Air Pollution Dispersion Modeling for Outdoor Wood Boilers in a Complex Terrain Setting

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Vermont Agency of Natural Resources
Department of Environmental Conservation
Air Pollution Control Division

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This report describes an evaluation of fine particulate matter (PM2.5), impacts from typical outdoor wood boiler settings in Vermont. The effort relies on air dispersion modeling with the Calpuff modeling system to quantify the impacts. The report includes an introductory section outlining the overall goals, then describes production of the meteorological fields used, continues with specifics of the dispersion modeling itself, a discussion about modeling unique to woodsmoke, and then states final conclusions.

Overall Goals in the Outdoor Wood Boiler Modeling Study

Field Inspectors in the Vermont Air Pollution Division (VTAPCD), have noted many instances of high opacity nuisance wood smoke being emitted from outdoor wood boilers. In 1997, regulations were adopted restricting the installation of outdoor wood boilers. In the regulations, current siting criteria state that an outdoor wood boiler be located at least 200 feet from any dwelling, except the owner's. Therefore a necessary goal of this modeling study is to evaluate impacts *beyond 200 feet* from typical outdoor wood boiler locations.

Field Inspectors have noted that outdoor wood boilers are often sited in *valley locations* in Vermont. The steepness and breadth of the valley locations is variable. Because of this fact, another primary goal of this modeling study is to examine the magnitude of impacts for different hyothetical outdoor wood boiler locations in valley settings to better understand and quantify how impacts may vary as a function of the terrain setting. To this end, comparative modeling of impacts has been performed for several different locations in a region near White River Junction, Vermont.

In addressing the two primary goals described above, modeled impacts of PM2.5 will be evaluated by comparison to the recently revised 24 hour and annual PM2.5 national ambient air quality standards (NAAQS). The new standards are 35 ug/m3 for the 24 hour, and 15 ug/m3 for the annual standard.

The Model Domain

In this study the CALPUFF modeling system will be utilized. The CALPUFF modeling system has been proposed by the U.S. EPA as a Guideline Model for source-receptor distances greater than 50 km, and for use on a case-by-case basis in complex flow situations for shorter distances. The CALPUFF system can simulate transport over a spatially varying windfield. It includes option settings that allow it to simulate the physics within the CTSCREEN - type complex terrain model genre, and its own set of regulatory default settings for acceptable usage. The

CALMET Model is used initially in a two-step process to produce the meteorological fields prior to the CALPUFF dispersion calculations.

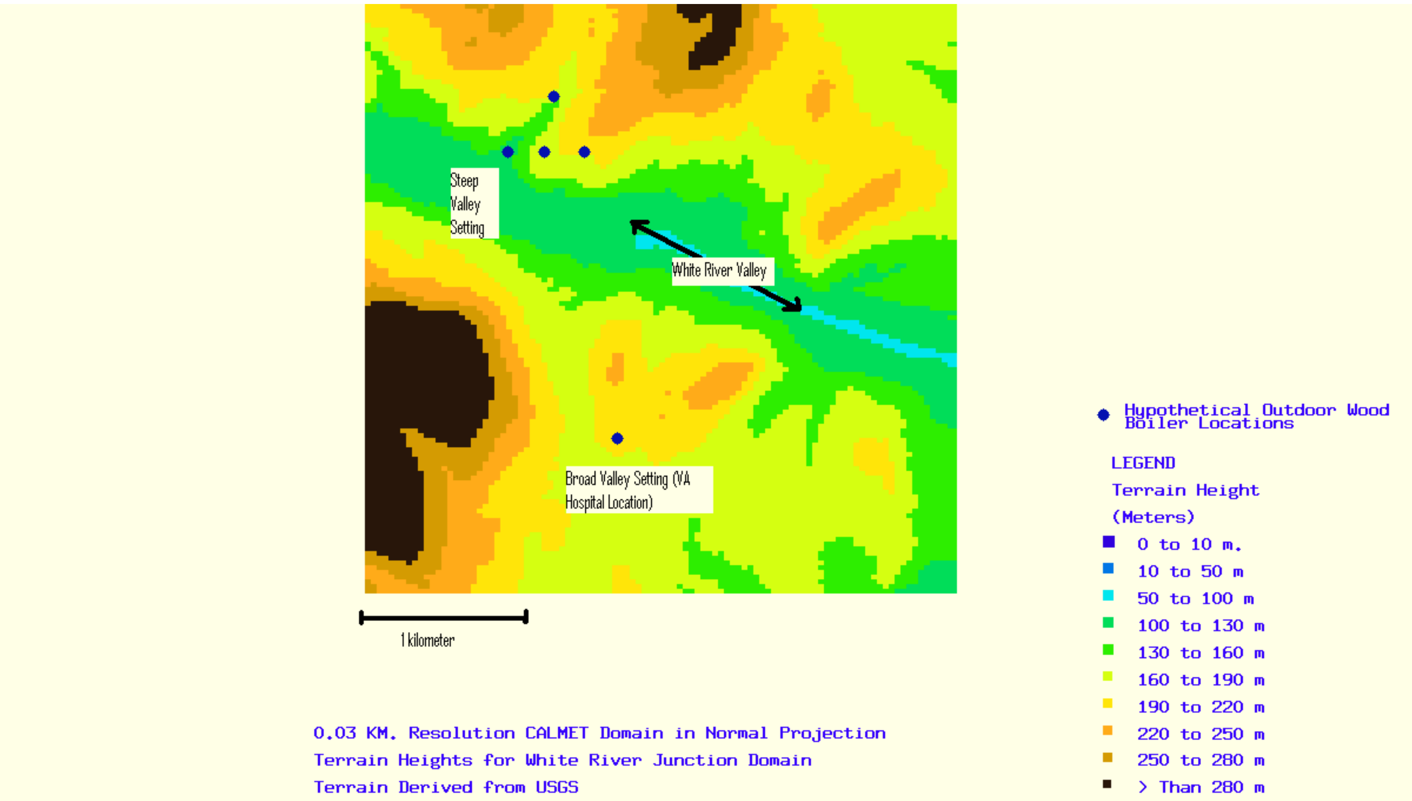
The first step in the outdoor wood boiler study involved establishing the modeled domain. With respect to meteorological field generation, an initial decision must be made regarding the horizontal and vertical resolution sufficient to simulate local-scale effects on surface wind field production. Previous modeling studies with the Calpuff modeling system in Vermont have indicated that a horizontal resolution of 30 meters is sufficient to represent the steeper terrain features around.

As mentioned previously, it has been noted that the majority of the homes in Vermont are sited in valleys imbedded in the mountainous terrain. Valley locations vary from narrow to broad in breadth with varying steepness of slope. To represent the likely variation in impacts for these scenarios modeling was performed for : a) a flat terrain scenario, b) a broad and gentle valley setting, then c), several different locations across a transect of a steeper valley.

The other primary features in the modeling study involved assessing two different scenarios of building downwash : a) for the OWB housing structure, b) for a residential house. The variation between two different stack heights, at 10 and 18 feet in height, was evaluated as well.

Because this modeling effort will involve local scale transport (i.e., transport within the surface layer), inspection of the geographical characteristics of the domain is essential so that the model runs may properly simulate atmospheric flow in the situation at hand. Figure 1) is a graphical depiction of the terrain elevations throughout the modeled domain, and the simulated OWB locations represented.

Figure 1. Terrain Heights for the White River Junction Modeling Domain.



Meteorological Observations Used for the White River Junction, Vermont Domain

Surface

For the domain used in this study surface meteorological data from the Lebanon Valley Airport for the year 1999 was used to ‘drive’ the wind field calculations performed in CALMET. The intent in selection of this observational site was to represent the ‘synoptic scale’ windfield for the general area. In the final step in the wind field production CALMET then adjusts the synoptic scale windfield by application of it’s own internal model physics for finer scale variations resulting from the geographical effects such as land use characteristics and complex terrain occurring over the domain.

Upper Air

For this study the NCEP Model Output – EDAS (ETA), from the National Climatic Data Center (NCDC) was used to represent upper air meteorological characteristics. For this study, involving such minimal transport distances, transport at levels above the surface does not usually occur. However, the upper air data is significant in modeling atmospheric stability.

Regarding validation of this approach, in a previous VTAPCD study, 'Production of Meteorological Fields for Toxics Modeling in Burlington, Vermont', a series of runs examining the wind fields produced at 370 meters elevation with the ETA upper air meteorological fields was then compared to runs using the Albany, NY, upper air meteorological fields to look for differences in the two methods. It was concluded that the CALMET wind fields using the ETA upper air meteorological fields compare favorably to the real wind fields, as determined from a national weather service map, both in direction and speed.

Choosing the Best CALMET Settings for the White River Junction, Vermont Domain

For this modeling exercise, simulating typical outdoor wood boiler locations, there are are many parameter settings in the CALMET model that affect the model's handling of surface terrain effects, especially when the effects of complex terrain are significant.

In the CALMET runs occurring in this study most of the parameter settings (i.e., those not associated with terrain representation in the model physics), were held constant for the runs and set to default mode. For the horizontal scale of this study, 3.6 km by 4.5 km, it was considered appropriate to use only one station as a meteorological observation site. When the CALMET model is applied over an area of highly complex terrain, the linear interpolation of more than one meteorological observation site is only beneficial to gridwide accuracy if synoptic-scale variation is represented by the meteorological observation sites. For the domain size utilized for this study synoptic-scale variation is not significant, so, effectively, a domain-constant windfield was then adjusted for the localized terrain effects.

For other modeling studies performed with the CALPUFF modeling system choice of the best switch settings sensitive to terrain effects has occurred in what has been termed a Progressive model evaluation procedure (PMVP). This procedure involves repetitive comparison of modeled to measured meteorological quantities as CALMET is run iteratively and is utilized to optimize CALMET model performance. Results from these studies, and recommendations in the users guide have dictated the model settings sensitive to terrain effects, such as model settings that affect whether an air parcel will 'wrap' around a terrain feature, or 'lift' over the terrain feature for various combinations of thermal stability, wind speed, and terrain elevation and gradient..

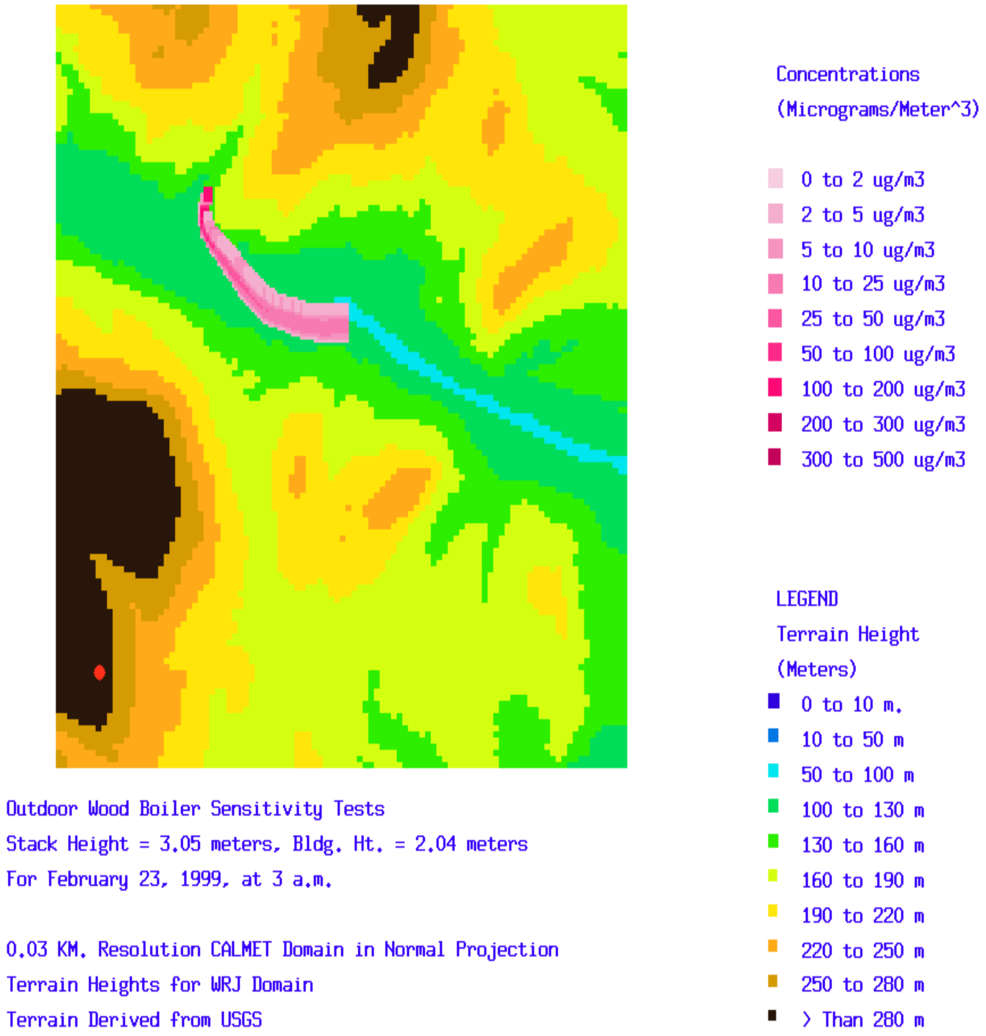
Dispersion Modeling

After the meteorological fields were produced with CALMET, the CALPUFF model was then run to simulate the effects of atmospheric plume dispersion and pollutant transport. To enable comparison to the NAAQS, the postprocessesor CALPOST was run to determine the incidence of violations of the 24 hour PM2.5 standard.

As mentioned previously, generally speaking this study is evaluating the likely impacts from outdoor wood boilers as a result of building downwash effects as well as the orographic effects from a complex terrain setting. Most of the parameter settings in CALPUFF dictating the dispersion estimate methods conform to the regulatory default settings established by the EPA for permit modeling of sources when examining impacts less than 50 kilometers from a source. The receptor grid was defined at a 15 meter resolution in a cartesian grid extending about 200 meters from the source. Deposition losses and other characteristics of particulate matter, such as the effects of settling velocity, were not simulated, after determining their effects were negligible. This will be further discussed in the following section. The building downwash effects are simulated within CALPUFF with what are known as the Schulman-Scire Algorithms which simulate the effects on dispersion from stacks in a directionally specific manner.

The wind fields that CALPUFF relies on to simulate dispersion are produced by the CALMET meteorological preprocessor have been ‘adjusted’ from the local airport observations so that they conform sensibly to terrain features and provide a realistic spatially varying wind field in a complex terrain setting. For instance, airflows approaching a significant terrain feature during thermally stable conditions may be adjusted to ‘wrap’ around the terrain feature, instead of rising over the terrain feature. This adjustment to the wind field is a function of wind speed, thermal stability, and the height and gradient of the terrain feature. This effect on wind fields may elevate impacts, especially for longer term standards (e.g., annual average impacts), because of the persistence of impacts at various receptors resulting from preferred wind flows. Figure 2. illustrates an example of the simulated source impacts when air flows are wrapping around terrain features, as overnight drainage flows travel down the valley axis.

Figure 2. An example of the simulated source impacts when air flows are wrapping around terrain features, as overnight drainage flows travel down the valley axis.



The other primary physical phenomena in complex terrain settings that acts to increase air pollution concentrations at the surface is the direct impact on terrain features that occurs at receptors whose elevation is similar that of the plume rise occurring from the source. This phenomena typically results in the highest modeled hourly impacts. If temporal persistence of this occurrence is sufficient, then it results in highest predicted 24 hour impacts as well.

Woodsmoke Emission Characteristics

Emissions from an outdoor wood boiler have similar characteristics to emissions from other wood combustion. This report focuses on emissions of particulate matter, specifically fine particulate matter – particles less than 2.5 microns in diameter (PM 2.5). EPA has defined 35 ug / m3, as the NAAQS 24 standard threshhold classified as Unhealthy for Sensitive Groups (USG), i.e., for asthmatics and other 'sensitive' groups of the general population.

In this study the PM2.5 emissions from the simulated outdoor wood boiler are modeled as an inert gas. After emission, the fine particulate matter is then dispersed and transported via the wind fields. Because impacts are being evaluated in very close proximity to the emission point, deposition losses and other characteristics of particulate matter, such as the effects of gravitationally induced settling velocity, were not simulated. Field observers with the VTAPCD have noted that in some cases a characteristic of woodsmoke emissions from a house or outdoor wood boiler is for the plume to descend to the ground almost immediately after being emitted in calm conditions. When the air flow is subject to *any* stirring, ie. At a wind speed of 1 mile / hour, the distance that a particle less than 2.5 microns in diameter descends to the surface of the earth is on the order of a few centimeters for a transport distance of 200 meters. Woodsmoke particles serve as *condensation nuclei* for water vapor in the atmosphere. It is possible that condensation may play a significant role in promoting the initial plume descent during humid, calm conditions so often occurring in valley settings in Vermont (especially overnight and early morning). It is also possible that this phenomenom results from building downwash effects under nearly calm conditions which significantly alter the vertical wind flows, such as air flows containing emissions from a wood stove 'sliding down', the lee side of a 45 degree angled roof. This particular example of downwash phenomena, is beyond the scope of the modeling effort herein. However, this is not as likely a scenario for an outdoor wood boiler setting, because the units are typically located some distance away from a residence. The plume descent effect, if it does occur, may be significant in very close proximity to the emission point, eg. within 25 meters, but this study is focused on a demonstration of impacts beyond 200 feet.

Another phenomenom which may act to bring woodsmoke to the surface from a slightly elevated emission point is downslope flow, either along the axis of a valley floor, or as a 'tributary' flow approaching the valley floor on a side slope. The wood smoke is transported downslope overnight and in the early morning under a downslope flow regime. As it reaches the valley floor, where the slope levels off, woodsmoke that has been transported at its initial plume rise elevation may effectively descend to the surface. This phenomena <u>is</u> simulated in the study.

Emission Parameters

Below is a listing of the stack parameters used in the modeling effort for various scenarios that will be compared later in the report :

Stack Height : 10 feet, 18 feet.
Stack Diameter : 0.1524 Meters
Exit Velocity : 1.05 meters/second
Exit Temperature : 419 degrees Kelvin
Building Downwash was simulated from : the OWB housing, and a residential home.

Emission Rates : Two sets of emission rates were used to produce predicted ambient impacts for the most realistic emission scenarios occurring for units purchased at this time and, if further regulations are adopted, for units purchased after April 1, 2010, (tentative date). They are termed Phase I , which refers to representative emission rates for OWB's purchased after March 31, 2008, and Phase II, which refers to representative emission rates for OWB's which may be required after April 1, 2010.

Because the VTAPCD regulations are specified in units of heat input and heat output rating values respectively for the phase I and Phase II emissions, the emission rates utilized in Calpuff for this modeling demonstration were taken from an average of 2 sets of emissions tests for outdoor wood boilers which meet the phase I. and phase II. requirements. From the emission tests, emission rates were calculated for a weighted annual average and highest individual test run emission rate quantities. Therefore, in Calpuff, to represent a realistic diurnal variation in the emission rates, the highest individual test run emission rate was represented as occurring for two hours in the morning (6-8 am), and the evening (5-7 pm), which generally correspond to maximum usage times for an outdoor wood boiler at a residence. For the remaining 20 hours of the day the annual average emission rates from the test runs were used.

Table 1. Phase I. and Phase II. Emission rates.

	Phase I. regulatory requirement (MMBTU/HR)	Average emission rate for model evaluation (grams/hour)	Peak usage emission rate for model evaluation (grams/hour)
Phase I.	0.44 (heat input rating)	21.1	34.1
Phase II.	0.32 (heat output rating)	7.4	17.81

Discussion / Results

To ensure that the modeling results were reasonable for a given location several different sites were modeled in areas within valleys ranging from ‘steep’ to ‘gentle’ in elevational gradient and breadth. Results were also compared to those in flat terrain, with the modeling identical in all other respects. In the steep valley location, impacts were modeled at the valley floor, on the valley slope, and at the ridgeline above the valley.

Table 2. is a comparison of predicted impacts using a unit emission rate (1 gram/hour), for all the complex terrain scenarios and a flat terrain scenario. Note that the values in Table 2. are *for intercomparison only*. Note that within 80 meters of the source location, the general effect of complex terrain is to increase predicted impacts. The very highest impacts occur at the valley floor locations very near the OWB location.

Because the results in table 2. are produced using a unit emission rate, the reader may multiply an emission rate in grams/hour that they wish to calculate predicted impacts for by the values in table 2.

Table 2.Maximum 2nd Ranked 24 hr avg (ug/M3) PM2.5 Concentration Predictions using a 1g-hr emi. rate – For a 10 foot stack height, downwash effects from OWB housing

Distance (meters) – for all directions of the compass.	24 hr avg (ug/M3) – Flat Terrain	Broad Valley Setting (Veteran’s Home)	Steep Valley – Valley Floor	Steep Valley – On Valley Slope	Steep Valley – Ridgeline	Steep Valley – Valley Floor at Notch
0-25 m	1.5	1.9	6.0	4.8	3.6	6.0
25-60 m	1.7	3.7	4.8	3.2	4.8	4.9
60-80 m	1.8	2.3	2.2	1.7	2.1	2.3
80 – 100 m	1.2	1.7	1.4	1.1	1.2	1.5
100 –120m	1.0	1.1	1.2	1.2	0.9	1.1
120 –140m	0.6	0.5	0.5	0.7	0.5	0.9
140 –160m	0.3	0.2	0.5	0.4	0.1	0.4

Tables 3. summarizes the results of the study using the Phase I. emission rates.
Note that background value for PM2.5 has not been added to these values. In addition, this exercise models impacts from individual units whereas, in reality, impacts may occur from multiple sources in many locations. Note that beyond 100 meters there are no predicted exceedances of the 24 hour PM2.5 standard of 35 ug/m3. Note that within 80 meters of the source location, the general effect of complex terrain is to increase predicted impacts. The very highest impacts occur at the valley floor locations very near the OWB location.

Table 3 .Maximum 2nd Ranked 24 hr avg (ug/M3) PM2.5 Concentration Predictions using Phase I.Emission Rates – For a 10 foot stack height, downwash effects from OWB housing. Exceedances of the 35 ug/m3 PM2.5 standard are indicated in bold print.

Distance (meters) – for all directions of the compass.	Broad Valley Setting (Veteran's Home)	Steep Valley – Valley Floor	Steep Valley – On Valley Slope	Steep Valley – Ridgeline	Steep Valley – Valley Floor at Notch
0-25 m	**49**	**150**	**106**	**90**	**134**
25-60 m	**86**	**114**	**80**	**115**	**120**
60-80 m	**53**	**53**	**41**	**50**	**54**
80 – 100 m	**39**	34	26	28	**37**
100 – 120 m	26	26	29	23	31
120 – 140 m	10	16	16	11	21
140 – 160 m	5	14	9	2	9

Table 4. summarizes the results of the study using the Phase II. emission rates.
Note that background value for PM2.5 has not been added to these values. In addition, this exercise models impacts from individual units whereas, in reality, impacts may occur from multiple sources in many locations. Note that beyond 60 meters there are no predicted exceedances of the 24 hour PM2.5 standard of 35 ug/m3. The variation of predicted impacts throughout different complex terrain settings is similar to results for the Phase I. modeling.

Table 4 .Maximum 2nd Ranked 24 hr avg (ug/M3) PM2.5 Concentration Predictions using Phase II.Emission Rates – For a 10 foot stack height, downwash effects from OWB housing. Exceedances of the 35 ug/m3 PM2.5 standard are indicated in bold print.

Distance (meters) – for all directions of the compass.	Broad Valley Setting (Veteran's Home)	Steep Valley – Valley Floor	Steep Valley – On Valley Slope	Steep Valley – Ridgeline	Steep Valley – Valley Floor at Notch
0-25 m	21	**63**	**46**	**37**	**53**
25-60 m	33	**46**	**38**	**45**	**49**
60-80 m	21	21	17	20	21
80 – 100 m	15	15	10	11	16
100 –120m	10	11	11	10	14
120 –140m	4	6	6	4	8
140 –160m	2	6	4	1	4

Table 5. is a comparison of relative impacts for a) an 18 foot stack height, b) building downwash from a typical residential home with a 10 foot stack height, and c) building downwash from the OWB housing with a 10 foot stack height. Note that for all the other simulations in this modeling study, the 10 foot stack height and building downwash from the OWB housing were used. The downwash algorithm used in this study assesses impacts in a directionally dependent manner and the incidence of building downwash is triggered by a plume rise height lower than the GEP stack height. The GEP stack height is calculated as a function of building height and width dimensions. The orientation and distance from the simulated source location is not specified in this approach. The comparison was performed for an outdoor wood boiler located on a valley floor.

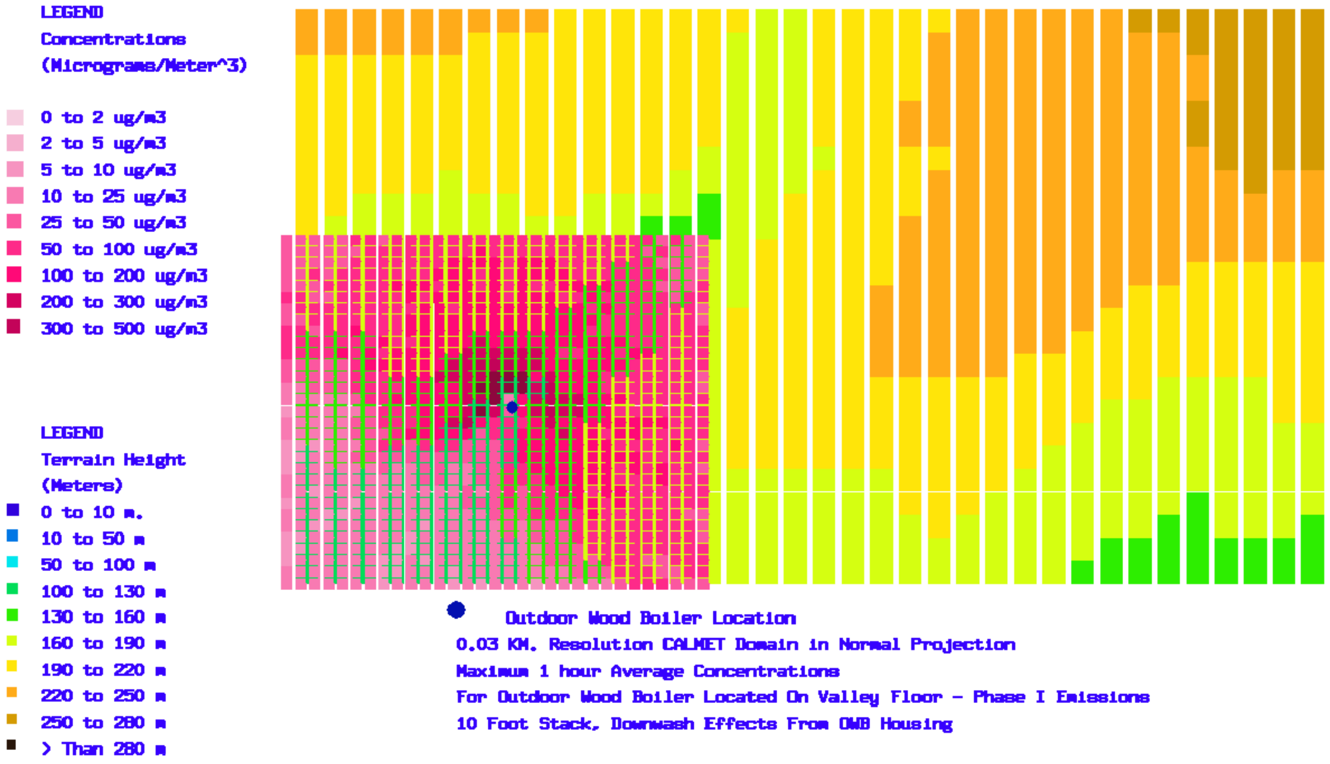
Table 5.Maximum 2nd Ranked 24 hr avg (ug/M3) PM2.5 Concentration Predictions using a 1 g-hr emission rate. For Varying stack heights and building downwash structures. For an outdoor wood boiler located on a valley floor.

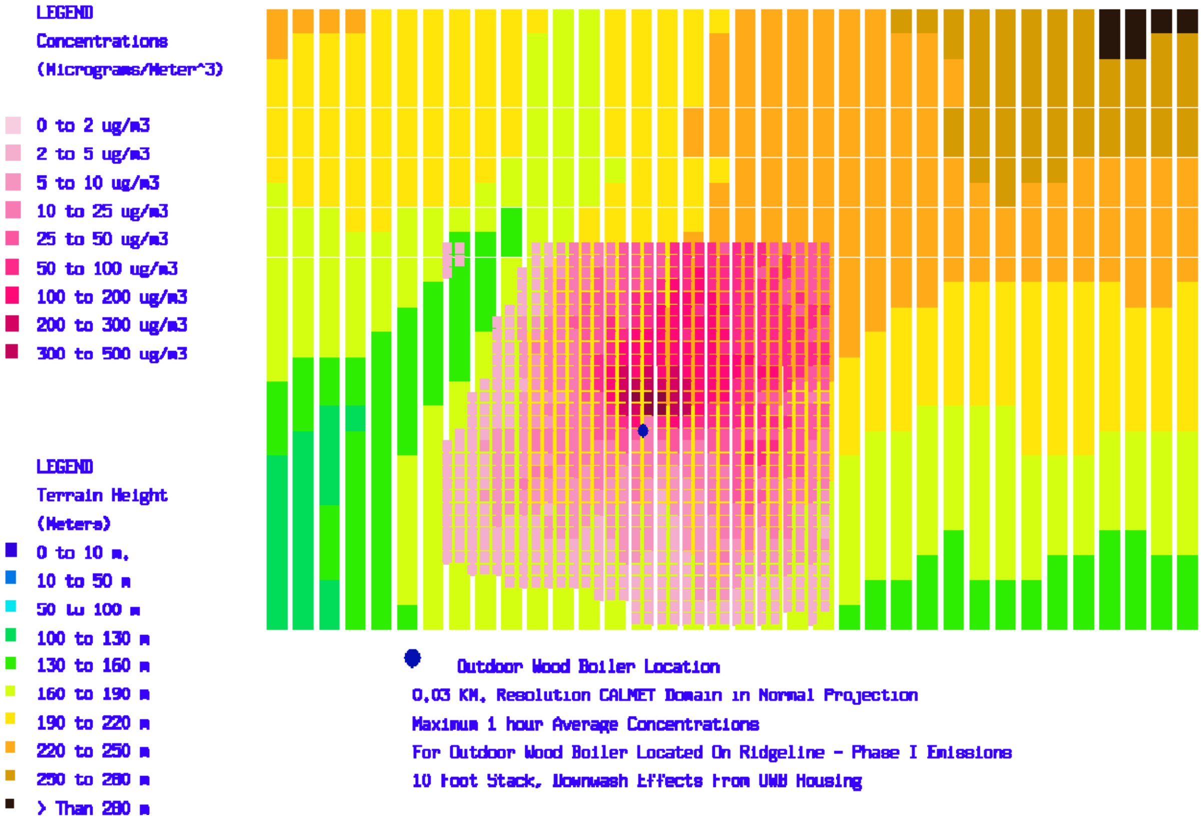
Distance (meters) – for all directions of the compass.	18 ft stack; building downwash from OWB Housing	10 ft. stack; building downwash from a residential home	10 ft stack; building downwash from OWB Housing
0-25 m	1	9.8	6.0
25-60 m	2.5	4.1	4.8
60-80 m	1.8	2.2	2.2
80 – 100 m	1.2	1.4	1.4
100 – 120 m	1.1	1.2	1.2
120 – 140 m	0.5	0.6	0.5
140 - 160	0.4	0.5	0.5

Note that the higher stack height greatly reduces impacts within 60 meters. The highest impacts in this comparison occur within 25 meters with building downwash simulated from a residential home.

Figures 3. and 4. are plots of the maximum one hour average PM2.5 concentrations for a simulated outdoor wood boiler located on a valley floor and on a ridgeline using the Phase I. emission rates. See the appendicies of this report for similar plots using the Phase II. emission rates.

Figures 3. and 4.: plots of the maximum one hour average PM2.5 concentrations for a simulated outdoor wood boiler located on a valley floor and on a ridgeline using the Phase I. emission rates. For the Background terrain elevations each plotted grid square represents a 30 meter square land area. For the superimposed PM2.5 concentrations, each plotted grid square is a 15 meter square area.



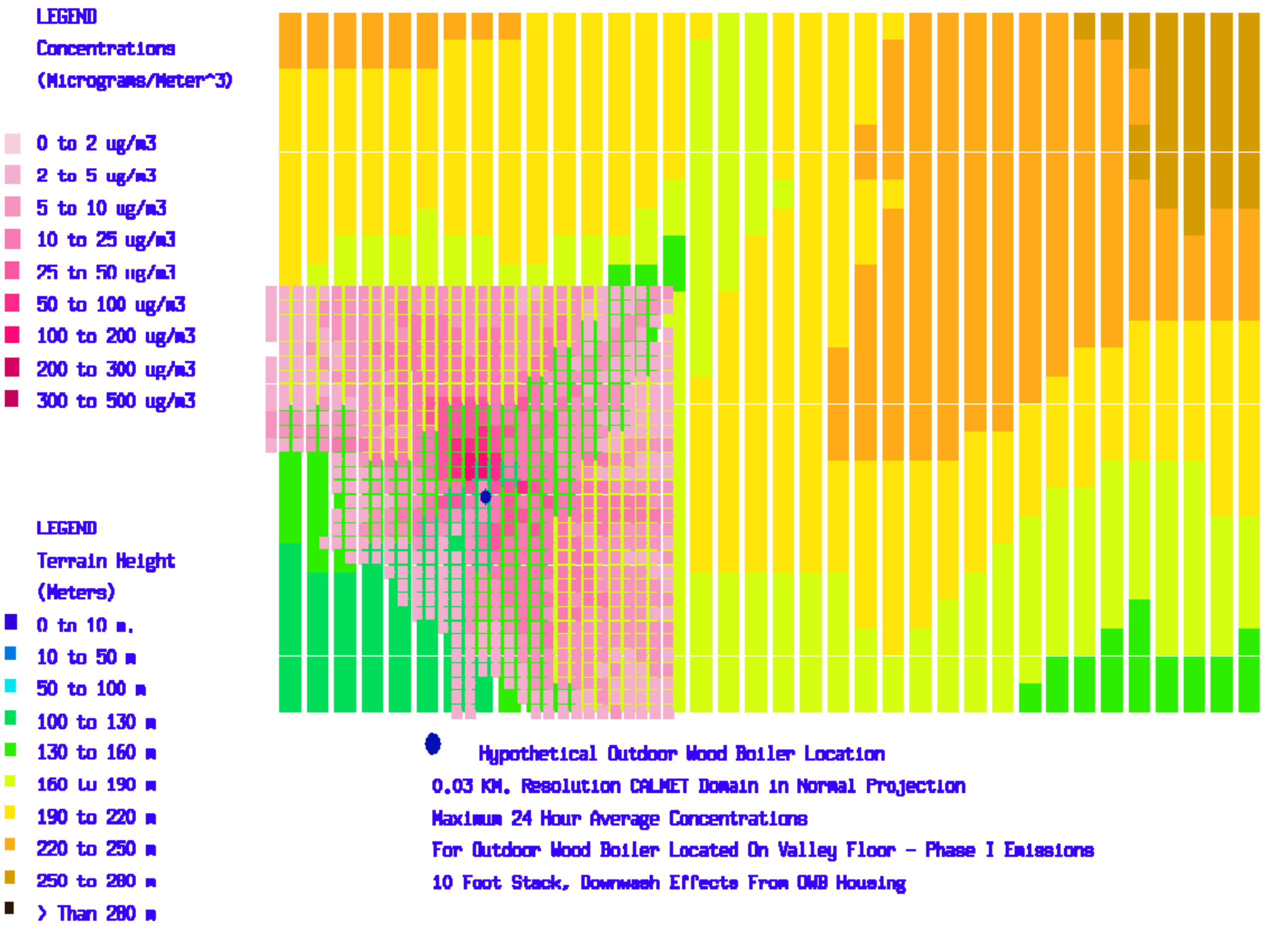


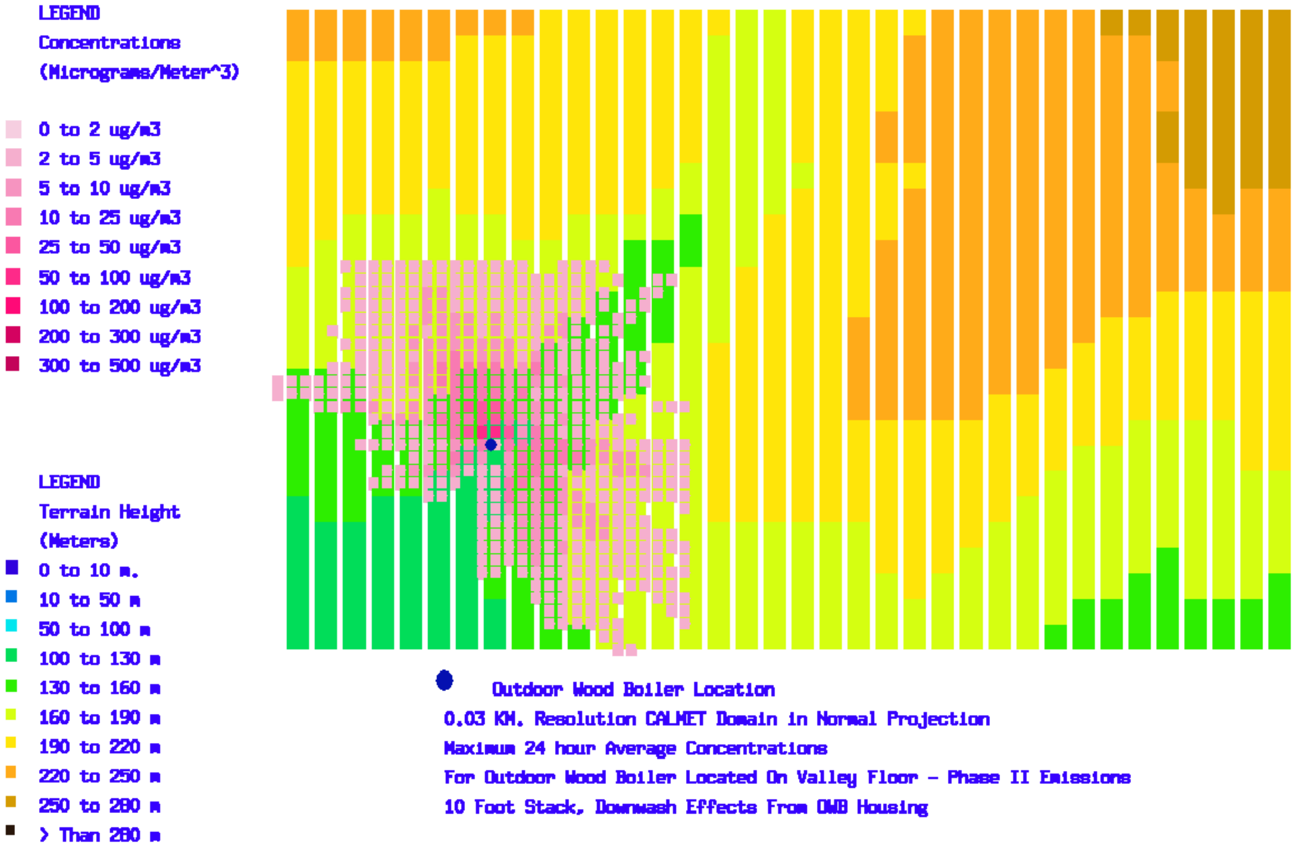
0.03 KM. Resolution CALMET Domain in Normal Projection
Maximum 1 hour Average Concentrations
For Outdoor Wood Boiler Located On Ridgeline - Phase I Emissions
10 Foot Stack, Downwash Effects From UWB Housing

For comparison, Figures 5. and 6. are plots of the maximum 24 hour average PM2.5 concentrations for a simulated outdoor wood boiler located on a valley floor using the Phase I. emission rates and Phase II. emission rates. Note that with the Phase II. emission rate, no exceedances of the 24 hours standard occur beyond 200 feet (recall that this is *without* adding background concentrations). The appendices of this report also include figures where the number of exceedances of the 24 hour standard is plotted in association with terrain elevations with numbers instead of color shading.

Examination of several days with the highest 24 hour averages reveals that a strong directional persistence in wind flow was associated with maximum 24 hour average values. For the steep valley settings modeled, where the valley opens southwards with elevated terrain immediately to the north, the persistent wind direction must have a southerly component. The thermal stability must range from stable to neutral. These atmospheric conditions were usually associated with the approach of a synoptic scale storm system to New England, where winds held for 12 hours or more from the southeast. In examination of figures 3. and 4. it appears that the most important factor for violation of the 24 hour standard is the *distance* from the simulated source location that terrain ascends to plume rise elevation, moreso than the surrounding complex terrain setting for a simulated source location. For maximum 24 hour impacts on elevated terrain near the simulated source location in any direction of the compass it is likely that over the course of a year high impacts will be observed at that location over the range of possible combinations of wind speed and stability affecting plume dispersion. While a valley location may act to increase the incidence of flow along the valley axis for stable conditions, it is apparent that these stable flow conditions actually reduce the incidence of direct impact on the nearby terrain features, so predicted short term impacts along the valley floor are usually lower.

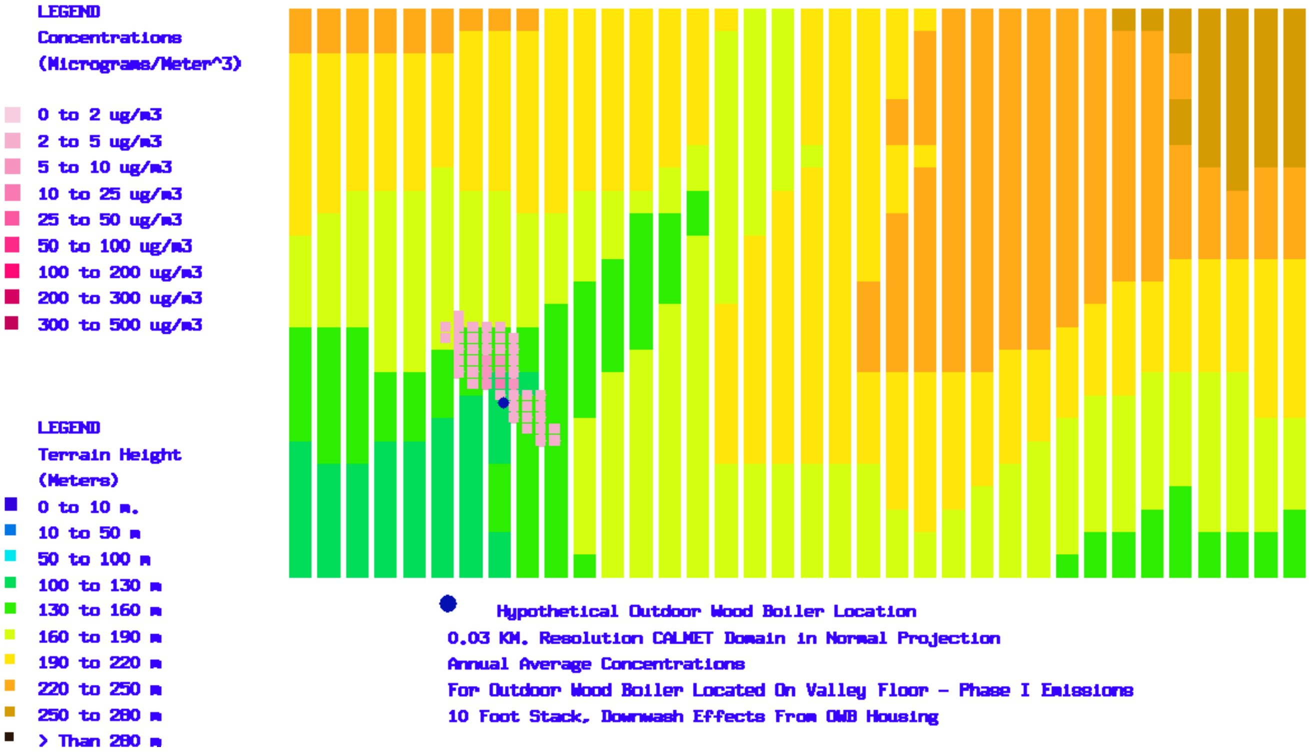
Figures 5. and 6. : The maximum 24 hour average PM2.5 concentrations for a simulated outdoor wood boiler located on a valley floor using the Phase I. emission rates and Phase II. emission rates. For the Background terrain elevations each plotted grid square represents a 30 meter square land area. For the superimposed PM2.5 concentrations, each plotted grid square is a 15 meter square area.

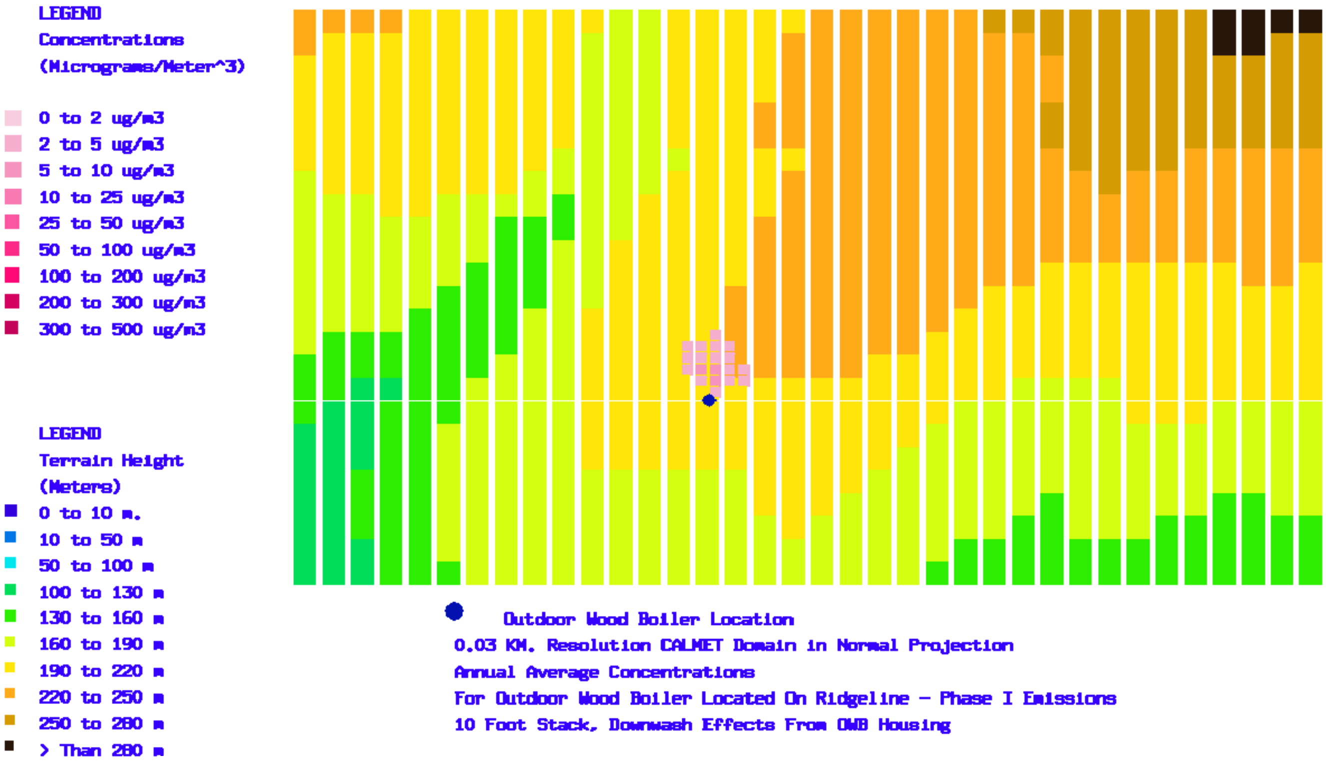




Figures 7. and 8. are plots of the annual average PM2.5 impacts in proximity to a simulated outdoor wood boiler located on a valley floor and on a ridgeline using the Phase I. emission rates. See the appendicies of this report for similar plots using the Phase II. emission rates. The appendicies of this report also include figures in which the annual average PM2.5 impacts is plotted in association with terrain elevations with numbers instead of color shading.

Figures 7. and 8. : The annual average PM2.5 concentrations for a simulated outdoor wood boiler located on a valley floor and on a ridgeline using the Phase I. emission rates. For the Background terrain elevations each plotted grid square represents a 30 meter square land area. For the superimposed PM2.5 concentrations, each plotted grid square is a 15 meter square area.





0.03 KM. Resolution CALMET Domain in Normal Projection
Annual Average Concentrations
For Outdoor Wood Boiler Located On Ridgeline - Phase I Emissions
10 Foot Stack, Downwash Effects From OWB Housing

Conclusions

In conclusion, based on this modeling exercise, the theoretical emissions of PM2.5 occurring with the proposed future Phase II. standard for outdoor wood boilers are sufficient to reduce ambient impacts to values less than the current 24 hour PM2.5 standard of 35 ug/m3 beyond 200 feet from the outdoor wood boiler location for most complex terrain settings. Note that this conclusion does not include background concentrations in its estimate. Beyond 200 feet, for most of the simulated outdoor wood boiler locations, the effect of complex terrain is to increase the impacts up to 30 percent above those for a flat terrain setting. Raising the stack from 10 to 18 feet reduces impacts about 20 percent beyond 200 feet. Within 200 feet, The frequency of the number of exceedances of the 24 hour standard annually can be as high as 50 days of the year on elevated terrain very near the source with the Phase I. emission rates, and 10 days of the year for the Phase II. emission rates.

Appendix 1). -

Figures 1.: plot of the maximum one hour average PM2.5 concentrations for a simulated outdoor wood boiler located on a valley floor using the Phase II. emission rates. For the Background terrain elevations each plotted grid square represents a 30 meter square land area. For the superimposed PM2.5 concentrations, each plotted grid square is a 15 meter square area.

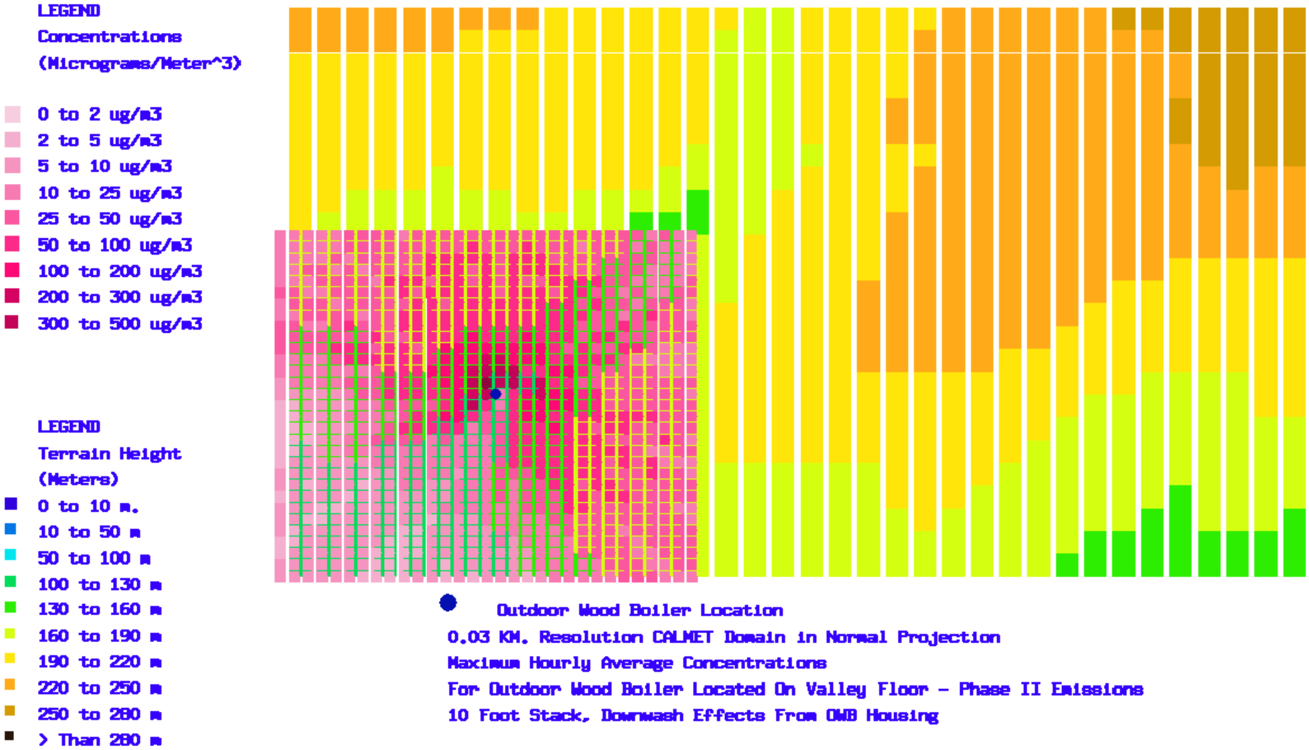
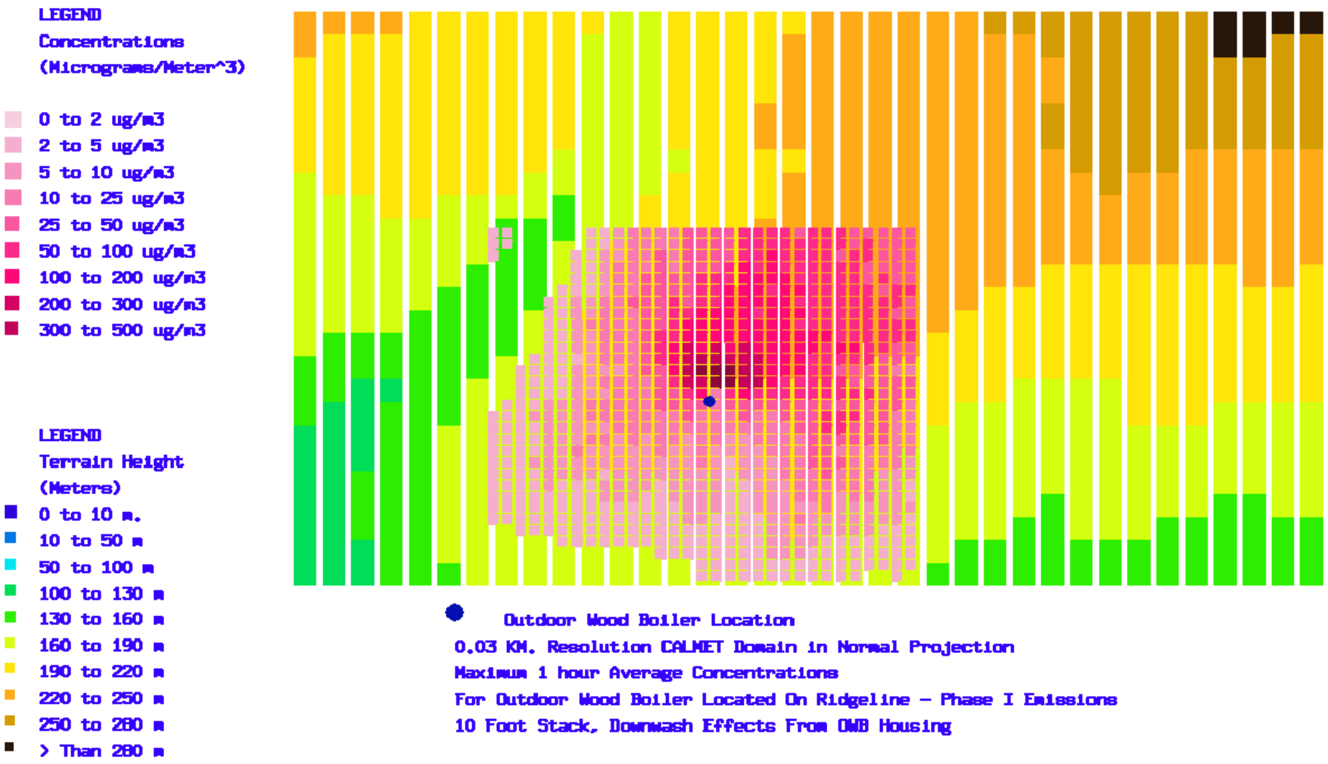
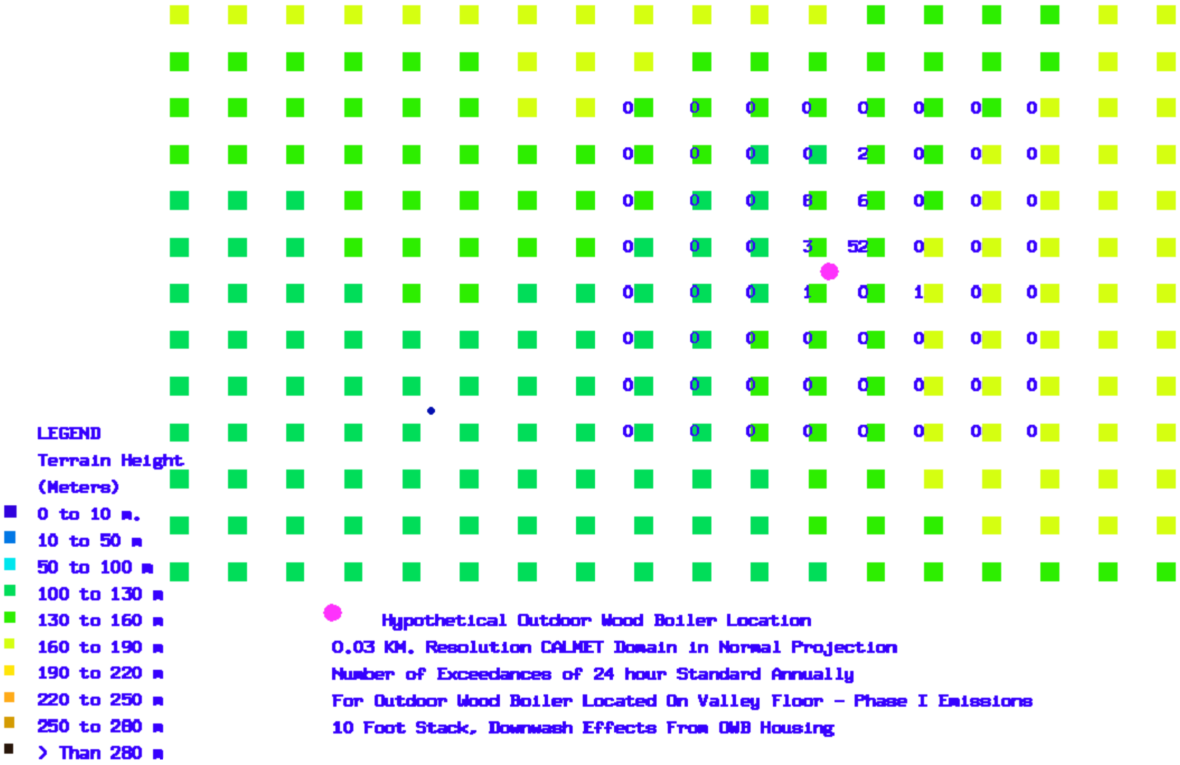
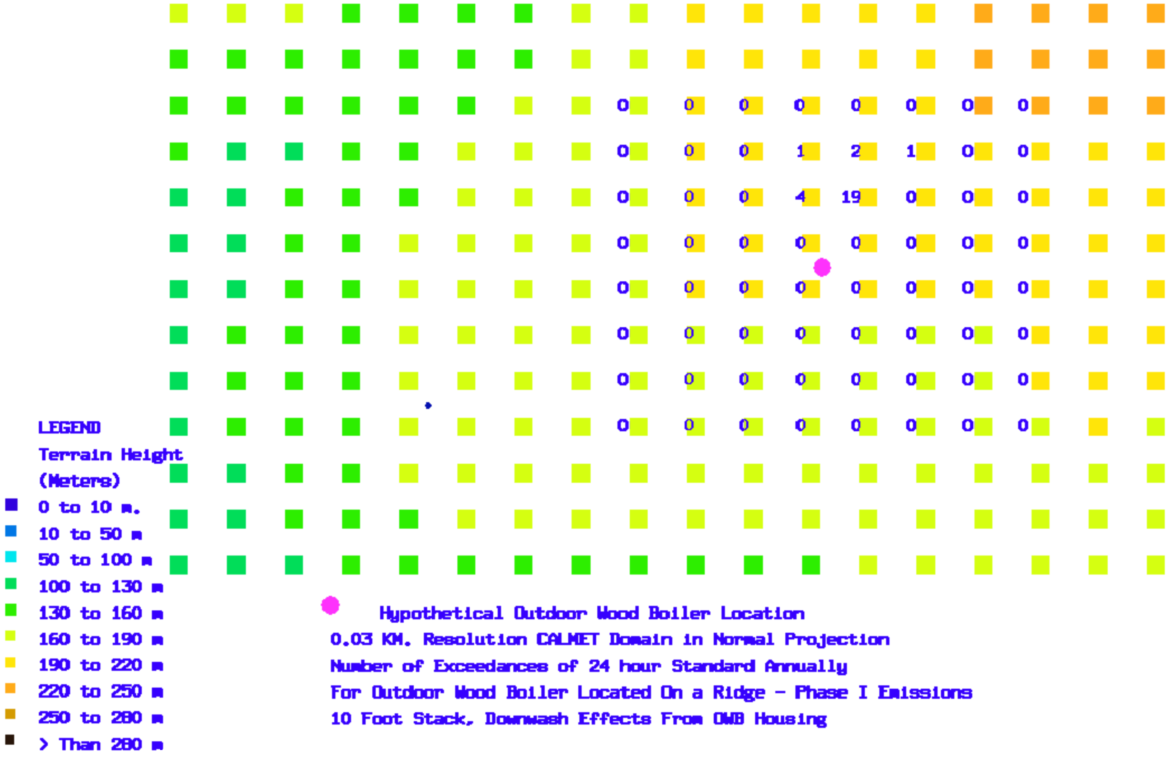


Figure 2.: plot of the maximum 24 hour average PM2.5 concentrations for a simulated outdoor wood boiler located on a ridgelin using the Phase I. emission rates. For the Background terrain elevations each plotted grid square represents a 30 meter square land area. For the superimposed PM2.5 concentrations, each plotted grid square is a 15 meter square area.

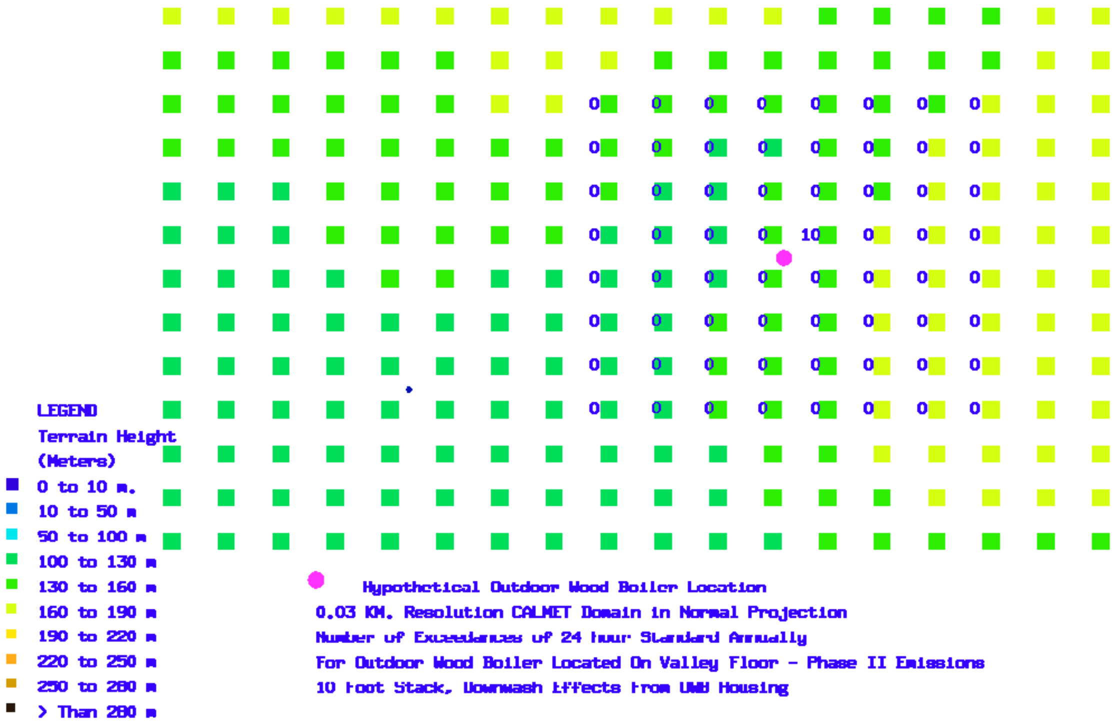


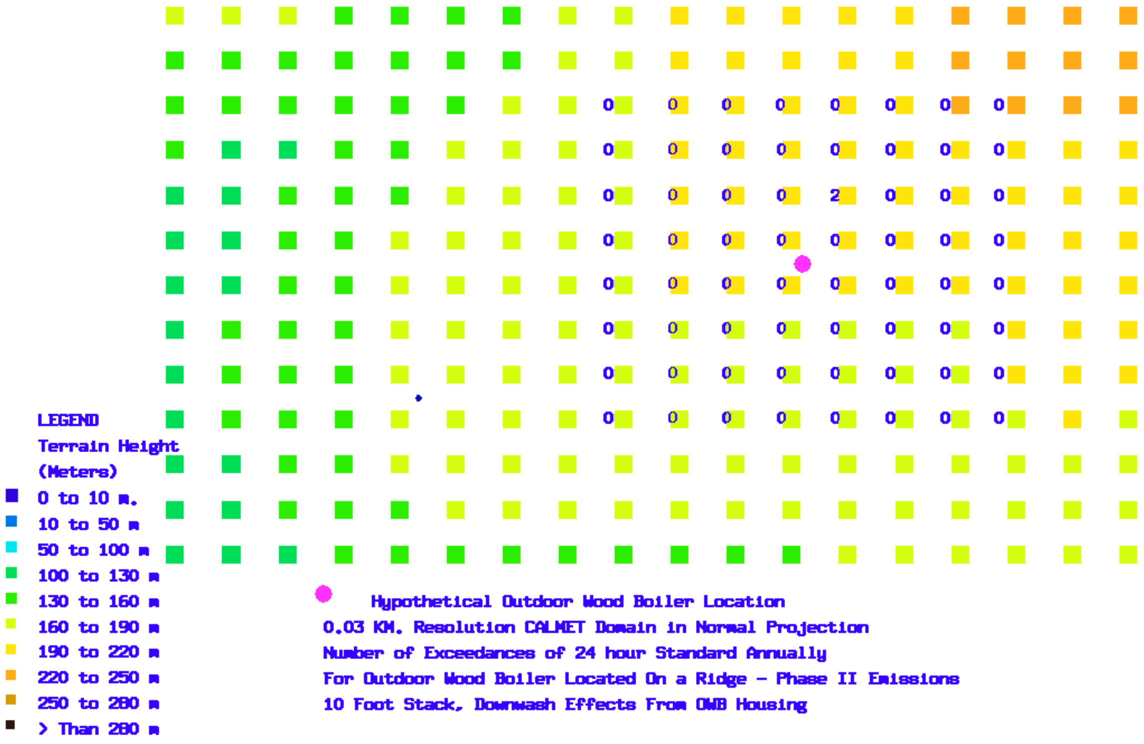
Figures 3. and 4. : The number of exceedances of the maximum 24 hour average PM2.5 concentration (35 ug/m3), for a simulated outdoor wood boiler located on a valley floor and on a ridgeline using the Phase I. emission rates. For the Background terrain elevations each plotted grid square represents a 30 meter square land area. The PM2.5 concentrations are also plotted at 30 meter resolution.




LEGEND
Terrain Height
(Meters)
0 to 10 m.
10 to 50 m
50 to 100 m
100 to 130 m
130 to 160 m
160 to 190 m
190 to 220 m
220 to 250 m
250 to 280 m
> Than 280 m
Hypothetical Outdoor Wood Boiler Location
0.03 KM. Resolution CALMET Domain in Normal Projection
Number of Exceedances of 24 hour Standard Annually
For Outdoor Wood Boiler Located On a Ridge - Phase I Emissions
10 Foot Stack, Downwash Effects From OWB Housing

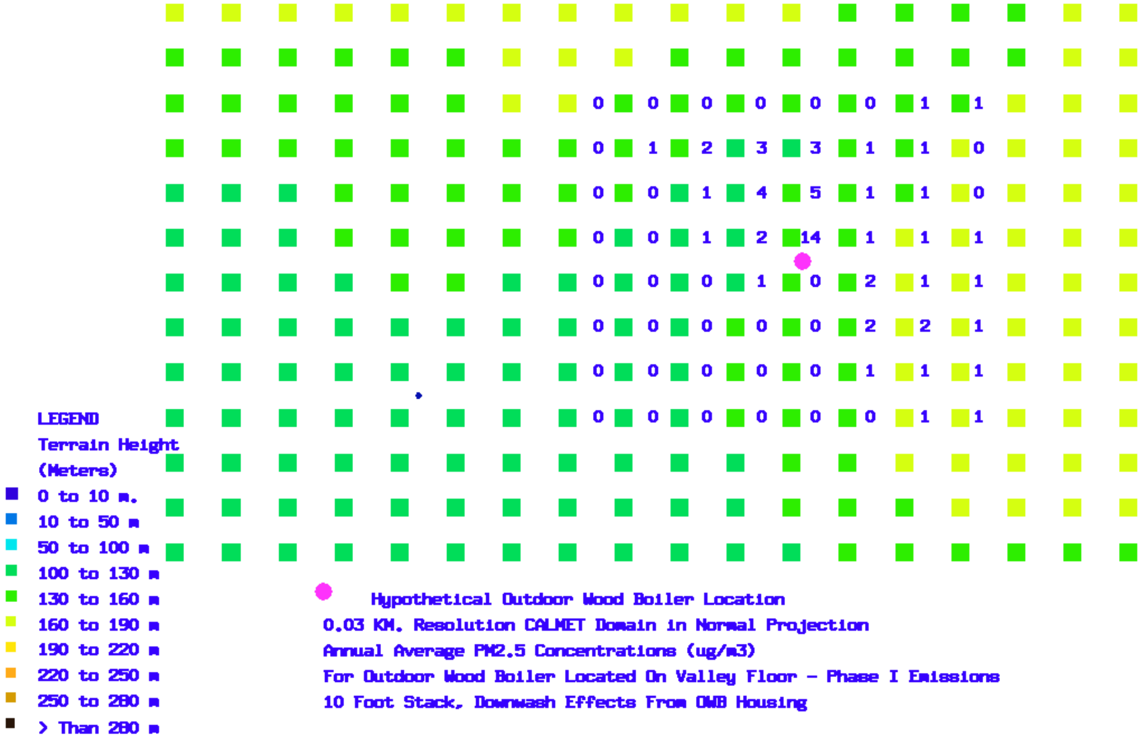
Figures 5. and 6. : The number of exceedances of the maximum 24 hour average PM2.5 concentration (35 ug/m3), for a simulated outdoor wood boiler located on a valley floor and on a ridgeline using the Phase II. emission rates. For the Background terrain elevations each plotted grid square represents a 30 meter square land area. The PM2.5 concentrations are also plotted at 30 meter resolution.

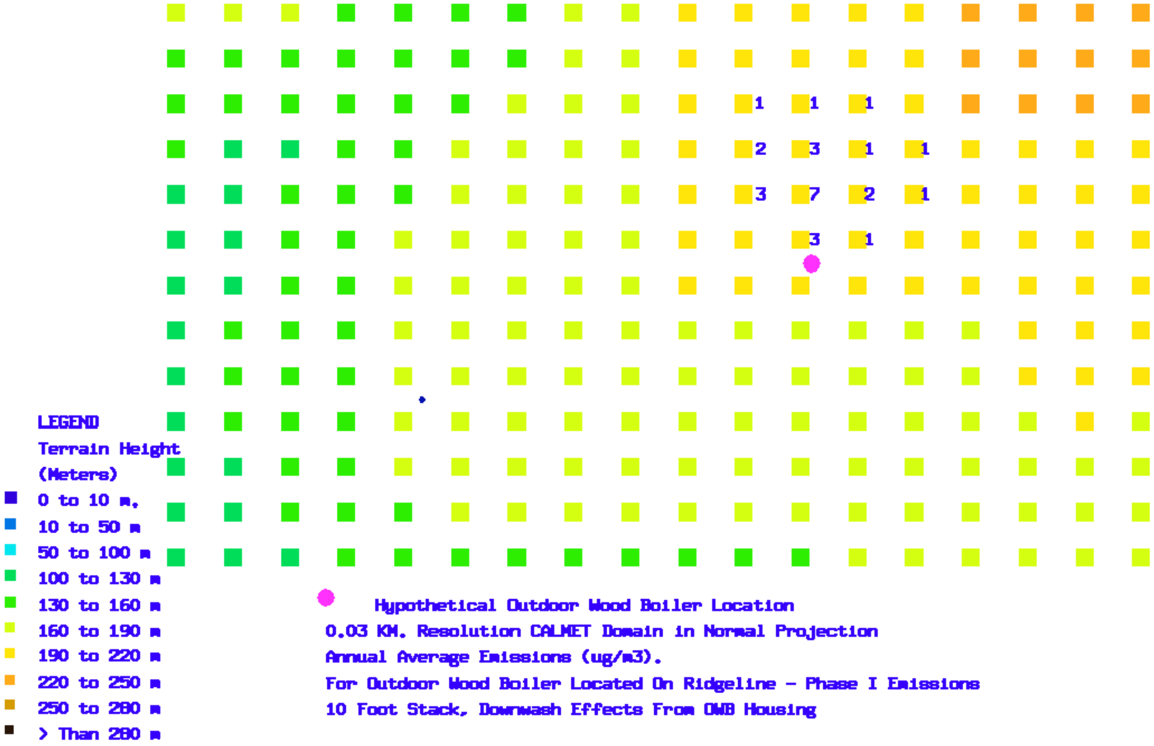




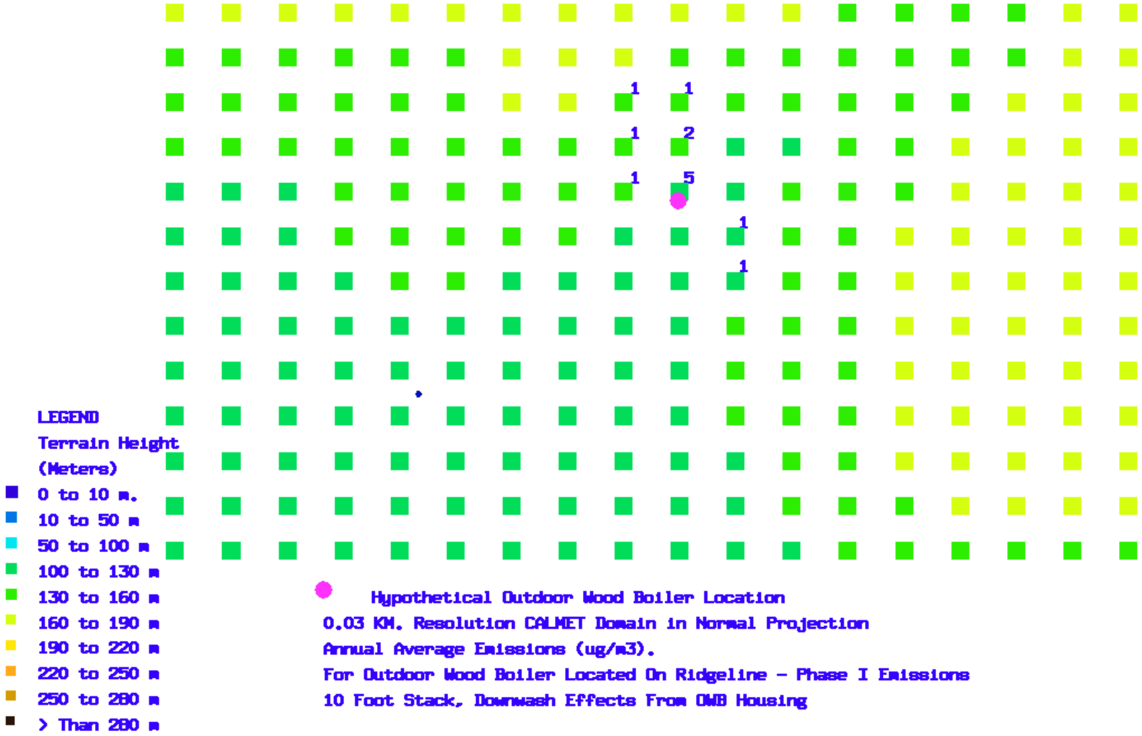
Hypothetical Outdoor Wood Boiler Location
0.03 KM. Resolution CALMET Domain in Normal Projection
Number of Exceedances of 24 hour Standard Annually
For Outdoor Wood Boiler Located On a Ridge - Phase II Emissions
10 Foot Stack, Downwash Effects From OWB Housing

Figures 7. and 8. : The annual average PM2.5 concentrations for a simulated outdoor wood boiler located on a valley floor and on a ridgeline using the Phase I. emission rates. For the Background terrain elevations each plotted grid square represents a 30 meter square land area. The PM2.5 concentrations are also plotted at 30 meter resolution.

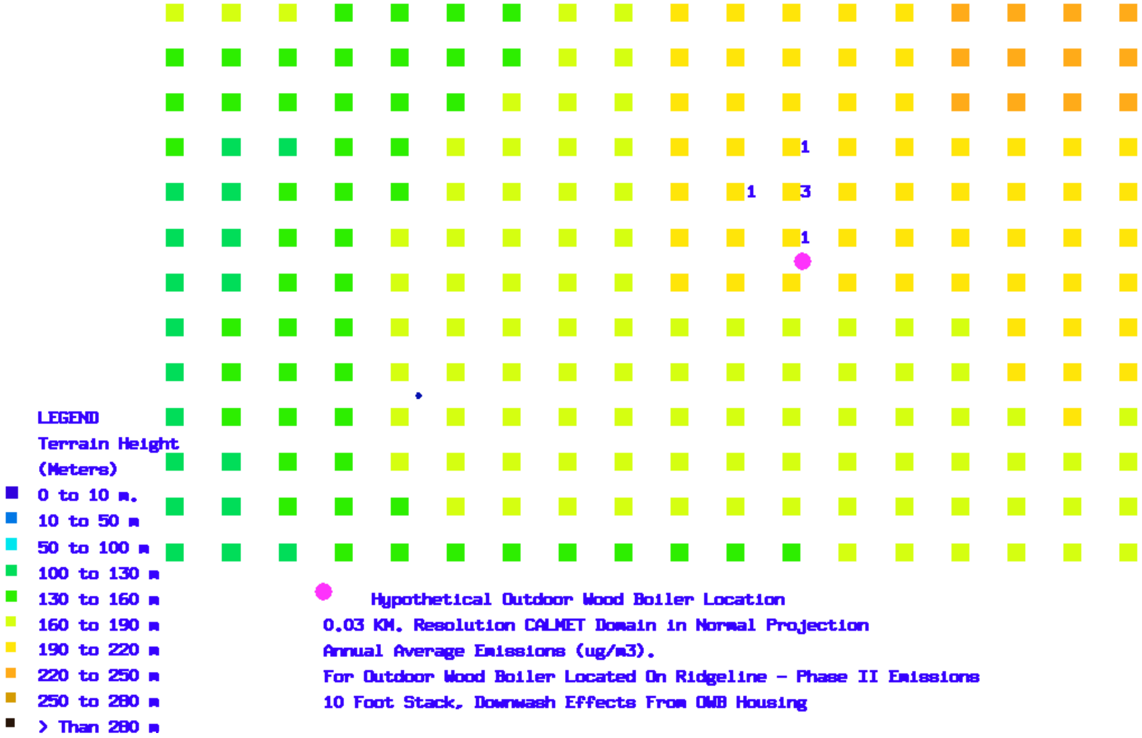




Figures 9. and 10. : The annual average PM2.5 concentrations for a simulated outdoor wood boiler located on a valley floor and on a ridgeline using the Phase II. emission rates. For the Background terrain elevations each plotted grid square represents a 30 meter square land area. The PM2.5 concentrations are also plotted at 30 meter resolution.



● Hypothetical Outdoor Wood Boiler Location
0.03 KM. Resolution CALMET Domain in Normal Projection
Annual Average Emissions (ug/m3).
For Outdoor Wood Boiler Located On Ridgeline - Phase I Emissions
10 Foot Stack, Downwash Effects From OWB Housing



● Hypothetical Outdoor Wood Boiler Location
0.03 KM. Resolution CALMET Domain in Normal Projection
Annual Average Emissions (ug/m3).
For Outdoor Wood Boiler Located On Ridgeline - Phase II Emissions
10 Foot Stack, Downwash Effects From OWB Housing