FOREST MANAGEMENT NOTE

Note 48 **Northwest Region**

USING RYAN'S WNDCOM MODEL TO PREDICT WINDS IN MOUNTAINOUS TERRAIN

The ability to predict mountain and valley winds is naturally valuable in forest fire management. Ryan (1983) presented a computational procedure named WNDCOM for estimating surface wind speed and direction in mountainous terrain. Thus, Ryan's model and procedure should find a ready audience.

Ryan's model requires considerable information about the area for which the wind estimates are to be made. Once the necessary data are at hand, lengthy and involved computations are required, computations that would be much easier to do on a computer.

Ryan's initial tests of his model (1976), and tests done while incorporating it into a fire dispatching information system (Pickford 1986, 1987) indicate that the model gives usably accurate results for forest fire dispatching. Consequently, an interactive computer program named WCM was written to make the model more accessible to interested users and to encourage further testing in near-operational situations.

Ryan's model appears to be fairly robust; it gives reasonable answers for input data that deviate from ideal or correct values by amounts that you would expect in real situations (Pickford 1986). The price paid for this is the large amount of data required to operate the model.

USING WCM TO PREDICT SURFACE WINDS

The requirements of WCM are an IBM-compatible microcomputer, a monochrome (text) video monitor, 256 kilobytes of RAM, a double-sided, double density diskette (360 kilobyte) drive, and MS or PC DOS 2.1 or higher. A printer is optional, and if available can be used to record input data and results on paper.

The program was developed on an IBM PC/AT-compatible machine running at 10 MHz, and it runs very quickly on these machines. A hard disk, if available, also makes WCM run much more quickly. IBM XTs or PCs running at 4.77 MHz will be noticeably slow, though still serviceable.

A diskette with the source files and an executable program file is available from NoFC or the author. The following discussion describes the use of this diskette and its program and files.

The diskette contains the following files:

READ.ME	General instructions on getting started.
WCM.EXE	The WCM program in executable form. You can run the program by typing "WCM" at the DOS prompt.
WCM.BAS SKBD.BAS TBWINDO.INC HRZN.BAS COMPUTE.BAS WELCOME.BAS	These "xx.BAS" and "xx.INC" files contain the source code, written in Borland's TurboBASIC, for the WCM program. These are included for those who may want to modify the program for their own needs.
RYAN.HRZ RYAN.INP	The RYAN.xxx files contain the data Ryan used in his 1983 General Technical Report.
SCHOONR1.DAT	This file contains data from the worked example in this guide.

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If you plan to install WCM on a hard disk, make sure that the WCM.EXE, RYAN.INP, and RYAN.HRZ files are copied into the same subdirectory.

Starting WCM

To run WCM from a diskette, put the diskette in the A: drive, make sure the prompt on the screen shows "A:" and then type the letters WCM followed by a carriage return (or the Enter key).

Starting WCM from a hard disk is similar. Make sure the current directory contains all the WCM and associated files. At the prompt, type "WCM" followed by a carriage return (or Enter).

Exiting WCM

You can stop WCM while it is executing or after it has completed a set of calculations.

1. Exiting in mid-execution
   (a) To stop the program before it has completed its computations, press the Control (CTRL) key with one finger and hold it down while pressing the Break or Scroll Lock key with another finger. Then, if the prompt symbol has not appeared on the screen, press the Escape ("ESC") key.

   (b) In some cases, you may need to repeat one or both of the above steps.

   (c) In particularly nasty cases, you may have to reboot—that is, start the system over again. You may be able to do this by holding down the ALT and Control keys with the fingers of one hand and pressing the Delete (Del) key with another finger. If that does not work, you will have to turn the machine off and back on again.

   WCM should not "bomb" and cause you to reboot. If it does, please let me know what you were doing when it happened (if you can remember), so I can fix it.

2. Normal Exit
   After WCM completes its computations it displays the results in a box. Another box beneath the results box asks you what you want to do next. You can
   (a) Print out these results (if you have a printer),
   (b) rerun WCM with another set of input data, or
   (c) quit.

You select which of these three actions you want to take by pressing the first letter: "P" for print, "R" for rerun, and "Q" for quit. Pressing "Q" exits the program and returns the "A:>" or "C:>" prompt to the screen.

DATA REQUIREMENTS

The kinds of data that WCM needs to predict surface winds at a site are time, site characteristics, horizon configuration, and free-stream or geostrophic winds. Times (i.e., time of year, time of day, and solar versus civil times) are important because mountain and valley wind systems are driven by the amount and duration of solar heating and radiational cooling, which in turn depend on such factors as times of sunrise and sunset and solar altitude.

The site is characterized by its latitude and longitude and by its slope percent, aspect, elevation, valley direction, and the presence of and distance to large nearby bodies of water. These features influence and modify the amount of solar radiation received or lost, duration of radiational effects, and land-sea breezes.

The height of the horizon above a level plane at the prediction site partly determines how long sunlight will illuminate the slope during a 24-hour day. Ryan expresses this height as the vertical angle from the site to the horizon at 24 points around the compass. Other procedures mentioned below can also be used. The model actually uses percent slope rather than vertical angle to the horizon.

The geostrophic wind, interacts with the other topographically dominated wind components. In Ryan's model, the various component winds are added vectorially to produce a resultant surface wind speed and direction at standard anemometer height.

Finally, in addition to the horizon configuration, the aspect of the terrain downwind from the site can have a diverting effect on wind direction. Likewise, high ground upwind has a sheltering effect on wind speed that depends on the height (vertical angle) of the horizon above the site in that direction.

GATHERING THE DATA NEEDED BY WCM

There are two general data sources for WCM: local weather observations and topography. Topographic data most often come from standard topographic maps, but there is no reason why digital topographic data could not be used with WCM.

Ryan suggests using U.S. National Weather Service (NWS) Limited-area Forecast Model grid-point data; however, such data may not be easily obtained. Weather observations from fire lookouts, remote automated weather stations, standard fire weather stations, or belt weather kits can be used. The effect of type and location of weather observations on the accuracy of WCM estimates has not been extensively explored.

The following procedure should provide reasonable values for the various WCM inputs. Where more than one way of obtaining some data inputs has been used, the better ones are described.

Latitude and longitude: Estimate latitude and longitude to the nearest whole degree from a topographic map of the area. Accuracy to the nearest whole degree is probably adequate, although Ryan's example shows both values taken to one decimal place.

Date: Enter today's date or the date for the day intended in the following order: month, day, and year. The model converts this form to the Julian date, i.e., the number of the day in the year. The program described here requires that the date be entered by the user, but the routine could be modified easily to get the date from the computer itself.

Time: Enter the current time or the time of day intended as 24-hour (military) clock time, expressed as hours:minutes. Ryan's procedure uses time in hours to the nearest 0.1 hour or to the nearest 6 minutes. The program converts hours and minutes to hours and decimal hours. Time data accurate to the nearest one-quarter hour is probably adequate for most purposes.

Time zone: Select the proper time zone and Daylight Savings ("D") or Standard ("S") time with the up or down cursor keys. The program will consider sites located from Alaska to the Maritime zone of Canada but excludes Newfoundland. Daylight or standard time and the time zone are used to determine the actual civil time at the longitude of the site. Both time zone and daylight and standard time depend on longitude, so the program flags values for these items that are too far out of line.

Geostrophic wind speed and direction: Enter speed (km/h) and direction (azimuth to nearest 15 degrees) of the geostrophic wind. Geostrophic winds are those high enough above the earth's surface to be unaffected by surface friction. The direction of the geostrophic winds parallel the isobaric contours on a standard weather map. Geostrophic wind information can be difficult to obtain. One of the three methods suggested below may work.

1. Use the wind data for the layer just above the top of the friction layer obtained from upper air observations. Ryan suggests using 850 mbar (millibar) data, or 700 mbar if the surface is near or above the 850 mbar level.

2. Use measured wind speed and direction from a station or site located on the top of an exposed ridge if upper air data are not easily available. This procedure is suggested to Fire Behavior Officer Trainees (Fire Behavior Officer, Field Reference, U.S. Forest Service Fire and Aviation Management) and should give usable values if no better information can be found.

   This method 2 may have an additional advantage because winds aloft may be decoupled from lower-level winds by such things as mesoscale return flows over large basins. Using the ridgetop wind data may more accurately represent general winds than the upper level flows[1].

3. Use surface wind data at any available station near the prediction site. Then apply these surface winds and the other necessary data from the weather site, and run WCM backwards to generate the geostrophic wind. Use this geostrophic wind to predict surface winds at the site. This method was

[1] Infonnal discussion in 1987 with forecasting personnel of the U.S. National Weather Service in Wenatchie, Washington.

used in initial tests of WCM and was also tried by Ryan, who reported good results.

Air temperature: Estimate or use the maximum forecast air temperature in degrees Celsius for the general area containing the prediction site. Air temperature is only used in computing the sea breeze component, so if no water influence is present, this item can be ignored.

Water surface temperature: Use the measured or estimated surface temperature, in degrees Celsius, of the water body judged to produce a land-sea breeze. Ryan gives a procedure for computing the coastal water temperature off the Pacific Coast of the U.S. Ryan's procedure may not be applicable in other areas, but the program requires the user to enter a value for the surface temperature. In such cases, enter Ø (zero) for both air and water surface temperature.

Sky conditions (atmospheric transmissivity): Use the up and down arrow keys to select a condition between clear (0.9) and overcast (0.4). The transparency of the atmosphere influences the amount of solar heating at and near the prediction site. Obtaining accurate estimates for this item will probably always be beyond practicality. Ryan suggests using values of 0.9 for clear skies and 0.5 for broken clouds or overcast. Sandberg suggested that a reasonable value for conditions of light haze and partly cloudy skies would be 0.7, and for smoke and heavy haze it would be 0.6[2]. The value for heavy overcast was therefore lowered to 0.4. The effects of changing these values on the accuracy of predicted winds is unknown.

Slope at prediction site: Measure or estimate the average slope (rise over run) of a 1.2-ha area around the prediction site to the nearest whole percent. (See Alexander et al. 1984 for instructions on determining slope percent[3].) An area of 1.2 ha is about 110 X 110 m, or a circle with a diameter of 125 m. Ryan's procedures use slope values accurate to one decimal place; however, accuracy to the nearest percent is probably good enough.

Aspect at prediction site: Determine the aspect over the same 1.2-ha area surrounding the prediction site. Express the result as degrees azimuth from north. Aspect can be thought of as the direction you would be facing if you looked down the steepest part of the slope. Ryan uses values in his example that suggest that aspect need only be given to the nearest 15 degrees.

Elevation: Estimate elevation in metres at the prediction site from a topographic map. Although Ryan's example shows elevation taken to at least the nearest 5 m, the use of the data suggests that accuracy to the nearest 10 m is sufficient.

Slope, aspect, and elevation at the prediction site are all easily obtained from topographic maps of the area containing the site. The area over which the data are averaged would be circles of various sizes, as follows, depending on map scale:

Map scale	Circle diameter (mm)
1:20 000	6.25
1:24 000	5.20
1:50 000	2.50
1:100 000	1.25
1:500 000	0.25

Upstream direction of valley: Determine the upstream direction of the valley axis at the nearest point to the prediction site. Record the azimuth from north to the nearest 15 degrees. The direction of the valley containing the prediction site controls the direction of the valley wind component. This information can currently only come from a topographic map unless some sophisticated programming is applied to digital terrain data.

Direction to ocean or large lake: Determine the direction to the closest point on the body of water judged to be the source of a land-sea breeze. The direction to this water controls the direction of the sea breeze wind component.

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[2] Personal communication in 1986 from D.V. Sandberg, project leader, Fire and air research project, U.S. Forest Service, Pacific N.W. Forest and Range Exp. Stn., Seattle, Washington.

[3] Alexander, M.E.; Lawson, B.D.; Stocks, B.J.; Van Wagner, C.E. 1984. User guide to the Canadian Forest Fire Behavior Prediction System: rate of spread relationships. Interim edition. Environ. Can., Can. For. Serv., Fire Danger Group, Ottawa, Ontario.

Like valley direction, accuracy to the nearest 15 degrees should be adequate.

Distance to ocean or large lake: Measure the distance (to the nearest kilometre) to the closest point on the body of water judged to be the source of a land-sea breeze. The distance from the source of any sea breeze affects the strength of this component. Judging from Ryan's example, distances to the nearest 0.1 km are sufficiently accurate.

Elevation angle to the horizon: Determine the vertical angle above a level plane to the horizon in the specified azimuth direction. Report the vertical angle as percent slope to the nearest whole percent.

1. Mark the prediction point on a topographic map, if not already marked. Note the elevation of the point; call it "P".

2. Determine representative fraction (RF) from the scale of the map. If the scale is 1:500 000, then RF equals 500 000. If it is 1:150 000, RF equals 150 000.

3. Using the prediction point as center, lay out a line at the required azimuth.

4. Locate the highest elevation along this line. Call this elevation "Hf" if elevations are in feet, or "Hm" if elevations are in metres.

5. Measure the distance to this highest elevation in centimetres. Call this distance "RUN".

6. Subtract "P" from "H". Call this difference "RISEf" if in feet, or "RISEm" if in metres.

7. Determine the vertical angle to the horizon, "E", as follows:

$$E = \frac{3048 \text{ X } (\text{RISEf})}{((\text{RF}) \text{ X } (\text{RUN}))}$$

or

$$E = \frac{10\,000 \text{ X } (\text{RISEm})}{((\text{RF}) \text{ X } (\text{RUN}))}$$

8. The point at "H" may be below the actual horizon as viewed from the prediction point. Lower but closer points may form the horizon. Check for any such points by finding the next highest point along the line toward the prediction point. Repeat steps 5 through 7. If the second "E" value exceeds the first "E" value, then the second point is the horizon. Check this point and the remaining high points in the same fashion until the largest value for "E" has been determined.

Horizon elevational data are time-consuming and tedious to collect if done by hand. The direction to the horizon along which the vertical angle is to be measured depends on the wind component being computed. Three means for obtaining these data are suggested:

1. Ryan suggests creating a table of 24 elevation angles taken every 15 degrees of azimuth starting at 0° North azimuth. This process assumes that the person desiring a prediction of surface winds has the time to make the necessary measurements. If that is the case, then WCM will store the values so generated and retrieve the appropriate value as it is needed.

2. Another approach that may save some work is to measure the vertical angle to the horizon only at obvious slope breaks. This method might be appropriate if the horizon was being mapped while the observer was physically at the prediction site. It could also be applied using a topographic map, if the observer is sufficiently skilled at topographic interpretation. This method and the one above rely on WCM to interpolate vertical angles between tabulated values for azimuths not actually contained in the table.

3. Finally, WCM can be instructed to ask only for vertical angle data from these azimuths that it actually needs. The user ordinarily will have no way of knowing what azimuth will be specified and will have to determine the elevation angles "on the fly" while running the program. Determining horizons and slope angles manually is extremely tedious work if done with ruler and compass rose. A device that might make these measurements easier to calculate is available from the author.

Aspect of facing terrain: Use an azimuth line such as the one laid out for finding the horizon angle. Work along each line starting at the prediction point until the terrain forms a "wall" or slope facing the prediction site. Determine the aspect of this "wall" and record it as the aspect of facing terrain along this azimuth.

The general wind and the sea breeze components are subject to topographic diversion if the downwind (facing) terrain is at an angle approaching 45 degrees to the direction of the wind. The maximum diverting angle approaches 35 degrees in this case, as the vertical angle to the downwind horizon approaches 150 percent. The diverting effect drops off as the horizon lowers and as the angle between the wind and diverting terrain decreases. Because wind components are added vectorially, the overall effect is reduced still further.

If the press of time or some other reason prevents getting a value for aspect of facing terrain, it could perhaps be ignored and the error in resulting wind direction be accepted. For applications such as initial fire dispatching, this seems to be an acceptable alternative.

Default values: Ryan's example computation uses a set of data taken from southern California. These data produce values for all four wind components and the resultant surface wind. The WCM program displays these default values when it is first invoked. Ryan's example data for elevation angles to the horizon and aspect of facing terrain are contained in the data file "RYANHRZN.DAT" that is included on the program diskette.

These default input values and the resulting predicted wind speeds and directions for component and resultant winds are given in Table 1.

S.G. Pickford[4]
January 1990

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[4] College of Forest Resources, University of Washington, Seattle, Washington.

Table 1. WCM default input values and results

Input data from Ryan (1983)

Latitude	34.2°N	Up-valley direction	30°
Longitude	117.3°W	Free air wind speed	7.5 m/sec
Date	8/31/77	Free air wind azimuth	225°
Time	16:00 h	Air temperature	36+C
Slope	12.5%	Water surface temp.	17.91°C
Aspect	180°	Direction to sea	240°
		Distance to sea	112.7 km
Elevation	685 m	Atmos. transmissivity	0.9

Horizon data

RYAN.HRZ File			SCHOONR1 File					
Azimuth (°)	Elevation (m)	Aspect (°)	Azimuth (°)	Elevation (m)	Aspect (°)	Azimuth (°)	Elevation (m)	Aspect (°)
30	37	270	15	12	225	195	18	360
75	30	270	30	12	225	210	13	360
90	31	270	45	12	225	225	17	360
135	32	270	60	18	225	255	12	360
210	6	270	75	16	270	270	2	360
255	18	270	90	13	360	285	0	90
300	40	270	105	10	360	300	1	180
315	44	270	120	7	360	315	2	180
			135	18	360	330	7	180
			165	51	360	345	10	225
			180	41	360	360	16	225

Results

	RYAN.INP and RYAN.HZN		SCHOONR1.DAT	
	Speed (m/sec)	Direction	Speed (m/sec)	Direction
General	2.69	192.66	1.23	203.02
Sea breeze	1.41	234.15	1.10	231.62
Slope	1.16	180.00	4.37	360.00
Valley	0.96	210.00	2.57	318.57
Resultant surface wind	5.87	202.11	2.57	318.57

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