Wind Modeling using WindPro and WAsP Software

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1.0 INTRODUCTION

The economic loss or gain in wind power investment is partly dependent on how well the energy production is estimated before the installation of the wind turbine. The most powerful tool used for this analysis is wind modeling software. In the Sustainable Energy Solution lab (SES) at Northern Arizona University (NAU), WindPro and WAsP wind modeling software have been available since 2006. These tools have been used to model the wind flow over simple or complex terrain, create wind statistics in terms of reports, generate wind maps, and predict the output of residential or commercial wind turbines.

2.0 OBJECTIVES

In spring 2009, Arizona Public Service (APS) funded SES to address aspects of small, distributed wind energy that of are interest to APS in Flagstaff, AZ. Following objectives have been identified for Task 3 (Modeling of wind energy potential for distributed, small wind turbine installations):

- Create a wind flow model using WindPro and WAsP
- Predict the energy output of a small wind turbine and compare to the actual energy production
- Compare wind speed predictions to met tower data
- Create wind resource maps of Doney Park at 10 and 30 meters

3.0 SOFTWARE

WindPRO is a wind modeling software created by EMD used to design and plan single wind turbines and wind farms. This software consists of several modules which means only needed modules are chosen and paid for. At SES, eight different modules are available which enables WindPRO to create wind statistics, perform simple or complex energy calculations, and generate resource maps. WAsP is among these modules and is purchased separately from RISØ.

WindPRO is used as the base to import all data into the program and WAsP is the solver and is in charge of wind or energy simulation and generation of resource maps. WAsP uses the linear atmospheric model to extrapolate wind climate data within a region by considering orography and roughness. This model uses linear components of Navier-Stokes equations to solve for wind speed at different locations.

4.0 PROCEDURE

4.1 Overview

In order to create wind and energy models of an area using WindPro and WAsP, the coordinates, wind data, and maps are imported to WindPro. WAsP uses these sets of data to generate wind statistics. Along with the power curve, WAsP is able to create outputs. Summary of a procedure is shown in Figure 1.

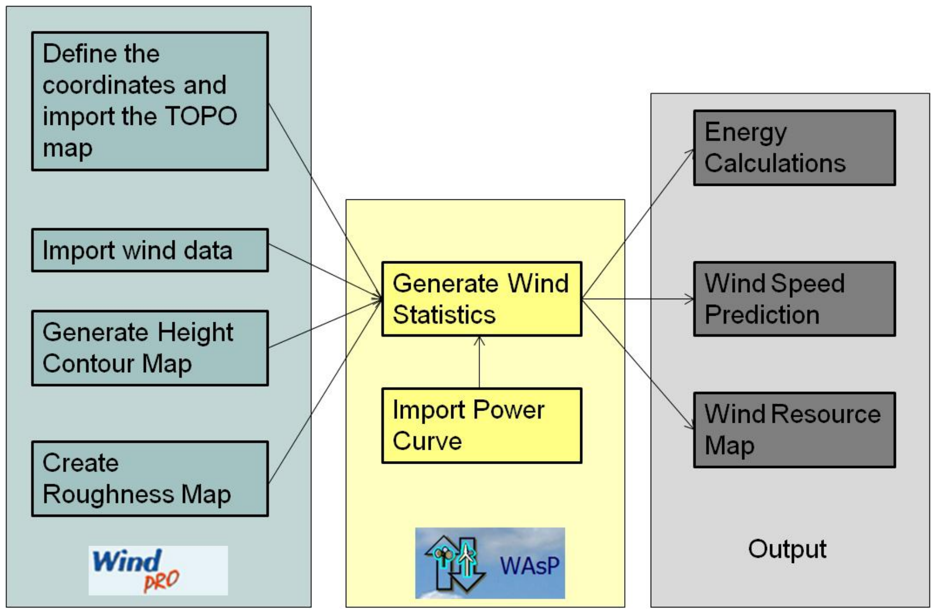


Figure 1- Wind modeling procedure using WindPro and WAsP

4.2 TOPO map and wind Data

When this project was performed, there were no met towers installed on Doney Park area where the wind model was about to develop. (However, on 06/25/2010, a met tower was installed at Nova Kinetics on highway 89). Therefore, one to four years of wind data was imported from 7 different met towers around Flagstaff with anemometers installed at different heights such as:

- 0130Anderson 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 represents the TOPO map of Flagstaff and surrounding along with met towers used

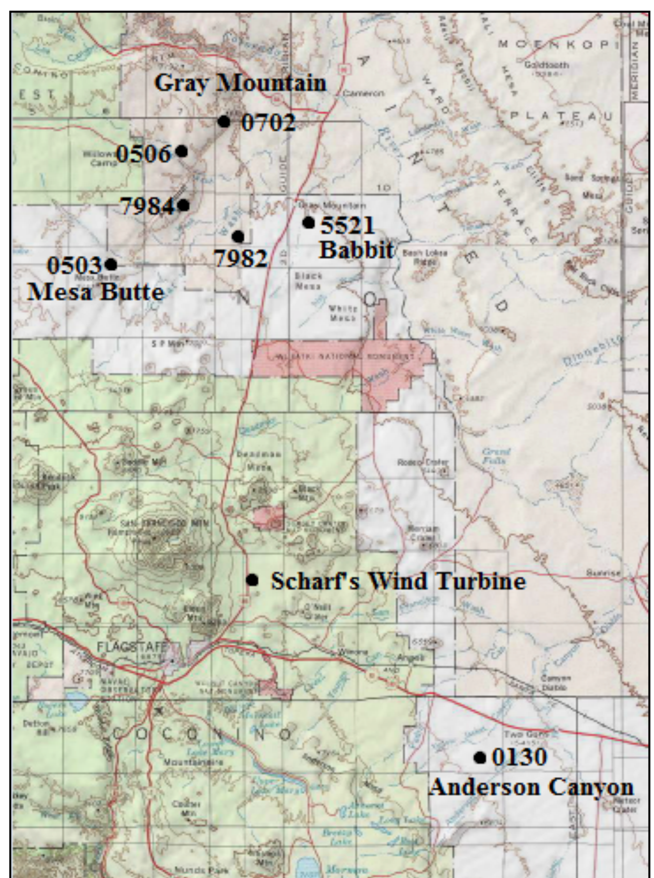


Figure 2- TOPO map of Flagstaff and surrounding

for this research. The 4-digit numbers are used to distinguish met towers. Wind speed and direction are measured every second with the average and standard deviation recorded every ten minutes and saved on data chips. Data from the chips is then exported as text files and imported to WindPro.

4.3 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 different counties of Arizona to Global Mapper software and exporting them as a shape file (.shp) which is readable by WindPRO. Once this file is imported to WindPro, this software performs TIN triangle calculations and displays them on the screen. Figure 3 shows the DEM file, contour lines, and the TIN triangles of the area.

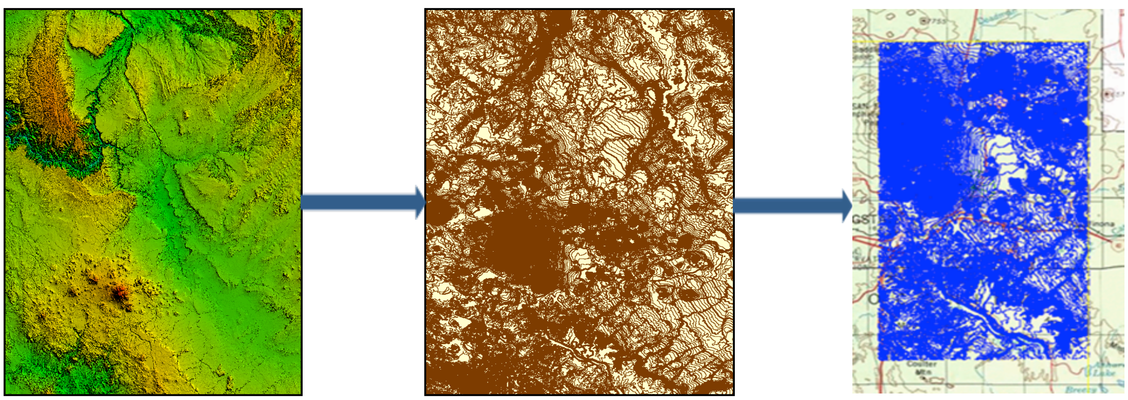


Figure 3- DEM file and height contour lines of Flagstaff and surrounding

4.4 Roughness

Wind profile is dependent on the roughness of the surface. Turbulence increases when there is a change in roughness. This changes the height of the internal boundary layer is demonstrated in Figure 4. Therefore, roughness is classified in different categories and is given a certain length. WindPro enables the user to create different areas and it associates different colors to appropriate roughness lengths as shown in Table 1. Each roughness length is $\frac{1}{30}th$ of the actual length of elements. Figure 5 presents the roughness map of Flagstaff.

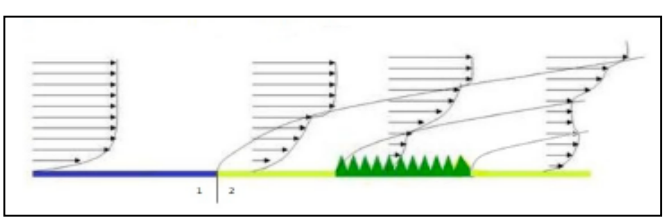


Figure 4-Influence of roughness on boundary layer

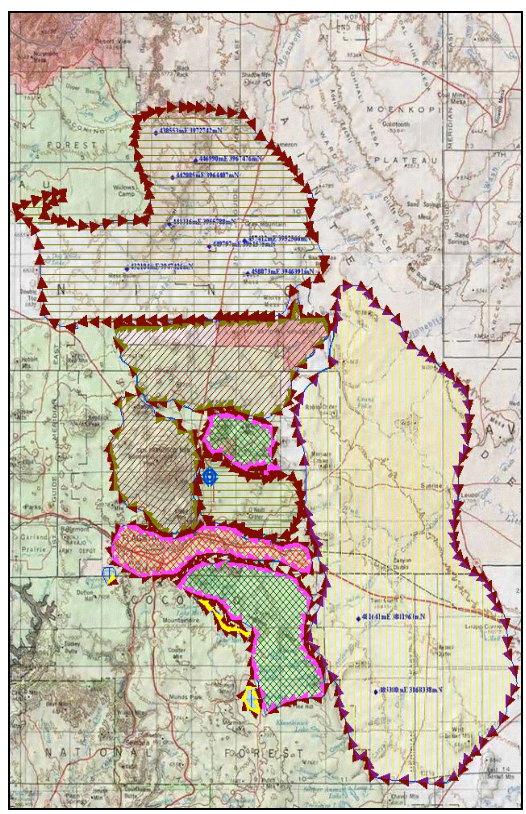


Figure 5- Roughness map of Flagstaff

Table 1- Roughness length and color associated with each area type in WindPro

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

4.5 Wind Statistics

Once wind data from all met towers are imported to WindPro, wind statistics are created for each site and are saved as ".wws" files and can be used in wind and energy calculations. In order to create wind statistics for a site with unknown wind data, WAsP uses the known wind statistics and extrapolate that data based on the height and roughness changes from the known to unknown sites. The closer the known wind data site is to the unknown site, WAsP assigns higher weight to that site for wind statistics prediction compared to other sites.

For example, Gray Mountain 0702 wind statistics are used to generate wind statistics for Scharf sites. Figure 6 presents the Weibull distribution of Gray Mountain 0702 in blue and Scharf's in green. For this project, all seven met tower data was used to generate wind statistics for Scharf site.

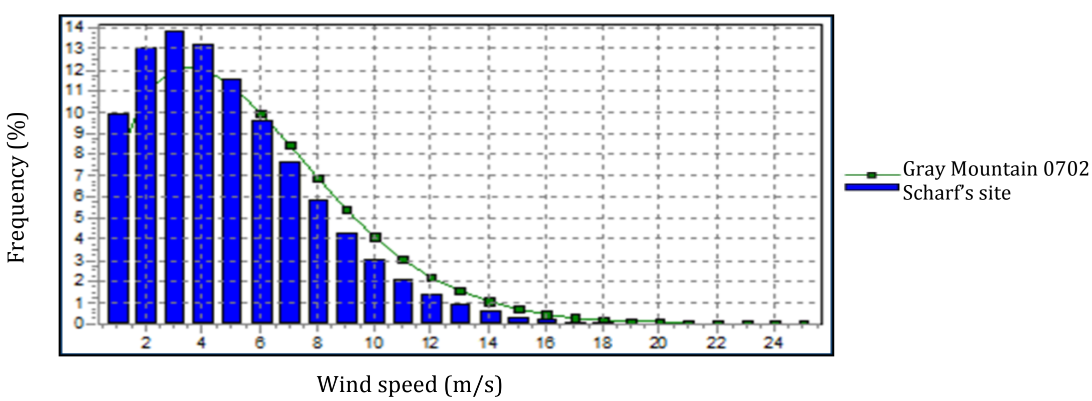


Figure 6- Weibull distribution of Gray Mountain 0702 and Scharf sites

4.6 Power curve

Power curve of Skystream3.7 was created in WindPro by inputting the wind speed and expected power output. This curve is displayed in Figure 8.

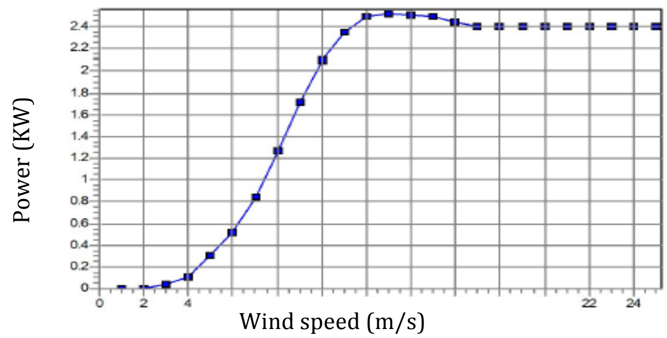


Figure 7- 2.4 KW Skystream 3.7 power curve

Once the wind statistics for all sites were generated and power curve was imported, WAsP solver generated wind and energy calculations at Scharf site . For this case, it is assumed that the air density is about 1.06 $\frac{kg}{m^3}$ at the elevation of 2050 m and average annual temperature of 14 °C .

5.0 RESULTS

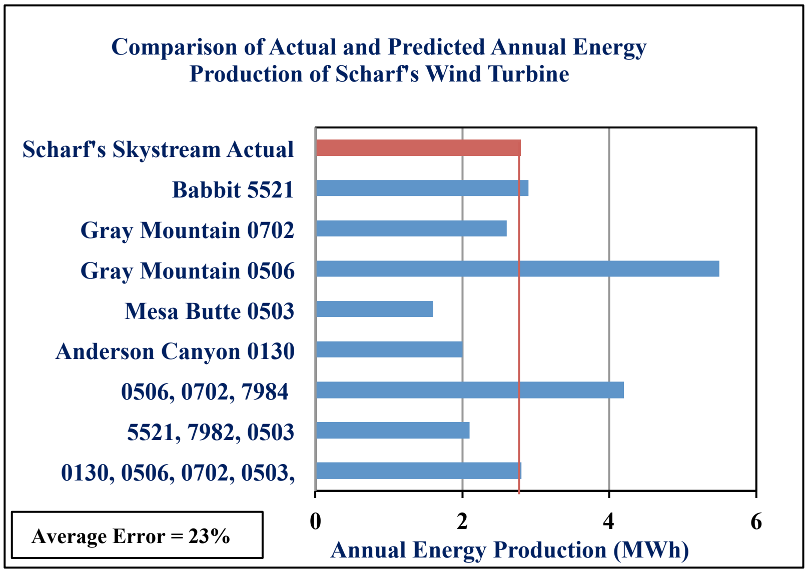
5.1 Annual Energy Production

One of the most important outputs of WAsP calculations is the annual energy production of a wind turbine. It was found that selection of sites and the height of met tower have significant result on the annual energy production. Therefore, the following three cases were considered.

- Met tower data **only at 10 meter**
- Met tower data over 10 meter
- Met tower data at all heights

Energy calculation was performed for each height or met tower of these cases and the results are presented in the following charts. The red bar represents the actual energy production of Scharf site and blue bars are the predictions. In some cases, several met towers were grouped and used for energy predictions. These met towers are circled in blue on TOPO maps next to the charts.

- Met tower data **only at 10 meter**



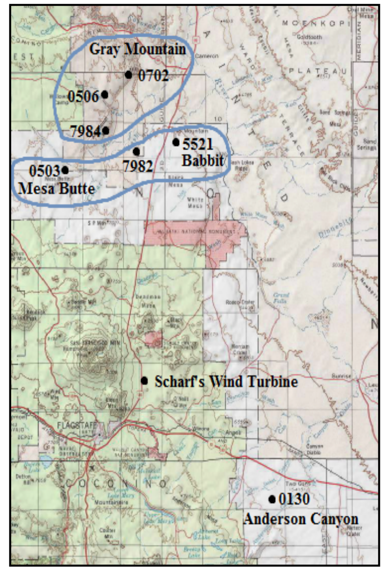


Figure 8- Comparison of actual and predicted energy production using ONLY 10 METER WIND DATA

The actual energy production of Scharf's Skystream was 2.79 MWh in 2009-2010. Figure 8 presents the comparison of actual and predicted energy production using only 10 meter wind data. Individual met tower data at 10 meter did not predict the annual energy production accurately. In fact, wind data from Gray Mountain 0506 overestimated the annual energy production significantly. However, the last case used all 10 meter data available at 10 meters and was the best prediction. Error calculated for this prediction is 0.3%. The largest and lowest predictions were excluded and overall average error of these predictions was about 23%.

- Met tower data **over 10 meter**

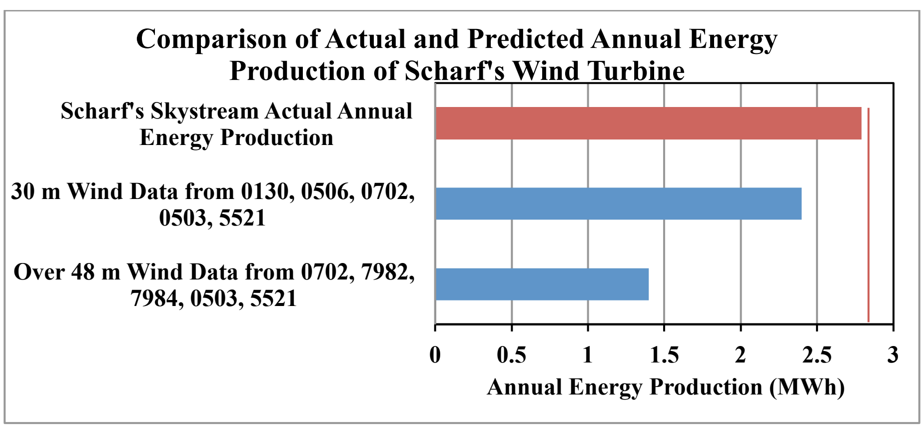


Figure 9- Comparison of actual and predicted energy production using ONLY OVER 10 METER WIND DATA

Figure 9 indicates that the higher the wind data is collected compared to the desired hub height, the more the error is generated for predicting the energy output of a wind turbine.

- Met tower data at **all heights**

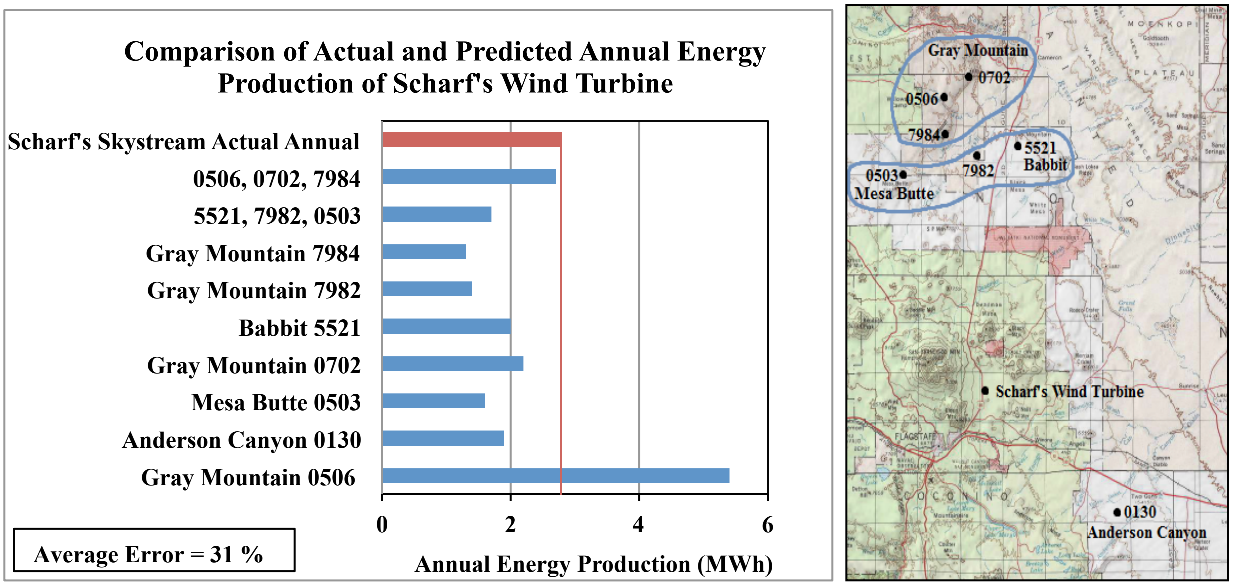


Figure 10- Comparison of actual and predicted energy production using ALL HEIGHTS

Figure 10 shows that wind data from all heights of individual met towers poorly estimated the energy production of a wind turbine. However, one of the grouped wind data (0506,0702,7984) estimated the energy production with the percent error of 3.2%. Once the highest and lowest predictions were excluded, the overall average error in energy prediction for this case was 31%.

5.2 Wind Speed Prediction

In June 2010, a met tower was installed on highway 89 as part of Task 3 of APS project. This tower was erected on Nova Kinetics owned by Jim Corning. Two anemometers were installed at 30 meter and one at 20 meter. WindPro software was used to import this wind data and create wind statistics. The average wind speed for Nova Kinetics is about 4.4 m/s at 30 meters.

All sets of wind data at 30 meters were used to predict wind speed at Nova kinetics in order to be compared to the actual wind speed. These sites are circled in blue in Figure 11. This prediction estimated the wind speed of 4.6 m/s which only has an error of 4.5%.

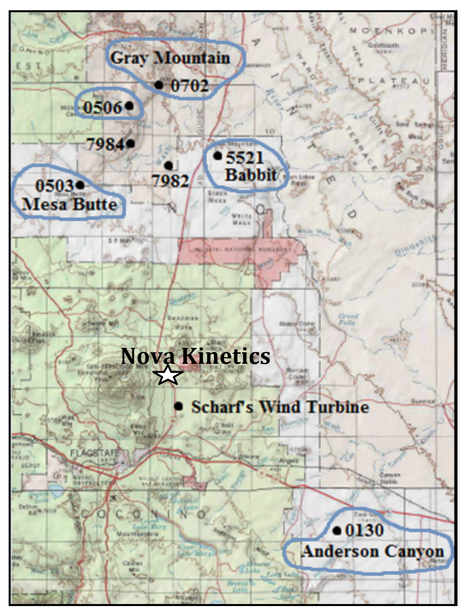


Figure 11- TOPO map of Flagstaff and the location of Nova Kinetics

5.3 Wind Maps

Wind maps are created in WindPro buy running series of automatic WAsP calculations for a grid. Figure 12 shows the wind resource map of Flagstaff and surrounding. This map shows wind speed at 12 meters (hub height of Skystream3.7) in terms of different colors. All wind data sets at 10 meters were used to create this map with the resolution of 100 meter.

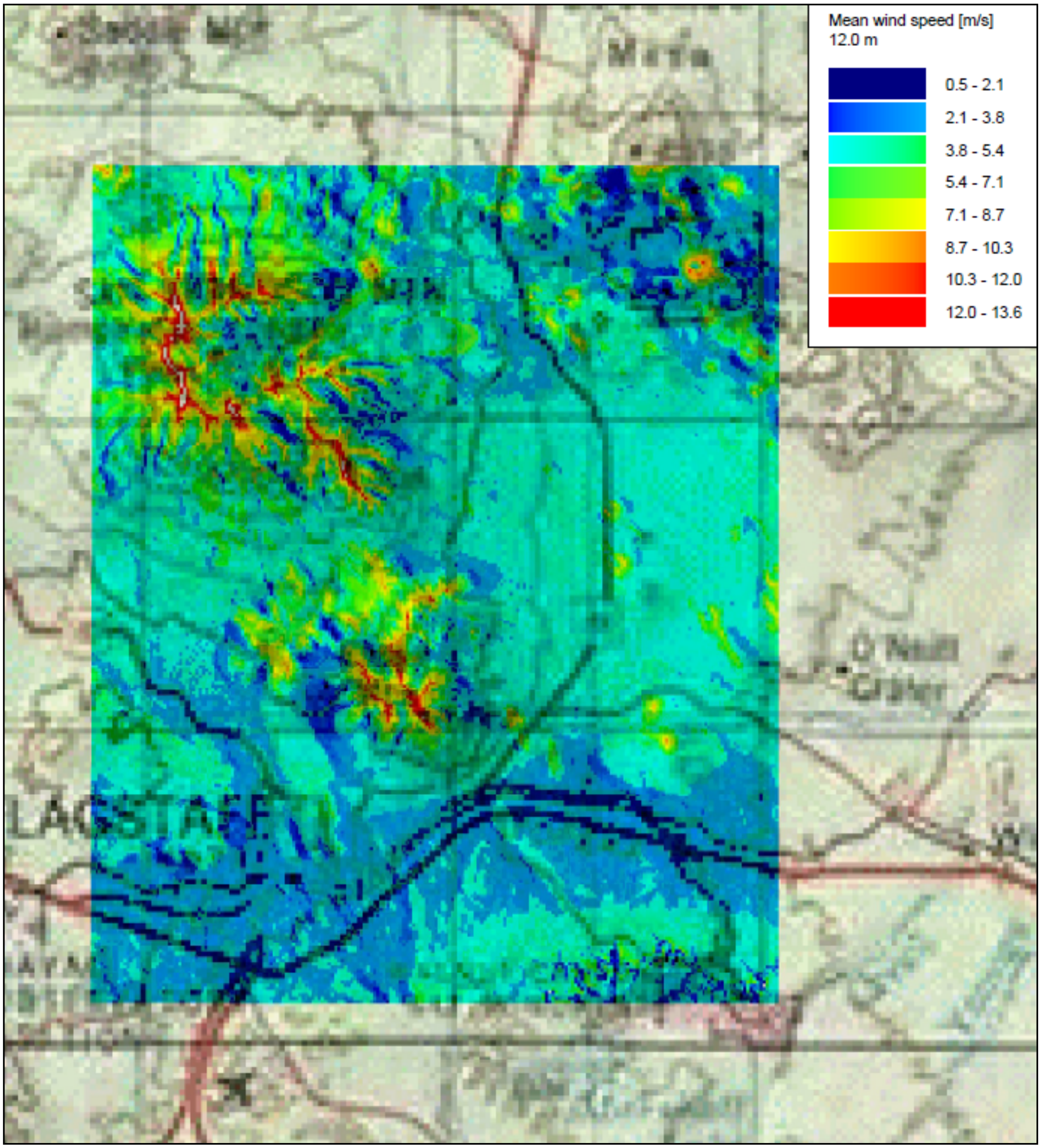
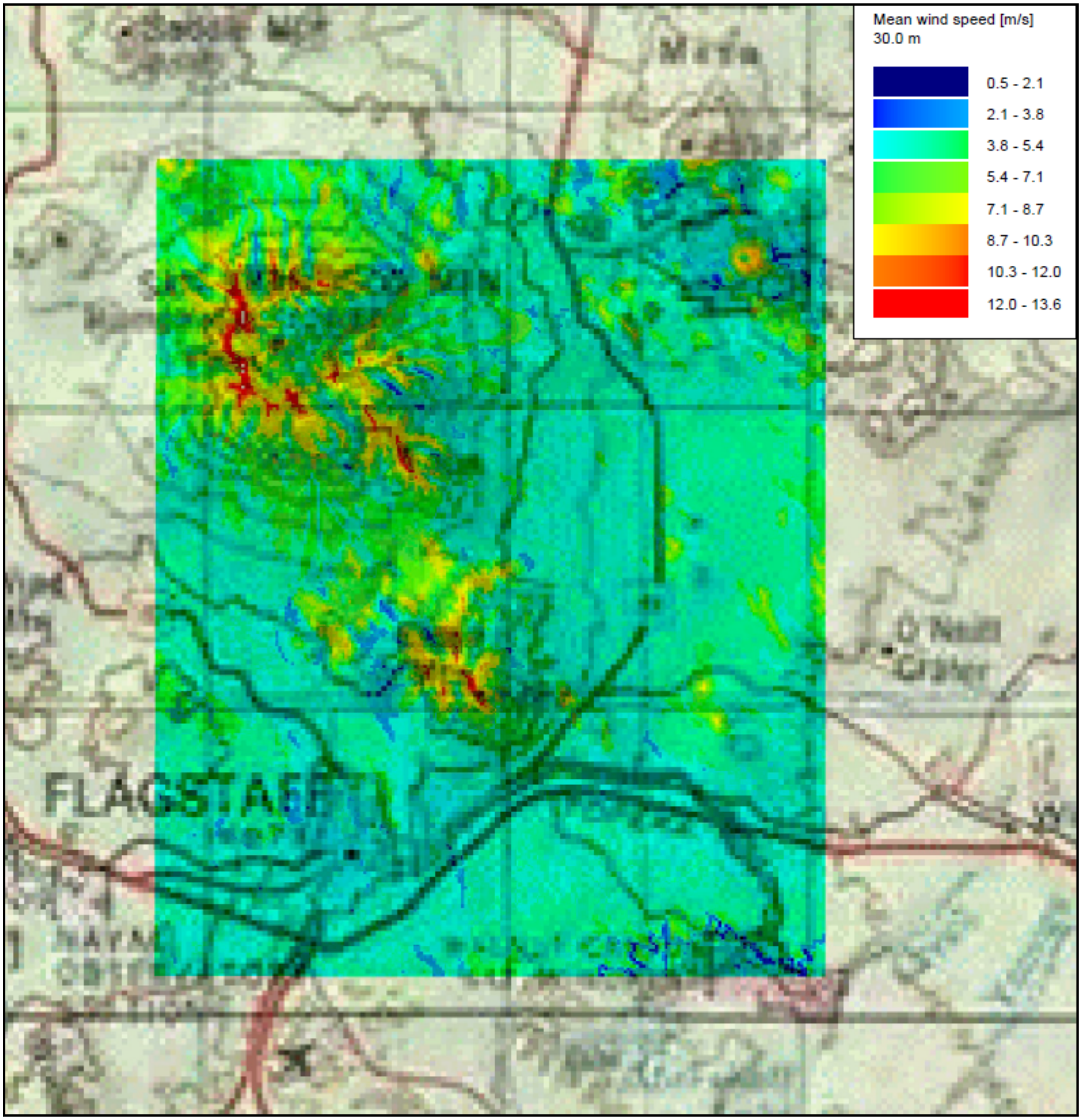


Figure 12- Wind resource map of Flagstaff at 12 meters with 100 meter resolution

Figure 13 presents the wind map of Flagstaff at 30 meters. All wind data at 30 meter was used to generate this map with the resolution of 100 meter.



6.0 CONCLUSIONS

A wind model of Flagstaff and surrounding was created using WindPro and WAsP software. This model was then used to predict energy production of a Skystream 3.7 at Doney Park area using different sets of wind data around Flagstaff. These predictions were then compared to the actual energy production of this wind turbine. Comparison of actual and predicted energy production revealed the following about WindPro and WAsP wind modeling software:

- WAsP calculation is most accurate when the heights of wind data sets used for the calculation are close to the hub height of the wind turbine.
- Once the height of the wind data used for the prediction increased higher than the wind turbine's hub height, energy predictions contained more error. This may be due to poor wind shear calculation of WAsP software.

Based on these results, all wind data at 30 meter was used to predict the average wind speed at Nova Kinetics. This prediction was then compared to the actual average wind speed measured at 30 meters at Nova Kinetics. Several wind maps were generated using the closest wind data to the proffered hub height and were presented in Figure BLAH and BLAH.

6.0 REFERNECES

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