PRELIMINARY ASSESSMENT OF ELECTROMAGNETIC INTERFERENCE EFFECTS OF THE CAPE BLANCO WINDFARM

Final Report

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EXECUTIVE SUMMARY

The potential interference effects of the proposed Cape Blanco Windfarm consisting of Flo 170, DAF 6400 or MOD-2 wind turbines (WTs) on the performance of various electromagnetic systems in its vicinity have been assessed theoretically. The present assessment has been carried out on the basis of information supplied by the sponsor. Specific non-military systems considered are: one VOR (Very High-Frequency Omni Range) system in a nearby airport; one Loran-C system whose transmitter is located at Cape Blanco; a number of radio systems used either for point-to-point communication (link) or for area communication; TV reception from a geostationary satellite at a home adjacent to the windfarm; TV reception of available commercial channels at a region adjacent to the windfarm. AM and FM broadcast reception outside the windfarm should not be affected significantly; within the windfarm, the reception within a few rotor diameters of the individual WTs may experience unacceptable interference effects. These systems have been excluded from further assessment.

The interference assessment has been carried out by assuming that the windfarm may consist of 475 Flo 170, 259 DAF 6400 or 31 MOD-2 wind turbines. Windfarm interference effects to each of the systems named earlier have been assessed on the basis of known criteria, and the assessment of such effects are summarized below.

(i) Navigation Systems

VOR. The VOR system at the airport will not experience any unacceptable effects due to the windfarm consisting of any of the three candidate WTs.

Loran-C. The windfarm of the candidate WTs will not have any significant effect on the Loran-C performance.

(ii) Miscellaneous Radio Systems

If the systems are used as links, it is unlikely that their performance will be adversely affected by the windfarm using any of the three candidate WTs. However, more detailed evaluation should be carried out before deciding on the actual distribution of MOD-2 WTs.

If the systems are used for area communication, their performance within and in the immediate vicinity of the windfarm may be affected adversely. More work is needed to quantify such effects.

(iii) TV Reception from Satellite

The windfarm of any of the two VAWTs may produce slight TVI effects at a site adjacent to the windfarm. With MOD-2 WTs the effects would be strong and unacceptable. Further work would be required to judge the severity of the effects.

(iv) TV Reception

At the same site under consideration, only the windfarm of MOD-2 WTs may produce strong and unacceptable TVI effects on some or all of the available TV Channels.

The above assessment is preliminary and identifies the potentially unacceptable effects by considering the average effects of the windfarm. It is recommended that further work be carried out to estimate the severity of adverse TVI effects. For this, it would be necessary to consider the detailed distribution of the WTs in the farm and the TV signal strengths in the area.

ACKNOWLEDGEMENTS

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1. Introduction

The present report is concerned with a preliminary assessment of the potential effects of interference produced by the proposed Cape Blanco Windfarm on the performance of various electromagnetic systems in its vicinity. The assessment is carried out theoretically on the basis of the information supplied by the sponsor, and is semi-quantitative; emphasis is placed on the identification of potentially unacceptable interference effects, if any. The specific systems considered are: (i) VHF Omnidirectional Range or VOR navigational system and LORAN-C, (ii) microwave repeating and point-to-point communication systems, (iii) television (TV) reception, (iv) TV reception from a Satellite Broadcast system and (v) FM and AM broadcast systems. There may be other electromagnetic systems in the neighborhood, e.g., microwave links; if information about them are available in the future they also should be considered.

There are a large number of AM and FM broadcast systems operating in the area. Reception of AM broadcast signals is usually vulnerable to various locally generated interference effects. The highest AM broadcast frequency being 1.6 MHz ($\lambda \simeq 188$ m), it is unlikely that the windfarm will produce any adverse effects unless the receiver is located within a few rotor diameters of a wind turbine (WT). The reception of FM broadcast signals would be even less vulnerable to such effects. Of the transmitters of all the AM and FM broadcast signals available in the area, the nearest to the windfarm being about 30 miles away (e.g. those at Coos Bay and Gold Beach), it is anticipated that their reception will not be adversely affected at points outside the windfarm.

For these reasons, these two systems have been excluded from further assessment.

The interference effects of concern arise because of the time varying multipath created by a rotating wind turbine (WT) blade [1]. The primary signal is generally reflected in an almost specular (mirror-like) manner off a blade to produce a secondary (interfering) signal. The strength of the latter is proportional to the equivalent scattering area (A_e) of the blade and decreases with increasing distance from the turbine; at any given distance it is also decreases with increasing frequency. If this secondary signal is sufficiently strong, it may combine with the primary signal at the receiver to produce unacceptable interference effects on the performance of the system under consideration. A key point is that because the reflection is specular, any given receiver will be affected only when the blade is suitably oriented. The nature and amount of the interference effects observed by the receiver depend on the nature of the electromagnetic system and its associated signal processing logic.

It should be pointed out that the observed interference caused by the assembly of WTs in the windfarm will generally be statistical in nature [2] depending on a number of parameters, and actual interference effects, if any, may be observed only over a fraction of time. However, we shall use non-statistical analyses to estimate the effects produced by the WTs, either singly or together, on each of the electromagnetic systems mentioned earlier. Our assessment will thus pertain to the maximum effects that may occur in a given case under worst conditions. The assessment procedure used is similar to that of our previous studies [3,4].

2. Background Information

Various information needed for the assessment are described in the present section.

2.1 Windfarm and Its Environment

The proposed windfarm (when fully established) will develop a wind energy facility of up to 80 MW capacity on a 1500 acre site south of, and about three miles from Cape Blanco, OR, as indicated on a road map section in Fig. 1(a), a project study area map of the windfarm is shown in Fig. 1(b). In addition to Cape Blanco, the large residential communities nearest to the windfarm may be at Denmark (~6 miles), Langlois (~9 miles) and Port Orford (~4 miles) (Fig. 1a).

The proposed windfarm site superimposed on the topographical map of the area is shown in Fig. 2; for future reference the approximate center of the windfarm is denoted by CF in Fig. 2. It is believed that there are a few residential homes in the region marked AA which borders almost on the windfarm (Fig. 2).

The total number of wind turbines to be deployed in the farm will depend on the specific choice made from the following three candidate WTs: FloWind 170, DAF 6400 and Boeing MOD-2. As presently planned, the total number of machines will be 475, 259 and 31, respectively, for the above three WTs. The windfarm itself is an unpopulated region with a maximum elevation of about 160 ft above sea level.

2.2 TV Stations

It is understood that TV signals on Channels 3, 5, 6 and 11 are generally available in the area. Table 2.1 lists the appropriate information about these TV signals.

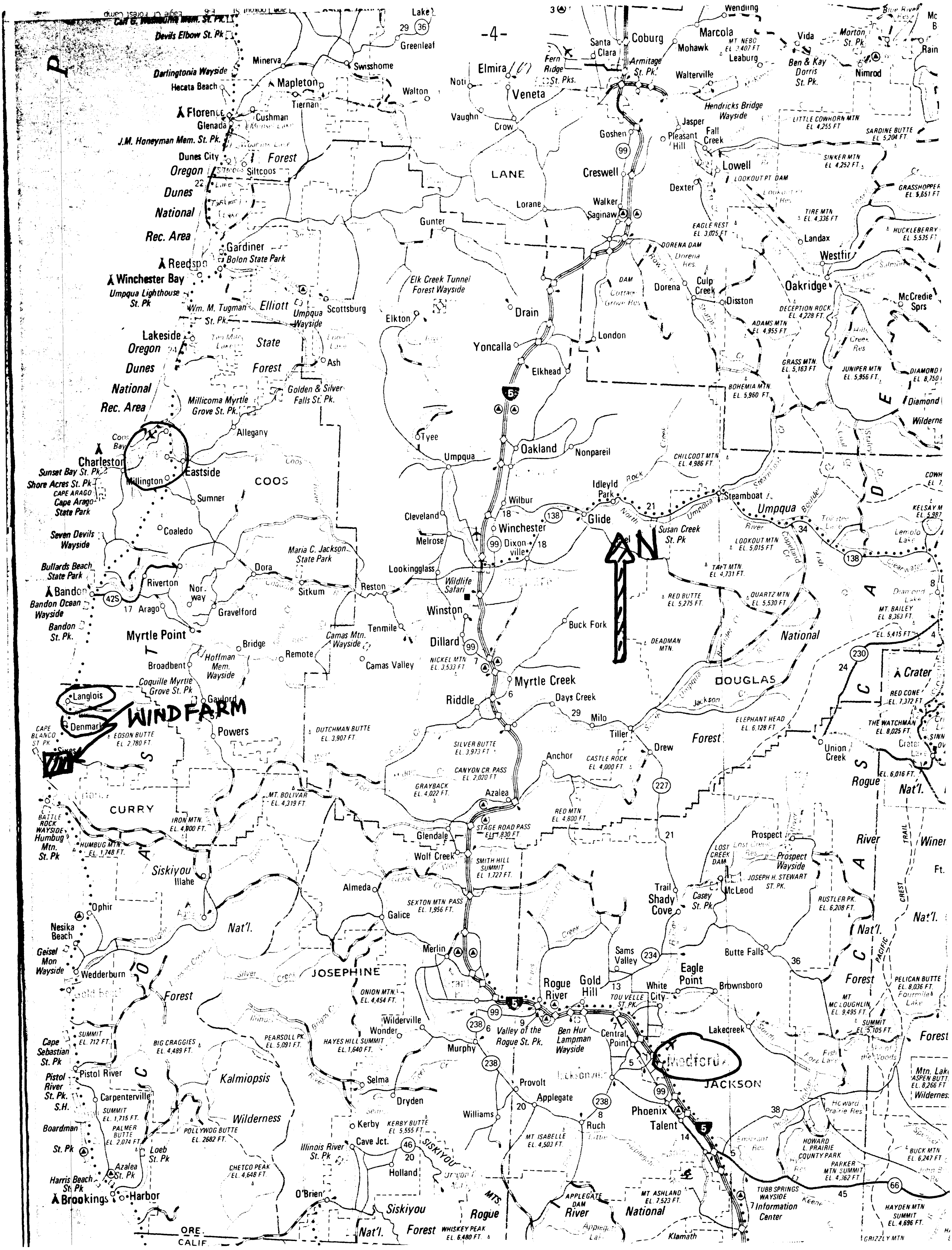

Fig. 1a: Road map of the Cape Blanco area, showing the general location of the windfarm indicated by ▨. (Scale: 1 inch = 15 miles)

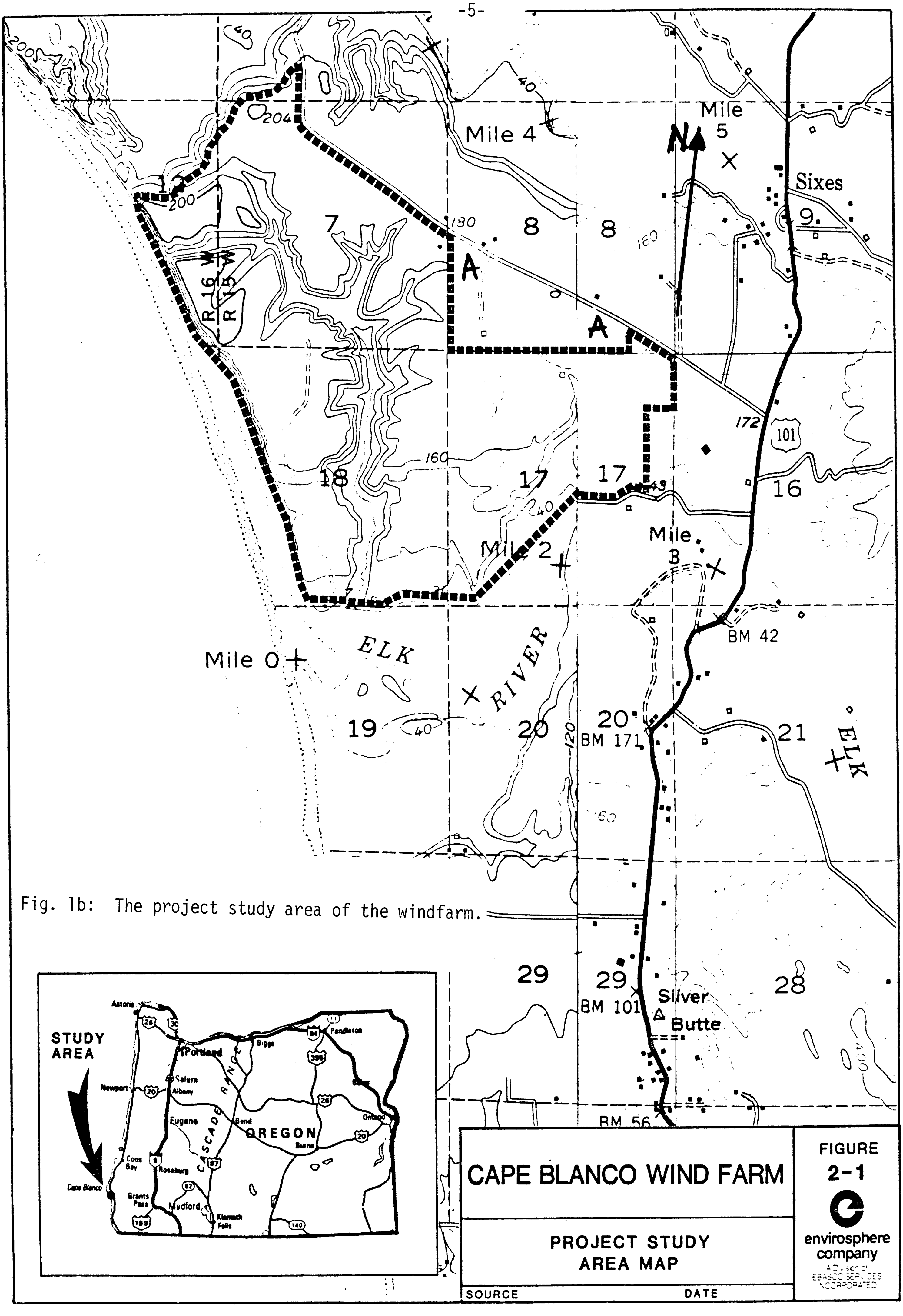

Fig. 1b: The project study area of the windfarm.

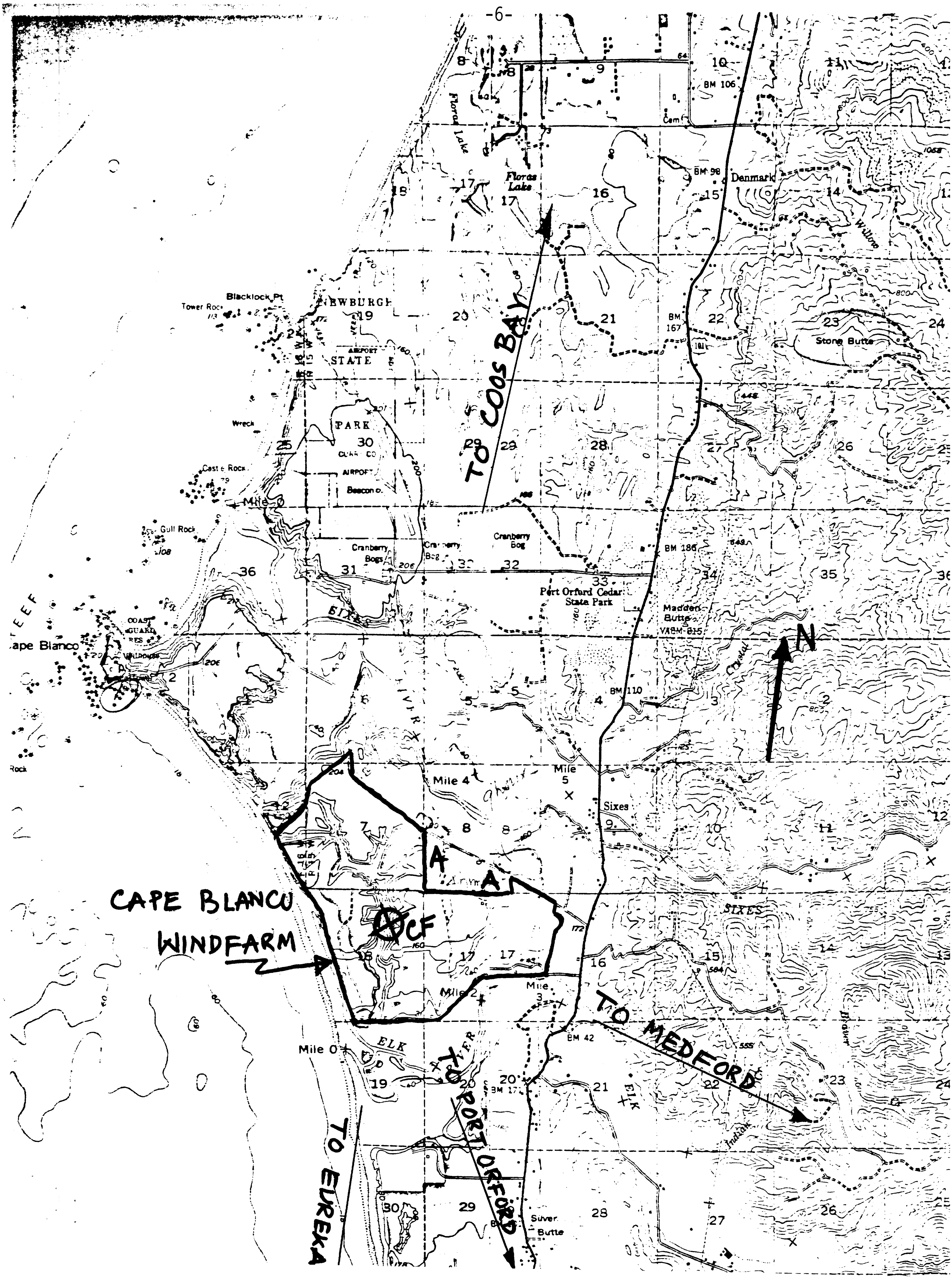

Fig. 2: Topographical map of the Cape Blanco windfarm. Approximate directions of the TV transmitters are shown.

Table 2.1

Available Channel Signals in the Windfarm Area

Station	Number	Video Frequency (MHz)	Origin	Distance from Windfarm (miles)
KIEM	3	61.25	Eureka,CA	>100
KOBI	5	77.25	Medford,OR	90
KVIQ	6	83.25	Eureka,CA	> 90
KCBY	11	199.25	Coos Bay,OR	40

A repeating station is located on a hill above Port Orford, OR (4 miles south of the windfarm site, see Fig. 1a) which receives the signals on Channels 5 and 11 and re-transmits them on Channels 8 and 2, respectivly, for local area coverage.

There are a few homes, in the region AA in Fig. 2, which are about 0.9 to 1.1 miles from the center of the windfarm; the nearest turbine is about 500 ft from these homes. Approximate directions of origin of various TV signals with respect to the windfarm are indicated in Fig. 2. It is believed that one of the homes in the region AA receives TV signals from a geo-stationary satellite; the five-foot dish antenna used by this home will generally be directed up towards the satellite in a southerly direction.

2.3 Navigation Systems

North of the windfarm, there is an airport located about 3.5 miles from the center of the windfarm. It is believed that there is a VOR ground station there to provide a navigation information to aircraft in flight. For computational purposes we shall assume that the operating frequency of the VOR is f = 120 MHz, with wavelength λ = 2.5 m.

At Cape Blanco, there is a 300 ft steel antenna tower located above a counterpoise made of 300 ft radial ground system. It is believed the transmitting antenna is used for LORAN-C system whose frequency f = 100 kHz, λ = 3 km.

2.4 Miscellaneous Radio Systems

There exists a number of radio systems (150 - 500 MHz) which along with repeating stations are used either for local area communication or for point-to-point communication purposes. They are:

i) Coos-Curry Electric Cooperative--Port Orford transmitter at Port Orford and repeater at Stone Butte,

ii) Oregon State Police repeater on Stone Butte,

iii) Curry County Sheriff repeater on Stone Butte. In the absence of precise knowledge of the frequencies of operation, it is assumed that the above three repeaters operate at $f = 200$ MHz, $\lambda = 1.5$ m.

iv) Bonneville Power Administration (BPA) repeaters at Cape Blanco link with a number of repeaters at distance places as shown in Table 2.2 where the frequencies shown are approximate values assumed for ease of calculation.

The geometry of the various link paths with respect to the windfarm is shown in Fig. 3.

2.5 Wind Turbines

It is understood that the wind turbine constituting the windfarm will be one of the following three models: FloWind 170, DAF 6400 and MOD-2. Of these the first two are vertical axis wind turbines (VAWTs) and the third is a horizontal axis wind turbine (HAWT). Relevant information about the three candidate WTs needed for their electromagnetic interference assessment are given in Table 2.3. All three machines have metal blades.

The most important parameter needed for the assessment of the electromagnetic interference caused by a wind turbine is the equivalent scattering area (A_e) of its blade [1]. For the two candidate VAWTs the appropriate A_e will be obtained by using the following [5]:

Table 2.2

BPA Repeaters at Cape Blanco Linking with Other

Repeaters and Their Frequencies

Repeater Location	Distance from Cape Blanco (miles)	Frequency (MHz)
Leneve	29	415
Rogue	25.9	415
Langlois	7.7	170
Port Orford	6.7	170
Gold Beach (retired)	30.3	415

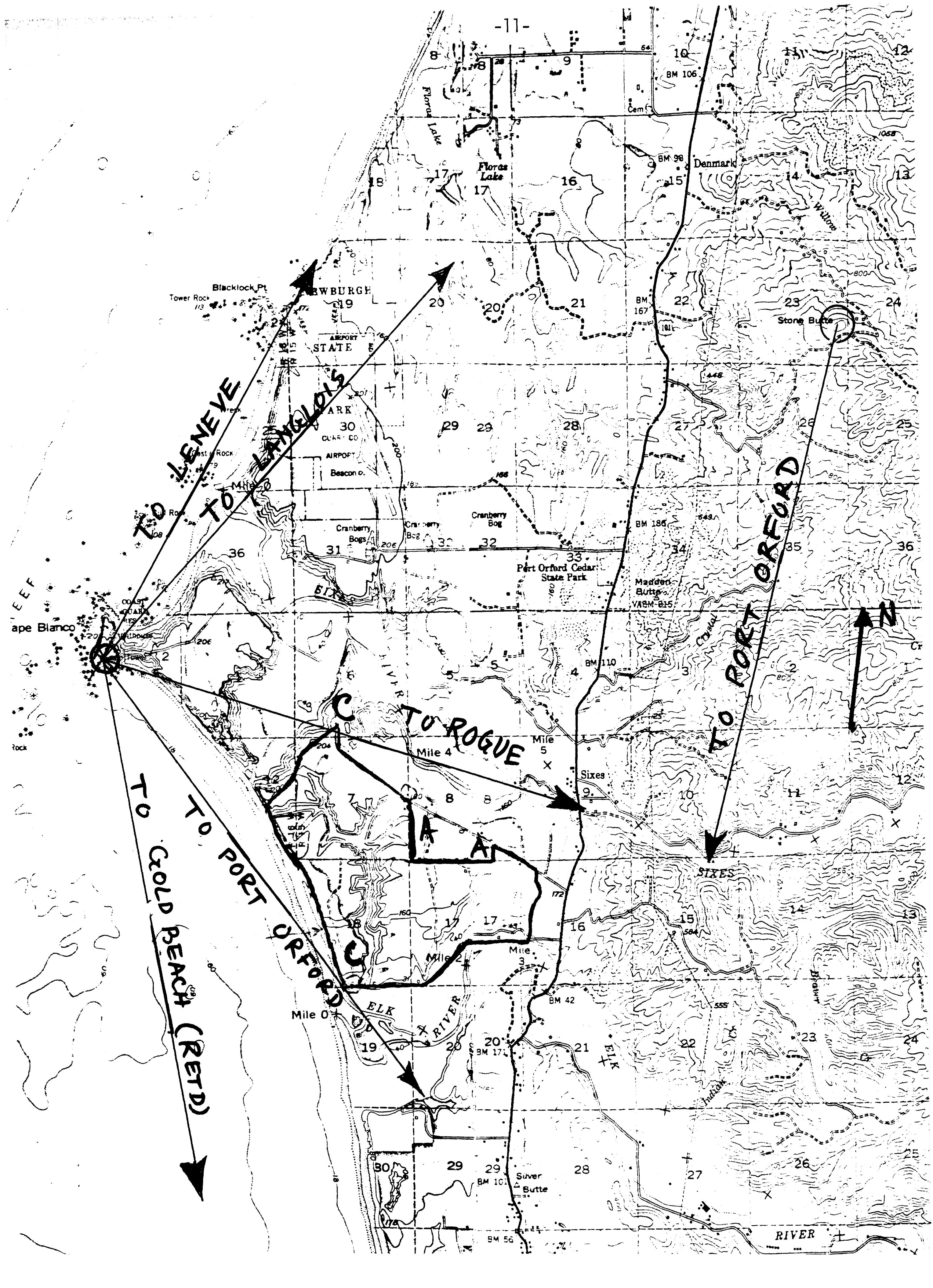

Fig. 3: Various radio systems in the windfarm area.

Table 2.3

Relevant Information about the Three Candidate

Wind Turbines

WT Type	Blade Width (m)	Rotor Dia. (m)	Overall Ht. (m)	rpm	Total Number To Be Used
F10 170 (170 kW)	0.61	17.1	28.0	53	455
DAF6400 (500 kW)	0.74	24.4	36.6	45	259
MOD-2 (2500 kW)	---	91.4	106.7	17.5	31

$$A_e = w\sqrt{D\lambda} \quad (1)$$

where w = blade width,

D = rotor diameter and

λ = wavelength.

For Flo 170, w = 0.61 m, D = 17.1 m and we obtain

$$A_e = 2.52\sqrt{\lambda}\ m^2 \quad . \quad (2a)$$

Similarly, using w = 0.74 m, D = 24.4 m we obtain for DAF 6400

$$A_e = 3.66\sqrt{\lambda}\ m^2 \quad . \quad (2b)$$

From our previous work [6], it is known that for MOD-2, A_e = 140 m^2. We shall use the above information for the assessment of interference to all systems cuased by the WTs.

3. Interference Assessment Procedure

The interference assessment which has been carried out is analytical and, in the case of those systems which are impacted, quantitative. The procedures used are based on the analyses and techniques developed by the Radiation Laboratory during our previous studies of electromagnetic interference produced by WTs, the details of which may be found in [1,6-8]. In the present section we merely quote the basic criteria used to judge the acceptability (or unacceptability) of the interference effects produced in a given situation, and these same criteria are also used to judge the acceptability (or unacceptability) of a particular WT at a given site.

The basic parameter that is used to judge the effect of WT-produced interference on an electromagnetic system is

$$\Gamma = \frac{\text{amplitude of the interference signal caused by one WT}}{\text{amplitude of the desired (direct) signal}} , \quad (3)$$

where the fields are computed at the receiver of the system under consideration. As mentioned in the Introduction, the interference signal is produced by scattering off the WT blade(s), and in general

$$\Gamma = \frac{E_B}{E_R} \frac{A_e}{\lambda d} , \quad (4)$$

where E_B, E_R are the amplitudes of the ambient electric fields at the WT and the receivers, respectively

λ is the operating wavelength and

d is the distance between the WT and the receiver.

Γ also depends in a rather complicated manner on the ambient signal strengths at the WT and receiver locations, and on the receiving antenna characteristics [8]. In our previous studies we developed approximate expressions for Γ under various situations. In the absence of specific information about E_B and E_R we shall make appropriate approximations in individual cases. Assuming that the interference effects produced by the individual machines are additive in power, the total effect produced by N WTs is then judged by the parameter Γ_T:

$$\Gamma_T = \left(\sum_{n=1}^{N} \Gamma_n^2 \right)^{1/2} ,$$

where Γ_n is that produced by the nth WT. In many cases we shall assume $\Gamma_1 = \Gamma_2 .. = \Gamma_N = \Gamma$, and use

$$\Gamma_T = \sqrt{N}\,\Gamma \quad . \tag{5}$$

In some cases only the machine(s) closest to the receiver cause most of the problem, but in other cases there can be many machines which contribute significantly to the total effect. The actual criteria (including the values of Γ_T or Γ) which are used to judge the interference effects depend on the electromagnetic system under consideration, and are discussed in the following sections.

3.1 Interference to VOR

In the vicinity of a VOR ground station the FAA prohibits [9] the existence of any tall scattering object which makes an angle of more than 1.5 degrees (for metal objects) and 2.5 degrees (for wooden or non-metallic objects) at the phase center of the VOR antennas. It is also recommended that the amplitudes of any reflected or scattered interfering signal relative to that of the desired signal at the receiver not exceed 20 percent. We shall use the following acceptability criterion for assessing the effect of interference on VOR performance:

$$\Gamma_T \text{ (or } \Gamma) \leq 0.2 \text{ (or -14 dB)} \quad . \tag{6}$$

3.2 Interference to Microwave Links and Radio Systems

The satisfactory performance of a microwave link system requires that there be adequate clearance between link path, i.e., the optical line-of-sight transmission path between the two link antennas, and any nearby scattering objects. It is often required [10] that all scattering objects lie outside the first few Fresnel zones as shown in Fig. 4 and in the present case we shall use the acceptability criterion

$$H \geq 3H_1 \quad . \qquad (7)$$

The parameter H_1 is obtained from a knowledge of d, d_1 and the operating wavelength.

In the case of a radio system used for area communication, the Γ_T (or Γ) criterion (Eq. 8) is applied to estimate the magnitude of the scattered (or interfering) signal relative to the desired one.

3.3 Interference to Television Reception from a Satellite

Interference to TV reception from a geo-stationary satellite can be assessed by using the Fresnel distance criterion, given by Eq. (7). We have also used the acceptability criterion

$$\Gamma_T \leq 0.01 \text{ (-40 dB)} \qquad (8)$$

to estimate the level of interference signal at the receiving antenna.

3.4 Interference to Television Reception

WT interference effects to TV reception generally appear in the form of video distortion occurring at twice the rotation frequency of the blade. The dominant parameter determining the interference by a WT is the equivalent scattering area of its blade. However, at a certain

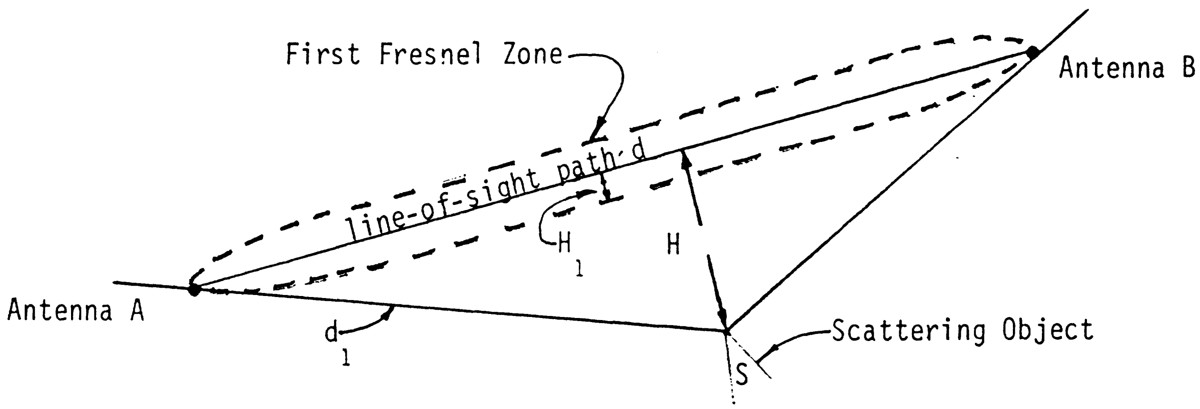

Fig. 4: Diagram showing a scattering object outside the first Fresnel zone of the link antennas.

H_1 = first Fresnel zone distance and

H = the clearance of S from the link path.

distance from the WT the maximum video distortion observed depends on the state of the WT blade (i.e., pitch, plane of rotation, etc.), the ambient signal strengths at the WT and the receiver, the characteristics of the receiving antenna, and on whether the receiver is located in the forward or backward region of the WT. In the backward region the directional property of the receiving antenna may be used to discriminate against the interference effects but in the forward region this cannot be done and hence the effects may be more severe.

When the blades are stationary the scattered field may appear on the TV screen as a ghost whose position (i.e., separation from the direct picture) depends on the difference between the time delays suffered by the direct and scattered signals. A rotation of the blades then causes the ghost to fluctuate, and if the ghost is sufficiently strong, the resulting interference can be objectionable. In such cases, the received picture displays a horizontal jitter in synchronism with the blade rotation. As the interference increases, the entire (fuzzy) picture shows a pulsed brightening, and still larger interference can disrupt the TV reciever's vertical sync, causing the picture to roll over ('slip') or even break up. This type of interference occurs when the interfering signal reaches the receiver as a result of scattering, primarily specular, off the broad face of a blade, and is called the backward region interference. As the angle between the WT-transmitter and WT-reciever directions increases, the separation of the ghost decreases, and a somewhat greater interference is now required to produce the same amount of distortion. In the forward scattering region, when the WT is almost in line between the transmitter and the receiver, there is virtually no difference in the times of arrival of the primary and secondary signals. The ghost is then superimposed on the undistorted picture and the video interference appears as an intensity (brightness) fluctuation of the picture in synchronism with the blade rotation. In all cases, the amount of interference depends on the strength of the scattered signal relative to the primary signal at the receiver, i.e., on the modulation index of the total received signal, and the modulation threshold is defined to be the largest value of the modulation index for which the distortion is still judged to be acceptable.

It can be shown [1,2,7,6] that in the case of television interference (TVI) caused by WTs, the parameter Γ_T (or Γ), defined earlier, can be interpreted as the amplitude modulation index m_T (or m) suffered by the received signal due to the scattering by the rotating WT blades. Judgement of TVI effects or the video distortion observed in made on the basis of m_T (or m).

In the backward region for all levels of ambient signals, and in the forward region where the ambient signal is weak, interference effects are judged to be acceptable if

$$m_T \text{ (or } m) \leq 0.15 \quad (\sim -17 \text{ dB}) \quad . \tag{9}$$

For a receiver in the forward region where the ambient signal is strong, the corresponding criterion is

$$m_T \text{ (or } m) \leq 0.35 \quad (\sim -9 \text{ dB}) \quad . \tag{10}$$

The above criteria are based on the subjective assumption [6] that the resultant video distortion is acceptable. For satisfactory performance of a CATV Head-end the requirement on the interfering signal is more severe [11] and we shall assume the following acceptability criterion:

$$m_T \text{ (or } m) \leq 0.05 \quad (-26 \text{ dB}) \quad . \qquad (11)$$

4. Assessment of Interference

The windfarm interference effects on various systems are estimated in the present section. The assessment includes the effects of 475 units of FloWind 170, 259 units of DAF 6400, and 31 units of MOD-2 WTs. The present assessment being preliminary, the detailed distribution of the WTs has not been taken into account. As mentioned previously, the purpose of the present assessment is mainly to identify any potentially unacceptable effects.

4.1 Interference to Navigation Systems

VOR. It is assumed that there is a VOR ground station located (at the airport) 5.6 km from the center of the windfarm. Table 4.1 gives the acceptable minimum distances from the VOR where the three types of WTs may be installed.

Sample calculations also indicate that Γ_T obtained with the windfarm satisfy the criterion given by Eq. (6). The windfarm being 5.6 km from the VOR station, it is concluded that any interference effects produced would be insignificant.

Table 4.1

Acceptable Minimum Distances of WTs from the VOR Ground Station

WT Type	Distance (km)
F10 170	1.07
DAF 6400	1.22
MOD-2	3.90

Loran-C. The Loran-C transmitting antenna is located (at Cape Blanco) about 4.8 km from the center of the windfarm. The wavelength of Loran-C system being 3 km, it is concluded on the basis of our previous work [2] that a windfarm consisting of any of the three candidate WTs will not have any signficant effect on the performance of the Loran-C transmitter or receiver.

4.2 Interference to Miscellaneous Radio Systems

Assuming that all the systems shown in Fig. 3 are meant for point-to-point communication, i.e., used as links, it is found that on the basis of Fresnel distance criterion Eq. (7) their peformance would not be adversely affected by the windfarm using any of the three candidate WTs. However, if a choice is made to use the MOD-2 WT, detailed calculations be made to ensure that WTs placed in the regions marked C in Fig. 3 satisfy the acceptability criterion.

If the systems are used for area communication, it seems that their performance within and immediate vicinity of the windfarm will be adversely affected depending on the system. Detailed calculations would be necessary to estimate the severity of the interference effects.

4.3 Interference to TV Reception from Satellites

It is believed that one of the residential homes in the region AA of Fig. 2 received TV signals from a geo-stationary satellite with the help of a five-foot dish antenna. Assuming that the distance of the home from the center of the farm to be about 1.6 km and the receiving antenna discrimination to be -25 dB and the operating frequency f = 4.0 GHz (λ = 0.075 m) Γ_T values have been calculated for the

Table 4.2

Γ_T Values at the Receiver for Different WTs

WT Type	Γ_T Due to the Windfarm
Flo 170	-37 dB
DAF 6400	-36 dB
MOD-2	-3 dB

Note: acceptable $\Gamma_T \leq -40$ dB.

windfarm using different WTs; and the results are shown in Table 4.3

According to the criterion given by Eq. (8) it appears that the TV reception would be affected adversely. However, if the acceptability criterion is relaxed slightly the two VAWTs would be acceptable. A windfarm of MOD-2 WTs most probably will adversely affect the TV reception at this home.

4.4 Interference to TV Reception

As mentioned earlier, TV signals on Channels 5, 11,3 and 6 are generally available in the area; the transmitters of Channels 5 and 11 are located at Medford (~90 miles from CF) and Coos Bay (~40 miles from CF), respectively and those of Channels 3 and 6 are located at Eureka, CA (more than 100 miles from CF). Channels 5 and 11 are usually recieved on Channels 8 and 2, respectively, though repeaters located on a hill above Port Oxford, OR, about four miles away from the windfarm. The general orientation of the origins of the various signals are indicated in Fig. 2. We shall concentrate on the TV reception in the region AA (Fig. 2) where some residential homes are located. These homes will be looking through the windfarm to receive their desired signals (except for receiving Channel 11 directly from Coos Bay), and hence may be vulnerable to unacceptable television interference (TVI) effects. In the absence of a precise knowledge of the signal strengths at the receiving site and at the wind turbines, it is arbitrarily assumed that $E_B/E_R \simeq 2$. Assuming that receiving site is located in the region AA (Fig. 2) and at a distance of 1.6 km from the center of the windfarm, we have calculated the appropriate m values at the receiver caused by the windfarm using the three candidate wind turbines. The results are shown in Table 4.3.

Under the assumption that unacceptable TVI effects would occur for $m_T > -17$ dB, the results of Table 4.3 indicate that the MOD-2 windfarm would adversely affect the RV reception under consideration. The windfarm using either Flo 170 or DAF 6400 WTs would not produce any unacceptable interference to television reception at the site.

5. Conclusions

The fundamental parameter required to estimate the electromagnetic interference effects of a WT is the equivalent scattering area of its blade. To the best of our knowledge, such information about two of the candidate WTs (e.g., Flo 170, DAF 6400) for the Cape Blanco windfarm is not yet precisely known. We have obtained, only approximately, the required information by applying extrapolation laws to our present knowledge of the scattering area of the 17-m Darrieus developed by the Sandia Laboratories. Since the two candidate VAWRs are similar to the Darrieus, it is believed that the estimates of the scattering areas used for the present assessment is valid.

The TVI effects at a receiving site depend quite strongly on the ratio of ambient signal strengths at the receiving and WT sites, and also on the nature of the terrain. It is difficult to determine these signals theoretically. Although we have made approximations to these parameters based on our experience the actual signal ratios may be different. Moreover, detailed considerations of the actual distribution of the WTs in the farm have been omitted during the assessment. For more precise TVI assessment, it is recommended that better estimates of the ambient

Table 4.3

m_T Values for TVI Effects at a Site in AA-Region Due to the Windfarm

(Receiving antenna isotropic)

TV Channel No.	Flo 170	m_T (dB) DAF 6400	MOD-2
2	-25	-25	-10
3	-24.3	-23.7	-8.2
6	-22.8	-22.3	-5.3
8	-19.6	-19.1	~ -2

Note: TVI effects acceptable if $m_T \leq -17$ dB signals be made (either by measurement or better approximation based on the precise knowledge of the terrain) and the assessment be carried out more rigorously.

References

1. D. L. Sengupta and T.B.A. Senior, "Electromagnetic Interference to Television Reception Caused by Horizontal Axis Windmills," Proc. IEEE, Vol. 67, No. 8, pp. 1133-1142, August 1979.

2. D. L. Sengupta and T.B.A. Senior, "Wind Turbine Generator Interference to Electromagnetic Systems," University of Michigan Radiation Laboratory Report 014438-3-F, August 1979.

3. D. L. Sengupta, T.B.A. Senior and J. E. Ferris, "Assessment of Electromagnetic Effects of the Solano Windfarm," Radiation Laboratory Report 388266-1-F, November 1981.

4. D. L. Sengupta and J. E. Ferris, "Assessment of Electromagnetic Interference Effects of the Ellenville Windfarm", Radiation Laboratory Report 388629-1-F, November 1983.

5. D. L. Sengupta and T.B.A. Senior, "Measurements of Television Interference Caused by a Vertical Axis Wind Machine," SERI/STR-215-1881, Solar Energy Research Institute, Golden, CO 80401.

6. D. L. Sengupta and T.B.A. Senior, "Electromagnetic Interference by Wind Turbine Generators," University of Michigan Laboratory Report 0.4438-2-F, March 1978.

7. T.B.A. Senior and D. L. Sengupta, "Large Wind Siting Handbook: Television Interference Assessments," University of Michigan Radiation Laboratory Report 014438-5-T, April 1981.

8. D. L. Sengupta, T.B.A. Senior and J. E. Ferris, "Measurements of Interference to Television Reception Caused by the MOD-1 WT at Boone, NC," University of Michigan Radiation Laboratory Report 018291-1-T, January 1981.

9. "Handbook: VOR/VORTAC Siting Criteria," Federal Aviation Administration, Department of Transportation, Report 6700.11, August 7, 1968.

10. Members of the Technical Staff, "Transmission Systems for Communications," Fourth Edition, Bell Telephone Laboratories, Inc., December 1971.

11. ITT, "Reference Data for Radio Engineers," Sixth Edition, Indianapolis, Indiana, p. 30-18, 1975.