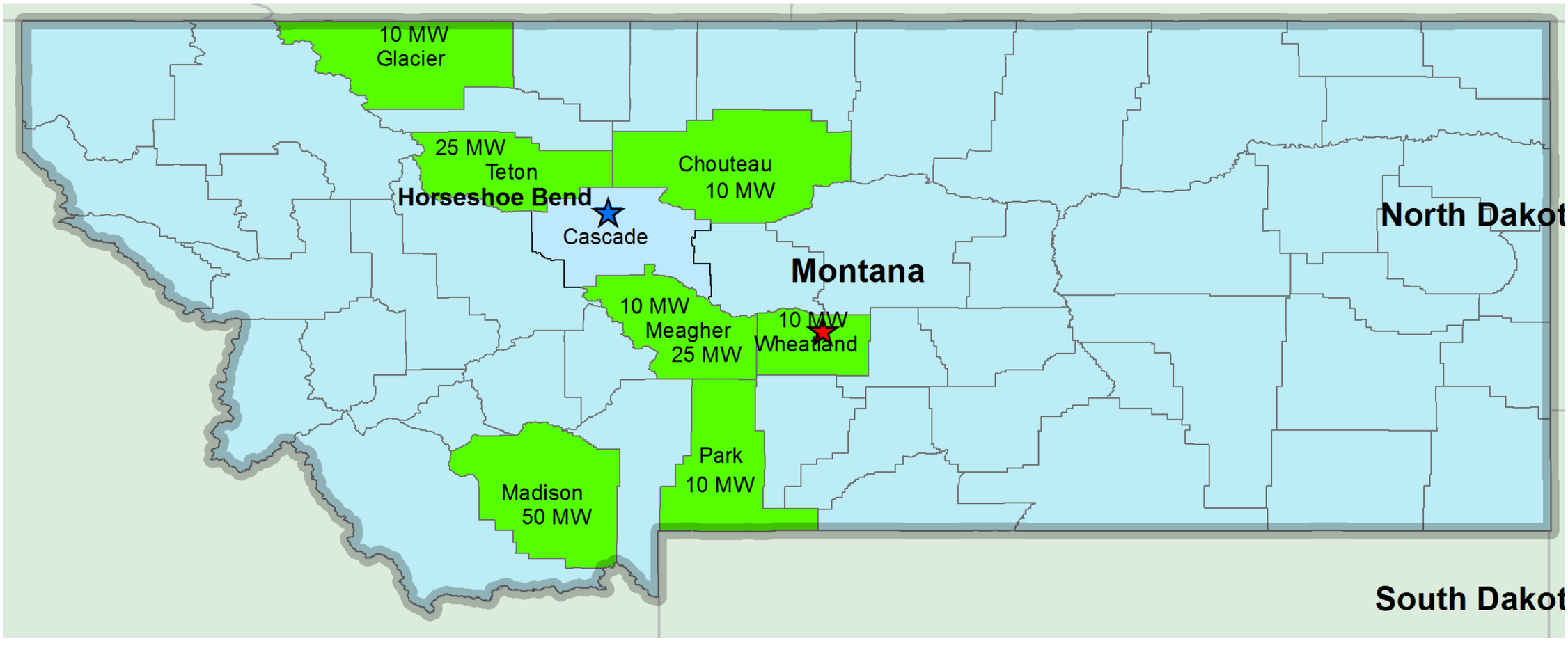
Scenario Descriptions

→ Scenario E5: Add 150 MW

- One 50 MW project, two 25 MW projects, and five 10 MW projects added
- Nameplate Wind Capacity: 294 MW



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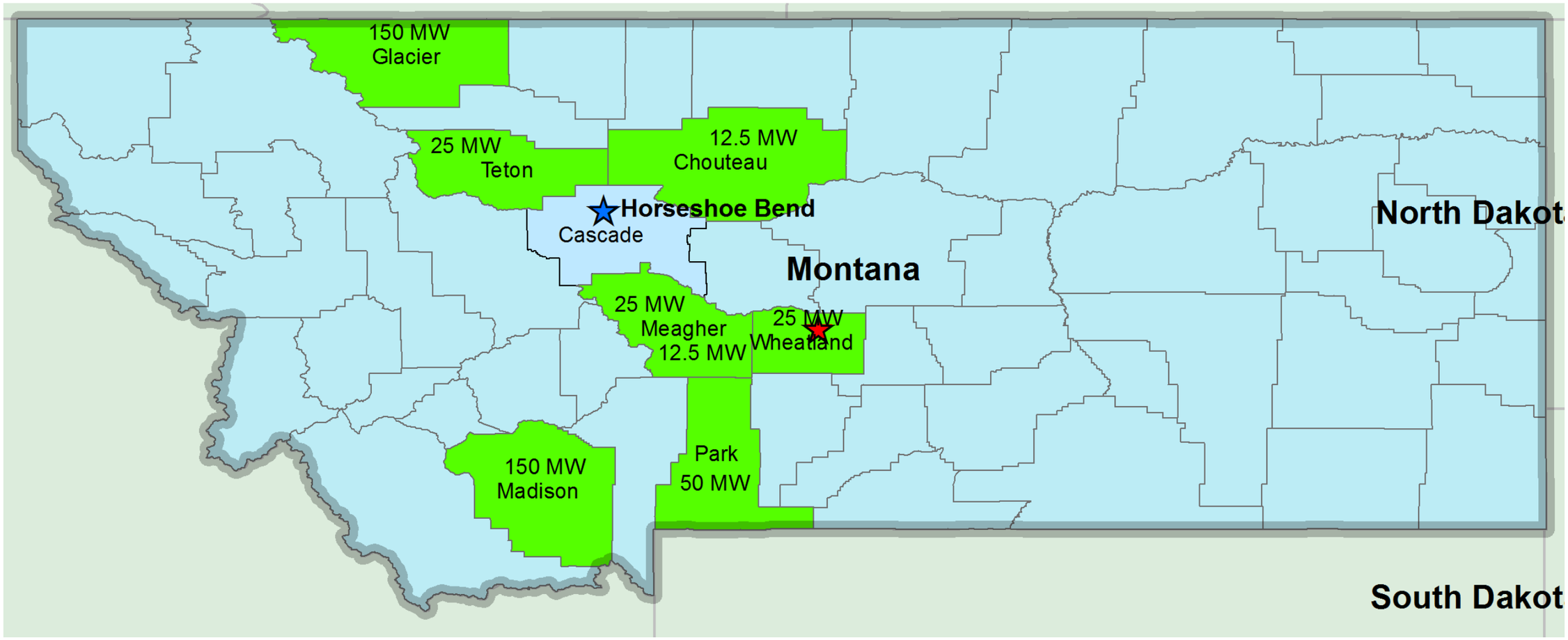
Scenario Descriptions

→ Scenario F: Add 450 MW, 594 MW Nameplate Wind Capacity

- Two 150 MW projects, one 50 MW project, three 25 MW projects, and two 12.5 MW projects added



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Scenario Descriptions

→ What information can be extracted from these scenarios?

- Correlation of wind speeds across counties (or lack thereof)
- Magnitude of wind fluctuations (wrt geographical diversity or wrt added capacity)

Dispatch Simulation Overview

- Model Inputs
  - Simulated Wind Power
  - Historical system load, load forecast, and interchange schedule
  - Operational parameters (regulating range and rates, supply capacity and rates)
- Methodology
  - Methodology developed by AESO and used for previous NWE Study
  - Overall simulation approach maintained but specific algorithms were adapted
  - Validate by simulating with historical data and comparing to actual performance
  - Establish Benchmark: historical wind data with current regulating reserves
  - Determine regulating requirement to maintain a minimum monthly CPS2 Score of 92% and 94% for all wind scenarios

Dispatch Simulation Overview

Raw Data Inputs
- Hourly Historical Day-Ahead Load Forecast
- Minutely Historical Load
- Minutely Historical Scheduled Interchange
- Minutely Available Wind Power (actual or simulated from wind speed)

Processed Data
- Hour-Ahead Load Forecast (from Historical Day-Ahead Load Forecast and Minutely Historical Load)
- Scheduled Interchange Hourly Average (from Minutely Historical Scheduled Interchange)
- Hourly Wind Forecast (from Minutely Available Wind Power)

Control Parameters / Operational Limits
- Regulating Reserve Lower Limit, Regulating Reserve Upper Limit
- Regulating Ramp Rate Limit (units of MW/min)
- Small Change Threshold (typically set to 20 MW)
- Generation ramp rate limits, interchange limits (limitless for this study)

Simulated System Dispatch and Response – Repeat for every hour in study period

Hourly Dispatch

Expected demand is evaluated every hour and the appropriate supply is dispatched:
- Steady State Dispatched Generation Level = Scheduled Interchange Hourly Average + Hour-Ahead Load Forecast – Hourly Wind Forecast
- If the change in Steady State Dispatched Generation Level from previous hour is less than the Small Change Threshold, maintain the previous hour's level
- The Minutely Generation is prescribed as follows: the generation ramps linearly starting 10 minutes before the top of the hour from the previous hour's steady state level and ending 10 minutes after the top of the hour at the Steady State Dispatched Generation Level and holds for the next 40 minutes.

Minutely System Response
- On a minutely basis, the imbalance between the Minutely Generation and minutely demand is termed "Pre-Regulation Imbalance".
- Pre-Regulation Imbalance = Minutely Generation – [Minutely Historical Load + Minutely Historical Scheduled Interchange – Minutely Curtailed Wind Power]
- Real-time response calculated to alleviate Pre-Regulation Imbalance. Real-time response can include 1. Regulation or 2. Regulation and Wind Curtailment.

  1.- Minutely Curtailed Wind Power = Minutely Available Wind Power

  -Available Regulation = max (Regulating Reserve Lower Limit, min(Regulating Reserve Upper Limit, -1*Pre-Regulation Imbalance))

  -Regulation = max(previous minute regulation – Regulating Ramp Rate Limit, min(previous minute regulation + Regulating Ramp Rate Limit, Available Regulation)

  2.-For each 10-minute increment (excluding the last ten minutes of each hour), calculate

  -Max Curtailment Amount = 10-minute average of Pre-Regulation Imbalance + 0.9 *Regulating Reserve Lower Limit - $0.5*L_{10}$

  -For each 10-minute increment (excluding the last ten minutes of each hour), determine if both of the following conditions are present:

  a. 90% of the available regulating reserves have been deployed
  b. Aggregate wind generation is over producing versus aggregate schedule

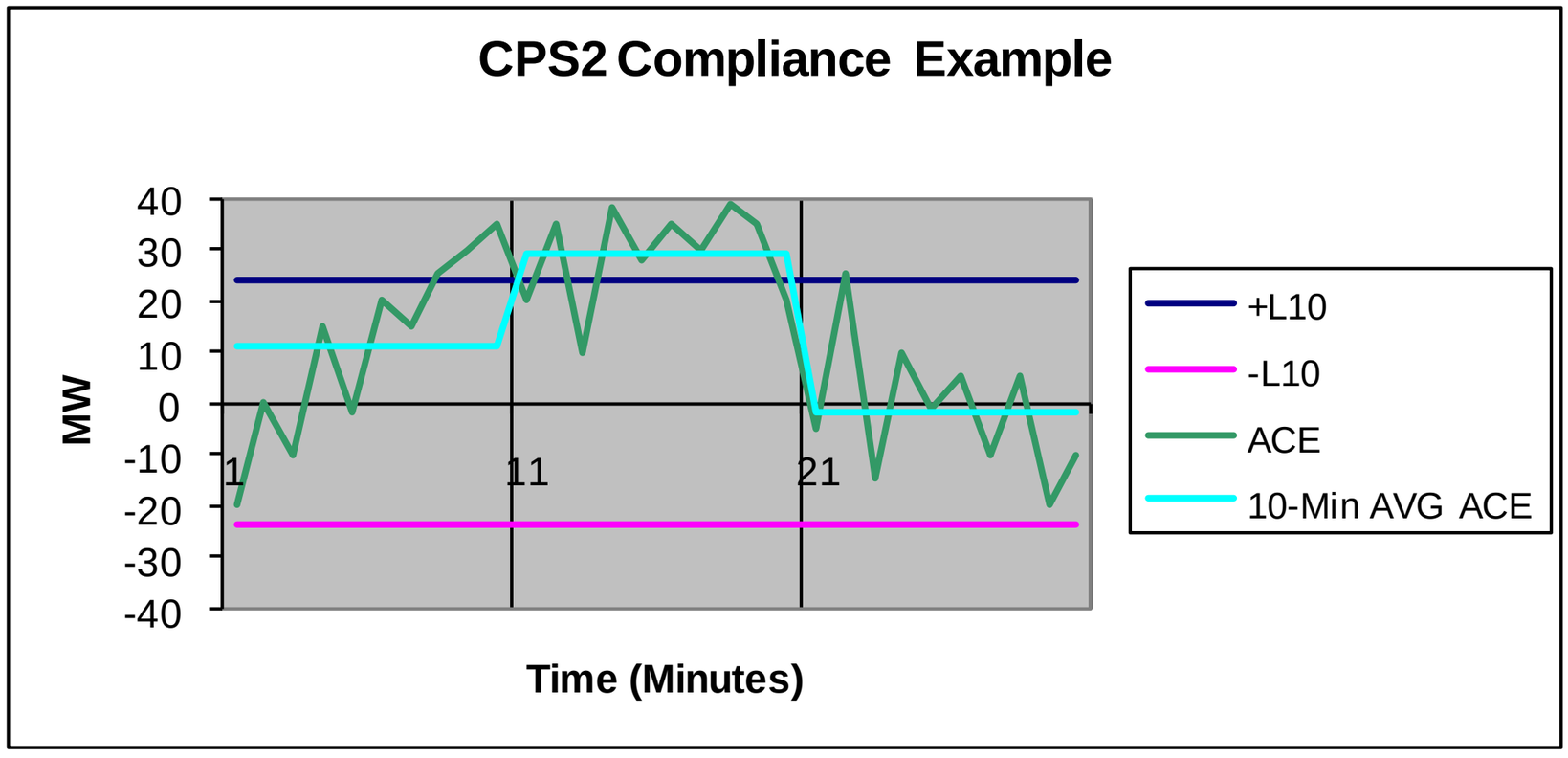
  -If both conditions "a" and "b" are present, for the next ten 1-minute increments, calculate:

  - Minutely Curtailed Wind Power = max(Hourly Wind Forecast, [Minutely Available Wind Power - Max Curtailment Amount])
  - Pre-Regulation Imbalance and Regulation as before.
- Minutely ACE = [Minutely Generation + Regulation + Minutely Curtailed Wind Power - Minutely Historical Load] – Minutely Historical Scheduled Interchange

CPS2 Performance for Study Period from Minutely ACE

Dispatch Simulation Overview

- Control Performance Standard 2 (CPS2)
  - Performance rating established by North American Electric Reliability Corporation
  - Limits the Area Control Error (ACE) for each balancing authority
  - Definition: 90% of the clock-ten-minute averages of ACE for a calendar month must be below a certain threshold, known as L10. NWE L10 is 23.99 MW



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Dispatch Simulation Overview

Model Validation

Raw NWE Data

Minutely ACE as used to file CPS2 with NERC – CPS.ND.CPS_ANALOGS.NACE
Minutely Historical Load – SOCC.OPA.MPC.LD
Minutely Interchange == Minutely ACE + Minutely Historical Scheduled Interchange
Minutely Available Wind Power – from Judith Gap and Horseshu
Minutely Regulation – from AVISTA, BPA, PWX, and GRANT

Simulated Outputs using Historical Actual Wind

Minutely ACE
Minutely Generation
Regulation

Check Dispatched Supply

- Simulated Minutely Generation is compared to actual dispatchable supply
- Since NWE does not have internal dispatchable generation, a proxy to actual dispatchable supply can be expressed as: Minutely Historical Actual Interchange + Minutely Historical Load - Minutely Available Wind Power - Minutely Regulation
- Discrepancies might indicate errors in input data or might identify deficiencies in simulated hourly dispatch algorithms – either deficiencies in load and wind scheduling or deficiency in minutely execution of generation

Check ACE

- Simulated Minutely ACE is compared to actual minutely ACE
- Since Minutely ACE is the final output of the simulation, comparing it to the actual minutely ACE provides comfort that the entire simulation procedure acts as a good proxy for the NWE system
- Particular emphasis is placed on validating the ACE at times of major wind events – ie when Minutely Available Wind Power varies significantly from the Hourly Wind Forecast

Check Regulation

- Simulated Regulation is compared to actual minutely regulation
- Theoretically, regulation operates at/near its limits when the magnitude of the ACE is large, therefore particular emphasis is placed on comparing simulated and actual regulation during these times
- If observed peak usage of regulation does not match the nominal limits (especially at times of high ACE), this might justify modification of the Regulating Reserve Lower Limit and Regulating Reserve Upper Limit control parameters

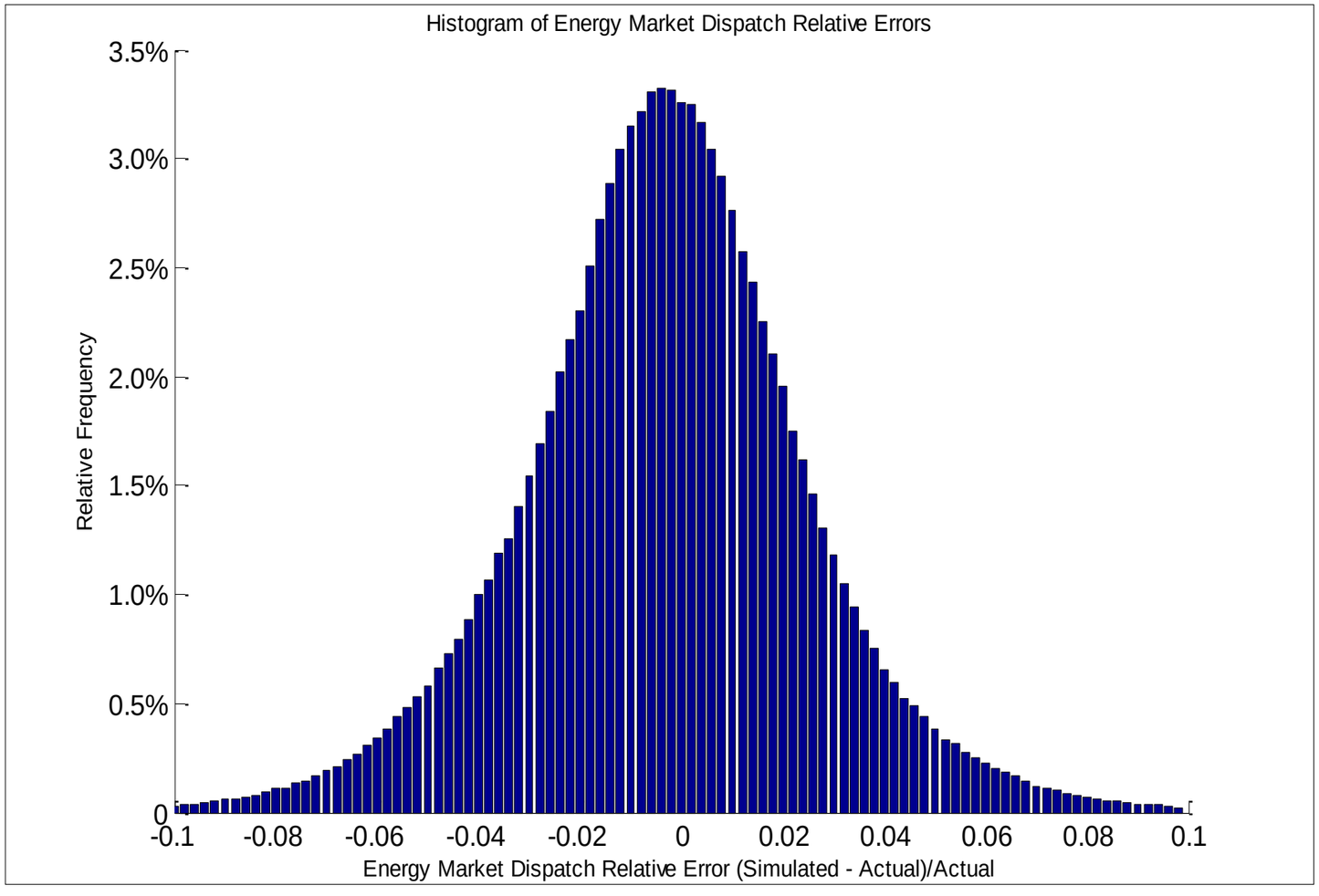
Check CPS2

- Compare CPS2 Performance as calculated from simulated Minutely ACE and from actual minutely ACE
- Provides comfort that the entire simulation procedure acts as a good proxy for the NWE system

Dispatch Simulation Overview

→ Validation

- Actual historical supply dispatch vs. simulated historical supply dispatch



Mean relative error = -0.23%

Standard deviation of relative error = 3.02%

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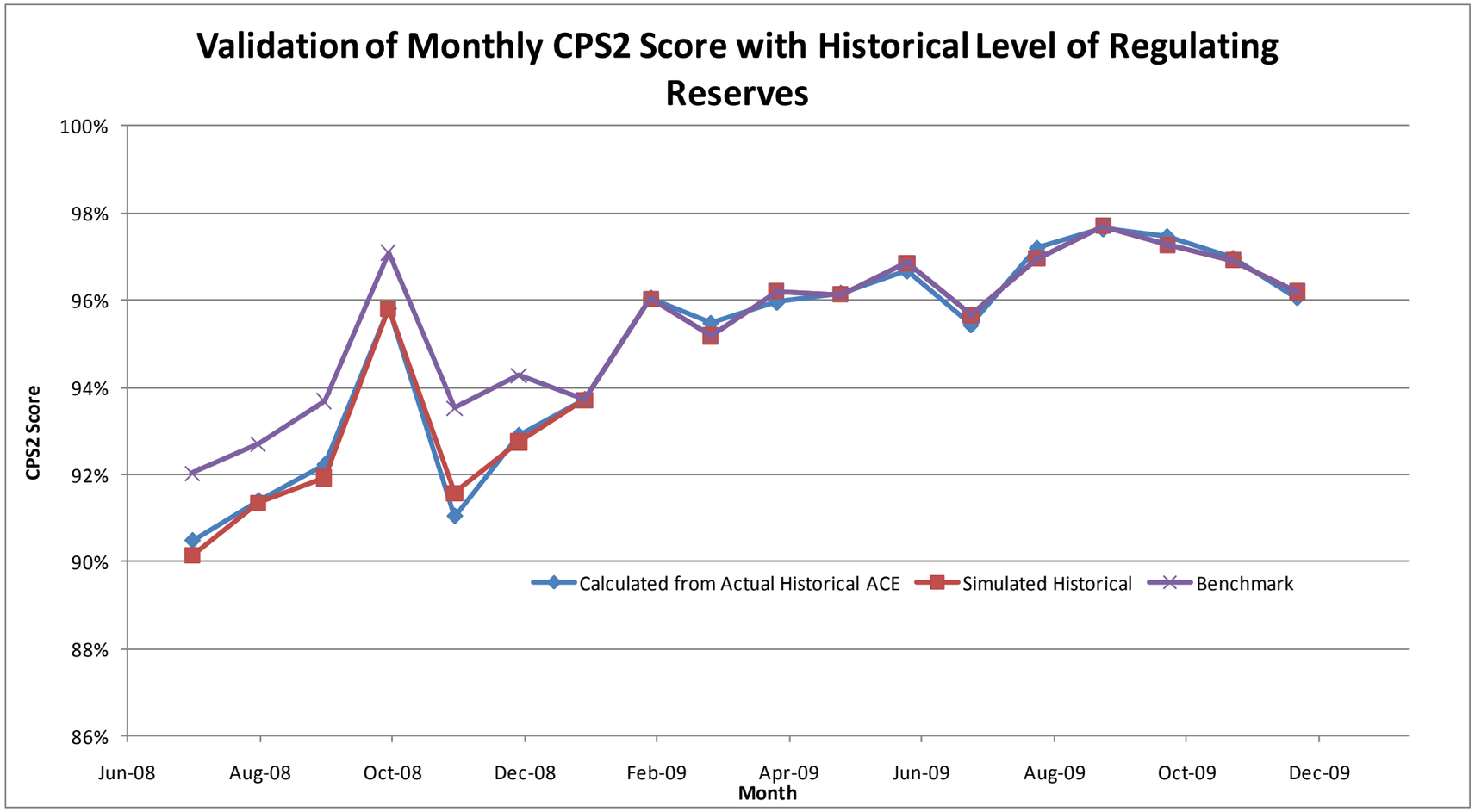
Dispatch Simulation Overview

→ Validation

- Actual historical CPS2 Scores vs. simulated historical CPS2 Scores vs. benchmark
- Benchmark level of regulating reserve is 96 MW



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Dispatch Simulation Overview

→ Sensitivity Case Description

- Sensitivity 1: Run Scenario E5 using 30-minute persistence forecasts for wind
  - The wind generation observed 30 minutes in advance of the beginning of the scheduling hour is the scheduled amount
- Sensitivity 2: Run Scenario E5 limiting wind generators as follows
  1. For each 10-minute increment (excluding the last ten minutes of each hour), determine if both of the following conditions are present:
     a. 90% of the available regulating reserves have been deployed
     b. Aggregate wind generation is over producing versus aggregate schedule
  2. If both conditions 1a and 1b are present, for the next 10-minute increment, cap the output of the wind projects at the higher of:
     a. The scheduled wind generation amount
     b. The amount necessary to bring the ACE to 12 MW and maintain a maximum of 90% reserve deployment
- Sensitivity 3: Run Scenario E5 using intra-hour supply adjustment as follows
  - At 10 minutes past the hour, calculate system imbalance as:

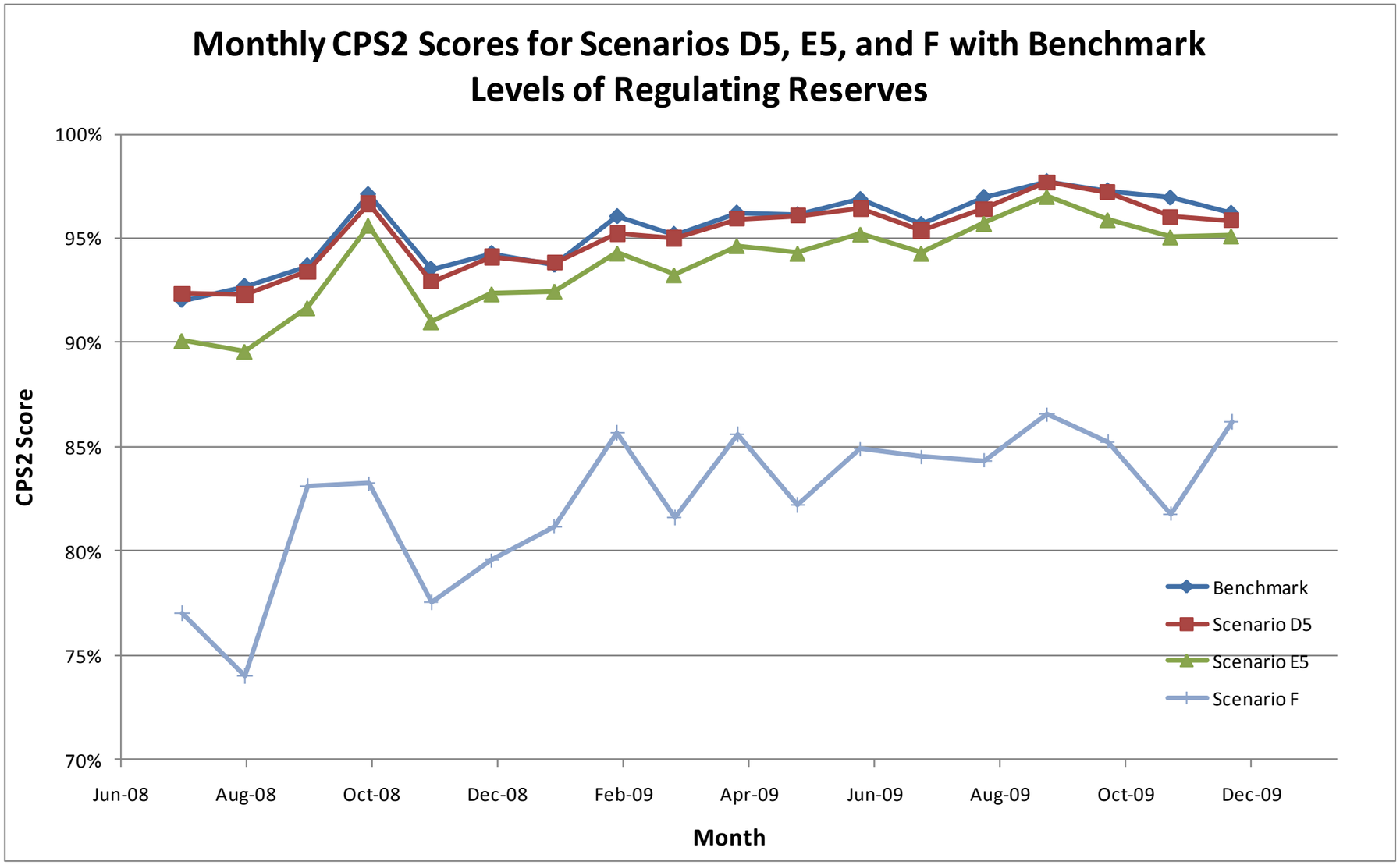
    System Imbalance = Wind Generation + Other Generation - Load - Scheduled Interchange
  - If the magnitude of the system imbalance exceeds 25 MW, increase or decrease the supply by a magnitude equal to the system deficit or surplus, respectively.

Dispatch Simulation Results

- CPS2 Scores
  - Calculated for each of the 16 wind scenarios and 3 sensitivity cases
  - Scenarios were compared to characterize effect of wind power w.r.t. geographical diversity and w.r.t added capacity
- Required Regulating Reserves
  - Dispatch simulation model was run iteratively to determine the amount of regulating reserves required to achieve target CPS2 performances
  - The targeted performances were 92% and 94%

Dispatch Simulation Results

→ CPS2 comparison example: D5, E5, and F



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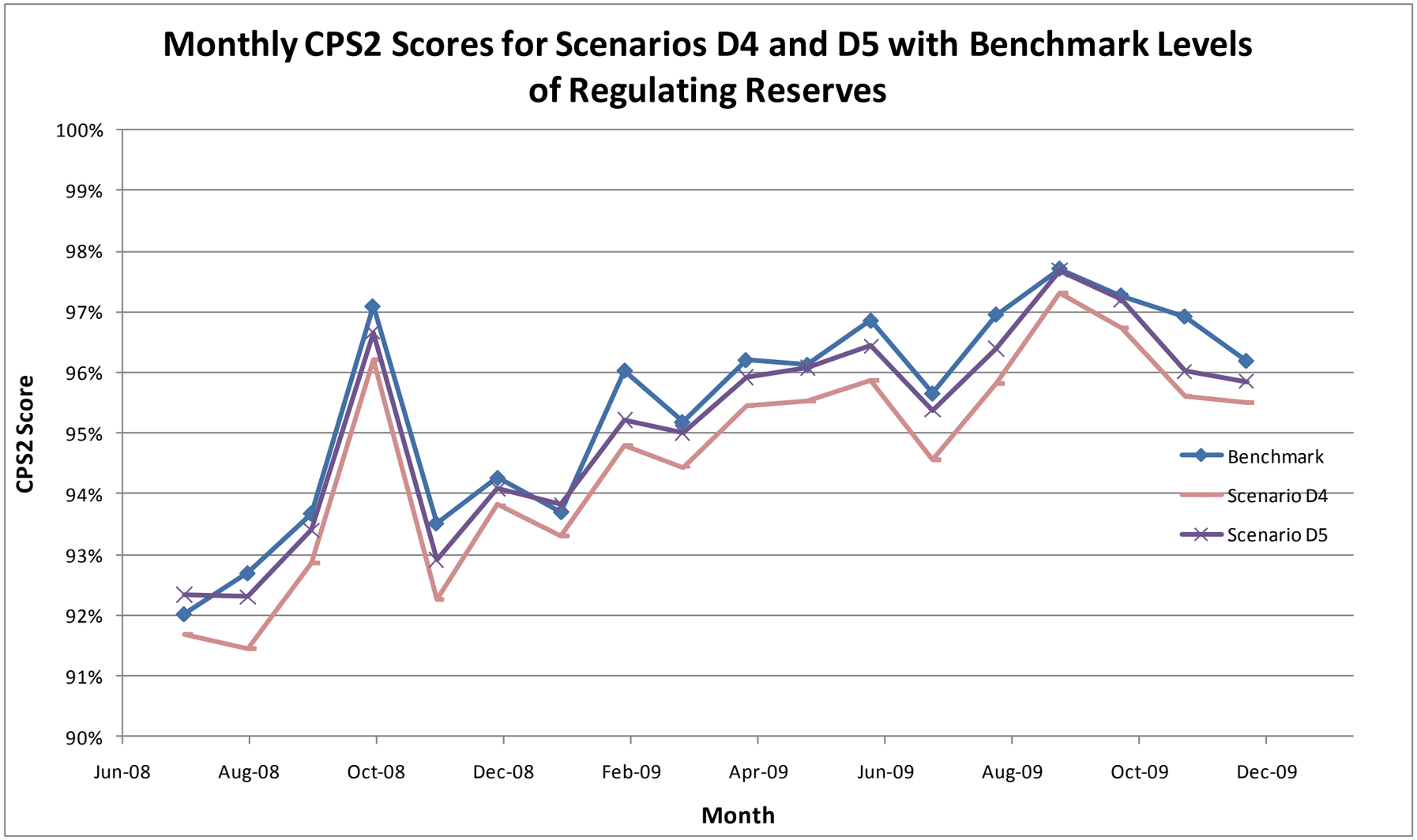
Dispatch Simulation Results

→ CPS2 comparison example: D4 and D5



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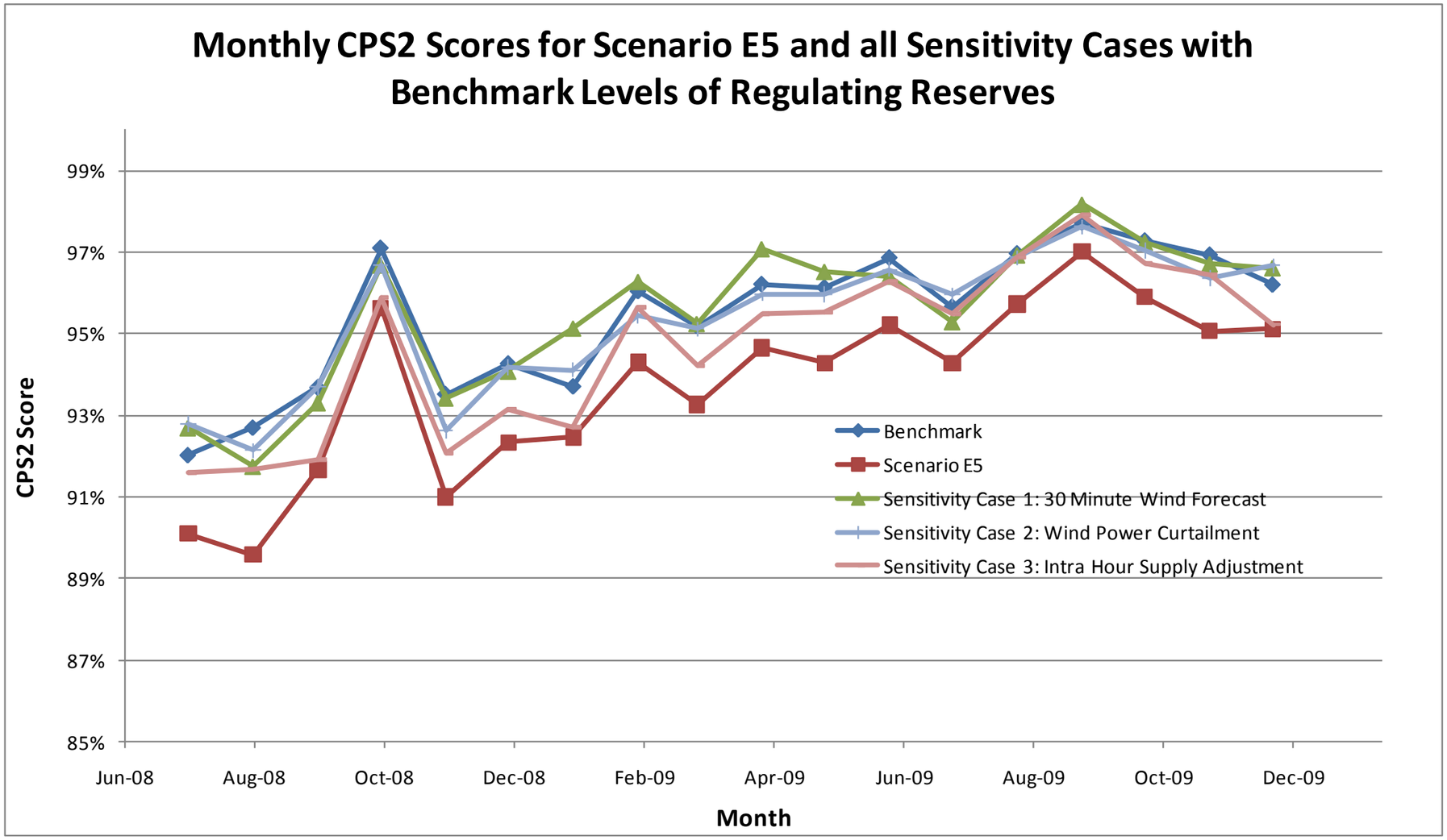
Dispatch Simulation Results

→ CPS2 comparison example: E5 and Sensitivity Cases



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Dispatch Simulation Results

- Regulating Reserve Requirements

Scenario Name	Regulating Reserves Required to Achieve CPS2 Target (MW)	
	Minimum CPS2 Score of 94%	Minimum CPS2 Score of 92%
A	110	96
B	69	59
C1	113.8	97.1
C2	108.7	92.6
C3	109.2	94.6
D1	136	117
D2	112	97
D3	120	101
D4	120	101
D5	105	95
E1	209	181
E2	149	130
E3	163	144
E4	144	126
E5	132	114
F	223	194
Sensitivity Case 1 - 30 min Wind Forecast	114	98
Sensitivity Case 2 – Wind Curtailment	114	94
Sensitivity Case 3 – Intra-hour Supply Change	119	100

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Dispatch Simulation Results

- Descriptive results Sensitivity Case 1:
  - Variance of minutely wind forecast errors using 60-minute persistence was 22.5 MW
  - Variance of minutely wind forecast errors using 30-minute persistence was 17.7 MW
- Descriptive results Sensitivity Case 2:
  - The amount of curtailed wind energy was 22.5 GWh over the 18 month study period.
  - This corresponds to 1.88% of the 1467.1 GWh wind potential.
  - Qualitatively, the amount curtailed is sensitive to the accuracy of wind forecast

Lessons Learned

- Benefit of geographical diversity
- *Effect of* incrementing wind capacity is less than the increment
- System performance is sensitive to wind forecasting performance
- System performance benefits from curtailing wind (only in extreme cases)
- System performance benefits from intra-hour supply change (only in extreme cases)

and/or demand response

Other Possibilities

- The possible wind development scenarios are many
- The dispatch simulator is capable of capturing actual dispatch of very different systems: AESO and NWE
- The dispatch simulator is adaptable
  - Can be used to experiment with any dispatch strategy

Questions and Discussion