Wind Farm Wake Analysis

Summary of Past & Current Work

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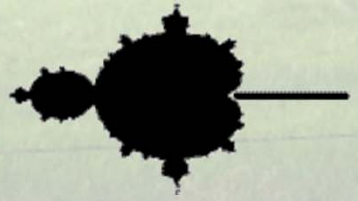
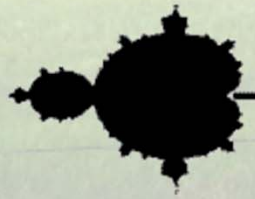
Resource Assessment & Micrositing



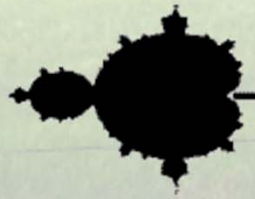
Current Wake Model Implementation

	RAM Associates
Date of implementation	2005
Model Theory	Conservation of Energy
Software Used	Excel VBA
Proprietary Modifications	All Proprietary
Model Settings Vary by Location?	Yes (shear, expansion rate, mixed layer depth)
Uncertainty due to Wake	15% to 20% of loss



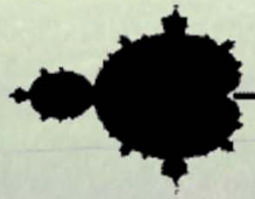
Early Wake Studies

- 1985 – US Windpower (Kenetech) 56-100
  1.4 x 8 RD, 3 rows, turbines on/off
- Observed significant wake losses ~15 to 25%
- 1989 – Howden HWP 330/33
  2.0 x 11 RD, 2 rows, turbines on/off, day/night
- Unstable losses insignificant, stable losses ~11%
- 1989 – Altamont Pass Macro Wake Analysis (Nierenberg), WS deficit analysis



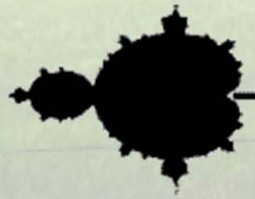
RECENT WAKE MODEL VERIFICATION

- E.On Deep Array (Wolfe et al 2010)
- MHI 1000A, 5 rows, free-stream WS model (RAMWind & pre-construction met data)
- Modeled WS correlated to unwaked turbine power, used to model free-stream power at waked turbine sites and wake losses
- Wake Models: WindFarmer EV (deep array), WindPro & WAsP Park, RAM
- Overall, models did not underestimate observed losses



Current Wake Model Verification

- Two verification tests underway
- Wind Farm in Mountainous West
  Five rows in mountain pass
- Wind Farm in Great Plains
  Two rows in open terrain
- Turbine performance data:
  100% availability, power > 0 kW,
  No curtailment
  Prevailing, southerly WD



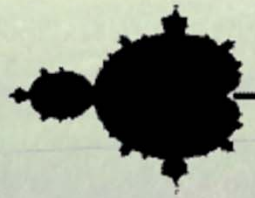
Methodologies for Terrain FX Normalization

Traditional

- Develop WS Model (WS vs. RW exposures)
- Relationship of free-stream Power vs. WS
- Apply relationship to waked turbines based on modeled WS
- Wake FX = % Δ between modeled free-stream & obs. power

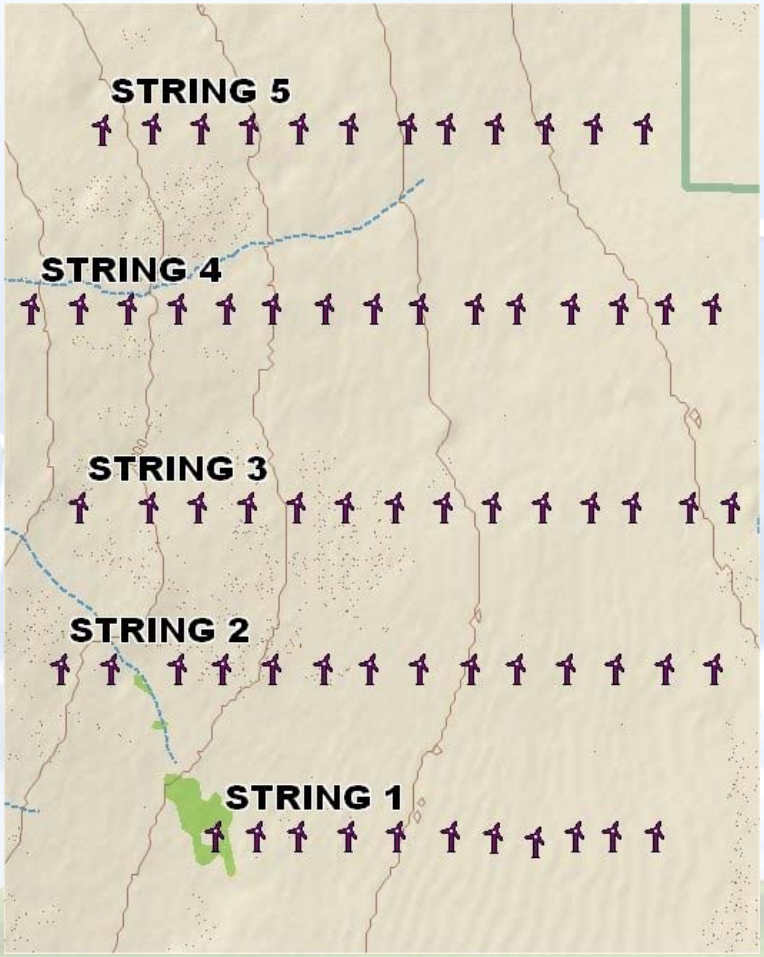
New Approach

- Eliminate the "middle man" – no WS model
- Develop Power Model (Free-stream P vs. RW exposures)
- Apply relationship to waked turbines based on exposure
- Wake FX calculation same



Site 1 - Mountain Pass

5 Strings, ~3 RD x ~12 RD, Southerly WD



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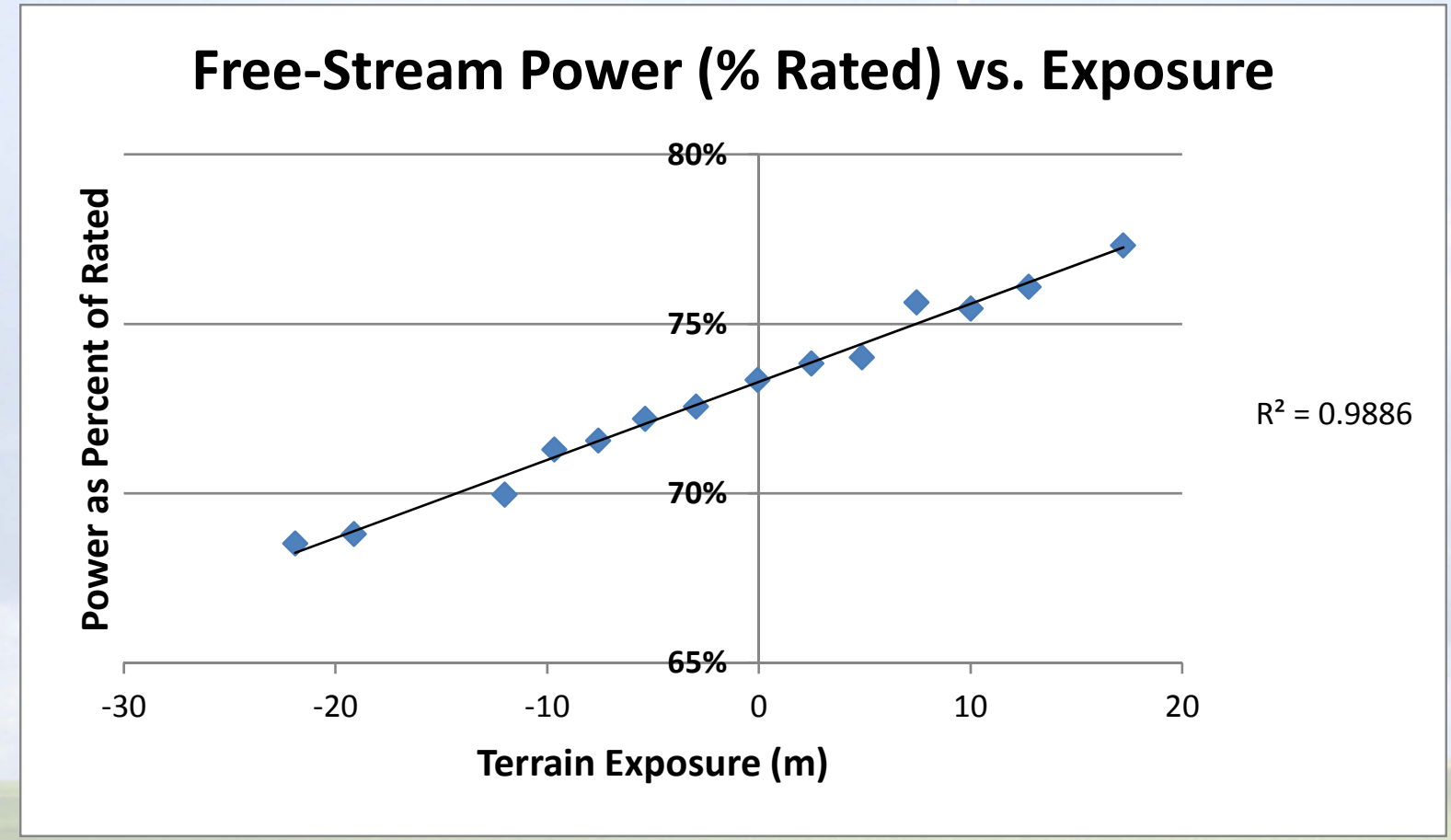
Free-Stream Turbine Mean Power (14 units) vs. Exposure



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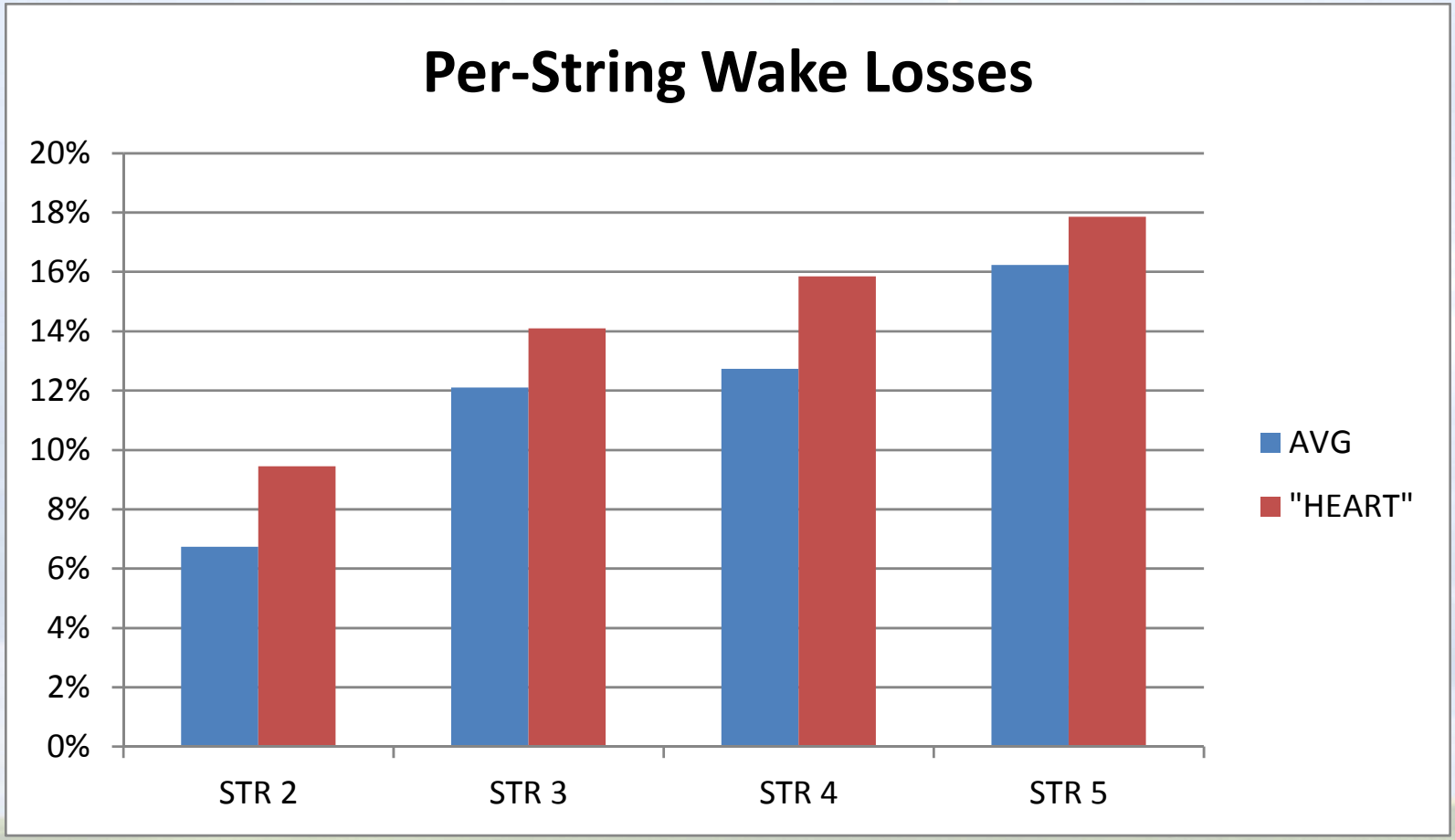
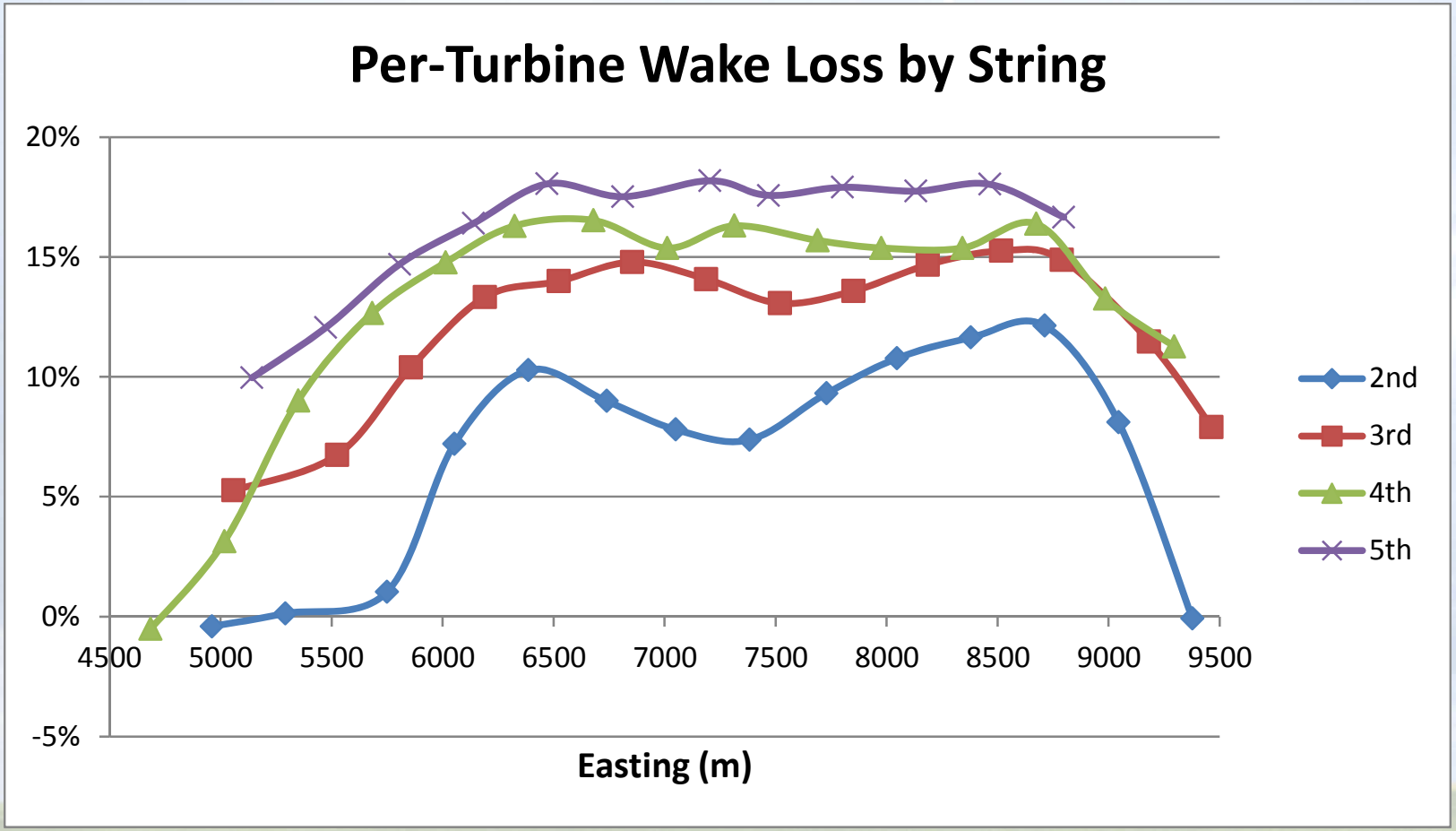
Observed Wake Loss by String



Per-Turbine Wake Loss by String



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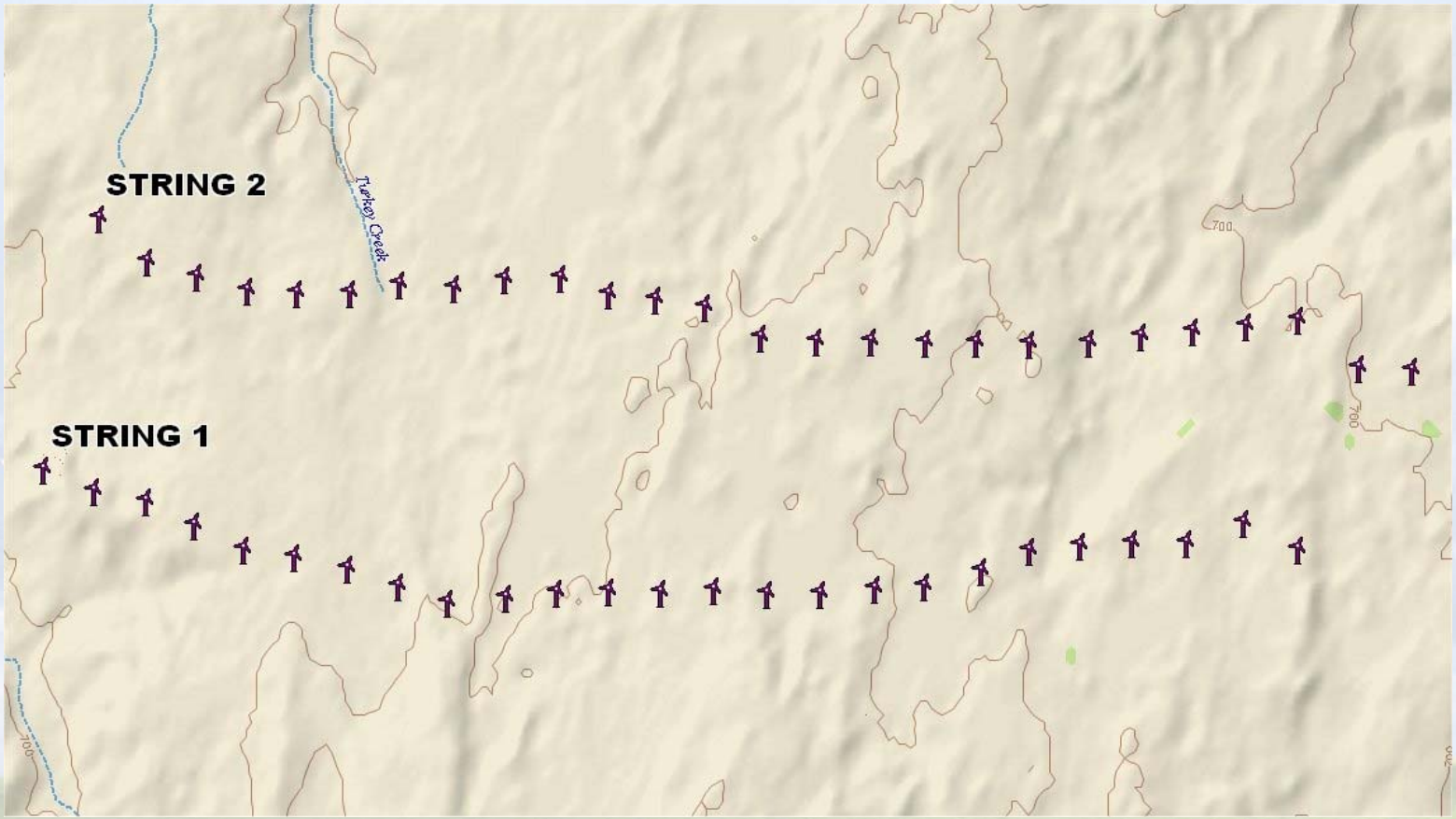
Site 2 – Great Plains

2 Strings, ~3.25 x ~12 to 19 RD, Southerly



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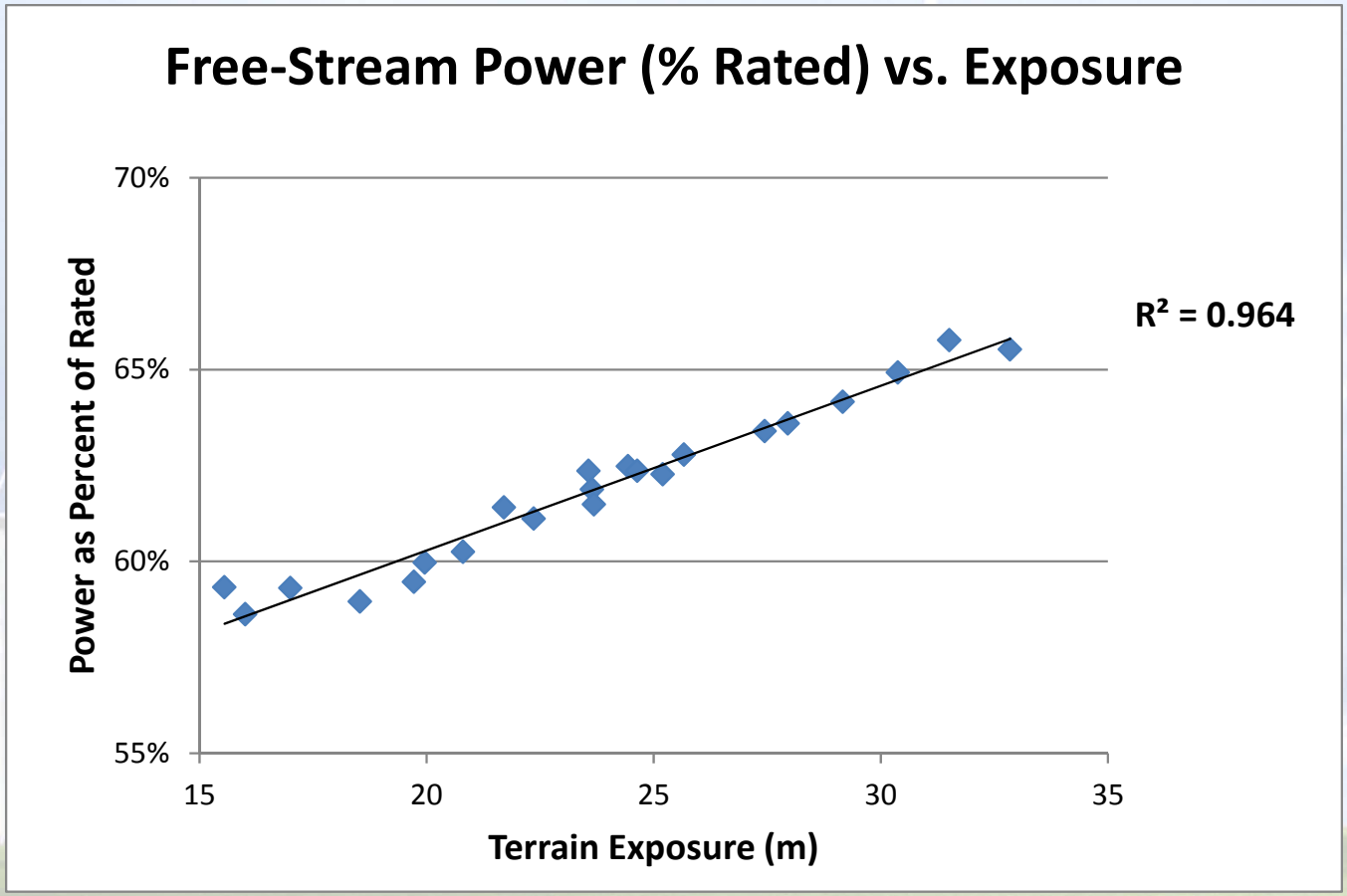
Free-Stream Turbine Mean Power (22 units) vs. Exposure



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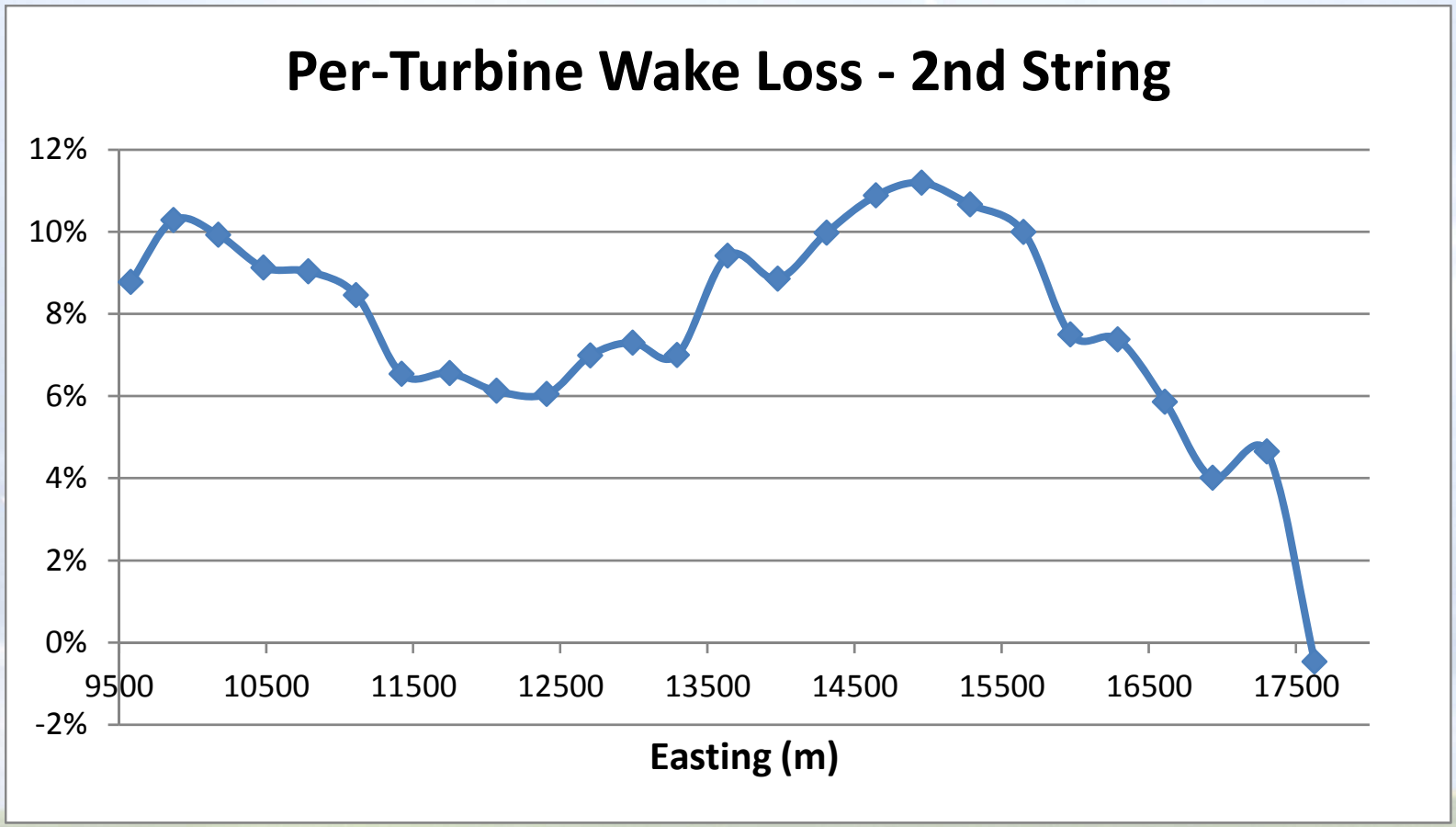
Per-Turbine Wake Loss



Conclusions

- A new method of analyzing wake losses has been developed
- High level of correlation between free-stream power and RAMWind exposure
- Observed wake losses to be compared to modeled wake losses at both sites
- New modeling technique can be used to identify performance anomalies