

A COMPARATIVE WIND ENERGY INVESTIGATION USING WIND MODELING SOFTWARE AND EXPERIMENTAL DATA AT FLAGSTAFF, ARIZONA

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Sustainable Energy Solutions

Introduction

- Wind Turbines are becoming more and more popular in Flagstaff, AZ specifically on Highway 89. Currently four 2.4 KW Southwest Wind Power Skystream wind turbines are deployed in this area.
- The main purpose of this project is to predict the energy output of Mr. Scharf's Skystream wind turbine located on highway 89 shown in Figure 1. This prediction is then compared to the actual energy production of this specific wind turbine.
- The challenge in this project is that there is no wind data available at Scharf's site. Therefore, wind data is imported from seven different sites near Flagstaff to wind modeling software WindPro and WASP for required interpolation and wind modeling. Questions of interest:
 - How close is this prediction to the actual energy production?
 - How does the selection of the wind data affect the energy prediction?
 - What sections of Flagstaff are good resources for wind energy?



Figure 1- Skystream3.7 Wind Turbine at Scharf's site

WindPro and WasP Software

- WindPro is a software used for designing and planning for single wind turbines and wind farms. This software is capable of digitalizing information on maps such as height contour lines or roughness values, simple energy estimation, noise and shadow calculations, and photo montages of the landscapes with wind turbines.
- WASP is a wind simulation software which calculates energy output based on a linear flow model and is reliant on input wind data. This tool is used to estimate and optimize wind farm energy production generate wind resource maps.
- WindPro is used as the base to import all data into the program and WASP is in charge of wind or energy simulation and generation of resource maps.
- WindPro and WASP use a linear flow model, Wind Atlas, to solve wind flow equations. This Model requires wind data, height contour lines, and Roughness map of the area to calculate energy production of a wind turbine.

Wind Data

- One to four years of wind data was imported to the WindPro software from 7 different Meteorological towers around Flagstaff.
 - 0130 Anderson Canyon at 10, 30 m
 - 0506 Gray Mountain at 10, 30 m
 - 0702 Gray Mountain at 10, 30, 50 m
 - 7982 Gray Mountain at 48, 59 m
 - 7984 Gray Mountain at 48, 59 m
 - 0503 Mesa Butte at 10, 30, 50 m
 - 5521 Babbit at 10, 30, 50 m
- Figure 2 shows the topographical map of Flagstaff and surrounding along with the site center (Scharf's wind turbine) and met towers.



Figure 2- TOPO map of Flagstaff and surrounding with the locations of met towers and the Scharf's wind turbine

Height Contour Lines

- Elevation data is defined in WindPRO in terms of height contour lines.
- These lines are generated by importing Digital Elevation Model (DEM) files of Flagstaff and surrounding to Global Mapper software.
- These files are then exported as a shape file (.shp) which is presented in Figure 3.
- Figure 4 shows the contour lines of the area. The height contour lines are essential since change in height changes the wind profile.

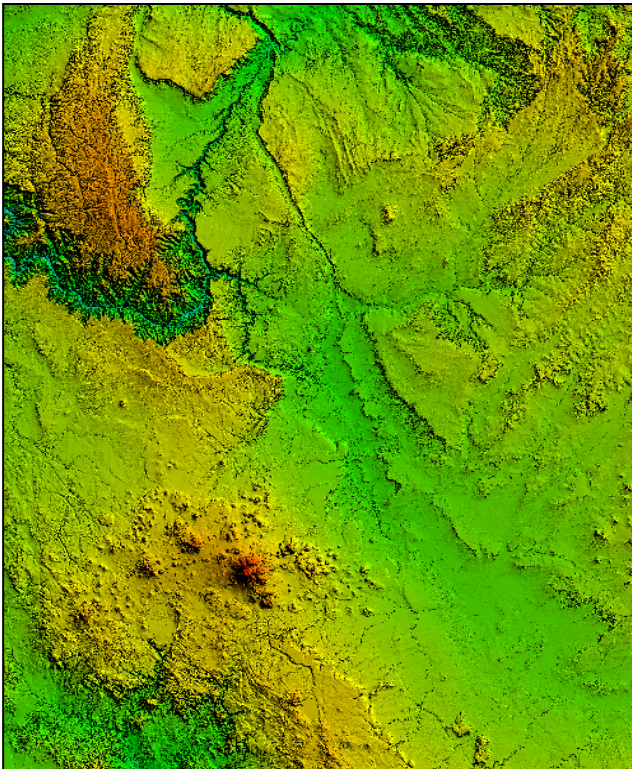


Figure 3- Digital Elevation Model of Flagstaff and surrounding

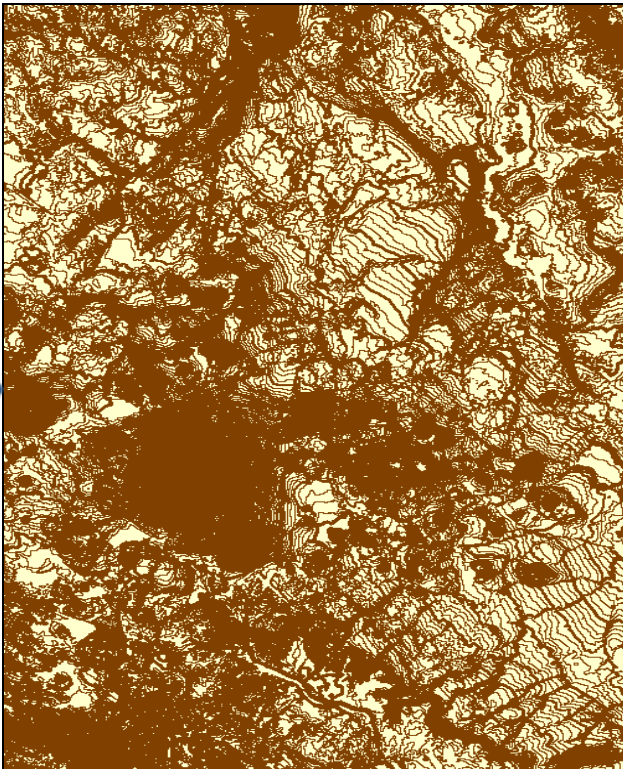


Figure 4- Contour lines created by Global Mapper

Roughness Map

- Wind profile is dependent on the roughness of the surface. The height of the internal boundary layer changes when there is a change in roughness as demonstrated in Figure 5.
- Roughness is classified in different categories and is given certain color and length. This is presented in Table 1.
- Roughness of different sections of Flagstaff and surrounding was estimated by visiting the area and using Google Earth software. The roughness map is presented in Figure 6.

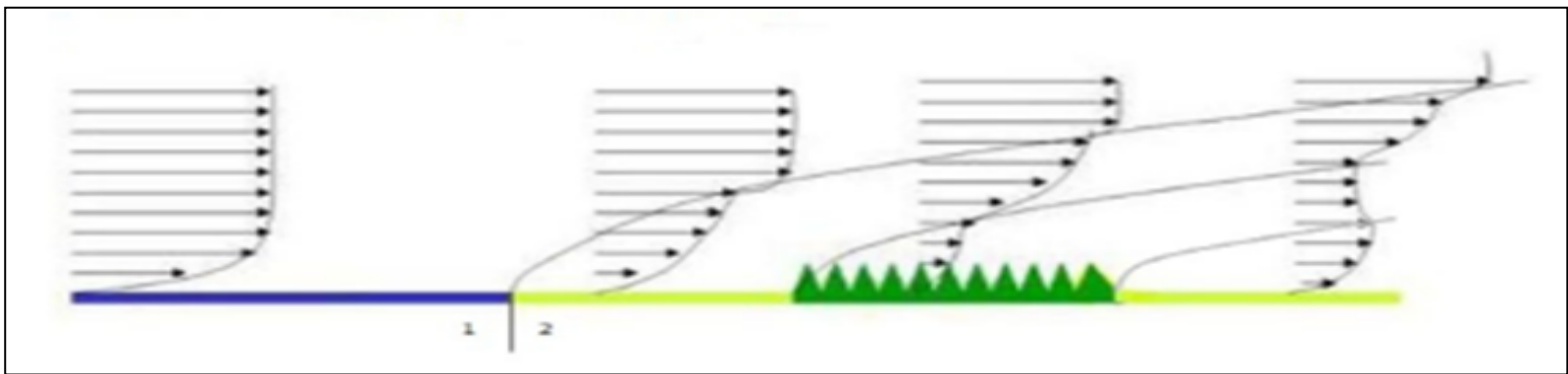


Figure 5- Effects of change in roughness on boundary layer. EXPLAIN HERE

Table 1: Roughness type, color and length

Area Type	Color	Roughness Length
City		0.4000
Farmland, partly open		0.1000
Farmland, rather open		0.0548
Farmland, open		0.0300
Farmland, pretty closed		0.2000
Forrest		0.4000
Water inlet		0.0005
Water		0.0000

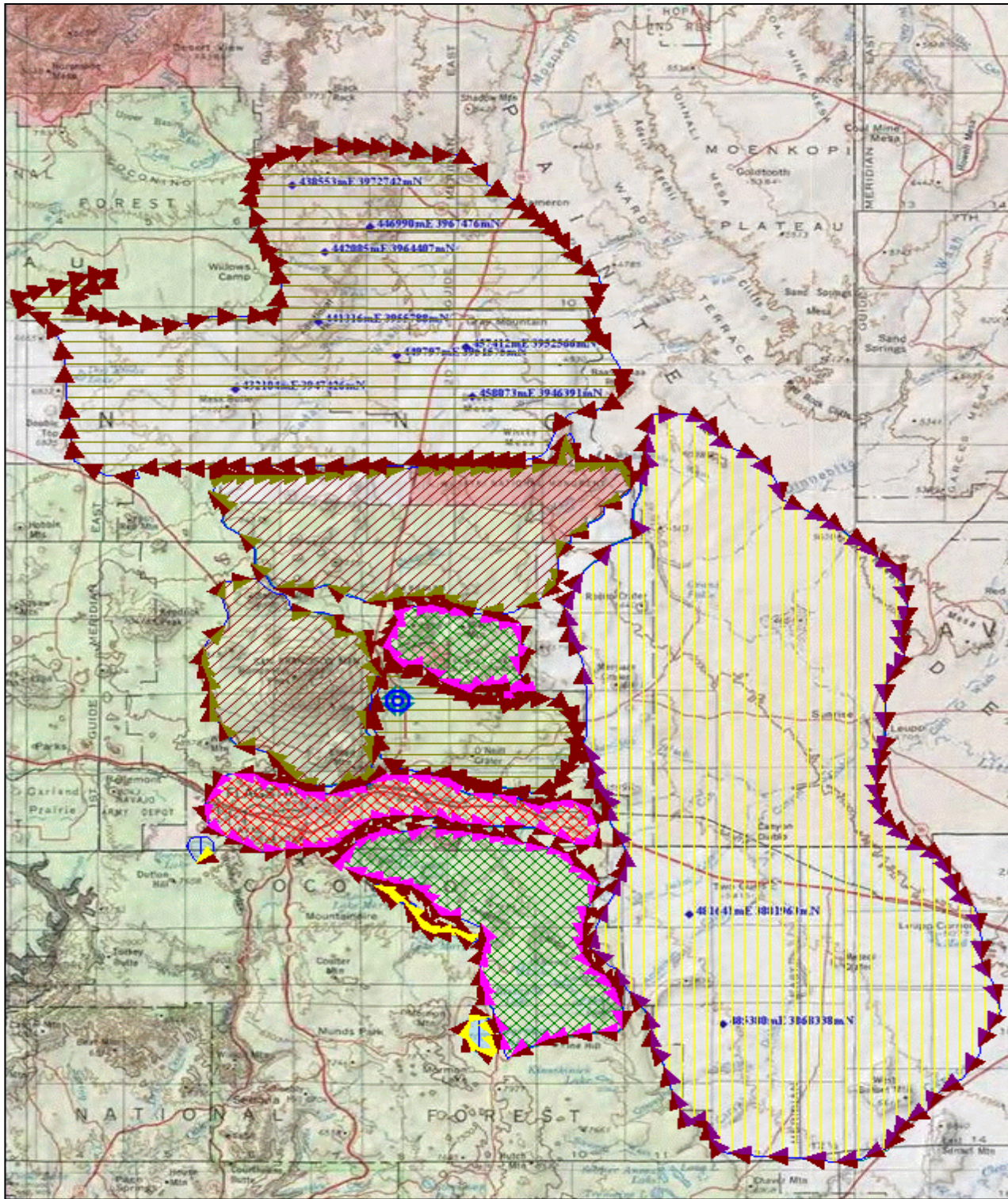


Figure 6: Roughness map of Flagstaff and surrounding

Results

- Once wind, height, and roughness data was imported to WindPro, WASP created wind statistics, Energy Production, and a wind map for Scharf's area.

Wind Statistics

- Wind data from seven different sites was input along with local effects such as roughness and orography to predict wind speed at Scharf's.
- Wind data from five sites measuring wind speed at 10 m above the ground near Flagstaff was used and appropriate weights were given

to them for based on their distance to Scharf's site (Table 2). Weibull Distribution

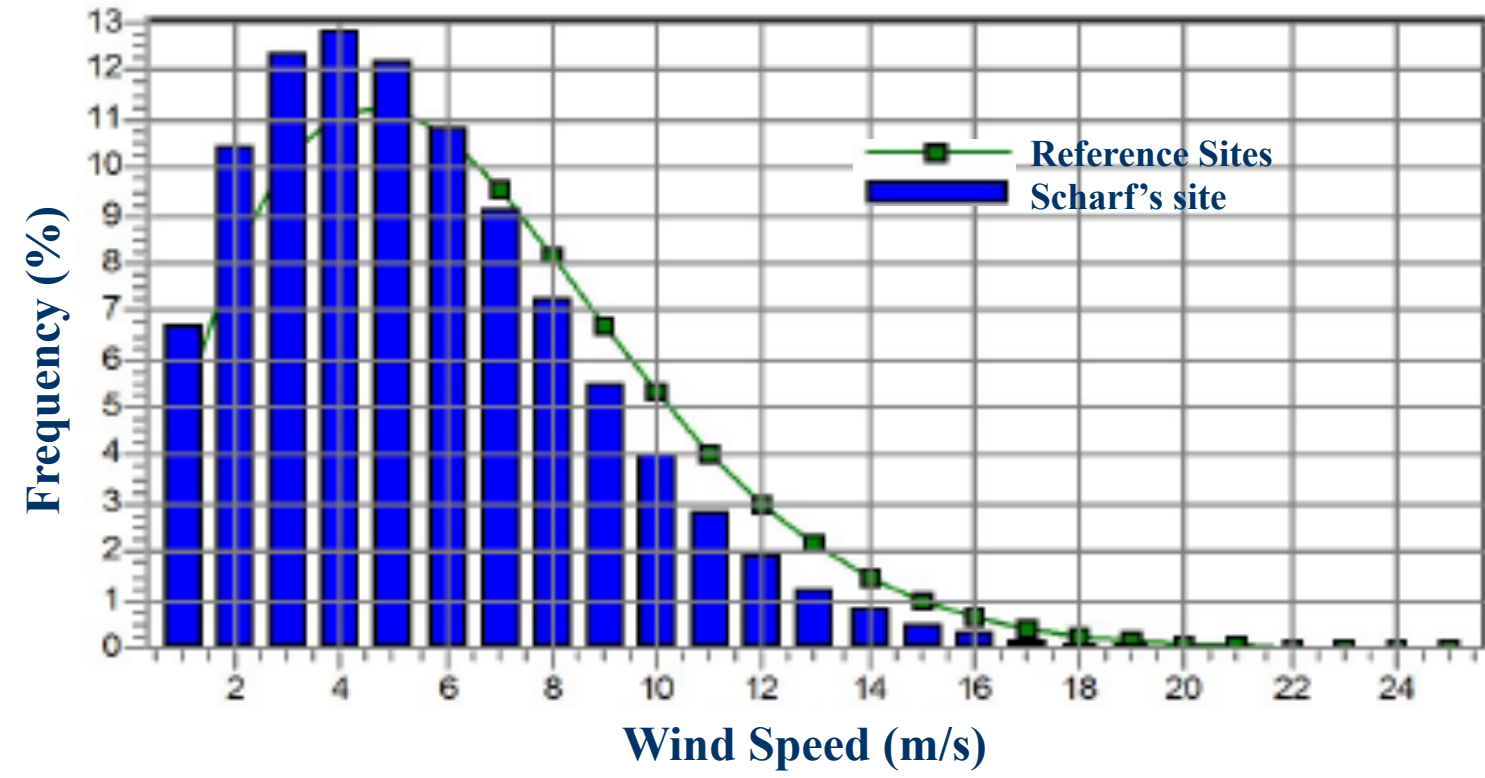


Figure 7- Weibull Distribution of the wind at Scharf's site. This figure shows the frequency of wind blowing at different speeds. The green line represents the Weibull Distribution of the reference site and it is comparable to the Scharf's Weibull Distribution in blue columns.

Table 2- Wind data used to create wind statistics at Scharf's site

Wind Data	Distance (Km)	Weight (%)
10 m 1030 Anderson Canyon	40	24
10 m 0503 Mesa Butte	44	22
10 m 0506 Gray Mountain	58	17
10 m 0702 Gray Mountain	58	17
10 m 5521 Babbit	46	21

Mean Wind Speed (m/s)

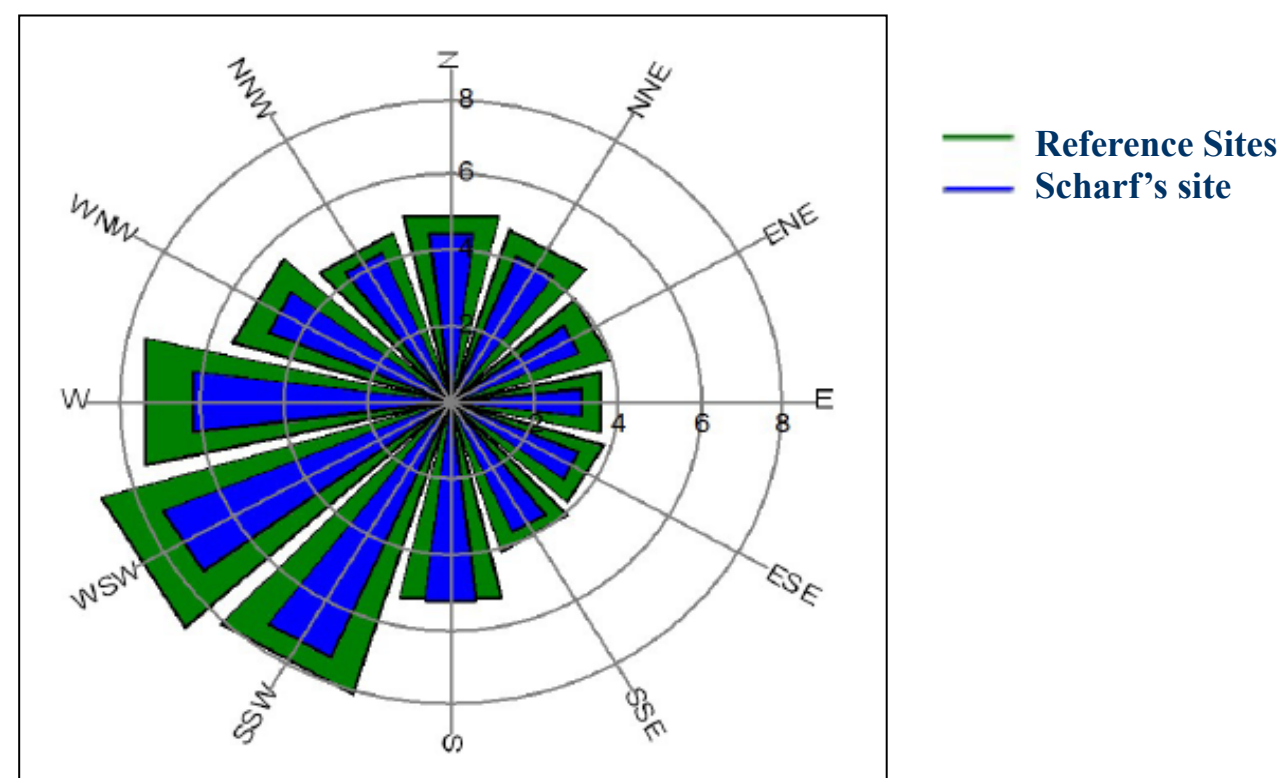


Figure 8- Mean wind speed at different sectors. Wind speed of reference sites is presented in green and predicted mean wind speed in blue. It can be seen that the dominant wind speed direction is southwest.

Energy Prediction

- Actual energy production of the Skystream3.7 wind turbine at Scharf's site in 2009-2010 was 2.79 KW.
- The power curve for the Skystream3.7 was imported into WindPro and is presented in Figure 9.
- Several cases were considered to predict wind energy in order to compare effects of wind data selection on the prediction of wind energy production. These predictions are shown in Figure 10.
- It was found that selecting wind data at 10 m which is very close to the hub height of Scharf's wind turbine generates 2.8 KW. This is within 0.3% error.
- 0506 Gray Mountain is the windiest site and if used solely, WASP overestimates the energy production.

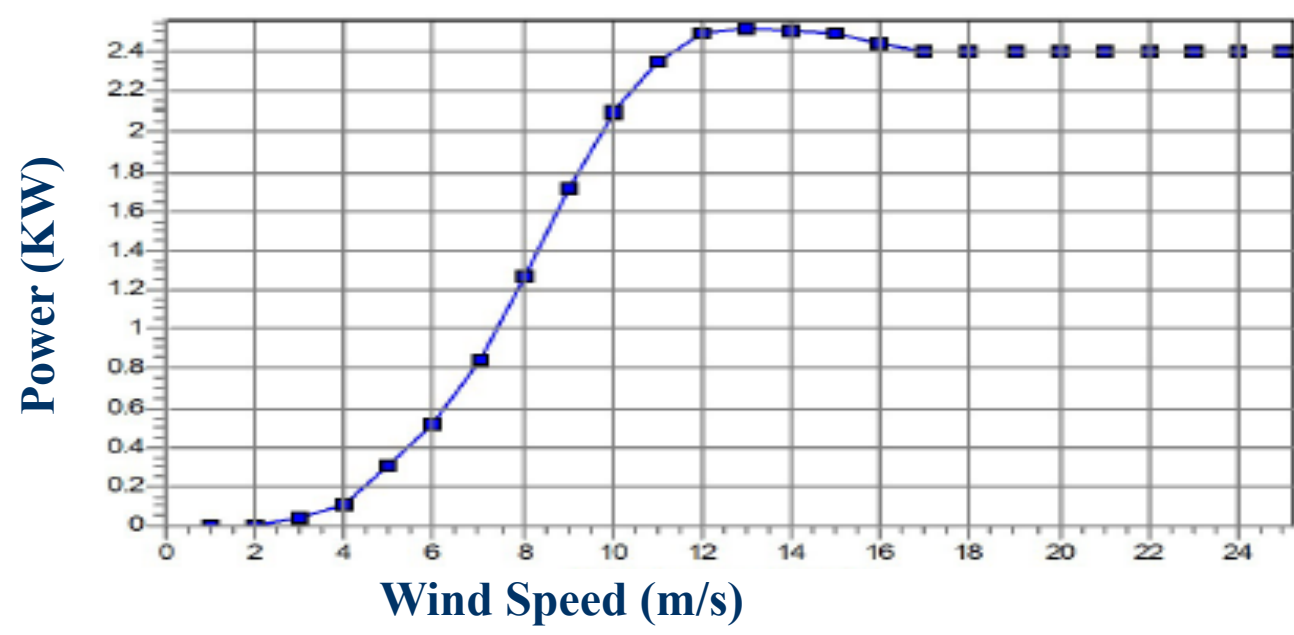


Figure 9- Skystream3.7 power curve. This figure shows power production of the wind turbine at different wind speeds.

Wind Map

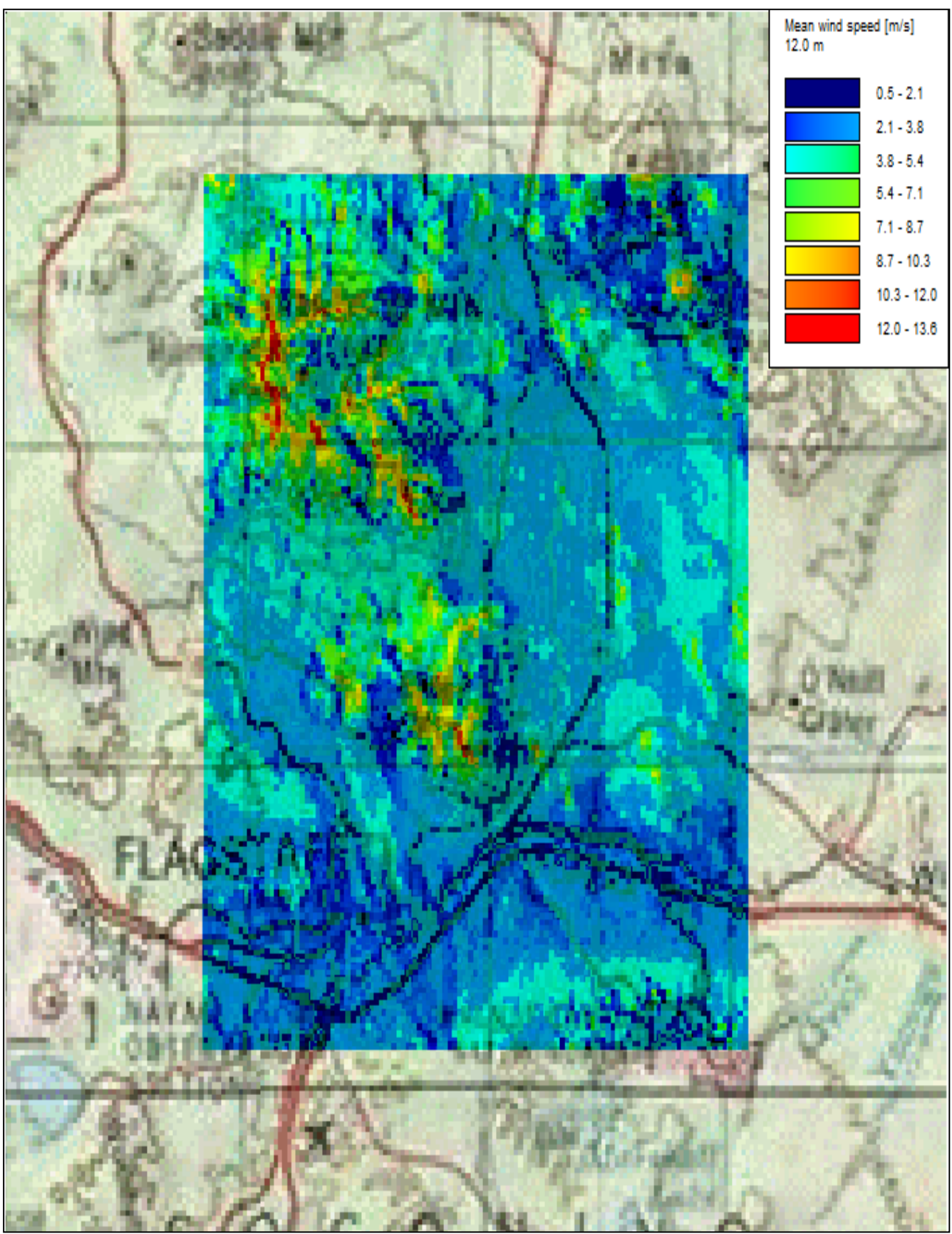


Figure 11- Wind map of Flagstaff at 10 m using WindPro and WASP software. It can be seen that Doney Park has good potential for small wind.

Comparison of Actual and Predicted Annual Energy Production of Scharf's Wind Turbine

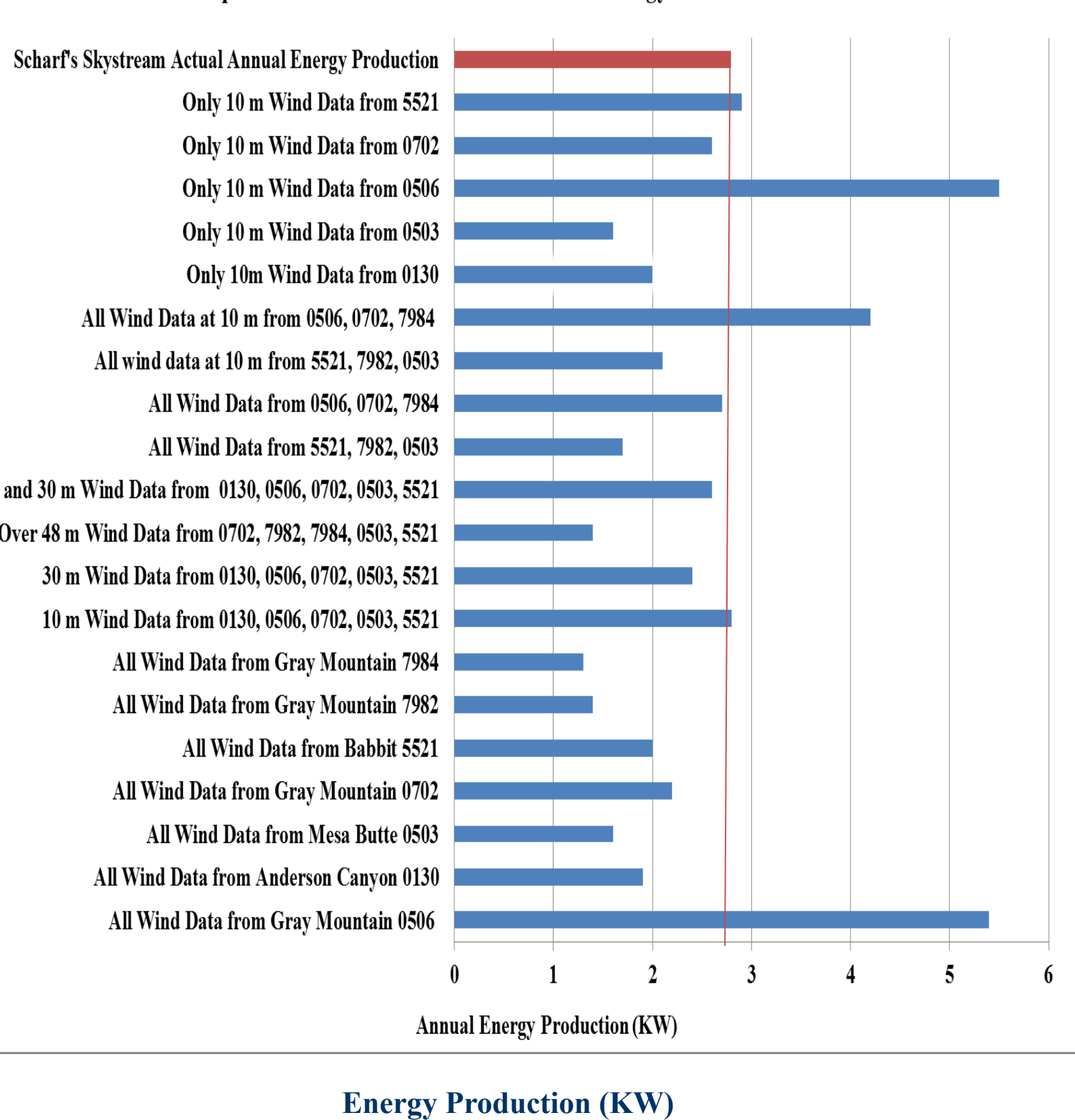


Figure 10- Annual energy production predicted by WASP using several cases of wind data selections. It was found that choosing wind data at the same height as the wind turbine produces the best result.

Conclusion

- WindPro and WASP can be reliable programs for predicting energy production and wind modeling.
- Energy production was the most accurate when wind data was selected at the same height as the wind turbine.
- The wind map reveals that mean wind speed near the Flagstaff area is mostly between 0.5 to 3 m/s at 10 m above the ground. Doney Park area is a great source for residential wind turbines that are designed to operate with the average wind speed of between 3 and 7 m/s.

References

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