Predictions and actual performance: key sources of variation

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Outline

Four key topics

1. Lessons learned in wind financing: where energy predictions can go wrong and by how much

2. Infigen portfolio reassessment: brief forensic analysis of pre-construction estimates

3. Best practice in wind resource assessment: robust approach incorporating mobile measurement and mesoscale modelling

Lessons learned in wind financing

Many projects over-predicted

- Aurecon has analysed a number of operating projects in Australia, New Zealand and Europe including:
  - Burton Wold (20 MW), UK
  - Havelland Portfolio (145 MW), Germany
  - Tivoli Portfolio (30 MW), Germany
  - Hau Nui Wind Farm (16 MW), New Zealand
  - Infigen Portfolio (330 MW), Australia
  - Cookhouse Wind Farm (140 MW), South Africa
- General trend of over-prediction of P50 energy production – why?
- Wind resource assessment generally a bigger issue than energy calculation
- Banks still wary of wind risk given achieved performance of assets

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Sources of Uncertainty

- On-site monitoring
- Long-term correction
- Wind flow modelling
- Extrapolation to hub-height
- Energy calculations

Sources of Uncertainty

1. On-site monitoring

- Number and location of masts to represent turbine locations: masts often located on hilltops that have highest wind resource and steepest terrain leading to modelling errors in predicting other parts of the site
- Height of masts: reduces error in extrapolating to hub-height
- Quality of sensors: accuracy, response to inclined flow and turbulence, condition (CLASSCUP classification, MEASNET calibration)
- Configuration of sensors: avoiding sheltering from mast and booms
- Data collection, quality and traceability

- Potential uncertainty:
  - a few percent of mean wind speed from anemometer configuration and sheltering
  - 3 - 5% in moderately complex terrain

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Sources of Uncertainty

2. Long-term correction

- Availability of good reference stations close to site
- Quality of data, consistency (drift, obstructions, changes)
- Length of data set, length of overlap with on-site data
- Similarity of wind regime and good correlation (not necessarily the same)
- MCP technique

- Potential uncertainty:
  - Difficult to define as it depends whether relationship in overlap period is representative of the long-term relationship (correlation of overlap period is a poor indicator for short periods)
  - Consistency of reference data set is critical
  - Seasonality influence can be large (less than a year of on-site data)
  - Error can be 5%+ even with a year of on-site data, greater for shorter periods

Sources of Uncertainty

3. Wind flow modelling

- Availability of good contour information
- Availability of good roughness information (can be as important as contours)
- Representativeness of mast locations
- Model limitations:
  - WAsP is a linear flow model, can't simulate flow separation
  - CFD models like WindSim, Meteodyn, Raport NL haven't proven to be consistently better
- Errors in model setup and operation, interpretation of results, manual adjustments (or lack thereof) in areas of known poor model performance

- Potential uncertainty:
  - Can be very large if model used incorrectly and mast locations poor
  - Possible to have 5- 10% error in predicted wind resource at turbine locations, 5% overall

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Sources of Uncertainty

4. Extrapolation to hub-height

- Wind shear is a complex phenomenon, strong diurnal variation interacts with wind speed diurnal variation
- Requires good quality data at multiple heights, at key levels there should be either no significant sheltering or dual anemometers
- Doesn't pick up changes in the wind climate above the top of the mast such as separation zones, and inversion layers that can affect shear extrapolation and turbine rotors
- Complex analysis required to incorporate directional and diurnal differences in wind shear

- Potential error:
  - 5 - 10% if low mast height, 10 - 20% if wind regime changes significantly with height

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Sources of Uncertainty

5. Energy calculations

- Application of power curve to wind speed data
- Calculation of wake losses
- Availability assumptions
- Electrical losses
- Other losses eg blade degradation, substation and grid availability

- Potential error:
  - Circa 5%, particularly if power curve used does not reflect real-world performance
  - Wake loss modelling can have high uncertainty, particularly when wake loss is high (multiple rows, tight spacing)

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Under-estimate of uncertainty

Probability of exceedance values not reliable

- Uncertainty in many of the calculation steps is difficult to quantify empirically so must rely on judgment and experience
- Historical tendency to under-estimate some uncertainty items or to exclude some items (not provide a complete assessment of uncertainty)
- Leads to P90, P99 values being too high, not representing the real downside risk
- Assumption of normal distribution falls down past about P95 and for upside risk as the input values are chosen to be about right at P90-P95
- Banks size debt and check debt service coverage ratios with these figures
- Finance provided based on non-robust down-side risk figures

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Infigen Portfolio Reassessment

Revised P50 and P90 figures based on actual operating data

- Detailed analysis of production data to determine actual performance over recent years
- Correction to long-term using 50 years of 3Tier mesoscale modelling
- Revised P50 figures still have circa 5 – 6% uncertainty vs 10% plus in pre-construction estimates

Infigen Portfolio Reassessment

Over-prediction at each site in pre-construction estimates

Wind Farm	Original P50	Revised P50	Revised P50 vs. Original P50		FY11 Budget	FY11 Budget vs. Revised P50	
	GWh	GWh	GWh	%	GWh	GWh	%
Lake Bonney 1	213.4	197.2	-16.20	-7.6%	190.0	-7.20	-3.7%
Lake Bonney 2	477.9	414.3	-63.60	-13.3%	426.0	11.70	2.8%
Lake Bonney 3	117.2	105.6	-11.60	-9.9%	77.6	-28.00	-26.5%
Alinta	366.8	344.9	-21.90	-6.0%	336.4	-8.50	-2.5%
Sub Total	1,175.3	1,062.0	-113.30	-9.6%	1,030.0	-32.00	-3.0%

10 Year P90

Wind Farm	Original P90	Revised P90	Revised P90 vs. Original P90	
	GWh	GWh	GWh	%
Lake Bonney 1	188.7	182.2	-6.50	-3.4%
Lake Bonney 2	415.6	382.8	-32.80	-7.9%
Lake Bonney 3	101.9	96.3	-5.64	-5.5%
Alinta	348.8	320.3	-28.50	-8.2%
Sub Total	1,055.0	981.6	-73.44	-7.0%

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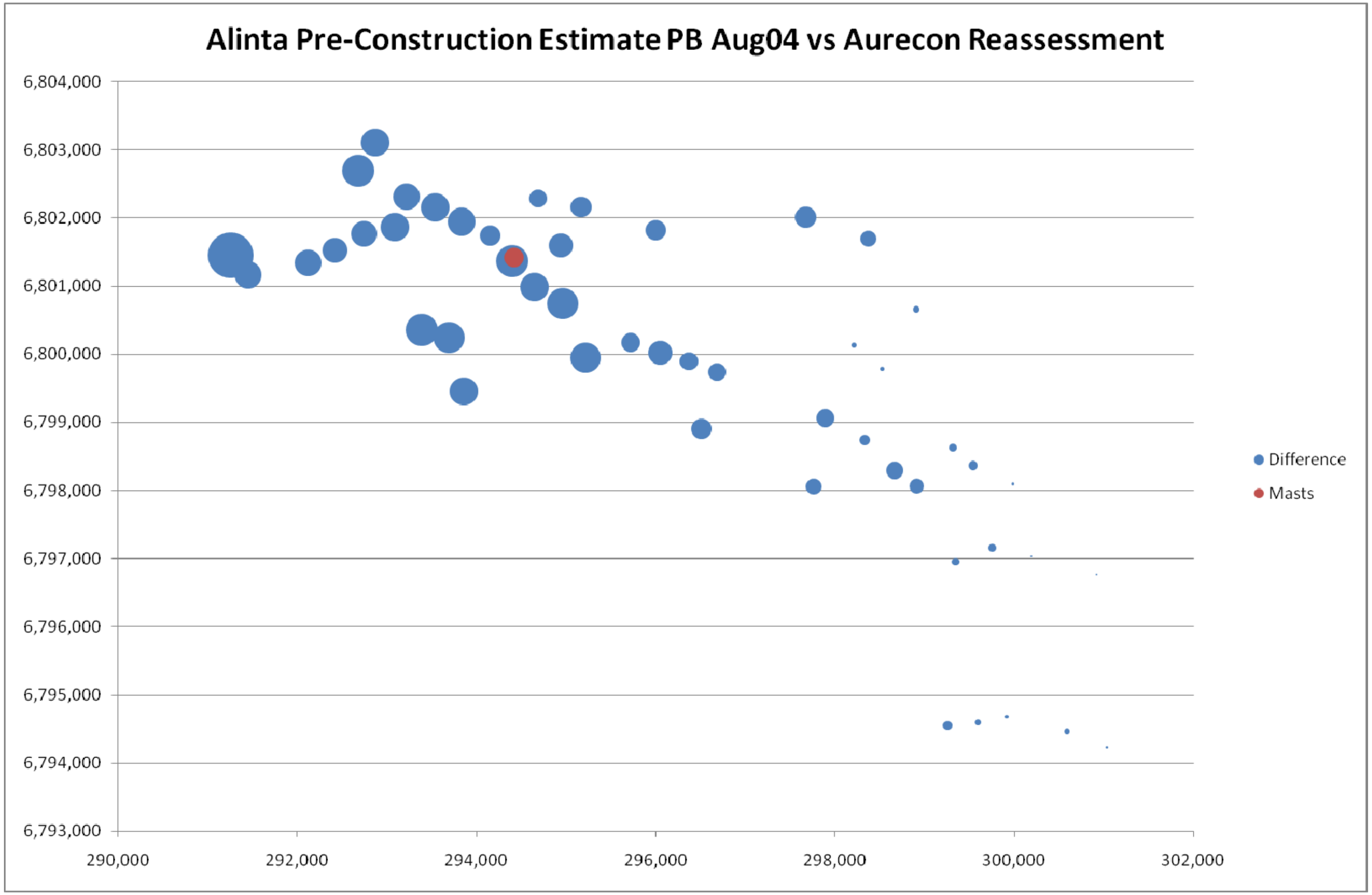
Infigen Portfolio Reassessment



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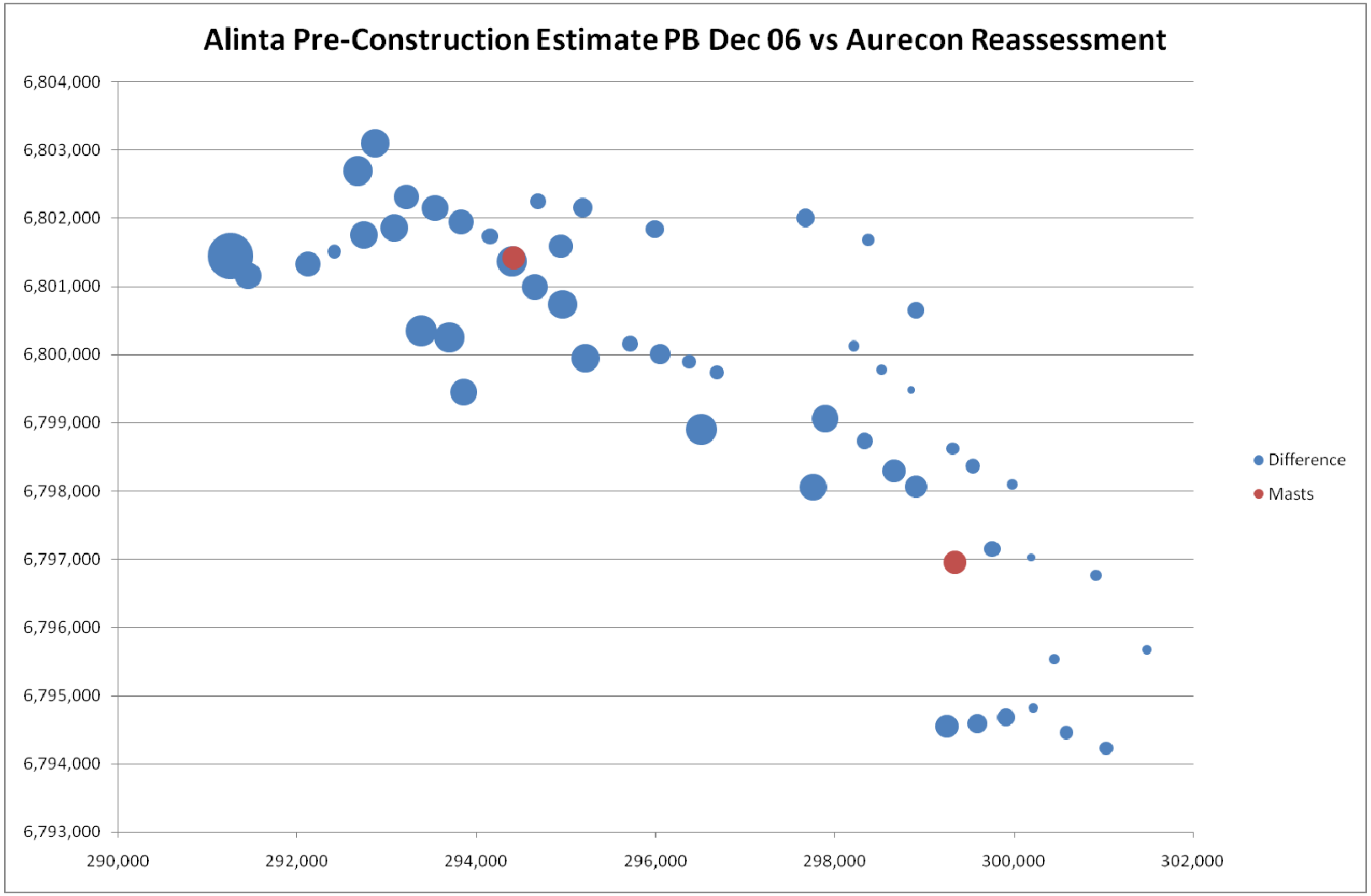
Infigen Portfolio Reassessment



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Infigen Portfolio Reassessment

Key observations from pre-construction estimate: Alinta

- 65 m mast – some uncertainty in extrapolation to hub-height
- Vaisala anemometers – less accurate in non-flat terrain
- Use of 78m mast reduced extrapolation uncertainty in 2006 analysis
- Monitoring locations generally OK – doesn't appear to be a WAsP issue
- Poor correlation with Geraldton BoM station – 54%
- Three levels of data on 65 m mast extended to long-term then used to extrapolate to hub-height – potential for error in skewing actual events
- 2006 analysis with more data and two masts gave identical results
- Uncertainty seems very low, 1-year P50/P90 spread 6.3%, 20-year 4.9%, cf 9.3% and 7.0% from reassessment

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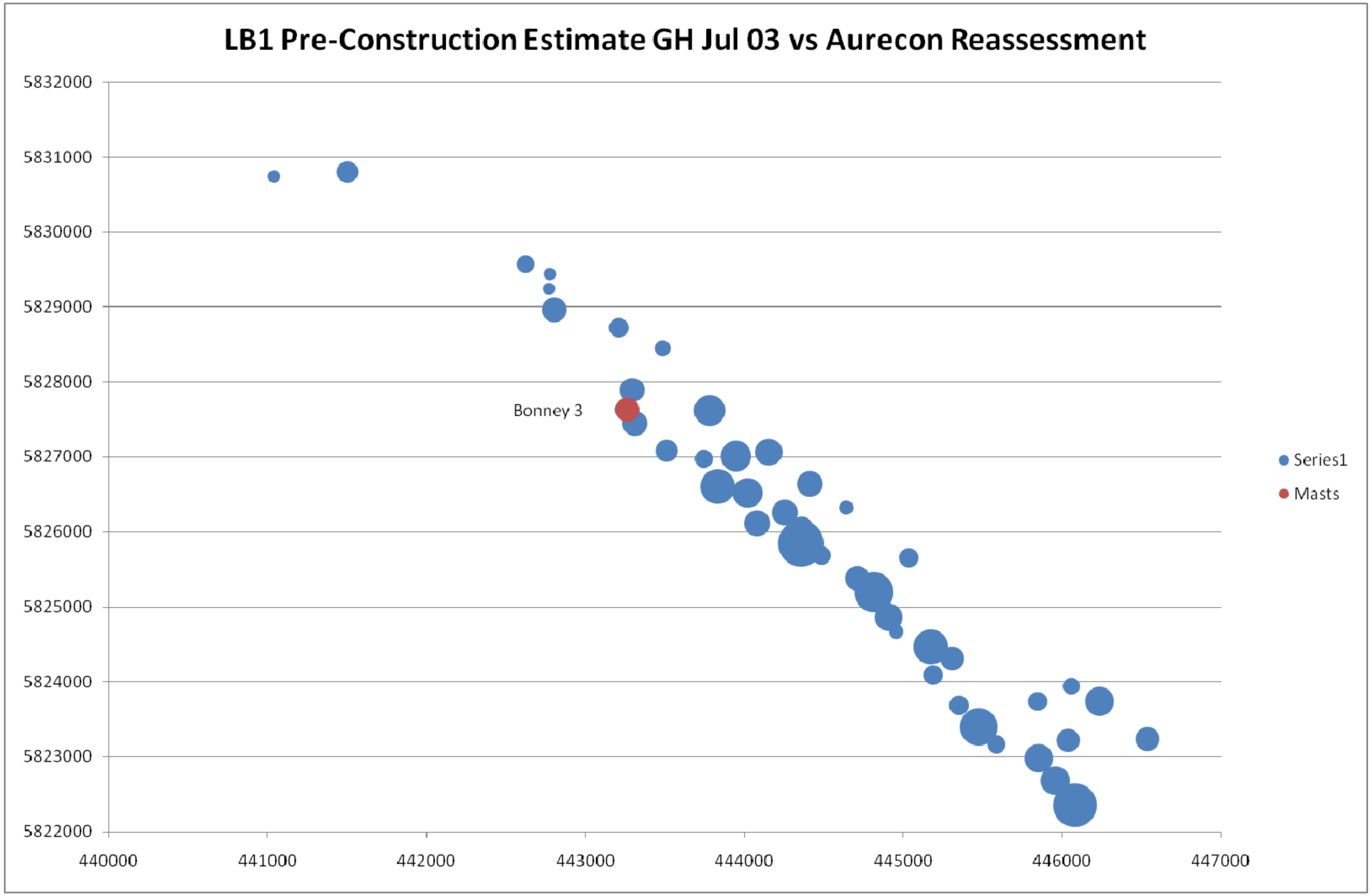
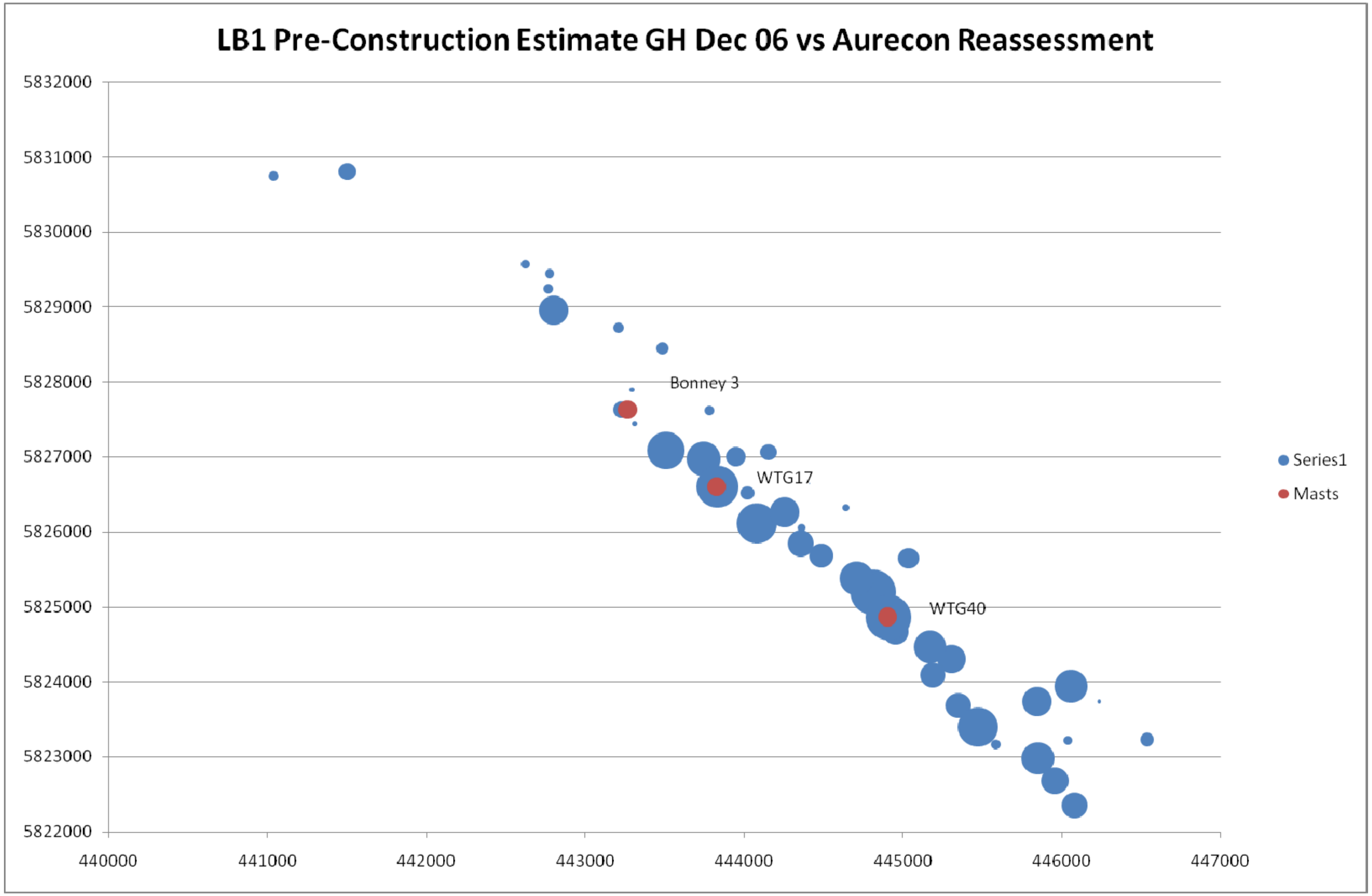
Infigen Portfolio Reassessment



Infigen Portfolio Reassessment



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Infigen Portfolio Reassessment

Key observations from pre-construction estimate: Lake Bonney 1

- 70 m Bonney 3B mast used as main input to wind assessment, safety harness housing at top of mast potentially sheltering anemometers
- 72 m anemometer added to try and avoid sheltering effect
- Climatronics anemometers, not common in the industry, no info on accuracy
- Extended with 30 m data from Bonney 2 mast to produce 7-year synthesized data set, no external correction used
- No info provided in GH reports on contours and roughness data used in flow modelling
- 2006 GH assessment used two PCV masts but only 3-4 months overlap with Bonney 3B, leading to apparent over-prediction in those locations
- Reasonable uncertainty assessment

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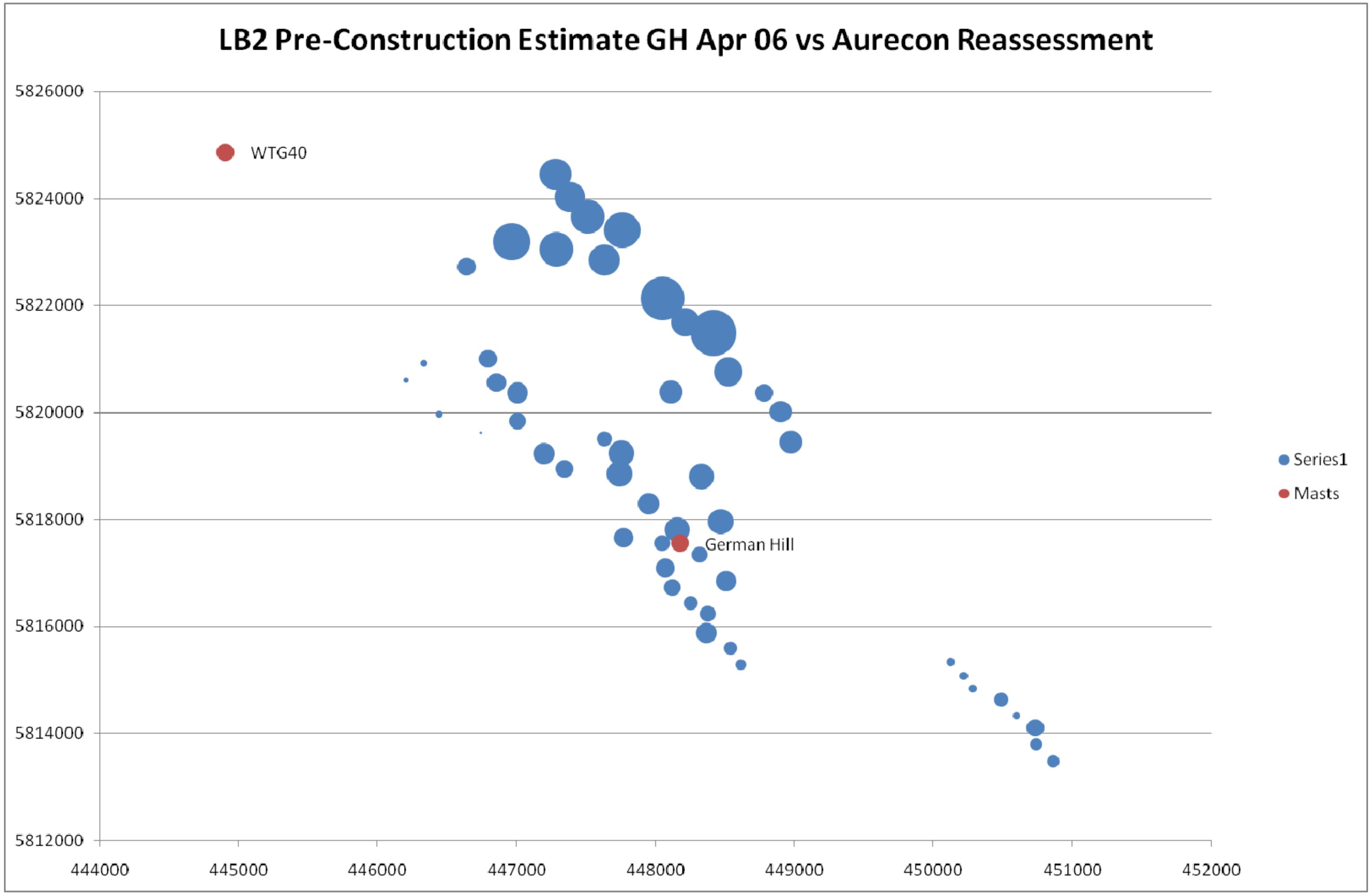
Infigen Portfolio Reassessment



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Infigen Portfolio Reassessment

Key observations from pre-construction estimate: Lake Bonney 2

- 65m German Hill mast, Vaisala anemometers, some concern on calibration
- 6.5 years of data from mast, extended with Bonney 2A to give nine years
- Only 4 months of data from WTG40
- Differences relatively small at German Hill mast but large to the north,
- Suggests a problem with WAsP modelling and/or over-prediction at WTG40 based on short data set

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Best practice in wind resource assessment

Supplementing mast data

- Good quality hub-height data is critical to confirming the feasibility of the site, finalising layouts and producing bankable energy yield predictions
- Can we do hub-height monitoring cost-effectively for taller turbines?
- Can be supplemented with other data
- LIDAR is very effective at reducing wind modelling uncertainty:
  - Deploy around site for short periods and link data to backbone of hub-height masts for long-term correction
  - Use as additional data points to initiate flow modelling (eg WAsP)
  - Correction for flow curvature proved in complex NZ conditions
  - Valuable additional information on wind shear, inflow angle and turbulence intensity
  - Can be deployed in positions where masts can't be erected (not enough space for guy wires)
- SODAR provides similar functionality but lower data capture rates due to weather

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Best practice in wind resource assessment

Supplementing mast data

- Mesoscale modelling can provide additional "virtual mast data points" to reduce flow modelling uncertainty in conjunction with mast data
- Can be used to independently verify mast data: check for drift in anemometers and wind vanes, synthesize missing data
- Can be used to generate reliable long-term data sets for correction of on-site data if no good weather stations around or in addition to weather stations

- Progressive transition from mesoscale model based assessment to mast-based during development phase

Key messages

Development drivers lead to compromised energy assessments

- Good energy predictions require robust monitoring and detailed analysis BUT marginal economics in many geographies lead developers to limit expenditure
- Long and risky development process (eg RMA in NZ) can drive non-optimal wind monitoring, wind farm design and resource assessment
- Bankable energy yield prediction from a consultant has become a commodity product: $25k to provide the key forecast that underpins the project economics, consultant's liability usually limited to 10 x fee or less
- Don't know if the prediction is right until you have 3+ years of operating data

- Why are so many projects over-predicted?
  - probably an equal number of project under-predicted but they are less likely to proceed to construction because of this
  - More over-predicted projects get built because their economics appear to be superior

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