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Final Map Draft Comparison Report

WIND ENERGY RESOURCE MODELING AND MEASUREMENT PROJECT

DRAFT MAP COMPARISON REPORT

Task 3: Focus Area Mapping

Contract No. 500-03-006

Submitted by:

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August 10, 2004

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TASK 3: FOCUS AREA MAPPING

The overall goal of this project is to improve the accuracy of wind resource estimates in promising areas of the State of California by addressing three key issues: the resolution of the original mesoscale and microscale model runs; the structure and modeling of the boundary layer; and measurements from tall towers and sodar. This report summarizes progress to date on Task 3: Focus Area Mapping, which seeks to address the first of the three issues.

1 Background

In Task 2 of the project, five promising areas of the state for wind energy development were selected for further study. The five areas are denoted as follows:

Group	Description	County
B	Desert areas	San Bernardino
C	Surrounding San Gorgonio wind farms	Riverside
D	Surrounding Tehachapi wind farms	Los Angeles/Kern
H	Ridgeline sites	Sonoma/Lake/Napa
I	Northern valley site	Siskiyou

A map of the five focus areas overlaid on the California wind power map is attached.

The immediate goal of Task 3 was to investigate the effect of model resolution on the wind resource in the five areas, with the ultimate aim of producing a more accurate wind resource map. Model resolution – expressed usually as the spacing between individual grid points in the simulations - is an important parameter because it affects how well the model can capture the influence of topography and variations in surface characteristics (such as roughness). In the California wind passes, in particular, we suspected that our mesoscale model, MASS, was unable to fully resolve mountain blocking and channeling effects, which have a large influence on the wind resource both along ridgelines of the coastal mountains and in the main wind resource passes of the state. The importance of mesoscale resolution is a reflection of California's unique wind climate. In late spring and summer, a powerful but shallow flow develops on a daily basis as a result of the contrast between the hot desert interior and relatively cool ocean. This flow traverses the coastal mountains mainly through gaps or passes. The strength of the flow is heavily influenced by factors such as the height of the surrounding mountains and the width of the pass. Without adequate resolution, the mesoscale model "thinks" the mountains are less high and the pass is less wide (or completely invisible to the model), and therefore it can underestimate the wind speed through the passes and overestimate it over the mountain peaks.

An additional factor is the resolution of the microscale model, WindMap, which affects the degree of acceleration over small hills and ridges embedded within a larger flow pattern.

However this effect is of much less importance than the mesoscale model resolution, as it is the mesoscale model that simulates the driving forces of the California wind climate.

2 Procedure

The MASS resolution used to create the original California wind map was 2 km, while the WindMap resolution was 200 m. In Task 3, we halved the MASS grid spacing to 1 km and halved the WindMap grid spacing to 100 m. The resulting wind speed maps are shown in the appendix and are discussed below.

2.1 Area B: Mojave Desert

Area B is located in the Mojave Desert in San Bernadino County near the city of Barstow. It was chosen because it contains typical examples of desert mesas, mountains, and passes, many of which are predicted to have a good wind resource (at least 7 m/s mean speed at 50 m). There are also numerous transmission lines crossing the area.

The high-resolution focus area wind speed map at 50 m is shown in Figure 1. A map showing the changes between this new map and the old (expressed as a ratio of mean speeds at 50 m) is shown in Figure 2.

The most striking feature of the ratio map is the zone of >10% increase in mean speed in the middle, which is centered on dry Coyote Lake. This area is in the outflow from a gap between the Calico Mountains and Lane Mountain to the west. This suggests that at a higher resolution, the model simulates more channeling through the gap. Despite the increase in average speed, however, the predicted wind resource in the area is modest, with a mean speed of about 5 m/s. There is a similar but smaller increase in wind speed at the eastern edge of the area. This appears to be another outflow zone formed by a gap, this one between the lower end of the Calico Mountains and Calico Peak. Once again, the predicted mean speed is modest.

By contrast, the large area of channeled flow through the Mojave Valley (through which I15 and I40 pass) is relatively unaffected by the higher mesoscale resolution, except to be extended somewhat farther to the east. This indicates that the original mesoscale resolution was sufficient to resolve this pass, but not the other two, smaller passes. The mean wind speed through the Mojave valley is predicted to be 6.5-7 m/s at 50 m height, a moderate but potentially attractive wind resource.

The pattern of change in the mountains is a good deal more complex. Although it is difficult to tell in these maps, the predicted wind speed along the ridgelines, by and large, increases by 5-10% compared to the original map. At the same time, the predicted speed just off the ridgelines is predicted to be lower. This is to be expected where the predominant effect of the higher resolution is to raise the peaks and steepen the slopes of the mountains. It is significant, however, that an increase in the blocking effect at the mesoscale, if it occurs, is not enough to offset the effect of sharper terrain at the microscale.

There is, unfortunately, limited data with which to validate the map changes. The one station in an area of significant change is a proprietary mast on a peak in the southern part of the area. The original map appeared to underestimate the wind speed at 50 m by about 10%. The new map appears to overestimate the speed by about 4%. There is not enough data with to draw firm conclusions, however.

2.2 Area C: San Gorgonio Pass

Area C, San Gorgonio Pass, was chosen because of the large concentration of wind projects in the area, and the potential for additional projects, as well as for the availability of considerable amounts of wind data, which can be used to verify the maps.

The high-resolution focus area wind speed map at 50 m is shown in Figure 3, and a map showing the ratio between the new map and the old is shown in Figure 4.

The ratio map shows an area of increased speed through the middle and particularly out the eastern end of the pass, and also extending southeast into the Coachella Valley. This is not surprising because of the ability of the MASS model to better resolve the pass and its outlet at the higher resolution. Once again, in the mountains, there is a more complex pattern of increases and decreases, with most ridgelines experience a moderate increase in the predicted wind speed.

To test whether the higher resolution helps to improve the accuracy of the model predictions, we compared both the original (unadjusted) and new maps with validation data from 18 stations gathered in the first project. We found that the original, unadjusted map was, on average, about 1.1 m/s below the measured speed extrapolated to 50 m, while the standard deviation between the map and data was 1.3 m/s. After the high resolution runs, however, the average bias was -0.65 m/s and the standard deviation was 1.0 m/s. Thus, there was a clear improvement in accuracy of the map. This is also evident in a scatter plot of the observed and predicted values, shown below. The r^2 value rose from 0.47 to 0.68 with the higher resolution.

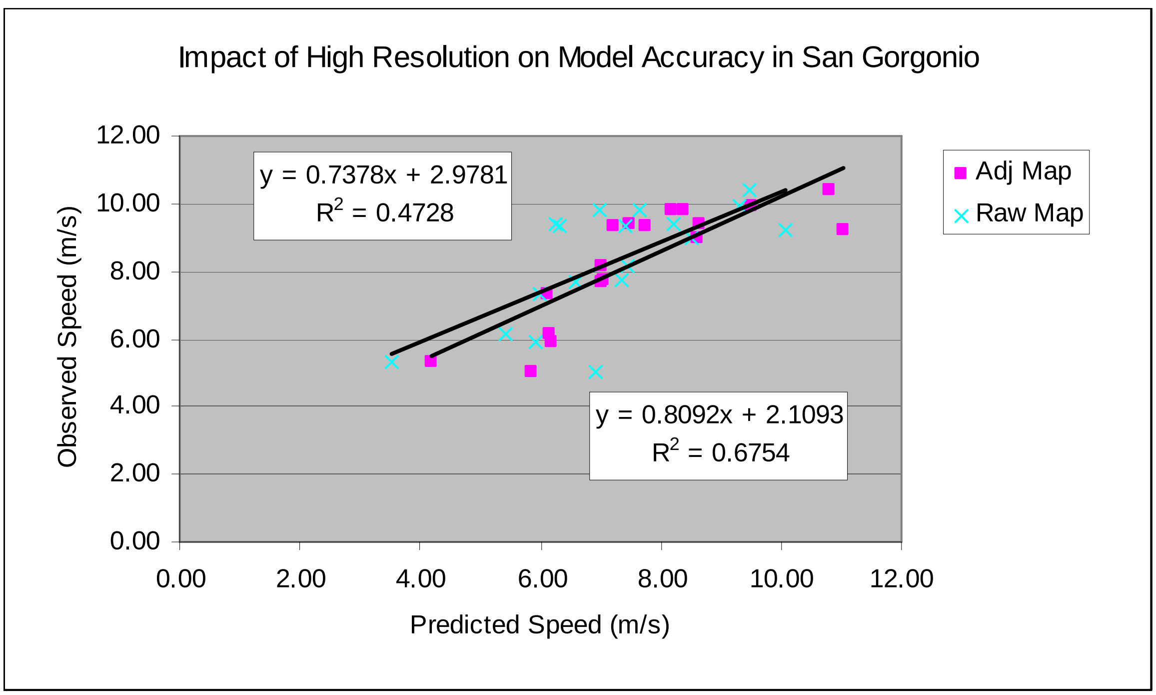

Figure 5. Comparison of predicted and measured/extrapolated data for 18 stations in the San Gorgonio Pass area. The raw map (upper trend line) represents the results of the original wind mapping project, without adjustments. The adjusted map is the result of the high-resolution runs. Note the increase in r^2.

We also found that the adjustments applied to the raw map in the first project were quite similar to the changes resulting from the higher resolution. In fact, the error statistics (average bias and standard deviation) for the original map after the adjustment were about the same as those of the high-resolution map. Thus, the original adjustment captured the effects of higher resolution with some skill.

However, it should also be noted that there are significant remaining discrepancies between the map and data. Other research we have carried out (reported elsewhere) suggests at least part of the remaining discrepancy may be due to incorrect soil moisture assumptions in the mesoscale simulations, which result in an incorrect pattern of surface heating and cooling.

2.3 Area D: Tehachapi Pass

The high resolution speed map of Tehachapi Pass and the map of the ratio of the new to old speeds are shown in Figures 6 and 7.

As there is in Area B, there is a clear pattern of significant increase within and downwind of several passes, most importantly Tehachapi Pass, but also two others, the one to the south known as Cottonwood, and the other to the north, Lone Tree Canyon. The increased wind resource out of Tehachapi Pass extends well out onto the valley floor. Why this occurs, both here and in Area B, is a matter for further study.

Accompanying the increase in the wind resource in the passes, there is a decrease downwind of the higher parts of the Tehachapi Mountains. This is to be expected, given that, with higher resolution, the MASS model simulates greater blocking of the shallow flow by the mountains, and correspondingly greater flow through the passes.

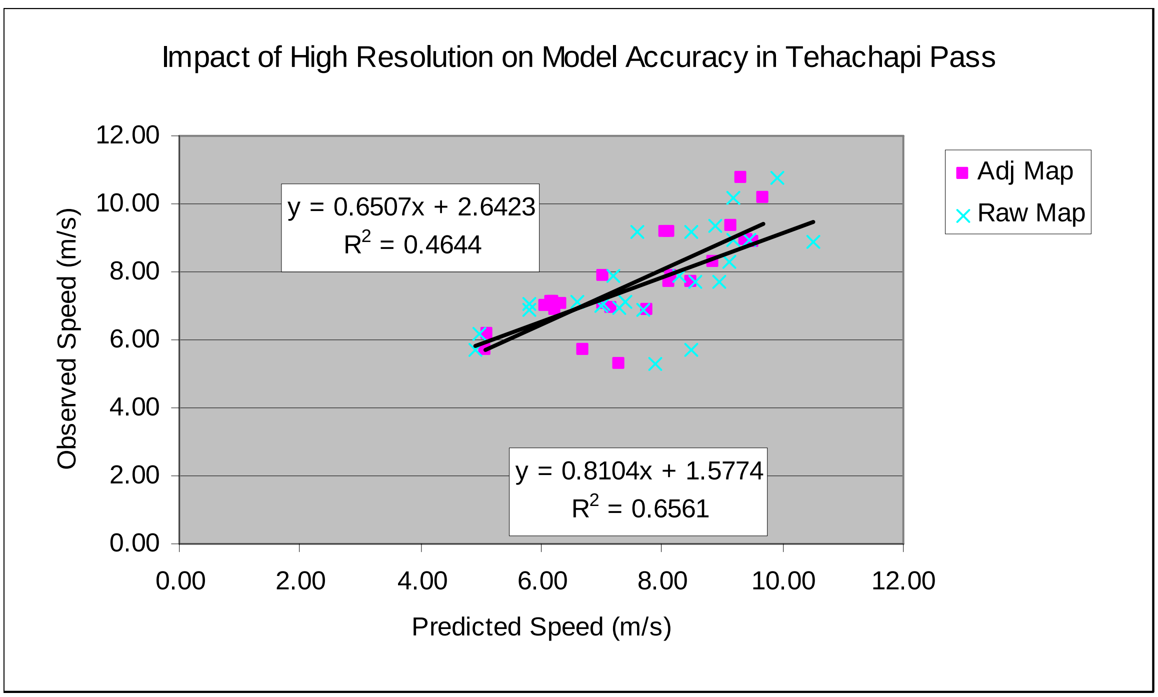

Figure 8. Comparison of predicted and measured/extrapolated data for 25 stations in the Tehachapi Pass area. The raw map (shallower trend line) represents the results of the original wind mapping project, without adjustments. The adjusted map (steeper trend line) is the result of the high-resolution runs. Note the increase in r^2.

Once again, we compared the results with the validation data (25 stations) and found some improvement. The original (unadjusted) wind map had very little bias overall (about 0.1 m/s), but the standard deviation between the data and map was 1.15 m/s. With the high-resolution map, the bias remains small (-0.1 m/s), and the standard deviation is reduced to 0.87 m/s. The scatter plot in Figure 8 reveals the improvement as a tighter fit between the model and data and a higher r^2 value.

The resulting accuracy improvement is comparable to that obtained in the adjustments to the original map. However, unlike the case of San Gorgonio Pass, the pattern of changes is quite different. In fact, while the correlation between the original map adjustments and the impact of higher resolution in San Gorgonio Pass is significantly positive (about 0.5), the correlation between the two in Tehachapi is slightly negative (-0.2). In other words, both the original adjustments and the higher resolution model runs improved the results, but in different ways.

The original adjustments, were, of course, based on the observed map errors, and thus (unless the data were wrong) we must conclude that whatever problems with the simulations caused the errors in those locations, they have nothing to do with the model resolution. Conversely, the changes wrought by higher resolution have improved the fit to the data in ways that were missed in the original validation and adjustment process.

Incidentally, combining the original adjustment with the higher resolution runs results in a standard deviation between map and data of 0.67 m/s, just over one half the standard deviation between the original map and data.

2.4 Area H: Ridgeline

Area H, which covers portions of Sonoma, Lake, and Napa counties, was selected for study as a typical example of a coastal mountain ridgeline, one that may offer some attractive sites for wind energy development because of its moderately good wind resource (predicted to reach about 7-8 m/s in places) and proximity to the transmission grid. The high resolution speed map of Area H and the map of the ratio of the new to old speeds are shown in Figures 9 and 10.

The ratio map presents a rather complicated picture. The average change in mean speed across the whole region is about -6%, i.e., a moderate decrease. This is probably mainly because of increased sheltering of the valleys in the high-resolution simulations. There are a few exceptions - broad valleys which, perhaps because of their orientation to the prevailing wind, are predicted to have a somewhat greater wind resource than in the original wind map.

Within the mountains, the impacts of higher resolution are too complicated to be easily interpreted. Most of the variations in the speed ratio are on too small a scale to have anything to do with the mesoscale model. Rather, they reflect small differences in elevation at the microscale. The impact is particularly noticeable on sharp mountain peaks, where slight changes in elevation due to the change in resolution can result in substantial changes in the predicted wind speed.

A close examination of the main ridgelines – which are the only areas in the region with a potentially attractive wind resource – reveals a slight decrease in the maximum predicted wind speed. This is to be expected since, at a higher resolution, the mesoscale model is able to simulate more mountain blocking. The impact, however, is quite modest – typically a few percent, or 0.1-0.3 m/s.

Unfortunately, we have data for only two stations in this area, one at the Geysers and the other at Mt. St. Helena, which is not enough to confirm an improvement in accuracy. The original map compared rather well to the data at these two stations, and there is no significant change with the new map.

2.5 Area I: Northern Valley

Area I was selected for study because it offers an interesting case study of mountain-valley interactions in northern California. Although the predicted wind speed in the region is generally low, except on the high peaks (especially Shasta Mountain, in the southeast corner), the predicted wind power density is moderately good (300-400 W/m^2) in places, particularly on the west side of the Shasta Valley and the northwest slope of Shasta Mountain. The contrast between the wind power and wind speed patterns is indicative of a highly variable wind resource. At certain times of day and certain times of year, the winds in these areas may be very strong, whereas they are probably moderate or weak at most other times. The likely mechanism for the strong winds is a mountain-valley circulation created by differential heating of the valley and mountain slopes. In a typical scenario, the valley is warmed by the sun much more than the mountain slopes are. The warm valley air rises, and the cold mountain air rushes down to take its place.

The high resolution speed map of Area I and the map of the ratio of the new to old speeds are shown in Figures 11 and 12. As with Area H, the ratio map presents a complicated picture. Focusing, however, only on the areas just mentioned, it appears that higher resolution has enhanced the predicted outflow from the mountains, particularly on the west side of the valley. Unfortunately, we do not have data from stations in these areas to confirm whether the predicted wind resource is accurate, nor whether the higher resolution has improved the accuracy of the map.

3 Summary and Conclusions

We have produced high-resolution wind resource maps of the five focus areas. The impact of the high resolution on the model results, though difficult to interpret in some cases, generally follows our expectations. In areas where mountain blocking and channeling are important, the higher mesoscale model resolution has increased the blocking effect and produced stronger flows through the passes. In other areas, the high-resolution runs produce more sheltering of the valleys by mountain peaks. Katabatic flows out of the mountains into valleys in northern California appear to be moderately increased at high resolution.

In the two regions – San Gorgonio Pass and Tehachapi Pass – where we have enough data to validate both the original and new maps, the high resolution runs have produced a definite improvement in accuracy. The standard deviation between the map and observed wind speeds dropped in both cases by about 25%, while the degree of correlation (r^2) between the map and data increased from about 0.46 to 0.65. Since errors in the data contribute to the standard deviation, the actual improvement in map accuracy is probably greater than these figures suggest.

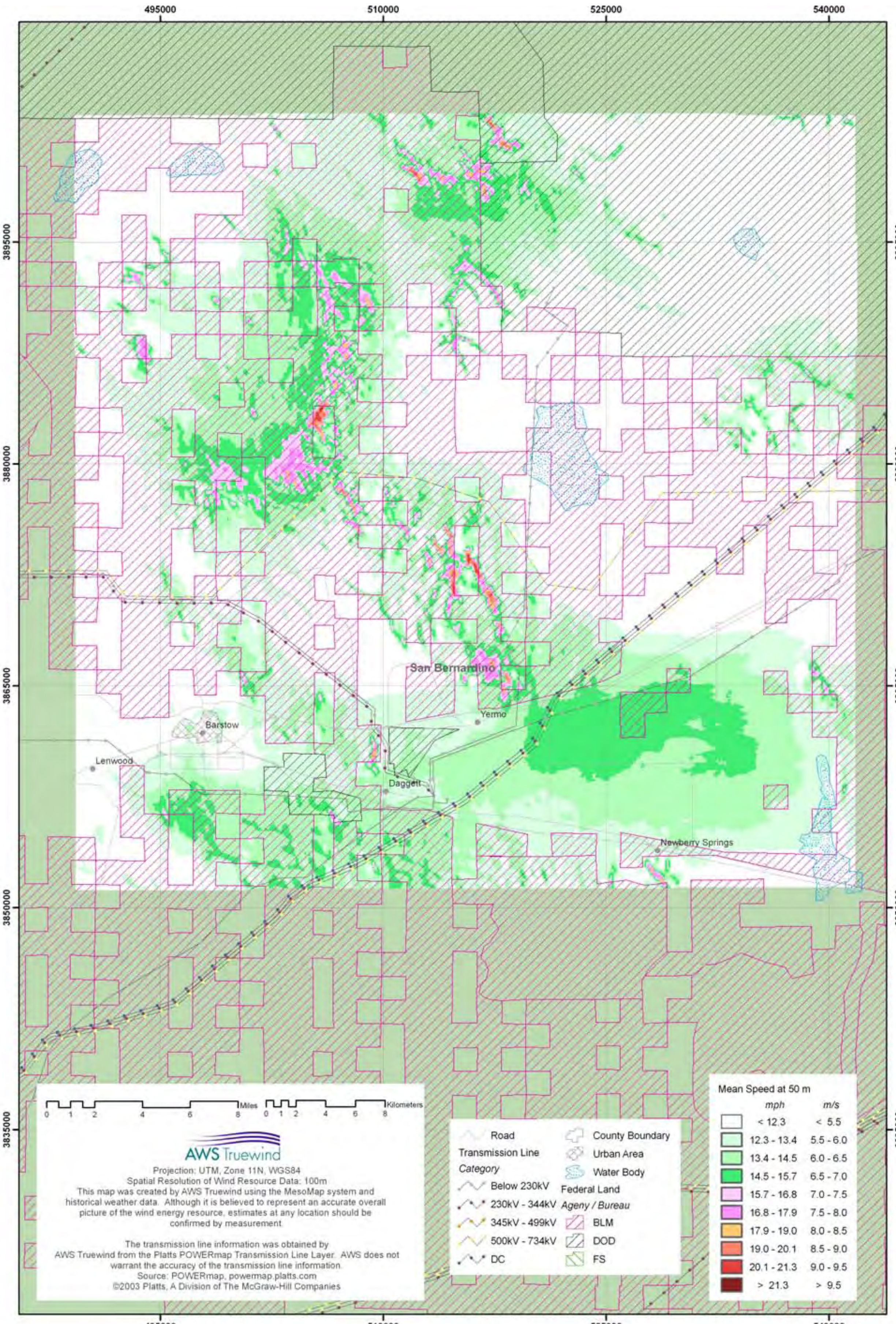

Figure 1: Wind Speed Map at 50 Meters, Focus Area B – Mojave Desert

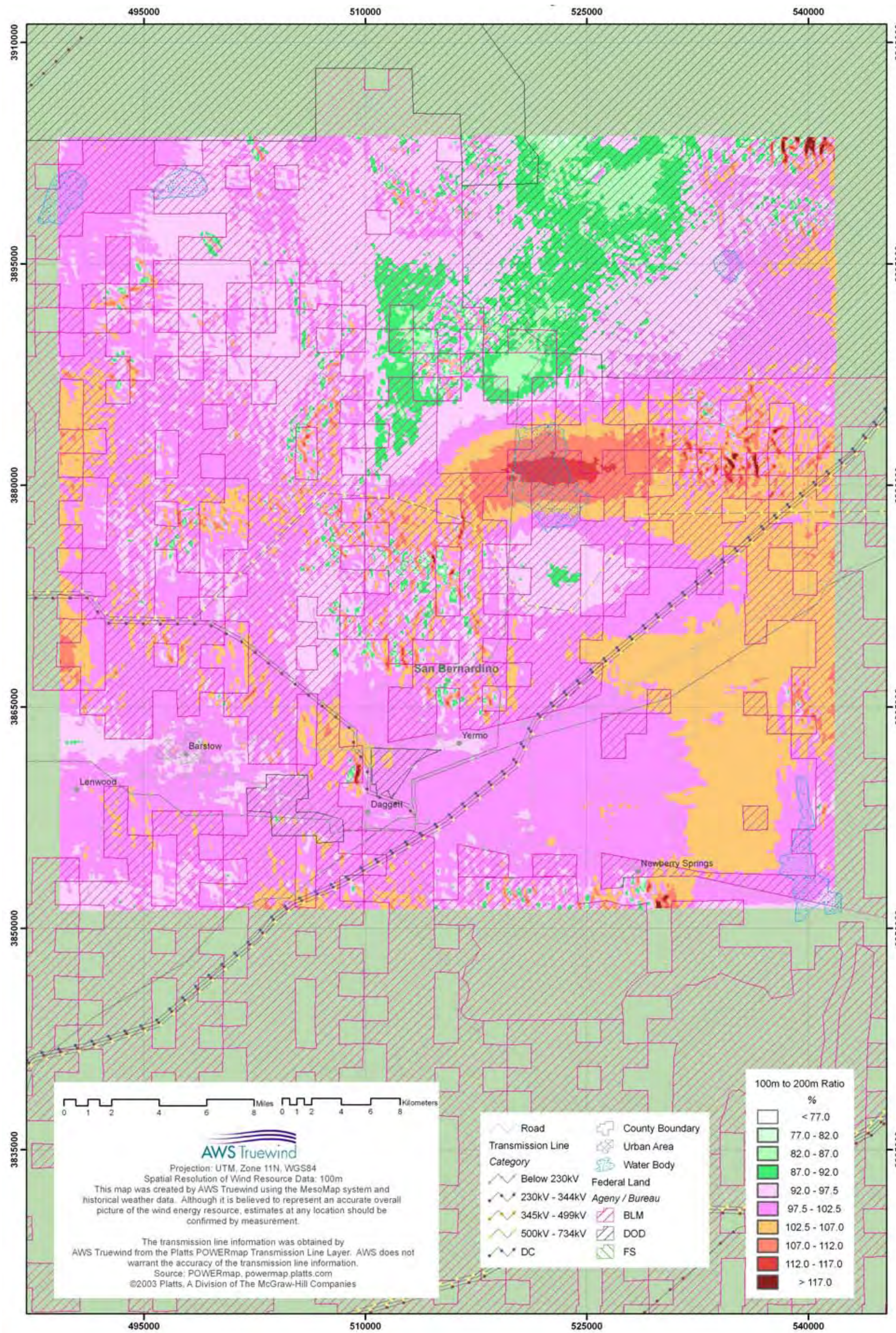

Figure 2: Percent Change in Wind Speed at 50 Meters, Focus Area B – Mojave Desert

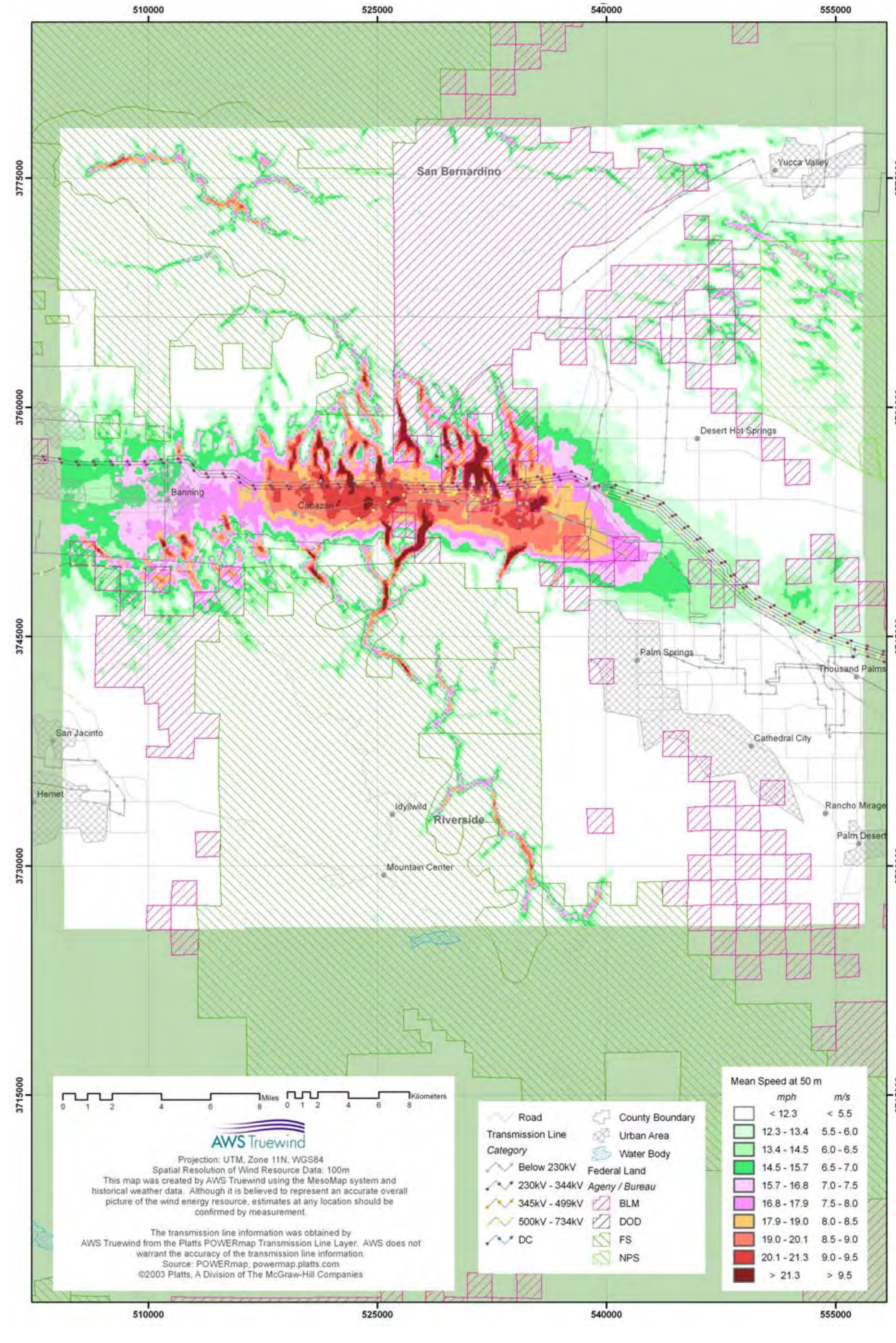

Figure 3: Wind Speed Map at 50 Meters, Focus Area C – San Gorgonio Pass

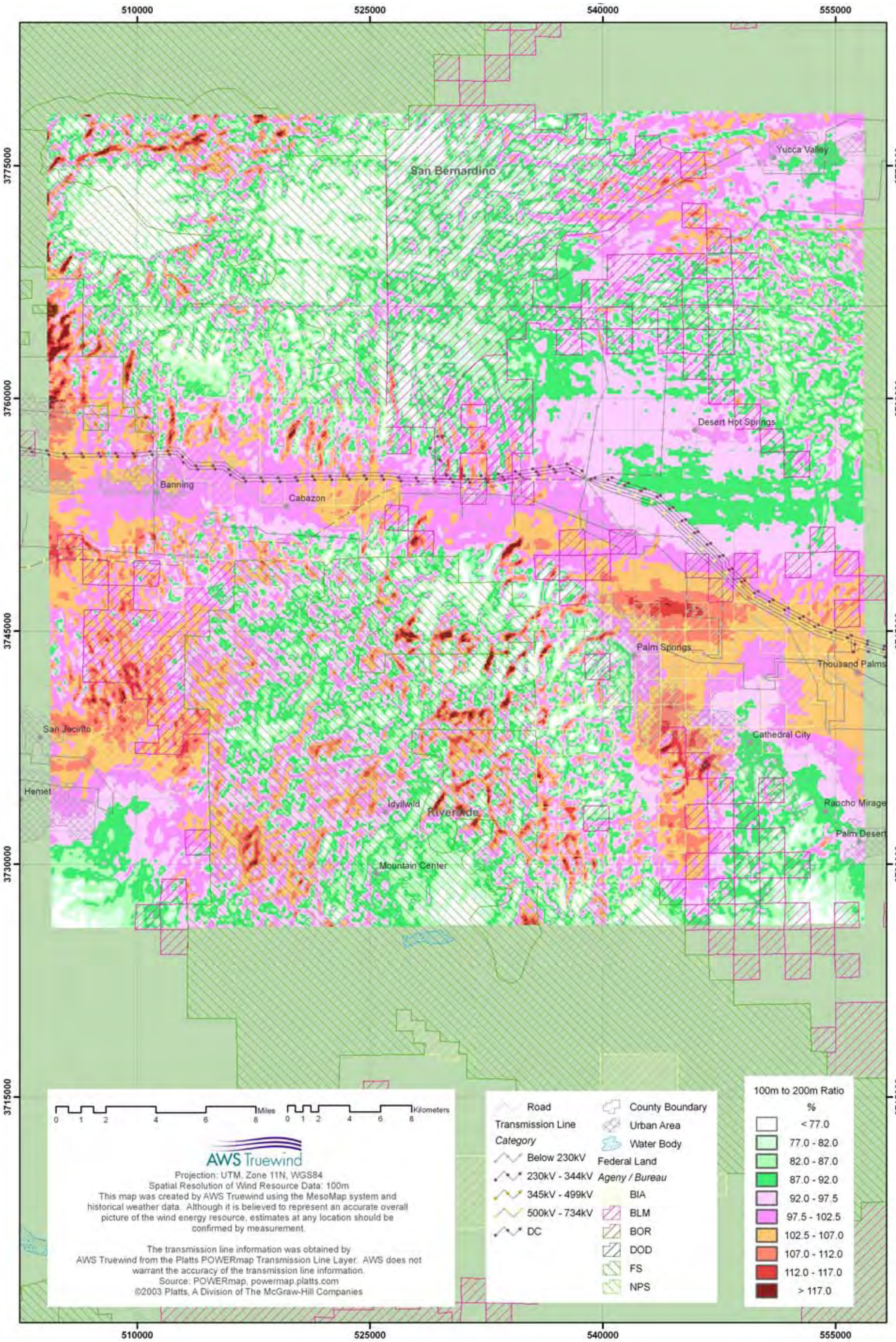

Figure 4: Percent Change in Wind Speed at 50 Meters, Focus Area C – San Gorgonio Pass

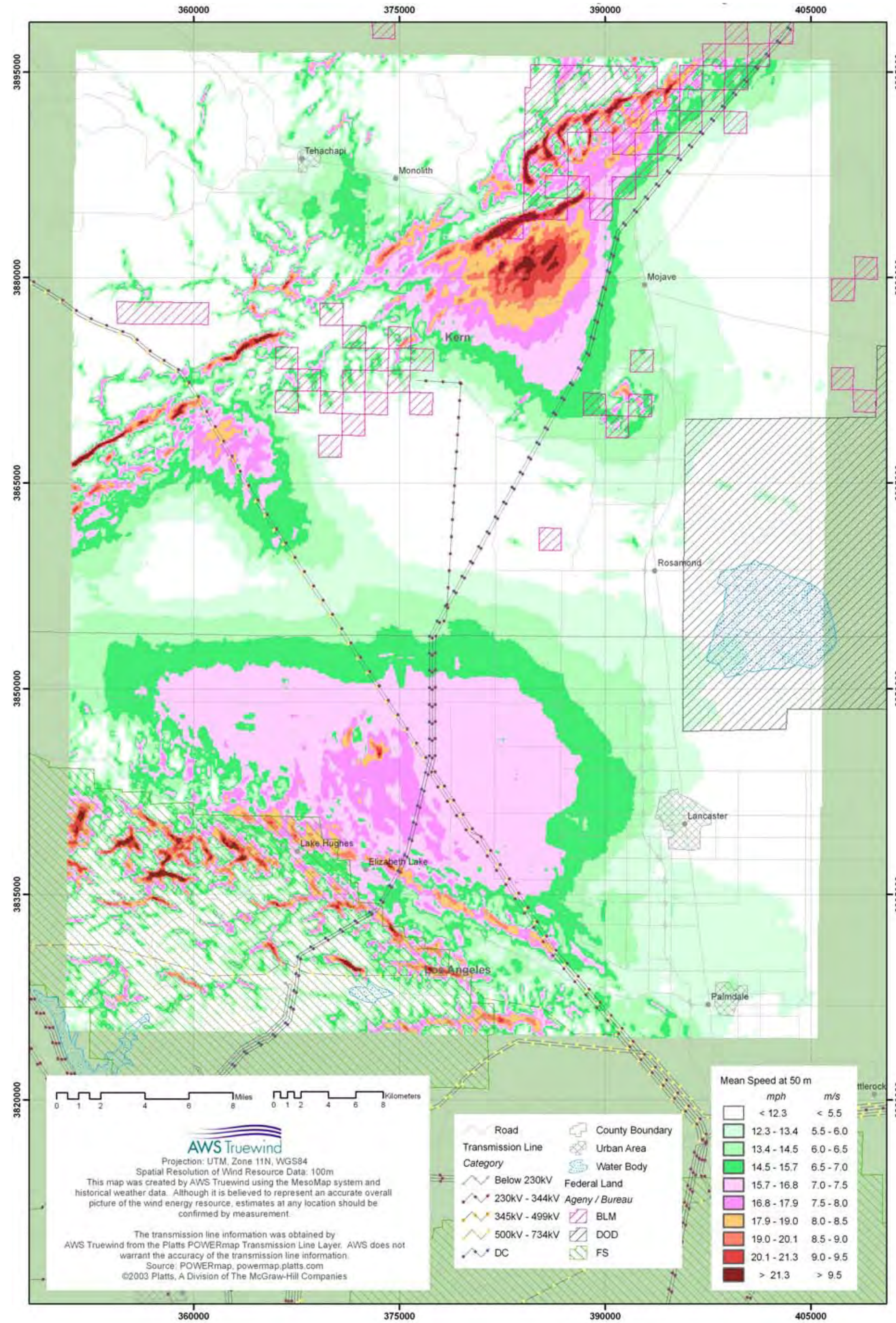

Figure 6: Wind Speed Map at 50 Meters, Focus Area D – Antelope Valley

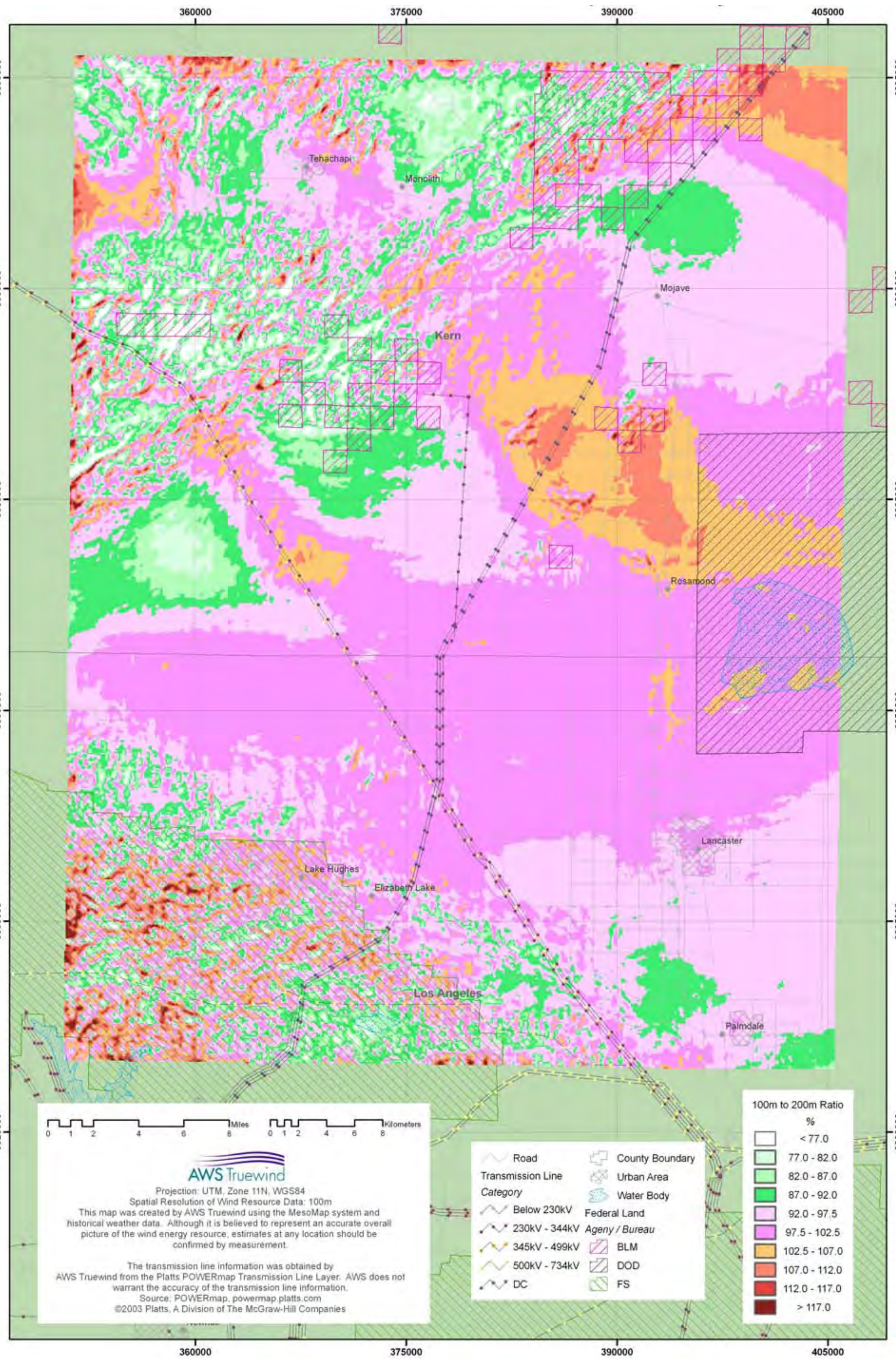

Figure 7: Percent Change in Wind Speed at 50 Meters, Focus Area D – Antelope Valley

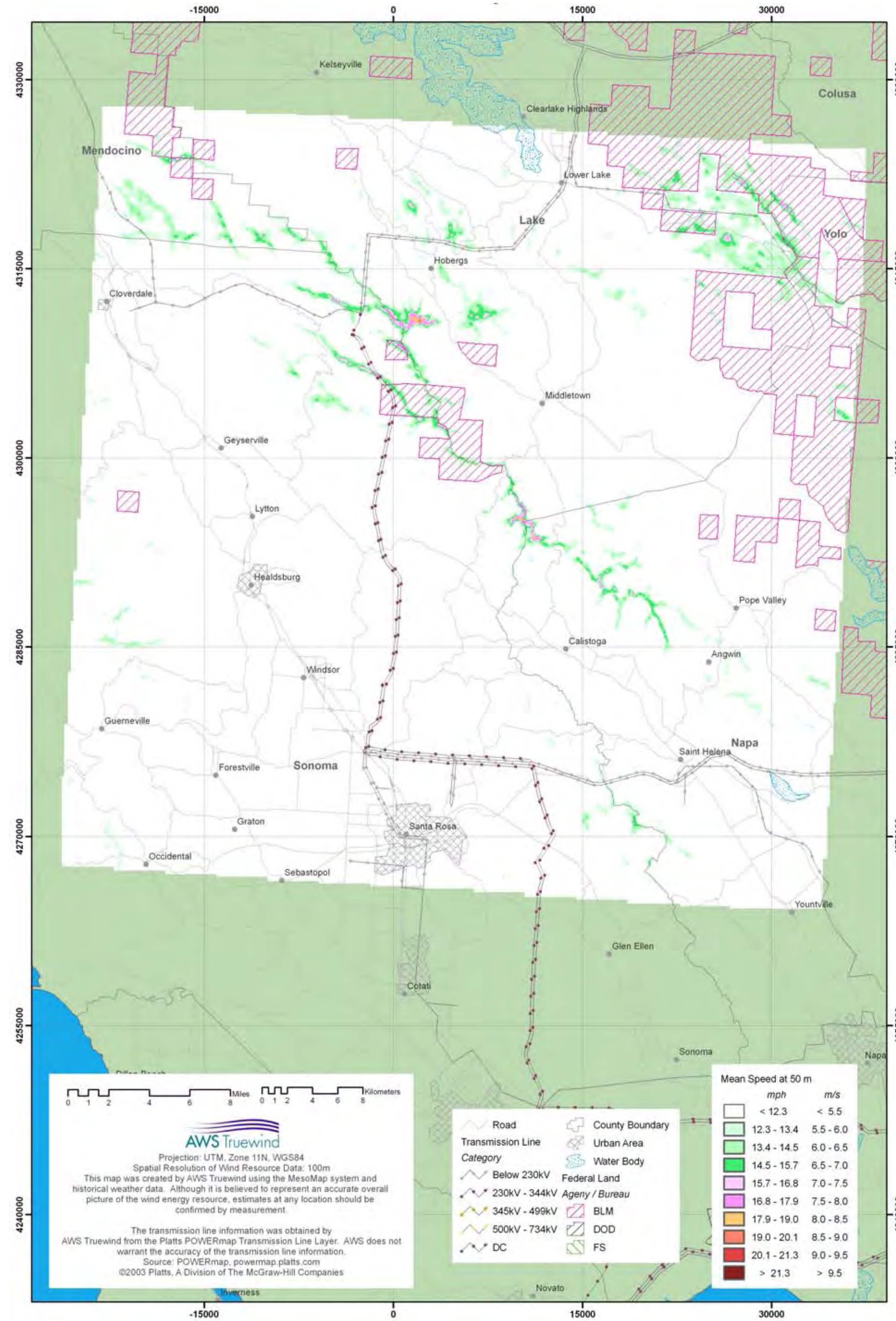

Figure 9: Wind Speed Map at 50 Meters, Focus Area H – Mayacamas Mountains

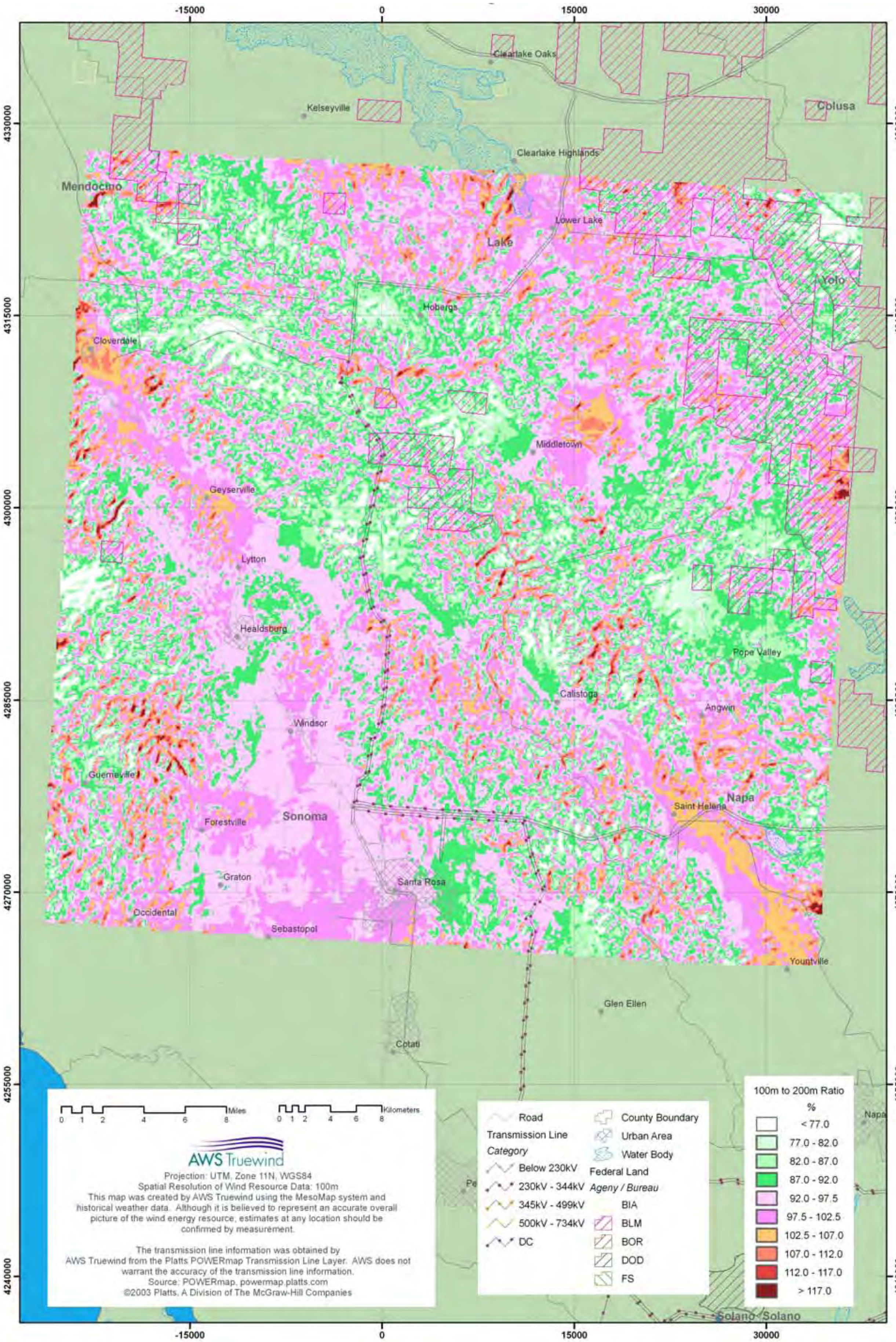

Figure 10: Percent Change in Wind Speed at 50 Meters, Focus Area H – Mayacamas Mountains

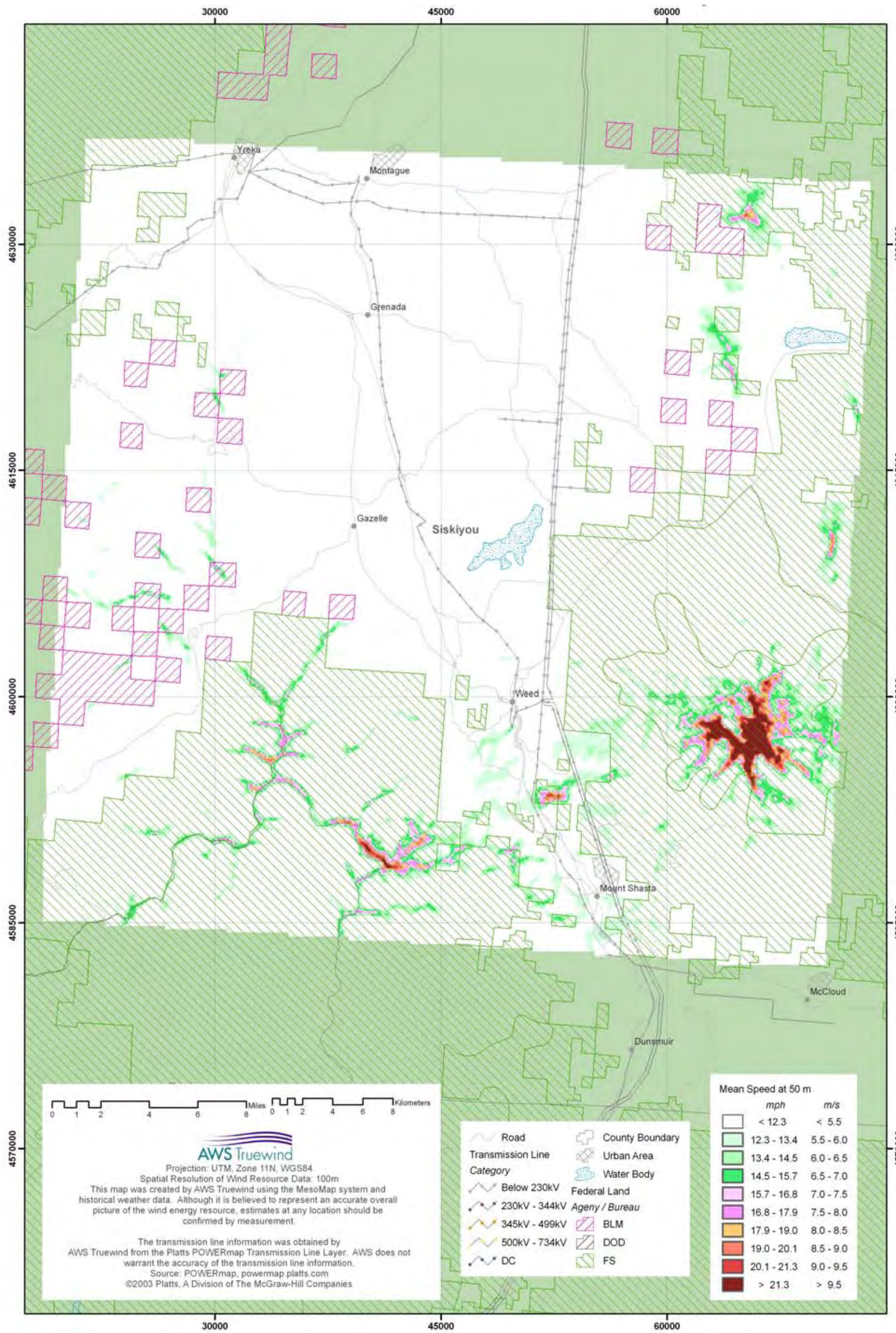

Figure 11: Wind Speed Map at 50 Meters, Focus Area I – Shasta Valley

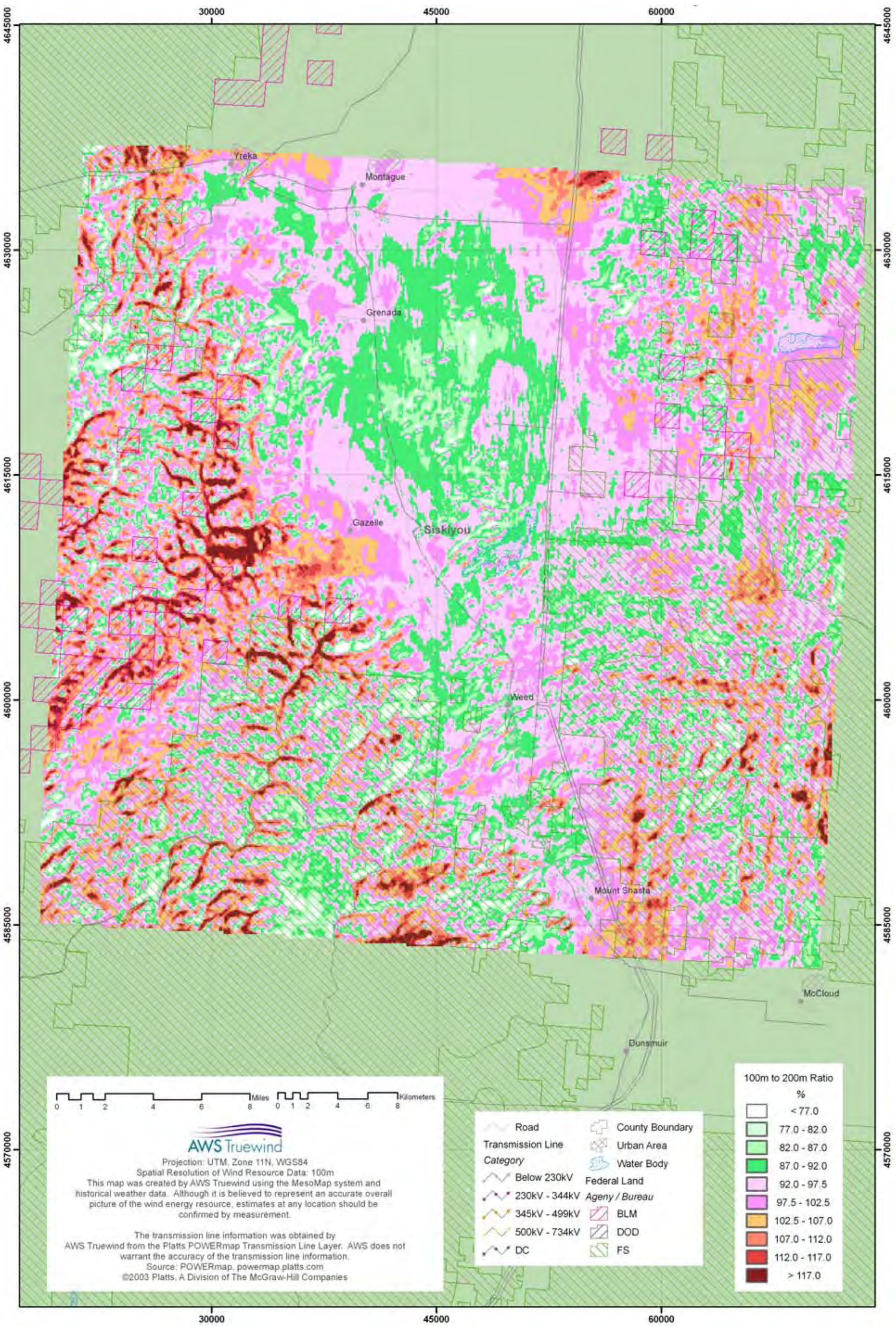

Figure 12: Percent Change in Wind Speed at 50 Meters, Focus Area I – Shasta Valley