

WIND ENERGY POTENTIAL

The average distribution of wind movements over the entire earth is called the general circulation. The primary features of this circulation are the equatorial belt of low pressure (the doldrums); the subtropical high pressure belts (the horse latitudes); the polar low pressure; and the polar caps of high pressure.

Winds blowing out of the poleward side of the subtropical high pressure belts are deflected toward the east as they move into higher latitudes. These winds, which extend from about 35 to 60 degrees (north and south) latitude, are known as the prevailing westerlies. These winds blow throughout the year, but are strongest in winter.

Montana is located in the zone of prevailing westerlies, and it is these winds, modified primarily by near-surface effects such as friction and turbulence, that provide the wind resource in the state.

Air, like all other substances, has inertia; force is required to set it in motion. The major factors that drive the circulation of air are:

- **Insolation:** Energy from the sun heats the air unequally, mainly because the surfaces with which the air comes into contact heat at different rates;
- **Gravitation:** Unequal heating of the air produces differences in its density, and gravity causes the cooler, heavier air to sink;
- **Condensation:** Latent heat released by condensation of water vapor supplies a large amount of energy;
- **Rotation:** The earth's rotation changes the direction of air movement and produces the eastward and westward motions of air in the atmosphere.

The interaction of these major air circulation factors creates more specific forces, the balance of which determines the motion of air in a given area:

- **Pressure gradient force:** This force drives air from areas of high pressure to areas of low pressure;
- **Coriolis force:** This force, due to the rota-

tion of the earth, deflects air to the right in the northern hemisphere;

- **Centripetal force:** This force arises when the air is moving in a curved, rather than straight, path along the earth's surface;
- **Frictional forces:** These forces include friction between the atmosphere and the earth's surface, as well as internal friction within the atmosphere.

Frictional forces are most important near the earth's surface and are the determining factors of the wind climatology at a specific location. Surface features associated with high wind speeds are mountain passes, high-elevation plateaus, long valleys extending down from mountain ranges, mountain ridges and summits, and the leeward slopes of mountain ranges perpendicular to the prevailing winds. Features associated with low average wind speeds include sheltered basins, valleys perpendicular to prevailing winds, and areas of high surface roughness.

There are four distinct wind provinces in Montana: western valley floors, eastern slopes, east and northeast plains, and exposed mountain crests. A discussion of each of these wind provinces follows.

Western Valley Floors

Most of the western third of Montana is mountainous. The region is crossed by many parallel mountain ranges with deep valleys between them. These valleys include: the Flathead, Bitterroot, and Deer Lodge valleys in western Montana; the upper Missouri River, Shields River, and Smith River valleys in the west-central portion of the state; and the Big Hole and Jefferson River valleys in southwestern Montana.

These valleys generally trend north-south or northwest-southeast and, thus, are oriented perpendicular to the prevailing wind direction. Because of their orientation, depth, and nar-

rowness, average wind speeds in these valleys are low. Periods of air stagnation, during which there is virtually no air movement, are common in these valleys, particularly in the autumn and winter. Certain limited areas in these valleys, such as the Kalispell-Columbia Falls area and the Hellgate Canyon just east of Missoula, occasionally experience high winds due to channeling through mountain gaps. Such occurrences, however, are comparatively rare.

Representative wind monitoring sites in the western valleys include the Missoula Hoerner-Waldorf site, the Ronan Nine Pipes site, and the Kalispell Airport site. Average annual wind speeds in these areas typically range from 5 to 10 miles per hour. Average annual wind power density generally ranges from 20 to 80 watts per square meter (watts/m²).

Eastern Slopes

Air flowing over the Rocky Mountains is compressed and accelerated as it descends the eastern slopes of these mountains. When a strong pressure gradient exists, as it frequently does, these winds can become very high. The winds are strongest when channeled through east-west trending valleys.

Downslope areas are found along the eastern front of mountain ranges adjacent to broad valleys, such as in the Anaconda area and in the lower Jefferson River valley near Whitehall, as well as along the entire Rocky Mountain Front where the mountains meet the plains. This wind province actually extends well out into the plains, covering much of central Montana.

Areas where channeling of the winds by east-west mountain valleys results in stronger winds include the upper Yellowstone River valley from Livingston to Big Timber, the Browning-East Glacier-Cut Bank area, the upper Musselshell River valley around Harlowton and Judith Gap, the Jefferson River valley around Whitehall, and the Missouri River valley from Cascade to Great Falls.

Representative wind monitoring sites are the Livingston Candidate Wind Turbine site, the Bureau of Reclamation's Judith Gap and Cut Bank sites, and the Whitehall Airport site. These areas show pronounced seasonal variations in wind speed and wind power density. Highest average seasonal wind speeds occur during the winter and are generally from 12 to 25 miles per hour. Lowest average seasonal wind speeds, most-

ly from 8 to 12 miles per hour, occur during the summer. Average annual wind speeds are generally from 10 to 16 miles per hour. Average seasonal wind power ranges from between 600 and 2,000 watts/m² in winter to between 100 and 500 watts/m² in summer. Average annual wind power density is generally between 150 and 500 watts/m². Other representative sites include Yellowtail and Gibson dams, with average annual wind speeds in excess of 12 miles per hour.

Prevailing winds in these areas are generally from the southwest through west. Highest average wind speeds, likewise, are from these directions. At a given location, however, the orientation of nearby mountains may have a marked effect on the prevailing wind direction and speed.

East and Northeast Plains

The eastern slopes of the mountains give way to the east and northeast plains, which roughly occupy the corner of the state east of a Malta-Baker line. Because of the low surface roughness and low to moderate relief in this area, wind movement is dominated by pressure gradient forces. Prevailing wind directions are northwest and southeast.

Representative wind monitoring sites in this area include the Scobey Hanrahan site, the Glendive Microwave site, and the Glasgow Airport site. Average seasonal wind speeds are highest in the spring, when they are generally from 12 to 16 miles per hour. Lowest average seasonal wind speeds, between 4 and 10 miles per hour, occur in the autumn. Average annual wind speed is generally from 10 to 13 miles per hour. Average seasonal wind power density varies from about 50 to 150 watts/m² in autumn to between 100 and 300 watts/m² in the spring.

Exposed Mountain Crests

High, exposed mountain ranges and summits intercept the prevailing air flow. Air moving over a mountain range is compressed and accelerated as it passes over the crest. These effects are variable and depend on the orientation of the mountains with respect to the prevailing wind direction, the slope and elevation of the range, and the location and height of other nearby mountains.

All mountain ranges in Montana have exposed ridges and crests where average wind speed and power are likely to be high. Unfortunately, data from these areas are sparse. The most extensive data set available is the National Fire Weather

Data Library, maintained by the U.S. Forest Service. These data, however, were collected only one to three times daily, and only during the fire season. Nevertheless, the data have been analyzed by Battelle Pacific Northwest Laboratories and indicate average wind power densities ranging from 200 to more than 500 watts/m² for sites in western Montana.

Aerial surveys of tree deformation caused by winds also provide information on the wind resource at exposed mountain crests. Several indices of tree deformation, such as the Griggs-Putnam Index and the Barsch Index, have been developed to show a qualitative relationship between average annual wind speed and tree deformation. Researchers from Oregon State University in May 1981 conducted aerial surveys of most of western Montana for the Bonneville Power Administration. These surveys indicated average annual wind speeds of 14 to 20 miles per hour on most exposed ridges.

Summary

In summary, Montana may be divided into four general wind provinces: the western valleys, the eastern slopes, the east and northeast plains, and the exposed mountain crests. Maps III-1 and III-2 present generalized isopleths of average annual wind speed and wind power density in Montana. Given the state's sizable territory and the consequently low density of wind data available for the state, isopleth lines cannot be drawn with a high degree of precision. In a few instances, given areas with low data density and complex terrain, isopleths cannot be inferred at all. These maps, however, do provide a good picture, from a statewide perspective, of the relative wind potential of different parts of the state.

