where

$(\partial T/\partial z)_m$ = maximum thermal gradients over the model (1 °Ccm^{-1}),
h = prototype characteristic hill height,
Ri_{10} = characteristic Richardson number at a reference height of 10m,
α = $\alpha(Ri,\ z_o)$ = velocity power law exponent (0.1 to 0.5).

Here Ri_{10} and α may be stipulated empirically for the various Pasquill-Gifford stratification categories. Figure 2 displays the result of stratification limitations on the performance envelope created in Figure 1.

Valley drainage flows

Local heating and cooling of hill surfaces are the driving mechanisms for anabatic and katabatic winds which inhibit or enhance separation over hill crests. Early laboratory work includes simulation of urban heat islands and heated mountains by Yamada and Meroney (1971) and simulation of flow and dispersion at shoreline sites by Meroney et. al. (1975). Equality of a Monin-Obukhov type length scale ratio would be appropriate for simulating surface heating situations with a finite flow wind field. Linear numerical analysis of Olfe and Lee (1971) and the experimental studies by Yamada and Meroney (1971) and Meroney *et al.* (1975) suggest that the intensity of heating or cooling by the land surface may be characterized by a heating ratio, HR = $[\Delta\theta_z L_x][\Delta\theta_x L_z]^{-1}$, where $\Delta\theta_z$ are characteristic temperature changes over a vertical scale L_z, and $\Delta\theta_x$ are similar changes over some horizontal scale L_x. Usually, since the vertical-to-horizontal modeling scale is undistorted, the parameter reduces to a single temperature ratio. In those situations where the gradient wind is extremely small, and where the lateral variations in surface temperature are negligible, another parameter called the Rayleigh number, Ra = $g\beta(\theta_w - \theta_H)h^3(\alpha\beta)^{-}$

^{1}, is appropriate. Note that the scaled temperature potential increases as the model scale cubed!

Stipulation of strict Rayleigh number similarity would essentially eliminate the possibility of modeling valley drainage flows; however, gravity current movement down steep valley walls will result in high local Reynolds numbers and turbulent mixing. In such circumstances the appropriate viscous parameter is the eddy viscosity, $\epsilon \approx UL$, not ν. Substitution of this variable transforms the Rayleigh number into the Richardson number introduced earlier.

Verification evidence

Not all of the terrain model study cases identified on Figure 1 and Figure 2 were successful. Many early studies had model approach flow velocity exponents near zero, were modeled as neutral flows whereas the field situation observed strong stratification effects, or simulated unrealistic boundary layer depths, integral scales or turbulence intensities. In seventeen of some forty terrain model studies examined by the author there are counterpart field data available (Meroney et. al., 1978). Few studies claimed unreasonable correlation, and some were strongly selfcritical. Nonetheless, most studies accomplished their prestated limited objectives. Meroney (1981) considers verification evidence from three such studies in detail.

3. Facilities for fluid modeling of complex terrain meteorology

The characteristics and capabilities of the fluid modeler's hardware determine whether program objectives can actually be attained in laboratory facilities. No single wind tunnel or water facility is adequate for all possible atmospheric tests. This section considers the size and performance characteristics of wind engineering facilities and instrumentation. The selection of an air versus water medium for modeling flow over hills or mountainous terrain will depend upon the availability of the facility, economics and the type of problem studied. The kinematic viscosity of water at normal room temperature is a factor of 16 less than that of air; hence, at the same scale and fluid speed the Reynolds number may be 16 times higher for a water experiment. Unfortunately, because water is so much heavier than air, structural and pumping requirements result in water facilities which tend to be much smaller than wind tunnels. Thus the larger Reynolds number potential of water facilities is seldom attained.

3.1. Wind tunnels

Low speed wind tunnel design is described by Rae and Pope (1984), who tabulate characteristics of over 300 low-speed wind tunnels in use world wide. These facilities include 64 in the United States of which 12 are non-aeronautical industrial-aerodynamic facilities. Special design attributes of meteorological wind tunnels are considered by Cermak (1981, 1984). Generally meteorological wind tunnels range in size from cross sections of 0.5 m x 0.5 m to 3 m x 4 m. Several of these facilities are equipped with moveable side walls or ceilings to adjust for model blockage, Figure 3. By utilizing a variety of devices such as vortex generators, fences, roughness, grids, screens, or jets a fairly wide range of turbulence integral scales can be introduced into the shear layer, Figure 4. Varying surface roughness permits control of surface turbulence intensity, dimensionless wall shear, and velocity profile shape.

Density stratification can be induced by means of heat exchangers, by use of different molecular weight gases, or by heat release during phase change.

Air with its low heat capacity is comparatively easy to stratify using heat. A few special meteorological wind tunnels have been designed to reproduce some aspects of the stratified atmospheric boundary layer (Meteorological Wind Tunnel, Colorado State University, Figure 5; Environmental Wind Tunnel, Mitsubushi Industries, Nagasaki, Japan; Meteorological Wind Tunnel, Bundeswahr Hochschule, Munich, BRD; CERL Stratifield Flow Tunnel, Leatherhead, UK). Recently Rau and Plate (1986) proposed a new design for a low-speed wind tunnel to study strongly stratified meteorological flows, Figure 6. Using this multi-duct return flow design it is anticipated undesirable standing waves and facility blockage may be avoided.

3.2. Drainage flow facilities

Aluminum shell models (LSR = 1920 and 2560) cooled by dry ice have been used by Petersen and Cermak (1980) to study drainage flows in the mountains near Crested Butte, Colorado. Richardson numbers based on the maximum surface jet velocity and jet height were found to vary from 0.5 to 2.0. These produced surface velocities equivalent to 1.0 to 3.5 m/s between 50 to 150 m above ground. Specific field conditions were not chosen in advance; rather model conditions were permitted to develop, and the equivalent field conditions were evaluated from the measured Richardson numbers. Hertig and Liska (1983) report drainage flow studies over a vertically distorted scale models of mountainous areas in Switzerland. They used a model with a horizontal scale of 1:100,000 and a vertical scale of 1:20,000 to adjust for large vertical eddy scales produced in the laboratory shear layers.

3.3. Water channels and rotating tanks

Several investigators have used water towing tanks, Figure 7, to examine flow over hills or other obstacles (Hunt et. al., 1978). This method is appropriate when considering atmospheric flows dominated by blocking, lee waves, and inversions, but it may distort surface layer predictions because the uniform approach profile simulated is not equivalent to the shear flow found near the earth's surface. In water most experiments using salt as a density ingredient have been performed with specific gravities between 1.0 and 1.1. Indeed the highest relative density obtainable in a water soluble solution is about 1.4. Nonetheless, excellent visualization studies have provided understanding of mountain wave and terrain blocking phenomena.

Faller (1966) used a water filled rotating basin to study instabilities in laminar boundary layers. Later Caldwell and Van Atta (1970) studied Ekman boundary layer flows in a turbulent boundary layer produced in a rotating air facility. Falvey and Dodge (1977) describes a rotating water tank for simulating the influence of Coriolis accelerations over mountainous terrain. The device was used to predict the dispersion in cloud seeding studies over the Sierra mountains.

3.4. Instrumentation

A variety of visualization and flow measurement techniques have been developed to allow accurate measurement of flow over model complex terrain in the laboratory. Conventional air and water metrology includes pitot-static tubes, hot-film anemometry, and laser-doppler velocimetry as described by Rae and Pope (1984) or Goldstien (1983). Pulsed wire anemometers are also useful to measure flow in separated regions up or downwind of hill ridges (Bradbury, 1976).

Traversing camera and lighting systems are often used with water channel systems, Figure 8. Hydrogen bubbles may be used to tag water channel path lines over terrain models, Figure 9. Smoke wire probes, Figure 10, can be combined with stereoscopic camera systems, Figure 11, to measure wind shear and wind veering over complex terrain models. Huber (1988) and Lee et. al. (1988) have demonstrated how video image analysis can produce velocity fields and concentration patterns in complex flow geometries.

Concentrations in plumes moving over complex terrain can be measured in wind tunnels by using thermal conductivity, flame-ionization, electron-capture or photo-ionization techniques. Aspirated hot-wire anemometers or *insitu* flame-ionization devices can follow concentration fluctuations to at least 60 Hz. Salts in conjunction with conductivity meters, acids with pH meters, temperature with thermistors, and dyes with colorimeters have been used as tracers for quantitative measurements of concentration in water. Conductivity probes in water typically respond to frequencies of 10 to 20 Hz.

4. Neutral flow over hills, ramps and escarpments

Mountains may alter atmospheric airflow characterstics in a number of different ways. These effects can generally be grouped into inertial-viscous interactions associated with a thick neutrally stratified shear layer and thermally induced interactions associated with stratification or surface heating. Near-neutral or adiabatic atmospheric boundary layers will exist over hills and mountains during situations when winds are high due to intense synoptic pressure fields, when continuous cloud banks impede surface heating, and when sharp terrain features produce separation eddies which mix the flow field vigorously in the vertical (Case a, Figure 12). When the static stability is neutral, airflow over mountains creates pressure gradients in the flow direction, which together with surface friction, may produce separation, flow reversal, and reattachment. Separation eddies at the windward or leeward side of a mountain can alter the effective shape of the mountain resulting in a modified wind profile at the crest. Scorer (1978) describes eight different variations of the separation phenomenon. He notes that separation may be changed in character by insolation, blocking, diabatic changes, and three-dimensional effects.

4.1. Idealized two-dimensional terrain flow studies

Flow over slight or moderate relief may result in enhanced wind speeds as a result of wind "overshoot" or "speedup." A few field measurement programs over such terrain features were carried out specifically to estimate wind power potential (Putnam, 1948; Golding, 1955; Frenkiel, 1962, 1963; Archibald, 1973; Hewson, 1973). These early results are to a large degree site specific and do not cover a wide enough range of terrain types to allow more than a very limited and qualitative generalization to other situations. In fact the combination of hill features, roughness, upstream topographies, and stabilities studied even appear to lead to a set of contradictory conclusions (Davidson et. al., 1964). A number of laboratory investigations of flow over topography have also been completed. Meroney et. al. (1978) identified ten studies among forty laboratory simulations of flow over terrain devoted to flow over idealized hills, ridges and escarpments. These studies which span some 46 years and more than seven countries, include gentle hills, cones, ridges, escarpments, and mountains.

Plate and Lin (1965) examined the wake flow behind wedge and sinusoidal shaped hills. They did not measure upwind over the hill itself, and they were primarily interested in the diffusive character of the wake region. Meroney *et al.* (1978) summarized a series of eight reports which examine the airflow over two- and three-dimensional hill shapes. Measurements were made in neutral and stably stratified flows with various combinations of surface roughness upwind or over the hills. Bowen and Lindley (1974, 1977), Bowen (1981) and Pearse (1982) examined various escarpment and hill shapes. Bowen also made field measurements at the bank escarpments formed by the wide New Zealand braided rivers. Arya et. al. (1987) returned to a set of "Russian" hill shapes with slopes ranging from 10 to 26 degrees to consider diffusion in the wake of the ridges.

Effect of ridge shape

Wind speed variation over a hill or ridge depends strongly on the upwind and downwind hill slopes. Speedup of the wind is highest for ridge slopes that just avoid flow separation. Such a speedup causes reduction of the minimum static pressure by a separated wake at either the upwind or downwind side of the crest. Figure 13 and Figure 14 present results which show the dramatic change in velocities and static pressures over symmetric triangular hills as a result of flow separation. No flow separation occurs for the hill defined by h/L =

1/6; whereas, flow separation occurs for the hill defined by h/L = 1/3 (Note L is twice the half height distance proposed by Jackson and Hunt (1975) taken between the crest and the point at the upwind side where the hill height is 0.5h).

The character of flow separation occurring at the upwind side of a hill is different from that on the downwind side. The upwind eddy nestles at the foot of the hill. The eddy in the downwind separation region interacts strongly with the main flow producing an extended wake. For steep downwind slopes the separation region may extend to a distance of 10 to 20 times the obstacle height. The interaction between the separation eddy and the main flow at the upwind side is constrained by the presence of the hill. With a slight variation that depends on the parameter h/δ the upstream separation region does not extend further than two hill heights upwind. The location of the flow separation point depends to some degree on the Reynolds number. A Reynolds number effect is avoided when studying the phenomenon of separation over triangular hill models that fix the separation point at the crest. In general a round crested hill results in flow separation downwind of the crest. The results obtained for the triangular hill are somewhat conservative if applied to round crested hills.

The extent of the downstream separation region depends strongly on the strength of the eddy just downwind of the separation point. For relatively gentle downwind slopes only weak eddies can develop. Weak eddies permit early reattachment of the separating streamline. The effect of h/L_d = 1, 0.3, 0.25, and 0.167 on the mean velocity field when $h/L_u = 0.5$ and $h/\delta = 0.1$ is illustrated in Figure 15. Huber et. al. (1977) showed that the separation phenomenon is not affected significantly by the upstream velocity distribution. Essential identical downwind separation regions were obtained for a uniform approach velocity profile and for values of $h/\delta = 0.3$. Bouwmeester (1978) identified the parameter space in h/L_d and h/L_u over which separation will occur. Separation is unlikely to occur if $h/L_u \leq 0.5$ and $h/L_d \leq 0.25$.

Hill perturbations in wind speed may be characterized by a fractional speed up ratio, defined as $\Delta S_{crest} = (u_{crest}(z) - u_o(z))/u_o(z)$, where $u_o(z)$ is the upstream velocity distribution and z is the distance from the surface. By normalizing the increase in wind speed with the upstream profile it was found that the fractional speedup ratio does not so strongly depend on the approach velocity distribution. The effect of detailed hill shape on the velocity field has been investigated by comparing velocity fields over symmetric triangular hill models with those measured over sinusoidal shaped hill models but with the same average slope. Almost identical velocity fields were measured. Rider and Sandborn (1977) considered alternate hill shapes with the same height and distance from crest to the foot of the hill. The models included full sine wave, half sine wave, triangular, trapezoidal, and box shaped hills, Figure 16. Speedup effects over the crest of the different hill models varied substantially since length scale L varied by a factor of two. Moreover, separation regions existed upwind and downwind of the box shaped hill. Nonetheless, hills with similar average slope had similar speedup factor profiles.

Figure 17 displays a comparison between the laboratory data of Meroney *et al.* (1978) and an inviscid, rotational solution of the Poisson equation and vorticity transport equations produced by Derickson and Meroney (1977). Success of this numerical approach demonstrates the effectively small role played by surface turbulence in the mean wind fields over small hills. Jackson (1978) also compared the Colorado State data against the Jackson and Hunt (1975) solution method and achieved remarkable agreement.

Effects of turbulence

When air passes over a hill the turbulence structure is distorted causing Reynolds stress gradients different from those found under equilibrium flow conditions. Consequently, the momentum transfer from one streamline to another is not at the same rate, and the total head across streamlines does not decrease uniformly over the height of the atmospheric boundary layer. Bouwmeester *et al.* (1978) provided an order of magnitude analysis to estimate the total head losses caused by the distorted turbulence. Laboratory data show that for the case of short hills the longitudinal turbulence intensity increases toward the base of the hill, then decreases over the crest. The vertical turbulence intensity shows a decrease at the base of the hill and an increase over the crest. Thus, additional total head losses close to the surface are approximately equal to $\Delta P' \approx 2\overline{u'^2}_{max}$. With maximum local turbulence intensities of 20% the total head close to the crest may then change by 8%. Contour plots of longitudinal intensities for triangular hill models are given in Figure 13 and Figure 14. The figures show that the decrease in turbulence intensity between the base and the crest along streamlines close to the surface is for the 1/4-hill 50% and for the 1/6-hill 25% of $\overline{u'^2}_{max}$.

The changes of dynamic head close to the surface are as large as 400%. Supposing that the change of additional total head causes an equal change in dynamic head, it may be concluded that the effect of the turbulence on the mean flow at the crest is not significant at least for $h/\delta < 2\ h/L_u$. The effect of turbulence on the dynamic head may be expected to be larger for hills with $h/\delta > 2\ h/L_u$ (long hills).

Downwind of the crest turbulence production increases and turbulence intensities in this region exceed upstream intensities. The relative effect of turbulence changes on the dynamic head increases, since the dynamic head returns to values approximately equal to upstream values. These considerations are illustrated by examining flow over a symmetric hill. According to inviscid flow theory the velocity and static pressure field over a symmetric hill is also symmetric. Therefore the measured degree of flow symmetry or asymmetry gives a direct indication of the effects of turbulence on the mean flow.

<u>Effects of surface roughness</u>

Two length scale parameters determine the velocity distribution of a fully developed turbulent boundary layer over a surface perturbation, namely z_o/h and h/δ. The effect of surface roughness, z_o/h, is most significant for small values of relative hill height, h/δ, for then mean velocity and turbulence structure are significantly different over a thickness of the order h. Surface roughness changes the fractional speedup ratio at the crest significantly only if $h/\delta < 1$. Flow separation may occur as a result of increased surface shear stresses over the top of the hill resulting from the speedup of the wind and adverse pressure gradients on the downwind side. Once flow separation takes place the interaction between the eddy in the wake and the main flow will dominate the flow. If the approach surface roughness is not uniform then location of flow separation or even the occurrence of flow separation may be affected. Consider, for instance, an upwind surface roughness that is larger than the surface roughness over the hill. In this case surface shear stress at the hillcrest may be less than in the case of uniform surface roughness. Consequently, flow separation may occur later or may not occur at all. Opposite effects can be expected if the surface roughness over the hill is larger over the hill than upwind.

4.2. Idealized three-dimensional terrain flow studies

Irregular three-dimensional surface obstructions are much more prevalent than the idealized two-dimensional ridge. Because of the large number of irregular geometric shapes, the problem has not been amenable to mathematical characterization except for a few simple cases such as flow around spheres or cylinders. Consequently the wind tunnel has frequently been used to investigate scale models of bluff bodies.

Early work tended to suggest that fields of turbulence and secondary flow around bluff bodies would be similar to those identified downwind of two dimensional fences or ridges. Hence, a cavity region downwind of separation was hypothesized, which communicated with the extended flow primarily by diffusion and pressure perturbations across free shear layers. Improved visualization techniques have revealed a more complex flow pattern.

Wakes generated by hills or other obstacles are characterized by increased turbulence, mean velocity defect, and, in certain situations by organized strong vortices with axes parallel to the main flow direction. The characteristics of the wake (the extent of the momentum wake, the strength and extent of the vortex wake, the rate of decay of excesses and defects in the wake, *etc.*) are highly dependent on the overall obstacle height, the aspect ratio of the hill, the hill width-height ratio, the shape (projecting corners, step structure, round portions, etc), approach wind azimuth, character of the surrounding terrain (extent of vegetation), and the atmospheric stability. For these reasons, a simple description or generalization of terrain wakes does not appear to be possible.

Measurements downwind of a hemisphere immersed in a turbulent shear layer are different from the wake of a rectangular body or building in two important ways. First, in the far-wake profiles there is a relative maximum in the velocity (or a relative minimum in the velocity deficit) on the wake centerline (Hansen and Cermak, 1975). A significant portion of the wake contains velocity excesses, Figure 18. The near wake velocity profiles have the shape of a momentum wake. A minimum velocity is observed at the center of the wake, but this profile shape quickly changes into a shape with a local maximum velocity on the wake centerline. Velocity profiles measured in the lower region of the wake show this transition from a momentum-wake profile to what can appropriately be called a vortex-wake profile. The upwind distortion of vortex lines by the presence of a hill in a stream with shear is responsible for the formation of "horseshoe" shaped vortex cells which wrap around the base. A general downflow is induced in the hill wake by these vortices tending to increase velocities where a momentum defect might otherwise exist. The profiles measured above the height of the obstacle show a momentum wake character far downwind. But the region which contains the characteristic vortex wake velocity profiles slowly grows upward giving almost all the far wake a vortex wake structure.

The second feature of the hemisphere wake is the extreme persistence of the wake. Mean velocity wakes of simple cubes and blocks in turbulent boundary layers extend at most to distances of 10 to 15h, but the wake of a hemisphere may still be evident beyond 60h.

Separation is generally the dominant feature perturbing flow over surface obstacles; however, thermal stratification or surface heating may further complicate the already confusing flow picture. Hawthorn and Martin (1951) considered flow with vertical velocity and density gradients over a heated hemisphere attached to a horizontal wall. For the stable case, vortex lines, which are horizontal and lie perpendicular to the flow far upstream, are held back by the obstacle and are therefore stretched and rotated so that, when seen from above, the vortex vector points upwind on one side and downwind on the other side of the obstacle. This introduces a secondary component, which produces downward motion behind the obstacle. Over a hot hump, the secondary vorticity generated by gravity is in the opposite direction. Close to the floor where the vertical displacement is negligible the effect is very small; whereas, the effect of holding back the vortex lines is a maximum. Consequently, there is on each side a surface above which the vorticity is dominantly produced by gravity. There is therefore an inflow towards the axis of the flow along these surfaces (See Scorer, 1978, Section 3.6).

Chien *et al.* (1978) measured velocities, pressures and turbulence over Gaussian and cone shaped hills with crest height to radius ratios of 1:6, 1:4

and 1:3. Pearse (1982) also made similar measurements over a range of smooth and roughened conical shaped hills. Arya and Gadiyaram (1986) examined the wake distributions of velocity, turbulence and shear out to 20 hill heights and found evidence for well defined recirculation and trailing vortices. Snyder and Britter (1987) studied flow and diffusion around a bell-shaped hill and moderately steep hills of triangular cross section and varying crosswind aspect ratio. Surface oil-film visualization revealed that even over a 1:6 slope hill an area of separation occurs starting near the crest and spreading downwind laterally at an included angle of 35°. This separation region was fluctuating and non-stationary. The separation regions, increasing in size with increasing aspect ratio, appeared to dominate the entire flow structure. Regions around the crest on the shoulders may produce local high wind velocities. Compared to the two-dimensional ridges, the isolated three-dimensional hills of similar slope do not produce as large magnitudes of fractional speedup.

4.3. Field/laboratory comparisons

Flow over complex terrain varies significantly as a function of topographical details and meteorological conditions. For this reason measurement programs were designed to distinguish between the generalizations outlined in the sections above and site-specific types of flow phenomena. Meroney *et al.* (1978, 1979) and Neal (1979, 1983) considered flow through mountain gorges and passes in New Zealand, respectively. Chien *et al.* (1979, 1980) examined flow over the Kahuku peninsula of the island of Oahu, Hawaii. Teunissen *et al.* (1987) reported the results of a multi-laboratory simulation of flow over Askervein Hill, Outer Hebrides, Scotland.

<u>Rakaia River Gorge, New Zealand</u>

Both terraced and contoured models of the Rakaia River Gorge region of New Zealand were prepared to an undistorted geometric scale of 1:5000 (Meroney, *et al.*, 1980). Flow over the contoured model was examined for three separate surface roughness conditions - smooth, uniform roughness, and detailed shelter-belts. Laboratory measurements included horizontal and vertical profiles of mean wind velocity, longitudinal turbulence, wind direction, turbulence spectra and correlation utilizing hot-wire anemometry, pitot-static pressure probes, and cobra pressure probes.

On two spring days, selected for strong adiabatic down valley wind flow, three teams of investigators surveyed up to 27 sites on either side and within the Rakaia river gorge. Measurements consisted of wind speed and direction at a 10 meter height on lightweight portable towers. All measurements were completed during the course of a five hour stationary wind event and normalized against continuous records taken from a New Zealand Wind Energy Task Force anemometer located near terrain center. The effectiveness of such a procedure depends upon spatial correlation of wind velocities over the same 100 square km region, and quasi-stationarity of the wind event over a 3 to 6 hour period, and the statistical significance of a 15 minute sample at a given point taken once during a 3 to 6 hr recording period. Climatological analysis by Corotis (1977) suggested high correlation (0.76-0.83) would exist over distances less than 22 km and high autocorrelation over periods from 3.5 to 7 hours.

A series of contour diagrams (*e.g.* Figure 19) were prepared from the laboratory velocity and turbulence intensity measurements into isotach and isoturb charts as show in Figure 20 and Figure 21. Note the wide variation in wind speed near ground level between points within the gorge and the nearby hill top. Simultaneously large relative gustiness exists within the river gorge when compared to the hill crest.

The laboratory results were compared with the field data by means of statistical correlation and scatter diagrams. The sample correlation coefficients ranged from 0.68 to 0.78, and the rank correlation of wind stations by wind speed ranged from 0.78 to 0.95. Correlation between equivalent field measurements at the same sites taken on independent days was 0.68. This suggests that there is an inherent limitation to the paired replication of any single realization of a wind flow pattern by any model whether physical or numerical.

The authors concluded that conventional simulation wisdom is appropriate for physical modeling of flow over complex terrain. Specific results of this study are:

a. Physical modeling can reproduce wind patterns produced by the atmospheric shear layer flowing over complex terrain to within the inherent variability of the atmosphere,

b. Physical modeling reproduced the average quantitative wind speeds from two field days to a sample correlation coefficient level of 0.81,

c. Physical modeling reproduced the site wind directions to sample correlation coefficient levels ranging from 0.65 to 0.67.

d. Optimum physical modeling of adiabatic shear flow over complex terrain requires accurate replication of surface roughness, terrain shape, and vegetation, and

e. Preferred wind energy system locations are the surrounding hills and ridges, and not the gorge or river bottom.