Environmental Report:
BENT TREE WIND PROJECT

In the Matter of the Wisconsin Power and Light Company
Application for a Certificate of Need for a 200 Megawatt
Large Wind Energy Conversion System in Freeborn County

PUC Docket No. ET6657/CN-07-1425

Energy Facilities Permitting
85 7th Place East, Suite 500
Saint Paul, MN 55101

June 2009

Responsible Governmental Unit	Project Proposer
Minnesota Office of Energy Security	**Wisconsin Power and Light Company**
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Abstract

Wisconsin Power and Light Company, (Applicant or WPL) made an application to the Minnesota Public Utilities Commission (PUC or Commission) for a Certificate of Need for the Bent Tree Wind Project and an 18-mile long161 kilovolt (kV) high voltage transmission line (HVTL) on June 27, 2008, pursuant to the provisions of Minnesota Statutes 216B.243 and 216F.

The Applicant is proposing to construct and operate a new 200 MW Large Wind Energy Conversion System (LWECS) and a 161 kV HVTL for Project interconnection to the transmission grid in Mower County. The Project would be part of the larger 400 MW Project that WPL would like to construct in multiple phases as proposed by WPL in its application for a Site Permit (PUC Docket No. ET-6657/WS-08-573).

The Office of Energy Security (OES), Energy Facilities Permitting (EFP) staff is responsible for preparing the Environmental Report (ER) required for the Certificate of Need. This report has been prepared as per Minnesota Rule 7849.0010-0110.

Persons interested in these matters can visit the Site Permit Project Docket webpage at http://energyfacilities.puc.state.mn.us/Docket.html?Id=19665 or contact Larry Hartman, 85 7th Place East, Suite 500, St. Paul, Minnesota 55101, phone (651) 296-5089, e-mail: larry.hartman@state.mn.us. Documents of interest can be found at the above website or by entering "07-1425" as the search criteria after going to https://www.eDockets.state.mn.us/EFiling/search.jsp.

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1.0 Introduction

On June 27, 2008, Wisconsin Power and Light Company (Applicant or WPL), filed an application with the Minnesota Public Utilities Commission (PUC or Commission) for a Certificate of Need (PUC Docket No. ET6657/CN-07-1425) for the Bent Tree Wind Project in Freeborn County. Wisconsin Power and Light Company, a Wisconsin public utility and wholly owned subsidiary of Alliant Energy Corporation, propose to build the Bent Tree Wind Project in northwest Freeborn County. The Project's wind turbines and associated facilities, which also include approximately 18 miles of 161 kV high voltage transmission line (HVTL), will be owned and operated exclusively by WPL, and all energy generated by the Project will be used to meet Wisconsin's Renewable Portfolio Standard (RPS) requirements and to meet the electricity needs of WPL's retail and wholesale customers.

The Minnesota Office of Energy Security (OES), Energy Facilities Permitting (EFP) is required to perform environmental review on applications for Certificates of Need. This process is undertaken to inform the public, the Applicants and decision makers concerning potential impacts and possible mitigations for the project and any alternatives.

Chapter 2 provides specific information about the proposed project, the project proposer, and the regulatory process for the Certificate of Need. Chapters 3 and 4 describe and analyze alternatives to the proposed Project that attempt to reduce, mitigate or eliminate the need for the proposed Large Wind Energy Conversion System (LWECS), associated facilities and 161 kV HVTL. This analysis of alternatives is required by Minnesota Rule 7849.0230 and 7849.7060 for the Certificate of Need application.

Chapter 5 provides the analysis of the impacts of the proposal and alternatives required under Minnesota Rule 7849.7060. Chapters 6 and 7 address possible mitigations to the human and environmental impacts of Applicant's proposal and the alternatives and the feasibility of each. Chapter 8 describes the additional permits that may be required for this project.

Much of the information used in this ER is derived from the *Application for a Certificate of Need for the Bent Tree Wind Project*, dated June 27, 2008. Additional information was gleaned from earlier, related Environmental Quality Board and EFP reports. First hand information was gathered by EFP staff field inspection and review of aerial photography for the proposed site.

2.0 General Description of the Proposed Project

Minnesota Rule 7849.7060, subp. 1. A requires the Environmental Report to provide a description of the proposed project. This section describes the proposed project and the proposed owners. Additionally, this section reviews the regulatory process for an environmental review at the Certificate of Need (CN) stage.

2.1 Project Description

The project under review is called the Bent Tree Wind Project (Project). The Project is a large wind energy conversion system, as defined in the Wind Siting Act, Minnesota Statute 216F.01–216F.07. This Project is also a large energy facility (LEF), as defined in Minnesota Statute 216B.2421.

The first phase of the Bent Tree Wind Project as proposed would be an LWECS of up to 200 MW and would consist of up to 121 1.65 MW wind turbine generators. The towers would be 80 meters (262.5 feet) in height. The rotor diameter would be 82 meters (269 feet), resulting in a maximum overall height of 121 meters (388.8 feet) when one blade is in the vertical position.

The electrical collector system would consist of underground 34.5 kV collection lines and facilities providing step-up transformation. The Applicant is also proposing to build a wind farm collector substation which would be comprised of: eight (8) 34.5 kV collector circuits that feed from the turbine sites into the substation; two (2) 34.5/161 kV transformers with high and low side circuit breakers for protection; circuit breakers and protection devices for each collector feeder line; a reactor/cap bank system installed on the 34.5 kV bus for generator reactive power compensation purposes; a 161 kV switch station with two terminals. One of the terminals will connect into the new 161 kV HVTL going to the Hayward ITC-Midwest substation. The second terminal will be reserved for connecting the second, north phase of the Bent Tree wind farm at a later date.

Power from the turbines would be collected at this substation and transmitted to the ITC-Midwest LLC (ITC) Hayward Substation, located east of Albert Lea, via a 18-mile long 161 kilovolt (kV) HVTL. The 161 kV HVTL will use single and double circuit poles; either steel or wooden. The steel poles will have a galvanized or weathering steel finish and construction on concrete foundations. The poles will average 90 feet in height, and the average span between structures will be 300 to 500 feet. The required right-of-way may vary in width from 50 to 100

feet, depending on design and constraints on or along the Freeborn county designated HVTL route.

If one assumes an estimated net capacity factor of approximately 38 percent, projected average annual output would be 666,000 megawatt hours (MWh). The annual capacity factor will vary based on weather conditions and operational and maintenance issues associated with the facility. Output will also be dependent on final design, site-specific features, and equipment.

The Project would be located in northwestern Freeborn County, northwest of Albert Lea. Appendix A contains a map of the proposed LWECS site boundaries and 161 kV transmission line study area. The four townships encompassing the Project Area (Hartland, Manchester, Bath and Bancroft) are zoned as agricultural, with exception of the incorporated towns of Hartland and Manchester. Towers will not be placed within the incorporated areas. The Applicant has designated approximately 50 square miles as the Project area.

The Project is part of a larger Bent Tree Wind Project site application. The entire project could be comprised of up to 242 Vestas 1.65 MW turbines with a nameplate capacity of approximately 400 MW.

2.2 Project Proposers

Wisconsin Power & Light Company (WPL), a Wisconsin public utility and wholly owned subsidiary of Alliant Energy Corporation, proposes to build the Bent Tree Wind Project (Project). The Project's wind turbines and associated facilities will be owned and operated exclusively by WPL, and all energy generated by the Project will be used to meet Wisconsin's Renewable Portfolio Standard (RPS) requirements and to meet the electricity needs of WPL's retail and wholesale customers.

WPL's Integrated Resource Plan (IRP) demonstrates a need for 300 MW of new wind resources between 2008 and 2010. WPL is acquiring the first one-third of the 300 MW of new wind resources with a 27.5 MW Purchased Power Agreement (PPA) with Forward Energy, and construction of the 68 MW Cedar Ridge Windfarm (Cedar Ridge) in Fond du Lac County, Wisconsin. Forward Energy began commercial operation in April 2008 and Cedar Ridge in the fourth quarter of 2008. This 200 MW portion of the Bent Tree Wind Project will complement WPL's existing Forward Energy and Cedar Ridge wind resources.

2.3 Summary of the Environmental Report Process

The Applicant filed its CN Application on April 1, 2008. On May 21, 2008, the PUC accepted the CN as complete, given the Applicant's filing of supplemental materials.

The OES is the responsible governmental unit required to prepare an Environmental Report on large energy projects for which a certificate of need is required from the PUC. Minnesota Rule 7849.7010–7849.1110.

OES staff has followed the process for preparing an Environmental Report outlined in Minnesota Rule 7849.7050. Interested persons were notified of the project by mail. A project page was constructed on the PUC's Energy Facilities website in conjunction with the site permit application site. In accordance with Minnesota Rule 7849.7050, subp. 3, OES EFP staff held public meetings on the project on October 21, 2008, in Albert Lea and Hartland. The public was provided with an opportunity to ask questions, present comments, and suggest alternatives and possible impacts to be evaluated in the Environmental Report. The public comment period closed on December 5, 2008. Twenty-eight written comments were received during the comment period. These comments addressed the draft site permit conditions, setbacks and health and safety issues associated with wind farms.

On January 2, 2009, OES Director William Glahn issued a scoping decision determining alternatives and items to be addressed in the Environmental Report and the schedule for completion of the Environmental Report. The Scoping Order is available in Appendix B.

3.0 General Description of Project Alternatives

Minnesota Rule 7849.7060, subp. 1. B requires the Environmental Report to address alternatives to the proposed project. The purpose of an Environmental Report is to provide the Public Utilities Commission and the public with information on the potential environmental impacts of a proposed project and of alternatives to the project that meet the stated need of the project. Normally, that would involve comparing the impacts of burning coal with burning natural gas or other fuels, or comparing the impacts of using renewable alternatives or constructing additional transmission facilities.

In this case, however, since the proposed project is a wind project intended to address WPL's obligations to increase its use of renewable resources for electricity generation, there is no reason to evaluate the impacts of 200 megawatts of generation from fossil fuels or the impacts associated with the use of increased transmission. Those options are not technologies eligible to be counted toward WPL's compliance with the Renewable Portfolio Energy Standards (REPS). Therefore, this Environmental Report analyzes the potential impacts associated with the Bent Tree Wind Project and the impacts of three alternatives to the proposed project: (1) a "no-build" alternative, (2) a generic 200 megawatt wind project in some other location; and (3) a biomass plant.

3.1 No-build Alternative

The no-build alternative means that no wind project is constructed.

3.2 200 MW LWECS

In most certificates of need proceedings, where the issue is whether additional electricity is needed to serve certain customers or a certain area, the PUC considers the various means by which an increased demand for electricity can be met. This usually involves analyzing the impacts associated with construction of new generating facilities burning various fossil fuels, such as coal and natural gas, and the impacts related to construction of new transmission facilities. After the PUC determines the need for a new facility, and the size, type, and timing of that facility, or voltage if the need is for more transmission, the Public Utilities Commission then determines the appropriate site for the new power plant or route for a new transmission line.

In this case, however, where the need is progress toward achieving the Renewable Energy Standard or Portfolio Standard, that kind of comparison is not applicable, as the electrical generating technologies eligible to be counted toward the RPS are limited to specific renewable

technologies. What is appropriate is to evaluate the impacts of a different wind project. A wind project could be constructed, for example, in another part of the state. The project could theoretically be one 200 MW system or a combination of smaller, dispersed projects. The analysis here will attempt to describe any differences in the impacts associated with the location of a generic 200 MW wind project and the Brent Tree Wind Project.

3.3 77 MW Biomass Plant

The third alternative to be evaluated in this Report is a biomass plant. Biomass includes materials such as trees and plant material. A biomass plant would be considered an eligible renewable technology and would count towards the Renewable Energy Standard.

There are various sources of biomass fuel that could be considered. One proposal was made a few years ago to burn alfalfa. St. Paul District Energy, a combined heat and power facility in downtown St. Paul is an active facility fueled primarily by waste wood and has an electric generation capacity of 25 MW. This capacity is sold to Xcel Energy to satisfy part of Xcel Energy's biomass mandate. The 55 MW Fibrominn plant completed in Benson, Minnesota, burns turkey litter. Finally, the Laurentian Energy Authority operates facilities in Hibbing and Virginia with a combined capacity of 35 MW that convert wood, wood wastes and agricultural biomass into electricity.

The biomass alternative included for review in this Environmental Report is one that would burn a combination of hybrid willows, poplars, and corn stover, with natural gas as a backup fuel. This alternative was considered because such a plant, a proposed NGPP Minnesota Biomass, LLC, electric generation facility, has already undergone environmental review in Minnesota, and data regarding potential environmental impacts associated with such a plant are already available. Given the likelihood of available feedstock in the project area, such a biomass plant is more feasible than one burning alfalfa or a second turkey litter plant.

The plant was reviewed by the Environmental Quality Board in 2003 when it prepared an Environmental Assessment Worksheet on the proposed facility. See EQB Docket No. 03-67-EAW-NGP Biomass. The EAW can be found on the EFP website at:

http://energyfacilities.puc.state.mn.us/Docket.html?Id=4452

At the time that it was reviewed by the EQB, the NGPP project was a 38.5 MW project. The analysis that was conducted on that facility by the EQB is still valid for use as an alternative analysis in this Environmental Report. Since the Bent Tree Wind Project calls for a capacity of

approximately 200 MW, but will have an estimated capacity factor of 35 to 40 percent, the biomass alternative examined in this document is an appropriately-sized generation alternative.

4.0 Addressing the No-build Alternative

Often, in conducting environmental review, the analysis of the no-build alternative involves a discussion of the environmental impacts of continuing the status quo. For example, with a proposed highway project, the no-build alternative would take into account the impacts associated with continuing to have traffic increase along existing roads and highways and for development to occur along these existing arteries.

Three categories of impacts have been identified if the Bent Tree Wind Project is not built. One is the impact not building the project will have on Wisconsin's goal to achieve greater production of electricity through renewable resources. The second is the impact not building the project will have on the people and the economy in the area where the Bent Tree Wind Project has been proposed. And the third is the impact associated with the generation of electricity in a manner other than by the Bent Tree Wind Project.

4.1 Renewable Energy Standard

WPL has indicated that all energy generated by the Bent Tree Wind Project will be used to meet Wisconsin's Renewable Portfolio Standard (RPS) requirements. WPL anticipates that the Project will satisfy 200 MW of its Renewable Energy Standard requirements.

4.2 Impacts on the Bent Tree Wind Project Area

Not building the Bent Tree Wind Project would, of course, impact the farmers and landowners who are participating in the project and who anticipate receiving annual payments from the project. No figures are available for what those payments would be, but the amounts are likely to be in the thousands of dollars annually for each participant. The Project will also provide income to the community through production tax payments of approximately $792,000 per year to the county and townships, jobs, and local spending. These income streams would not be available in the Bent Tree Wind Project area if this project were to be constructed elsewhere.

4.3 Replacement Power

If the Bent Tree Wind Project is not built, the electricity that it would generate would come from somewhere else. And, if the Bent Tree Wind Project is not built, WPL would have to find another renewable energy project to provide electricity, resulting in a delay in obtaining this 200 MW of renewable energy or a possible increase in the cost of energy.

It is possible to perform the math to determine how many additional tons of certain pollutants would be emitted into the atmosphere based on assumptions of what generating facility the electricity were to come from if the Bent Tree Wind Project were not available. The Minnesota Pollution Control Agency (MPCA) has determined the emission rates per unit of electricity generated for a number of generating facilities in the state. These results are found in the Energy Planning Report prepared by the Department of Commerce in 2001 at page 95, Figure A-4. That report is available at:

http://www.state.mn.us/mn/externalOESs/Commerce/Energy_Planning_Report_121602022402_2002PlanningRpt.pdf

The 200 MW Bent Tree Wind Project would produce approximately 700,000 MWh per year when it is up and running. If this electricity were replaced by electricity generated at Xcel Energy's Sherco Plant, for example, the additional emissions of NOx, SO2 and CO2, based on the MPCA figures in the Planning Report, would be:

1,100 tons/year of NOx
1,100 tons/year of SO2
836,000 tons/year of CO2.

The math is as follows: MWh/yr x (emission lbs/kWh x 1000 kWh) x 1 ton/2000 lbs = tons/yr. The emission rate per unit of electricity for NOx and SO2 is .003 lbs and 2.39 lbs per kWh for CO2.

5.0 Human and Environmental Impacts

Minnesota Rule 7849.7060, subp. 2 outlines the impacts to be addressed in the Environmental Review for any Large Electric Power Generating Plant in a Certificate of Need proceeding. Those 10 impacts are evaluated below for the proposed LWECS and each alternative.

5.1 Emissions

Minnesota Rule 7849.7060, subp. 2. A requires the Environmental Report to address the anticipated emissions of the following pollutants at the maximum rated capacity of the project and as an amount produced per kilowatt hour: sulfur dioxide, nitrogen oxides, carbon dioxide, mercury, and particulate matter, including particulate matter under 2.5 microns in diameter. The Environmental Report must also provide the calculations performed to determine the emissions.

5.1.1 200 MW LWECS

A 200 MW LWECS would not result in any emissions of these pollutants.

5.1.2 77 MW Biomass Plant

The following information was obtained from air permit application documents submitted to the Minnesota Pollution Control Agency (MPCA) in support of a biomass facility that had been proposed for construction in southern Minnesota. The proposed facility was a generation plant primarily fueled by a combination of hybrid willows, poplars, and corn stover, with natural gas as a backup fuel. The emissions were calculated based on a variety of vendor information and factors obtained from the Environmental Projection Agency (EPA). With the exception of the carbon dioxide emissions calculation, all of the emissions information presented in this Environmental Report was obtained from the MPCA permit application file for the biomass facility. The carbon dioxide emission rate was calculated based on an EPA emission factor of 195 lb/MM Btu heat input. For a 77 MW biomass plant the numbers in the following table would be doubled.

Table 5.1 Potential Emissions from a 38.5 MW Biomass Plant

Pollutant	CAS* #	lb/hr	lb/kWh
Sulfur Dioxide (SO2)	7446-09-5	26.37	0.0007
Nitrogen Oxides (NOx)	10102-43-9	79.12	0.0021
Carbon Dioxide (CO2)	NA	102,853	2.6715
Mercury	7439-97-6	1.58E-03	4.11E-08
Particulate Matter (PM)	NA	13.71	0.0004
Particulate Matter <10 microns (PM10)	NA	13.71	0.0004
Particulate Matter <2.5 microns (PM2.5)	NA	13.71	0.0004

(* Chemical Abstracts Services Number)

5.1.3 Bent Tree Wind Project and Associated 161 kV HVTL

The Bent Tree Wind Project will not result in any air emissions. Transmission lines, under certain conditions, do produce very limited amounts of ozone and nitrogen oxide emissions. The national and state standard is 0.08 parts per million (ppm) based upon the fourth-highest 8-hour daily maximum average in one year. Both averages must be compared to the national and state standards because of different averaging periods. Studies designed to monitor the production of ozone under transmission lines have generally been unable to detect any ozone and nitrogen oxide increases due to the transmission line.

5.2 Hazardous Air Pollutants and VOCs

Minnesota Rule 7849.7060, subp. 2. B requires the Environmental Report to address the anticipated emissions of any hazardous air pollutants and volatile organic compounds (VOCs).

5.2.1 200 MW LWECS

Regardless of where it is located, the 200 MW LWECS alternative would not result in any emissions of hazardous air pollutants or volatile organic compounds. There are three types of petroleum-based fluids used in the operation of wind turbines. These fluids are necessary for the operation of each turbine and include: gear box oil (synthetic or mineral depending on application), hydraulic fluid, and gear grease. The very low vapor pressure of these products inhibits the release of any measurable VOCs.

5.2.2 77 MW Biomass Plant

The following information was obtained from air permit application documents submitted to the MPCA in support of a 38.5 biomass facility proposed for construction in southern Minnesota. The emissions were calculated based on a variety of vendor information and factors obtained from the EPA. Reference to the specific document from which the emissions information was

obtained, a copy of the table, or a copy of the backup calculations, is on file with the Environmental Quality Board. The emissions information was obtained from the MPCA permit application file for the biomass facility. For a 77 MW Biomass Plant, the following numbers should be doubled. The concentrations of the compounds, as reported, are low and should not affect public health.

Table 5.2
Potential Hazardous Air Pollutants,
VOCs from a 38.5 MW Biomass Plant

		Potential Emissions	
Pollutant	CAS		
	#	lb/hr	lb/kWh
Volatile Organic Compounds (VOCs)	NA	8.97	0.0002
Acetaldehyde	75-07-0	4.38E-01	1.14E-05
Acetophenone	98-86-2	1.69E-06	4.38E-11
Acrolein	107-02-8	1.22E-02	3.16E-07
Antimony	7440-36-0	4.17E-03	1.08E-07
Arsenic	7440-38-2	1.16E-02	3.01E-07
Benzene	71-43-2	2.22E+00	5.75E-05
Beryllium	7440-41-7	5.80E-04	1.51E-08
Bis (2-Ethylhexyl)phthalate	117-81-7	2.48E-05	6.44E-10
Bromomethane	74-83-9	7.91E-03	2.06E-07
2-Butanone (MEK)	78-93-3	2.85E-03	7.40E-08
Carbon Tetrachloride	56-23-5	2.37E-02	6.17E-07
Cadmium	7440-43-9	2.16E-03	5.62E-08
Chlorine	7882-50-5	4.17E-01	1.08E-05
Chlorobenzene	108-90-7	1.74E-02	4.52E-07
Chloroform	67-66-3	1.48E-02	3.84E-07
Chloromethane	74-87-3	1.21E-02	3.15E-07
Chromium	7440-47-3	1.11E-02	2.88E-07
Cobalt	7440-48-4	3.43E-03	8.91E-08
1,2-Dibromoethene	106-93-4	2.90E-02	7.54E-07
1,2-Dichloroethane	107-06-2	1.53E-02	3.97E-07
Dichloromethane	75-09-2	1.53E-01	3.97E-06
1,2-Dichloropropane	78-87-5	1.74E-02	4.52E-07
2,4-DinitrophenolD	51-28-5	9.49E-05	2.47E-09
Ethylbenzene	100-41-4	1.64E-02	4.25E-07
Formaldehyde	50-00-0	2.32E+00	6.03E-05
Hexane	110-54-3	9.28E-01	2.41E-05
Hydrogen Chloride	7647-01-0	1.05E+01	2.74E-04
Lead	7439-92-1	2.53E-02	6.58E-07
Manganese	7439-96-5	8.44E-01	2.19E-05
Naphthalene	91-20-3	5.12E-02	1.33E-06
Nickel	NA	1.74E-02	4.52E-07
4-Nitrophenol	100-02-7	5.80E-05	1.51E-09
Pentachlorophenol	87-86-5	2.69E-05	6.99^{E}-10
Phenol	108-95-2	7.75E-03	2.01E-07
Phosphorous	7723-14-0	1.42E-02	3.70E-07

		Potential Emissions	
Pollutant	CAS		
	#	lb/hr	lb/kWh
Polycyclic Organic Matter (POM)	NA	6.58E-02	1.71E-06
Propionaldehyde	123-38-6	3.22E-02	8.36E-07
Selenium	7782-49-2	1.48E-03	3.84E-08
Styrene	100-42-5	1.00E+00	2.60E-05
2,3,7,8-Tetrachlorodibenzo-p-dioxins	1746-01-6	4.54E-09	1.18E-13
Toluene	108-88-3	7.91E-03	2.06E-07
1,1,1-Trichloroethane	71-55-6	1.64E-02	4.25E-07
Trichloroethylene	79-01-6	1.58E-02	4.11E-07
2,4,6-TrichlorophenolD	88-06-2	1.16E-05	3.01E-10
Vinyl Chloride	75-01-4	9.49E-03	2.47E-07
o-Xylene	95-47-6	1.32E-02	3.43E-07

5.2.3 Bent Tree Wind Project and Associated 161 kV HVTL

The OES does not anticipate the release of emissions of hazardous air pollutants or volatile organic compounds from the Project. There will be three types of fluids used in the operation of the wind turbines that are petroleum products. These fluids are necessary for the operation of each turbine and include: gear box oil (synthetic or mineral depending on application), hydraulic fluid, and gear grease. The very low vapor pressures of these products inhibit the release of any measurable VOCs.

5.3 Visibility Impairment

Minnesota Rule 7849.7060, subp. 2. C requires the Environmental Report to address the anticipated contribution of the project to impairment of visibility within a 50-mile radius.

5.3.1 200 MW LWECS

The installation of a 200 MW LWECS will alter the visual environment. By one measure of standards, the 200 MW LWECS could be perceived as an industrial visual intrusion, characterized by metal structures intruding on the natural aesthetic of the landscape. On the other hand, wind farms have their own aesthetic quality, distinguishing them from other non-agricultural land uses. The land use would not involve any ongoing industrial use of non-renewable resources or emissions into the environment. The area would retain the rural sense and remote characteristic of the vicinity. The turbines are a relatively new feature on the landscape; however, they are compatible with the rural, agricultural heritage of Minnesota.

Wind projects in Minnesota are generally located in rural areas with open space and minimal tree cover because these sites minimize energy losses from surface roughness. A 200 MW LWECS would include the addition of wind turbines, access roads, an operations and maintenance facility, electrical transformers and lines, and substation. A typical 200 MW project would permanently occupy approximately 120 to 200 acres. A potential impact of placing an equivalent wind farm in a place other than Bent Tree Wind Project is the possibility of needing different size turbines or a larger number of turbines, depending on the site specific wind resource characteristics and other human and natural resource features in the area.

A 200 MW LWECS could require as few as 66 turbines or as many as 121 turbines, depending on the capacity of the wind turbines installed. For instance, if a 2.3 MW turbine were installed (the size of the turbines in the High Prairie Wind Farm 1 Project located in southern Mower County) 86 turbines would be required to obtain 200 MW of capacity. If as has been proposed for the Bent Tree Wind Project, wind turbines with a capacity of 1.65 MW were installed, up to 121 turbines would be necessary to obtain the required capacity.

Other visual characteristics include turbine lighting, as required by 49 CFR Part 77, FAA Advisory Circular – AC 70/7460. In general, turbines on the perimeter of the wind project are lighted using dual lights. This system consists of red lights for nighttime and medium intensity flashing white lights for daytime and twilight.

Access roads are typically single-lane, low profile, Class 5 gravel roads. Operations and maintenance facility buildings are typically 2,000+ square feet pole barns that house the necessary equipment to operate and maintain the site.

5.3.2 77 MW Biomass Plant

A 77 MW biomass plant would be visible from all directions and have an industrial characteristic. The stack would be approximately 150 to 200 feet tall and the boiler house would be approximately 130 feet or taller. The conveyors used for handling fuel would rise at an incline between the fuel handling area and the boiler. The conveyors would be lighted at night to allow for continuous operation of the plant. A transmission line would connect the plant to the transmission grid.

The plant, associated buildings and parking would cover approximately 10 to 20 acres, and the fuel storage area would cover approximately 50 to 100 acres. A large portion of the site would be used for fuel storage. Fuels may include wood, wood waste materials, and agricultural biomass (corn stover and other biomass fuels).

The exhaust gas would have little particulate matter, so plumes or vapor clouds would not be visible from exhaust stacks for most of the year. On some occasions, particularly in cold weather, a water vapor plume from the exhaust stack may be visible. In addition to the vapor plume from the exhaust stack, a plume from the cooling tower may also be visible during periods of high humidity.

Stack lighting would be necessary and would conform to the current FAA Advisory Circular – AC 70/7460 and FAA recommendations for obstruction marking and lighting. Exterior lighting would be sufficient to allow 24-hour operation of the fuel handling system. Minor maintenance and walk down inspections of the conveyor systems would be required during all shifts of the 24-hour period. Exterior lighting is anticipated for all conveyors, walkways, stacks, and storage and reclamation areas. Lighting would also be required at all fuel receiving points, scales and vehicle access roadways, and parking areas.

The site for the biomass plant would not require a rural, open space, and it may be situated in a more urban or industrial setting.

5.3.3 Bent Tree Wind Project and associated 161 kV HVTL

The predominant character of the project area is rural. The installation of the Bent Tree Wind Project will alter the visual environment of the rural area. The Project would include up to 121 wind turbine generators that will alter the landscape. However, wind farms have their own aesthetic quality, distinguishing them from other non-agricultural land uses. The predominant existing land use would remain rural. The area would retain the rural sense and remote characteristic of the vicinity. Although the turbines would be new features on the landscape in Freeborn County, they are arguably compatible with the rural, agricultural heritage of Minnesota. The wind turbines would be visible on the horizon for a distance up to approximately five miles. The project site is spread across approximately 32,000 acres.

The towers will be 80 meters (262.5 feet) in height. The rotor diameter will be 82 meters (269 feet), resulting in a maximum overall height of 121 meters (396 feet) when one blade is in the vertical position. There will be a project substation within the site and 161 kV HVTL in order to transmit the electricity approximately 18 miles to the point of interconnection at the ITC Hayward Substation located east of Albert Lea.

Visual characteristics include turbine lighting, as required by 49 CFR Part 77, FAA Advisory Circular – AC 70/7460. In general, turbines on the perimeter of the wind project are lighted

using dual lights. This system consists of red lights for nighttime and medium intensity flashing white lights for daytime and twilight. Access roads are typically single-lane, low profile, Class 5 gravel roads. Operations and maintenance facility buildings are typically 2,000 square feet pole barns that house the necessary equipment to operate and maintain the site.

The 161 kV HVTL will on steel or wooden poles, approximately 90 feet tall, and will be located within or immediately adjacent to, where possible, public road rights-of-way, and will be visible to travelers along those roadways and residents living adjacent to the roads.

5.4 Ozone Formation

Minnesota Rule 7849.7060, subp. 2. D requires the Environmental Report to address the anticipated contribution of the project to the formation of ozone expressed as reactive organic gases. Reactive organic gases are chemicals that are precursors necessary to the formation of ground level ozone.

5.4.1 200 MW LWECS

Wind projects do not produce reactive organic gases. A 200 MW LWECS would not contribute to ozone formation

5.4.2 77 MW Biomass Plant

Based on the information presented earlier from the MPCA Air Quality Permit Application, the potential NOx and VOC emissions are approximately 694 tons per year and 78 tons per year, respectively. The proposed project area is designated as attainment for ozone by EPA for the current 1-hour standard and, based on ambient monitoring data, is expected to remain in attainment status when the new 8-hour standard becomes effective. Therefore, given the location of the proposed project (rural southern Minnesota) and the current attainment status of the area, ground level ozone would not be a concern.

5.4.3 Bent Tree Wind Project and Associated 161 kV HVTL

The Bent Tree Wind Project would not produce reactive organic gases and would not contribute to ozone formation.

Studies designed to monitor the production of ozone under transmission lines have generally been unable to detect any ozone and nitrogen oxide increases due to the transmission line.

5.5 Fuel Availability and Delivery

Minnesota Rule 7849.7060, subp. 2. E requires the Environmental Report to address the availability of the source of fuel for the project, the amount required annually, and the method of transportation to get the fuel to the plant.

5.5.1 200 MW LWECS

Wind projects do not require any fuel besides wind. The actual availability of wind varies considerably across Minnesota, and has been analyzed by the Minnesota Department of Commerce. Reference the historical documentation of Minnesota's wind resources, "Wind Resource Analysis Program 2002," by reviewing the report on their website at:

http://www.state.mn.us/mn/externalOESs/Commerce/WRAP_Report_110702040352_WRAP2002.pdf.

In addition to this effort, the Department of Commerce has developed updated wind maps showing the statewide potential that exists for wind energy. These maps were developed for the Department by *WindLogics*, a Minnesota-based company that is at the leading edge of wind resource assessment by using atmospheric modeling techniques. The 80-Meter Wind Speed and Capacity Factor maps are provided in Appendix C. In addition to illustrating wind speed throughout the state, the maps also provide an estimate of wind capacity factors based on a 1.65 MW wind turbine at 80-meters. Capacity factors represent a ratio of the amount of energy that a wind turbine will generate in a given wind resource to the total potential energy that the turbine could generate, i.e. nameplate capacity multiplied by the total annual hours (8760).

At an 80-meter hub height capacity factors of 35 to 40 percent are typically achievable in areas that are considered economically feasible for development.

5.5.2 77 MW Biomass Plant

A representative 77 MW steam turbine biomass plant would use approximately 80,000 tons of wood, wood wastes, and agricultural biomass materials per month. Fuel would most likely be delivered by truck using the existing highway network. The frequency of trucks is dependent on the demand for materials and the available payload of each vehicle. An average flow of five to ten semi-combination vehicles per hour would be typical for such a facility. The origin of loaded trucks and the destination of empty trucks would depend upon the location of the fuel source.

A biomass plant would most likely have some backup fuel available for startup or in the event that the biomass fuel supply was interrupted. Backup fuel may be natural gas or fuel oil. Natural gas would be delivered by a pipeline, and fuel oil would be delivered by truck.

5.5.3 Bent Tree Wind Project and Associated 161 kV HVTL

The Bent Tree Wind Project requires no fuel. Instead, it is dependent on converting wind energy to electricity at the site. Based on the most recent Department wind maps the estimated average annual wind speed at 80-meters (in meters/second and miles/hour) at the Project site is 8.0 m/s (17.89 mph), with a range of 6.66 to 9.38 m/s (14.89 to 20.98 mph). The estimated net capacity factor in the project area is in the range of 37% to 39.8%.

5.6 Associated Transmission Facilities

Minnesota Rule 7849.7060, subp. 2. F requires the Environmental Report to address associated facilities that would be required to transmit electricity to customers.

5.6.1 200 MW LWECS

A 200 MW LWECS alternative may require new electric transmission facilities to move the power to customers. A transformer is typically installed at the base of each turbine to raise the voltage to distribution line voltage, usually 34.5 kV. Power is typically run through an underground collection system, buried in trenches adjacent to project access roads, to the project feeder system. The feeder system delivers the power from the wind farm to a substation. At the substation the electric voltage is stepped up to transmission level voltage (69 kV to 230 kV or greater) and enters the grid. Based on engineering and safety requirements to connect to the high voltage transmission system, which differ based on the location of a project's connection, a wind facility may require a small to a quite large expenditure in new high voltage transmission line and substation construction to safely deliver electricity to customers.

5.6.2 77 MW Biomass Plant

The 77 MW biomass plant alternative could require new transmission facilities to provide power to customers. Transmission requirements would most likely include a transformer at the plant to step the voltage up to transmission levels and a transmission line between the plant and a substation where the power would enter the grid.

5.6.3 Bent Tree Wind Project and Associated 161 kV HVTL

The Bent Tree Wind Project would have a 34.5 kV project feeder electrical system that would feed power to the project substation. At the project substation, the electric voltage would be

stepped up to a transmission level voltage of 161 kV. Up to an 18-mile 161 kV transmission line would be required to deliver power from the project substation to the ITC owned Hayward Substation east of Albert Lea. The 161 kV transmission line that would be constructed as part of this project is going through local review for the necessary approvals.

5.7 Water Appropriations

Minnesota Rule 7849.7060, subp. 2. G requires the Environmental Report to address the anticipated amount of water that will be appropriated to operate the plant and the source of the water if known.

5.7.1 200 MW LWECS

A 200 MW LWECS alternative would typically require some water appropriations to supply potable water to the project's operations and maintenance facility. Because of the project's rural location, water would need to be supplied either through a rural water supply system or, more typically, construction of a single domestic-sized well. The source of the water will depend upon the location of the project.

5.7.2 77. MW Biomass Plant

The 77 MW biomass plant alternative would require water for both process and sanitary purposes. Project water could come from well water or city water. In addition, well water or city water effluent from a wastewater treatment plant could be used for cooling tower makeup, and possibly for other process water.

The amount of water used would depend upon the plant equipment and the water quality. A biomass facility may require a minimum water flow of 56.5 to 592 gallons per minute (gpm) and maximum water flows of between 550 to 1,000 gpm. Water use would be on the lower end of that range if effluent were used for part of the process water and on the upper edge of that range if only well water or city water is used. The source for the water would depend upon availability of water sources in the project area.

5.7.3 Bent Tree Wind Project and Associated 161 kV HVTL

The Bent Tree Wind Project would require water appropriations for potable and sanitary water for the operations and maintenance facility. Water would be supplied through either rural water or a single domestic-sized well.

5.8 Wastewater

Minnesota Rule 7849.7060, subp. 2. H requires the Environmental Report to address the potential wastewater streams and the types of discharges associated with such a project including potential impacts of a thermal discharge.

5.8.1 200 MW LWECS

A 200 MW LWECS would only generate wastewater at the operations and maintenance facility. Wastewater would be from the sanitary system and minor equipment maintenance. The wastewater would be disposed of in a septic system or sanitary sewer system.

5.8.2 77 MW Biomass Plant

A 77 MW biomass plant would generate wastewater from the following sources:

Table 5.8 Potential Wastewater Streams and Discharges

Wastewater Source	Well Water	
	gpm	Million gpy
Cooling Tower Blowdown	272.0	143
Sanitary	2.0	1.0
Plant Wash & Misc.	26.0	6.8
Demineralization	7.0	3.6
Oil/Water Separation	4.0	2.2
Total Discharge	311.0	163.4

The wastewater from a 77 MW biomass plant could be discharged without pretreatment to a municipal wastewater treatment facility with available capacity. It is also possible to approach zero discharge, but there would still be some wastewater associated with the cooling tower blowdown and boilers. The wastewater would include minerals and sanitizers, and have an increased temperature. The wastewater would be discharged to a holding pond where it would evaporate or infiltrate. The wastewater stream would be contained and not impact surface water resources. Sanitary wastewater would be disposed of in a septic system or sanitary sewer system.

5.8.3 Bent Tree Wind Project and Associated 161 kV HVTL

The Bent Tree Wind Project will generate wastewater at the operations and maintenance facility. Wastewater would be from the sanitary system and minor equipment maintenance, and it would be disposed of through a septic system.

5.9 Solid and Hazardous Wastes

Minnesota Rule 7849.7060, subp. 2. I require that the Environmental Report address the types and amounts of solid and hazardous wastes generated by the project, including potential impacts of a thermal discharge.

5.9.1 200 MW LWECS

The 200 MW LWECS alternative would generate solid waste during the construction of the facility. Material would be disposed of in an appropriate landfill facility. There would be a small amount of solid waste during operations of the facility that would be disposed of appropriately. Wind turbines require three types of petroleum-based fluids for operation: gear box oil, hydraulic fluid, and gear grease. All fluids are contained within the wind turbine structure.

The 200 MW wind project alternative would generate some very small quantities of hazardous wastes that may include fluorescent lights, lubricating oil, ethylene glycol, de-greasers, cleaning solvents, and batteries. Hazardous waste generation would fall below the quantity of a small quantities generator (220 pounds per month).

5.9.2 77 MW Biomass Plant

The 77 MW biomass plant alternative would generate solid wastes during construction. The solid waste would include normal construction debris such as, scrap wood, plastics, wallboard, packing material, cardboard, scrap metals, and electrical wires. No hazardous waste would be anticipated from project construction. A biomass facility would generate ash from fuel combustion. Typically ash would be collected and stored on site in an ash storage building. The ash would be removed periodically and re-used as a soil enhancer or disposed of at an off-site solid waste disposal facility.

The biomass alternative would generate very small quantities of hazardous wastes that may include fluorescent lights, lubricating oil, mineral oil, ethylene glycol, de-greasers, cleaning solvents, and batteries. It is anticipated that the facility would be classified as a "Very Small Quantity Generator" of hazardous wastes.

5.9.3 Bent Tree Wind Project and Associated 161 kV HVTL

The Bent Tree Wind Project would generate solid waste during the construction of the facility. Material would be disposed of in an appropriate landfill facility. There would be a small amount

of solid waste created during operations of the facility that would be disposed of appropriately. Used parts or other equipment could generally be rebuilt or recycled.

There are three types of fluids used in the operation of the wind turbines that are petroleum products (gear box oil, hydraulic fluid, and gear grease). All fluids would be contained within the wind turbine structure.

The Bent Tree Wind Project would generate some very small quantities of hazardous wastes during operations that may include fluorescent lights, lubricating oil, ethylene glycol, de-greasers, cleaning solvents, and batteries. Hazardous waste generation would fall below the quantity of a small quantities generator (220 pound per month). Any wastes, fluids or pollutants generated during the Project would be handled, processed, treated, stored and disposed of in accordance with Minnesota Rules Chapter 7045.

5.10 Noise

Minnesota Rule 7849.7060, subp. 2. J requires the Environmental Report to address anticipated noise impacts of a project, including the distance to the closest receptor where state noise standards can still be met.

5.10.1 200 MW LWECS

A 200-MW LWECS will create noise. The sound level varies with the speed of the turbine and the proximity of the receptor. Sound is generated from the wind turbine at points near the hub or nacelle, from the blade rotation, and from transformers near ground level.

The representative sound power level (L_p) of a GE 1.5 MW wind turbine, such as those used in the Trimont Wind Farm in Martin and Jackson Counties, is 104.5 dBA. It was converted to a sound pressure level for comparison to the Minnesota Daytime and Nighttime L_{10} and L_{50} Standards given in Minnesota Rule 7030.0040. Turbines were modeled using the following equation for a hemispherical point source: $L_p = L_w - 10 \log_{(}2*pi*r^2)-A_{atm}$ where L_p is defined as the sound pressure level at the distance of interest (r), L_w is the sound power level provided by the turbine manufacturer for a 1.5 MW turbine, and A_{atm} defined as the attenuation provided by atmospheric absorption.

The maximum distance calculated where an exceedence of a state noise standard would no longer occur is 623 feet for the Nighttime L_{50} standard of 50 dBA. Due to the possibility of cumulative noise levels being generated by the operation of multiple turbines, no turbines would

normally be sited within 1000 feet of an occupied residence in order to avoid exceeding the MPCA Nighttime L_{50} Standard.

5.10.2 77 MW Biomass Plant

A 77 MW biomass plant is predicted to produce operational noise from a variety of sources including the turbine/boiler building operations, conveyor/reclaiming system, hammer mill and bale choppers, front-end loaders, and idling trucks. The stationary equipment will be housed in buildings or enclosures designed to provide additional noise attenuation.

During peak hour operations, noise emissions from the facility are assumed to be steady state. Under steady state conditions, the modeling results are considered to be equivalent to an L_{50} (the average sound level). Also under steady state noise emission conditions, an L_{10} value is approximately 3 dB higher than an L_{50} value. Noise modeling results were directly compared to MPCA daytime and nighttime L_{50} limits.

As noted in the NGPP Minnesota Biomass, Environmental Assessment Worksheet, the maximum distance calculated where an exceedence of a state noise standard would no longer occur is 2,100 feet for the Daytime L_{50} standard of 60 dBA, and 6,200 feet for the Nighttime L_{50} standard of 50 dBA. This is a conservative estimate of maximum distance that has not been adjusted for shielding or soft-ground attenuation in the noise model. This distance is also based on maximum operation of equipment, and actual operation levels may vary. Decreased operations activity will result in decreased noise levels and shorter maximum distances.

5.10.3 Bent Tree Wind Project and Associated 161 kV HVTL

The Bent Tree Wind Project would generate noise during construction at or above the 85 dBA recommended for eight hour farm exposure by the National Safety Council; however, these impacts would be limited to 50 feet from operating equipment and would not be expected to affect local residents. The Applicant expects on-site noise exposures for project personnel would be managed within OSHA standards.

Noise levels produced by 161 kV HVTL's are generally less than outdoor background levels and are usually not audible.

Operating noise would occur from the wind turbines at points near the hub or nacelle, from the blade rotation, and from motors near ground level. The Applicant anticipates source noise levels of 96-99 dBA while operating, depending on wind speed, speed of the turbines and interference from other sources. Background ambient in the project area is estimated at about 33-38 dBA.

Turbine setbacks from residences would be required to meet compliance with the PCA noise standards.

In recent wind energy dockets, the public has expressed concerns about possible health effects associated LWECS. In order to address the issues raised by the public, the Office of Energy Security (OES) requested a "white paper" from the Minnesota Department of Health evaluating possible health effects associated with low frequency sound and vibrations arising from large wind energy conversion systems (LWECS). On May 22, 2009, the Minnesota Department of Health (MDH) Environmental Health Division provided OES with a document titled "Public Health Impacts of Wind Turbines" and is included as Appendix D in this Environmental Report and is available for downloading at:

http://energyfacilities.puc.state.mn.us/documents/3855/OES%20Response%20Letter%20-%20Bent%20Tree%20Radial%20Transmission%20Line,%20FINAL.pdf

The MDH report is comprised of several components. Section 1 provides an introduction and background to the report. Section II provides an overview of sensory systems, which includes hearing and the vestibular system, and sound which includes audible frequency sound, sub-audible frequency sound, resonance and modulation, human response to low frequency stimulation and sound measurements. Section III reviews wind turbine noise sources which include mechanical noise, aerodynamic noise, modulation of aerodynamic noise, wind farm noise and shadow flicker. Section IV reviews potential adverse reactions to sound and studies of wind turbine noise impacts on people from Sweden, the United Kingdom, the Netherlands and case reports. Section V reviews Minnesota Noise Regulations, low frequency noise assessment and regulation, wind turbine sound measurements and wind turbine regulatory noise limits. Sections VI provides several general conclusions noting that: 1) wind turbines generate a broad spectrum of low-intensity noise; 2) that higher frequency noise is attenuated by setbacks; 3) low frequency noise is a problem that may affect some people in their homes, especially at night; 4) the most common complaint in various studies of wind turbines effects on people is annoyance or an impact on quality of life; 5) complaints are more likely when turbines are visible or when shadow flicker occurs; 6) health effects are related to audible low frequency noise; 7) the Minnesota nighttime standard of 50 dB (A) not to be exceeded more than 50 percent of the time in a given hour, appears to underweight penetration of low frequency noise into dwellings; 8) low frequency noise from wind turbine is generally not easily perceived beyond ½ mile; and 9) shadow flicker can affect individuals outdoors as well as indoors, and may be noticeable inside any building with windows.

Section VII recommends that: 1) wind turbine noise estimates should include cumulative impacts (40-50 dB(A) isopleths) of all wind turbines; 2) isopleths for dB(C) – dB(A) greater than 10 dB should also be determined to evaluate the low frequency noise component; 3) that potential impacts from shadow flicker and turbine visibility be evaluated.

6.0 Mitigative Measures

Minnesota Rule 7849.7060, subp. 1. E requires the Environmental Report to provide an analysis of mitigative measures that could reasonably be implemented to eliminate or minimize any adverse impacts identified for the proposed project and each alternative analyzed.

6.1 No-build Alternative

The No-build alternative will have no impacts, and mitigative measures are not necessary.

6.2 200 MW LWECS

A 200 MW LWECS will have no significant impacts and mitigative measures are generally not necessary for the following issues: air emissions, hazardous air pollutants and volatile organic compounds, ozone formation, fuel availability and delivery, transmission facilities (although another project might require new transmission), water appropriations, and wastewater.

The potential mitigation for visibility impairment at a 200 MW LWECS must be balanced with maximizing turbine efficiency and exposure to wind. For example, mitigation measures that require shorter towers or placement of the turbines at alternate locations off ridgelines could result in less efficiency per unit. Mitigative measures for a 200 MW LWECS would generally be included as conditions in a site permit and could include the following:

- Turbines would not be located in biologically sensitive areas such as wetlands or relic prairies.
- Turbines would be illuminated to meet the minimum requirements of FAA regulations.
- Existing roads would be used for construction and maintenance where possible. Road construction would be minimized.
- Access roads created for the wind farm facility would be located on gentle grades to minimize visible cuts and fills.
- Temporarily disturbed areas would be reseeded to blend in with existing vegetation.

Mitigative measures for solid wastes at a 200 MW LWECS would include appropriate disposal of construction and facility operation wastes at a licensed landfill. A 200 MW LWECS may generate very small quantities of hazardous wastes during the life of the Project. Mitigative

measures for hazardous wastes would include appropriate handling, processing, storage, and disposal of wastes in accordance with Minnesota Rules Chapter 7045.

Mitigative measures for audible noise at a 200 MW LWECS would include siting turbines far enough away from residences in order to avoid exceeding the MPCA Nighttime L_{50} Standard (Minnesota Rule 7030.0040).

6.3 77 MW Biomass Plant

The biomass plant could be equipped with state of the art control equipment, technologies that would potentially decrease emissions. However, these alternate control technologies have a number of drawbacks as compared to the proposed equipment, such as cost, technological issues, and other adverse environmental impacts.

Many of the visual impacts from the biomass alternative can be mitigated by locating the facility in an industrial or rural area with good access to transportation. Fuel storage can be used to provide a visual buffer between the facility and some of the surrounding land uses. Locating the facility near existing transmission facilities can reduce visual impacts from transmission lines.

Mitigation strategies available to reduce water appropriations would depend upon the water source. Where appropriate, water appropriations can be reduced by cycling water through some of the plant processes multiple times as long as water quality is maintained. Effluent from wastewater treatment can be used in some instances to reduce ground or surface water appropriations.

Wastewater streams can be reduced, though not entirely eliminated, through use of evaporative or infiltration holding ponds. The use of holding ponds would also eliminate potential for impacts from a thermal discharge directly to a water body. Mitigative measures for solid wastes at the 77 MW biomass facility alternative would include disposal of construction and facility operation wastes at an appropriate landfill and re-use of the ash as a soil enhancer or disposal of the ash at an off-site solid waste disposal facility.
It is expected that a 77 MW biomass facility alternative would be classified as a "Very Small Quantity Generator" of hazardous wastes. Any wastes, fluids or pollutants generated during the Project will be handled, processed, treated, stored, and disposed of in accordance with Minnesota Rules Chapter 7045.

Locating the facility away from sensitive receptors can mitigate noise impacts. Enclosure of some of the heavy equipment would reduce noise impacts to surrounding land uses. Fuel

windrows can be located to provide noise attenuation to reduce the impacts from operations noise to sensitive receptors. Limiting the hours of fuel delivery and heavy equipment operation can also reduce noise impacts.

6.4 Bent Tree Wind Project and Associated 161 kV HVTL

The Bent Tree Wind Project would have no significant impacts and mitigative measures are not necessary for the following issues: air emissions, hazardous air pollutants and volatile organic compounds, ozone formation, fuel availability and delivery, water appropriations, and wastewater. Transmission facilities mitigations would have been reviewed in the Local Review Environmental Assessment.

The potential mitigation for visibility impairment at the Bent Tree Wind Project must be balanced with maximizing turbine efficiency and exposure to wind. Mitigative measures for Bent Tree Wind Project are included in the pending site permit conditions and include the following:

- Turbines would not be located in biologically sensitive areas such as wetlands or relic prairies.
- Turbines would be illuminated for safety to meet the minimum requirements of FAA regulations.
- Existing roads would be used for construction and maintenance where possible. Road construction would be minimized.
- Access roads created for the wind farm facility would be located on gentle grades to minimize visible cuts and fills.
- Temporarily disturbed areas would be reseeded to blend in with existing vegetation.

Mitigative measures for solid wastes at the Bent Tree Wind Project would include appropriate disposal of construction and facility operation wastes at a licensed landfill. The Bent Tree Wind Project may generate very small quantities of hazardous wastes during the life of the Project. Mitigative measures for hazardous wastes would include appropriate handling, processing, storage and disposal of wastes in accordance with Minnesota Rules Chapter 7045.

Mitigative measures for audible noise at the Bent Tree Wind Project would include not siting turbines within a sufficient distance of a residence in order to avoid exceeding the MPCA Nighttime L_{50} Standard (Minn. Rule 7030.0040).

7.0 Feasibility and Availability of Alternatives

Minnesota Rule 7849.7060, subp. 1. F requires that the environmental report address the feasibility and availability of each alternative analyzed.

7.1 No-build Alternative

The No-build alternative is available, but would not help WPL meet the state's Renewable Energy Standard.

7.2 200 MW LWECS

Minnesota's wind resources are more than sufficient to support numerous 200 MW LWECS facilities, and thousands of MW of wind energy are in development across the state and region. Feasibility and availability may be delayed or financially impacted depending on the location of the alternative's electrical interconnection to the high voltage transmission system, which is at capacity in many locations in Minnesota.

7.3 77 MW Biomass Facility

A 77 MW biomass facility alternative is feasible. A 38.5 MW biomass project underwent environmental review in late 2003. However, OES Energy Facility Permitting staff is not aware of any large biomass projects that are currently under development or planned that are available to meet WPL's needs in a timely manner.

7.4 Bent Tree Wind Project and Associated 161 kV HVTL

The Bent Tree Wind Project is feasible and could be developed to help WPL meet the state's Renewable Energy Standards.

8.0 Required Permits

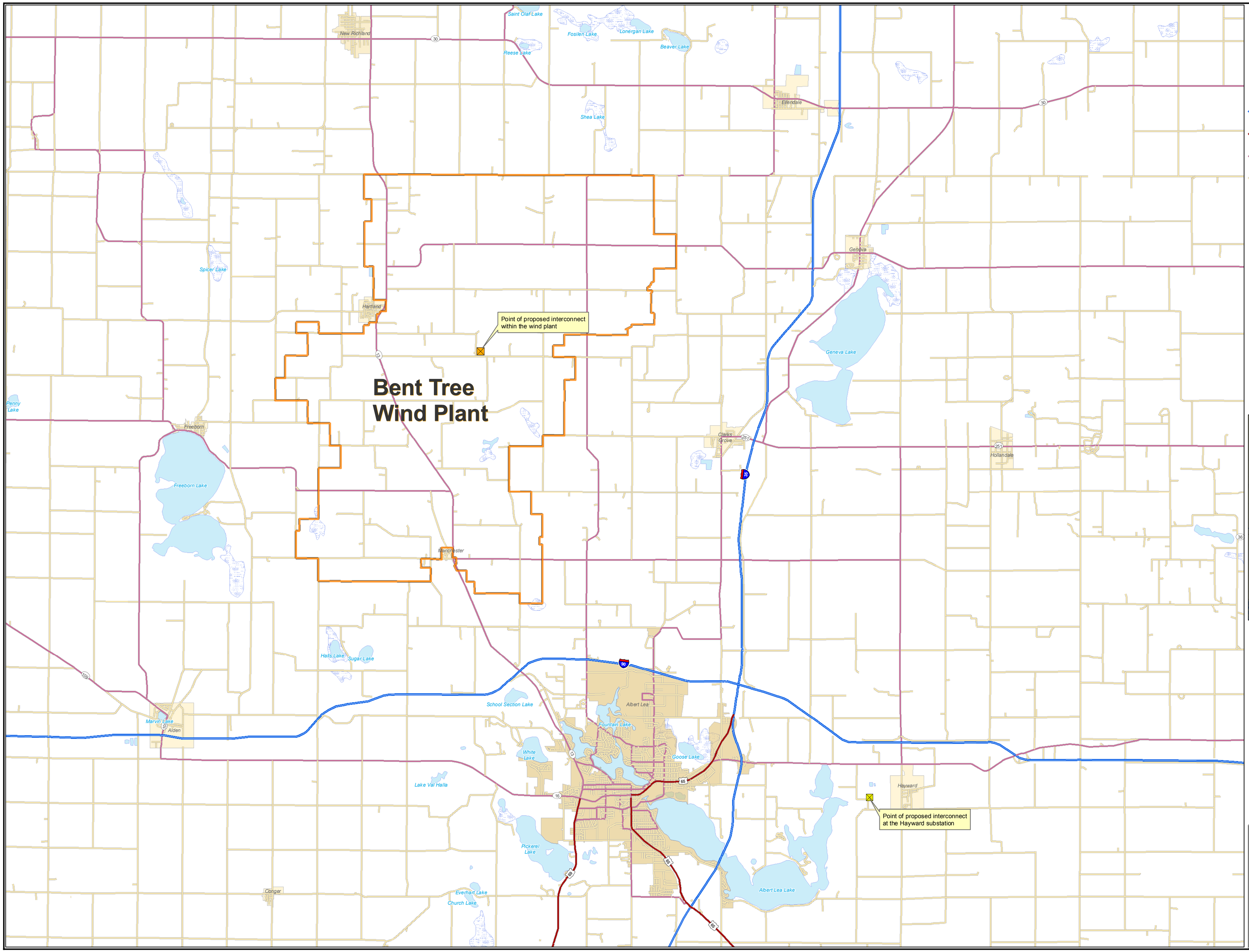
Minnesota Rule 7849.7060, subp. 1. G requires that the environmental report address other permits and approvals that the project may require. The federal, state and local permits or approvals that have been identified for the construction and operation of the Project are shown in Table 8.1.

Table 8.1 Potentially Required Permits and Approvals

Agency	Type of Approval
Federal	
Federal Aviation Administration	Notice of Proposed Construction or Alteration within six miles of Public Aviation Facility and structures over 200 feet to complete a 7460 Proposed Construction or Alteration Form; No hazard determinations; Notice of Actual Construction (Form 7460-2)
U.S. Army Corps of Engineers	Wetland (Section 404) Permit
State of Minnesota	
Minnesota Public Utilities Commission	Certificate of Need
Minnesota Public Utilities Commission	LWECS Site Permit
Minnesota Board of Water and Soil Resources	Wetland Conservation Act Approval
Minnesota Department of Natural Resources	Pubic Water Works
	License to Cross Public Lands and Waters
Minnesota Pollution Control Agency	NDPES Stormwater Permit for Construction Activities
	License for Very Small-Quantity Generator of Hazardous Waste
Minnesota Department of Health	Water Well Permit
	Plumbing Plan Review
Minnesota Department or Transportation	Utility Permit for Road Crossing, Hwy. Access Permit
	Oversize and Overweight Permit
	Tall Towers Permit
Local Permits	
Freeborn County	Building Permits, Driveway Permit
	Public Road and Utility Access Permit
	Utility Permit for Road Crossing
	Oversized Load Moving Permit
	Conditional Use permit for 161 kV Transmission Line
Townships	Road Access Permits, Utility Permit for Road Crossings

Appendix A

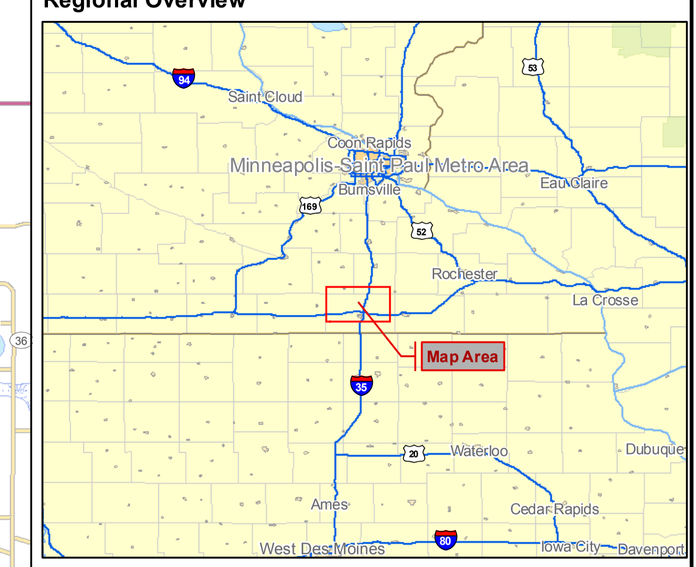
Bent Tree Project Site
and
161 kV Study Area



Legend

- Bent Tree Boundary
- Potential Substation
- Existing Substation
- Limited Access
- Highway
- Major Road
- Local Road

Regional Overview



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1 inch = 1 mile
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PROJECT:	BENT TREE WIND FARM FREEBORN COUNTY, MINNESOTA
MAP TITLE:	INTERCONNECTION OVERVIEW
DATUM: NAD83	
PROJECTION: UTM 15N	
PROJECT NUMBER: 712	
CREATED: MARCH 2008	
MODIFIED: 8/22/2008	
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Appendix B

Environmental Report Scoping Decision

office of energy security

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In the Matter of the Application of Wisconsin Power and Light for the 200 Megawatt Bent Tree Wind Project and Associated 161 Kilovolt High Voltage Transmission Line for a Certificate of Need in Freeborn County, Minnesota

ENVIRONMENTAL REPORT SCOPING DECISION PUC Docket No. ET6657/CN-07-1425

The above matter has come before the Director of the Office of Energy Security (OES) for a decision on the content of the Environmental Report (ER) to be prepared in consideration of the Wisconsin Power and Light Application for a Certificate of Need for the proposed 200 Megawatt (MW) Bent Tree Wind Project and associated 161 (kV) high voltage transmission line (HVTL) in Freeborn County.

Staff of the Minnesota Department of Commerce, Office of Energy Security, Energy Facilities Permitting Unit (EFP) held a public meeting on October 22, 2008, to discuss the project with the public and to solicit input into the scope of the ER to be prepared. The public was given until December 3, 2008, to submit written comments regarding the scope of the ER.

According to Minnesota 7849.7030:

> The Director of the Office of Energy Security of the Department of Commerce shall prepare an environmental report on a proposed high voltage transmission line or a proposed large electric power generating plant at the need stage. The environmental report must contain information on the human and environmental impacts of the proposed project associated with the size, type, and timing of the project, system configurations, and voltage. The environmental report must also contain information on alternatives to the proposed project and shall address mitigating measures for anticipated adverse impacts. The Director shall be responsible for the completeness and accuracy of all information in the environmental report.

An ER provides a high level environmental analysis of the proposed Project and system alternatives, and reviews environmental impacts associated with named and alternative projects. It is only one part of a larger Office of Energy Security investigation of the Certificate of Need Application. The OES in its overall review will address in detail all the issues and alternatives required by rule.

Having received 28 comments on the matter and, and having consulted with staff, I hereby make the following Order on the content of the ER:

MATTERS TO BE ADDRESSED

The ER will address the written comments received which include but are not limited to turbine setbacks, noise setbacks, low frequency vibration, public health and safety issues related to wind energy development and the following subjects/matters for the proposed project:

The Environmental Report is required to contain the specific alternatives that are outlined in Minnesota Rules Chapter 7849.7060, subp.1, B:

> *A general description of the alternatives to the proposed project that are addressed. Alternatives shall include the no-build alternative, demand side management, purchased power, facilities of a different size or using a different energy source than the source proposed by the applicant, upgrading of existing facilities, generation rather than transmission if a high voltage transmission line is proposed, transmission rather than generation if a large electric power generating plant is proposed, use of renewable energy sources, and those alternatives identified by the chair.*

The energy from the project will be produced by Wisconsin Power and Light for its own use to meet Wisconsin's Renewable Portfolio Standard (RPS) requirements and to meet the electricity needs of WPL's retail and wholesale customers. Under this scenario, it is not logical to conduct an analysis of an alternative that would not contribute to WPL's meeting its goals under the Wisconsin RPS. The alternative that will be discussed in the Environmental Report will be a 77 MW biomass plant. The 77 MW biomass plant is considered an "eligible energy technology" and can produce an equivalent amount of energy as the wind facility.

<u>Bent Tree Wind Project</u>

1.0 Description of Bent Tree Wind Project and Associated 161 kV Transmission Line [Minn. Rule 7849.7060, subp. 1, A]

2.0 Alternatives to be Evaluated [Minn. Rule 7849.7060, subp. 1, B]

- 2.1 No-build Alternative
- 2.2 A Generic 200 MW Wind Project and Associated Transmission Alternatives
- 2.3 A 77 MW Biomass Plant

3.0 Human and Environmental Impacts [Minn. Rule 7849.7060, subp. 1, C, D]

3.1 Emissions [Minn. Rule 7849.7060, subp. 2, A]
- No-build alternative
- 200 MW wind project
- 77 MW biomass plant
- Bent Tree Wind Project and Associated 161 kV HVTL

3.2 Hazardous air pollutants and VOCs [Minn. Rule 7849.7060, subp. 2, B]
- No-build alternative
- 200 MW wind project
- 77 MW biomass plant
- Bent Tree Wind Project and Associated 161 kV HVTL

3.3 Visibility impairment & shadow flicker [Minn. Rule 7849.7060, subp. 2, C]
- No-build alternative
- 200 MW wind project
- 77 MW biomass plant
- Bent Tree Wind Project and Associated 161 kV HVTL

3.4 Ozone formation [Minn. Rule 7849.7060, subp. 2, D]
- No-build alternative
- 200 MW wind project
- 77 MW biomass plant
- Bent Tree Wind Project and Associated 161 kV HVTL

3.5 Fuel availability and delivery [Minn. Rule 7849.7060, subp. 2, E]
- No-build alternative
- 200 MW wind project
- 77 MW biomass plant
- Bent Tree Wind Project and Associated 161 kV HVTL

3.6 Associated transmission facilities [Minn. Rule 7849.7060, subp. 2, F]
- No-build alternative
- 200 MW wind project
- 77 MW biomass plant
- Bent Tree Wind Project and Associated 161 kV HVTL

3.7 Water appropriations [Minn. Rule 7849.7060, subp. 2, G]
- No-build alternative
- 200 MW wind project
- 77 MW biomass plant
- Bent Tree Wind Project and Associated 161 kV HVTL

3.8 Wastewater [Minn. Rule 7849.7060, subp. 2, H]
- No-build alternative
- 200 MW wind project
- 77 MW biomass plant
- Bent Tree Wind Project and Associated 161 kV HVTL

3.9 Solid and hazardous wastes [Minn. Rule 7849.7060, subp. 2, I]
- No-build alternative
- 200 MW wind project
- 77 MW biomass plant
- Bent Tree Wind Project and Associated 161 kV HVTL

3.10 Noise, [Minn. Rule 7849.7060, subp. 2, J]
- No-build alternative
- 200 MW wind project
- 77 MW biomass plant
- Bent Tree Wind Project and Associated 161 kV HVTL

4.0 Mitigation measures [Minn. Rule 7849.7060, subp. 1, E]

4.1 No-build alternative
4.2 200 MW wind project
4.3 77 MW biomass plant
4.4 Bent Tree Wind Project and Associated 161 kV HVTL

5.0 Feasibility and availability of alternatives [Minn. Rule 7849.7060, subp. 1, F]

5.1 No-build alternative
5.2 200 MW wind project
5.3 77 MW biomass plant
5.4 Bent Tree Wind Project and Associated 161 kV HVTL

6.0 Required permits [Minn. Rule 7849.7060, subp. 1, G].

The ER will describe the federal, state and local permits anticipated to build the project.

ISSUES OUTSIDE OF THE ENVIRONMENTAL REPORT

The ER will only identify the general potential impacts from the construction, operation, and maintenance of the proposed LWECS and HVTL along the broad geographic areas proposed, and the measures generally available to mitigate these potential impacts.

The ER will not consider the impacts or mitigative measures associated with specific tower or road locations within the proposed site for the Bent Tree Wind Farm or for the alignment of the 161 kV HVTL that is a part of the Project.

The proposed 161 kV HVTL is integrated into the Project to serve as a transmission outlet for the energy produced by the Bent Tree Wind Project. This HVTL, similar to wind related HVTL's in Mower County, is designed to accommodate the connection of a proposed generating facility onto the grid.

SCHEDULE

The Environmental Review will be completed in February 2009.

Signed this 2nd day of January, 2009

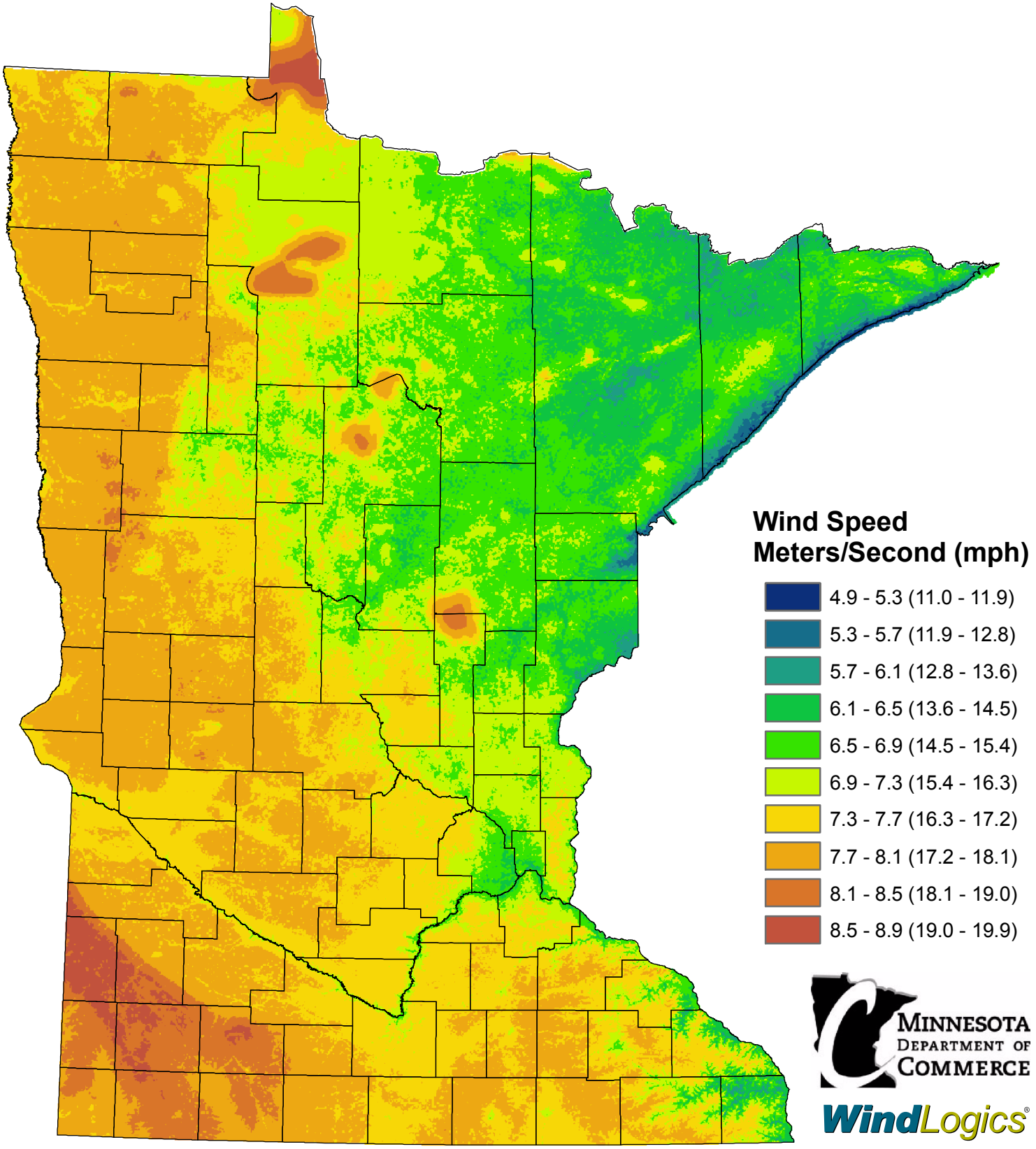
STATE OF MINNESOTA
OFFICE OF ENERGY SECURITY

Bill Glahn, Director

Appendix C

Minnesota Wind Resource Maps

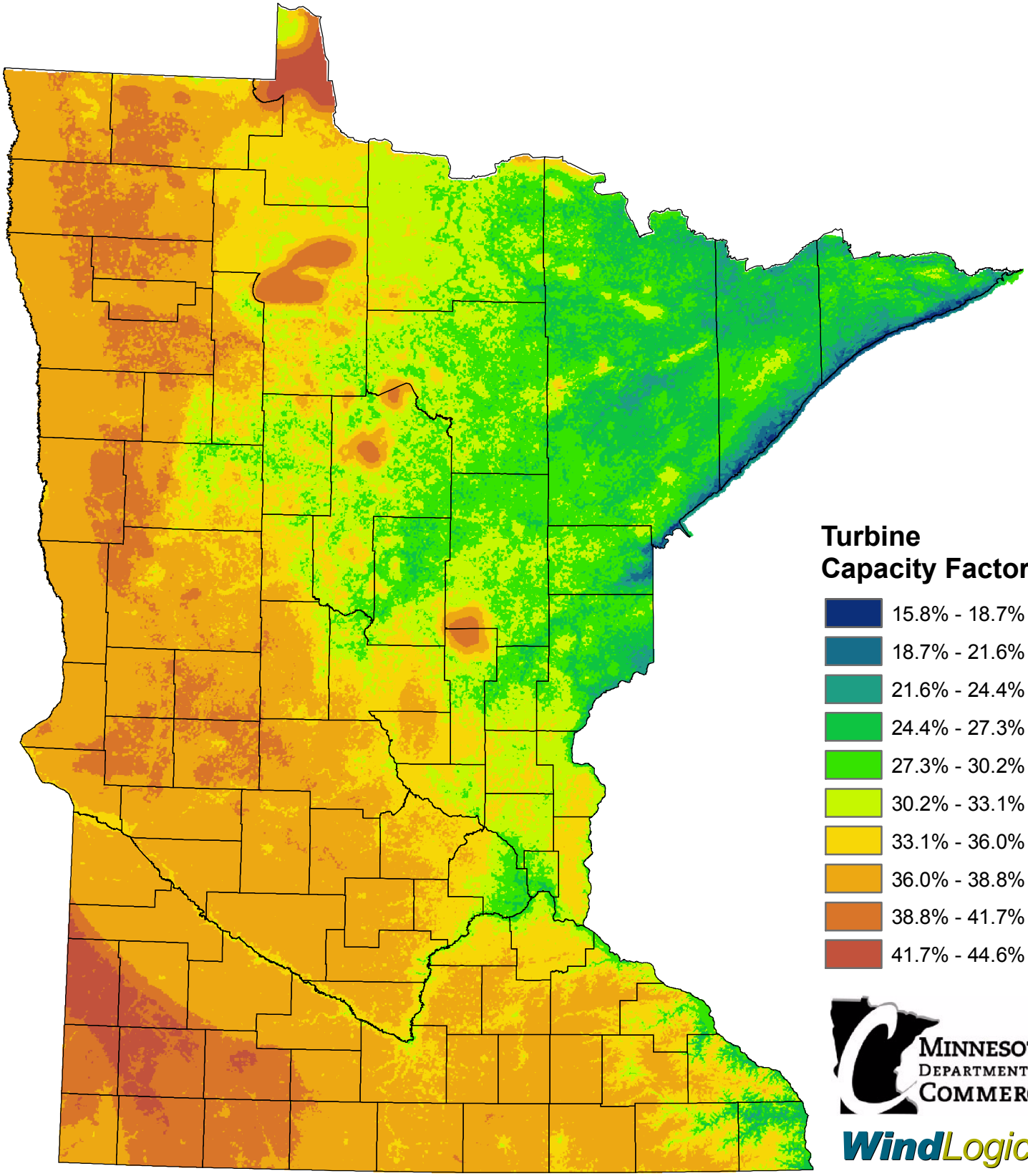
Minnesota's Wind Resource by Wind Speed at 80 Meters



This map has been prepared under contract by WindLogics for the Department of Commerce using the best available weather data sources and the latest physics-based weather modeling technology and statistical techniques. The data that were used to develop the map have been statistically adjusted to accurately represent long-term (40 year) wind speeds over the state, thereby incorporating important decadal weather trends and cycles. Data has been averaged over a cell area 500 meters square, and within any one cell there could be features that increase or decrease the values shown on this map. This map shows the general variation of Minnesota's wind resource and should not be used to determine the performance of specific projects.

January 2006

Minnesota's Wind Resource by Capacity Factor at 80 Meters



This map has been prepared under contract by WindLogics for the Department of Commerce using the best available weather data sources and the latest physics-based weather modeling technology and statistical techniques. The data that were used to develop the map have been statistically adjusted to accurately represent long-term (40 year) wind speeds over the state. Capacity factors are based on a 1.65 MW turbine, and production has been discounted 15% to represent real world conditions. Data has been averaged over a cell area 500 meters square, and within any one cell there could be features that increase or decrease the values shown on this map. This map shows the general variation of Minnesota's wind resource and should not be used to determine the performance of specific projects.

January 2006

Appendix D

Public Health Impacts of Wind Turbines

Public Health Impacts of Wind Turbines

Prepared by:
Minnesota Department of Health
Environmental Health Division

In response to a request from:
Minnesota Department of Commerce
Office of Energy Security

May 22, 2009

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I. Introduction

In late February 2009 the Minnesota Department of Health (MDH) received a request from the Office of Energy Security (OES) in the Minnesota Department of Commerce, for a "white paper" evaluating possible health effects associated with low frequency vibrations and sound arising from large wind energy conversion systems (LWECS). The OES noted that there was a request for a Contested Case Hearing before the Minnesota Public Utilities Commission (PUC) on the proposed Bent Tree Wind Project in Freeborn County Minnesota; further, the OES had received a long comment letter from a citizen regarding a second project proposal, the Lakeswind Wind Power Plant in Clay, Becker and Ottertail Counties, Minnesota. This same commenter also wrote to the Commissioner of MDH to ask for an evaluation of health issues related to exposure to low frequency sound energy generated by wind turbines. The OES informed MDH that a white paper would have more general application and usefulness in guiding decision-making for future wind projects than a Contested Case Hearing on a particular project. (Note: A Contested Case Hearing is an evidentiary hearing before an Administrative Law Judge, and may be ordered by regulatory authorities, in this case the PUC, in order to make a determination on disputed issues of material fact. The OES advises the PUC on need and permitting issues related to large energy facilities.)

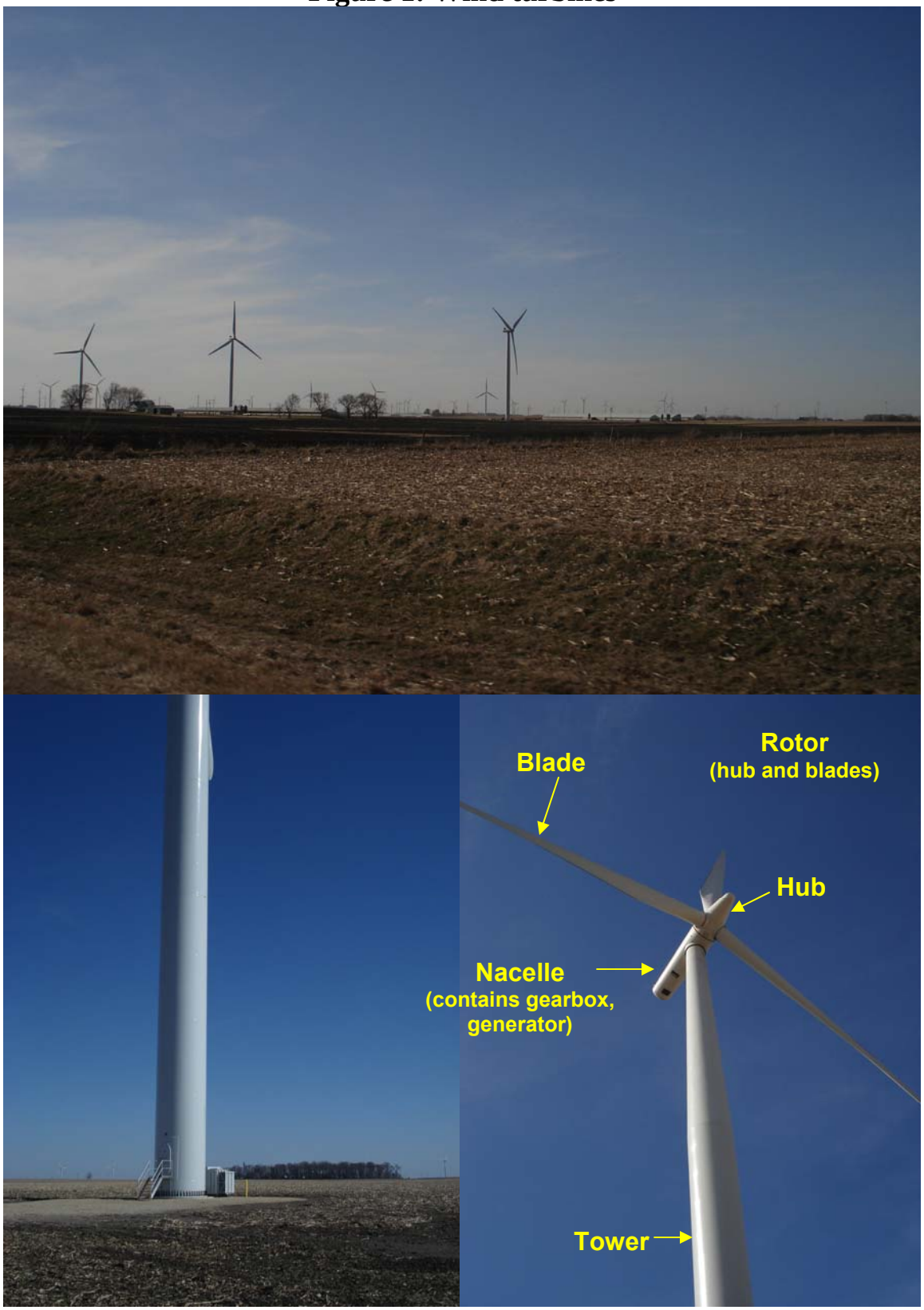
In early March 2009, MDH agreed to evaluate health impacts from wind turbine noise and low frequency vibrations. In discussion with OES, MDH also proposed to examine experiences and policies of other states and countries. MDH staff appeared at a hearing before the PUC on March 19, 2009, and explained the purpose and use of the health evaluation. The Commissioner replied to the citizen letter, affirming that MDH would perform the requested review.

A brief description of the two proposed wind power projects, and a brief discussion of health issues to be addressed in this report appear below.

A. Site Proposals

Wind turbines are huge and expensive machines requiring large capitol investment. Figure 1 shows some existing wind turbines in Minnesota. Large projects require control of extensive land area in order to optimize spacing of turbines to minimize turbulence at downwind turbines. Towers range up to 80 to 100 meters (260 to 325 feet), and blades can be up to 50 meters long (160 feet) (see Tetra Tech, 2008; WPL, 2008). Turbines are expected to be in place for 25-30 years.

Figure 1: Wind turbines



1. Bent Tree Wind Project in Freeborn County

This is a proposal by the Wisconsin Power and Light Company (WPL) for a 400 megawatt (MW) project in two phases of 200 MW each (requiring between 80 and 130 wind turbines). The cost of the first phase is estimated at $497 million. The project site area would occupy approximately 40 square miles located 4 miles north and west of the city of Albert Lea, approximately 95 miles south of Minneapolis (Figure 2) (WPL, 2008). The Project is a LWECS and a Certificate of Need (CON) from the PUC is required (*Minnesota Statutes 216B.243)*. The PUC uses the CON process to determine the basic type of facility (if any) to be constructed, the size of the facility, and when the project will be in service. The CON process involves a public hearing and preparation of an Environmental Report by the OES. The CON process generally takes a year, and is required before a facility can be permitted.

WPL is required to develop a site layout that optimizes wind resources. Accordingly, project developers are required to control areas at least 5 rotor diameters in the prevailing (north-south) wind directions (between about 1300 and 1700 feet for the 1.5 to 2.5 MW turbines under consideration for the project) and 3 rotor diameters in the crosswind (east-west) directions (between about 800 and 1000 feet). Thus, these are minimum setback distances from properties in the area for which easements have not been obtained. Further, noise rules promulgated by the Minnesota Pollution Control Agency (MPCA; *Minnesota Rules* Section 7030), specify a maximum nighttime noise in residential areas of 50 A-weighted decibels (dB(A). WPL has proposed a minimum setback of 1,000 feet from occupied structures in order to comply with the noise rule.

2. Noble Flat Hill Wind Park in Clay, Becker and Ottertail Counties

This is a LWECS proposed by Noble Flat Hill Windpark I (Noble), a subsidiary of Noble Environmental Power, based in Connecticut. The proposal is for a 201 MW project located 12 miles east of the City of Moorhead, about 230 miles northwest of Minneapolis (Figure 3) (Tetra Tech, 2008). The cost of the project is estimated to be between $382 million and $442 million. One hundred thirty-four GE 1.5 MW wind turbines are planned for an area of 11,000 acres (about 17 square miles); the site boundary encompasses approximately 20,000 acres. Setback distances of a minimum of 700 feet are planned to comply with the 50 dB(A) noise limit. However, rotor diameters will be 77 meters (250 feet). Therefore, setback distances in the prevailing wind direction of 1,300 feet are planned for properties where owners have not granted easements. Setbacks of 800 feet are planned in the crosswind direction.

Figure 2: Bent Tree Wind Project, Freeborn County

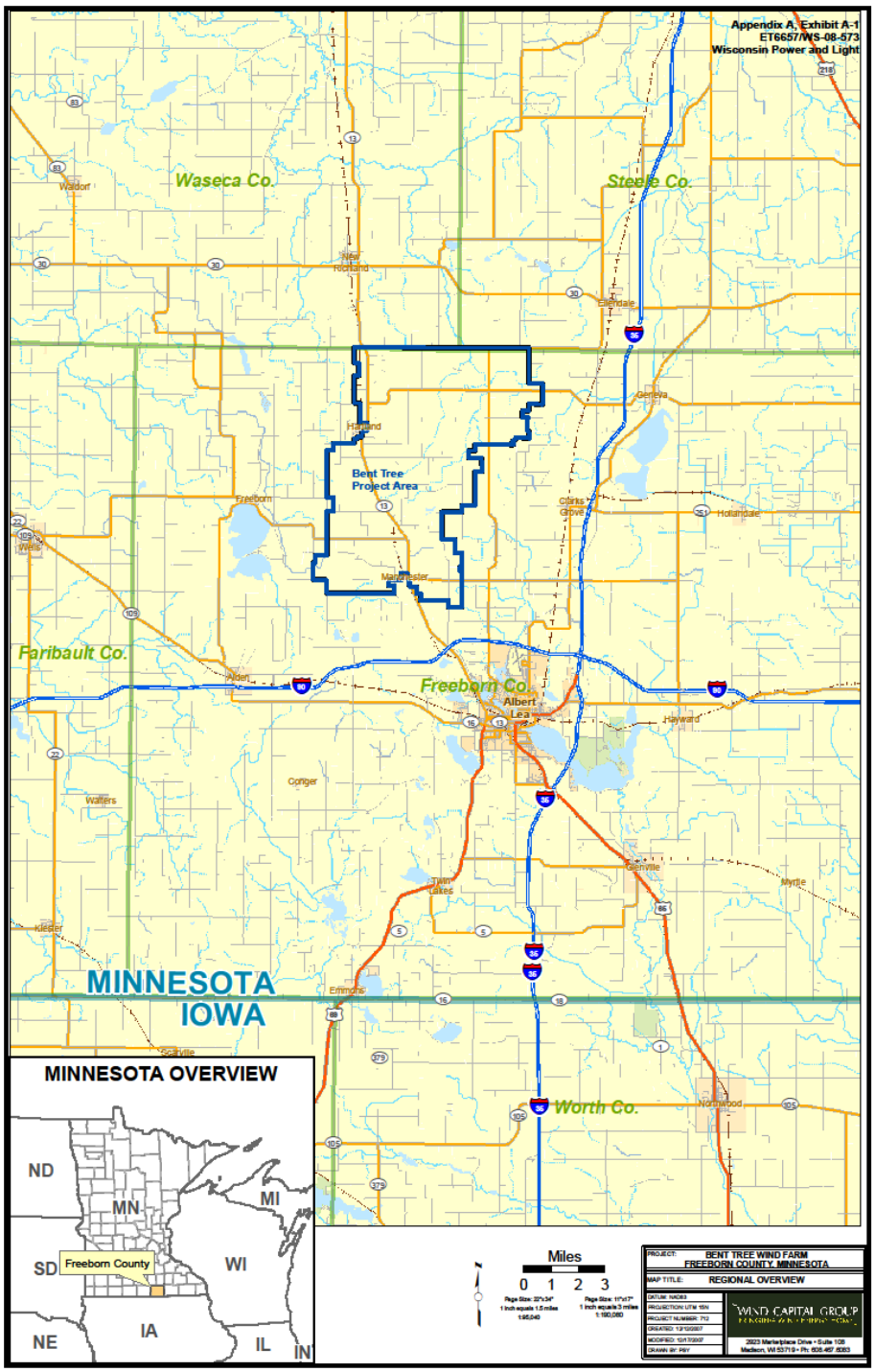
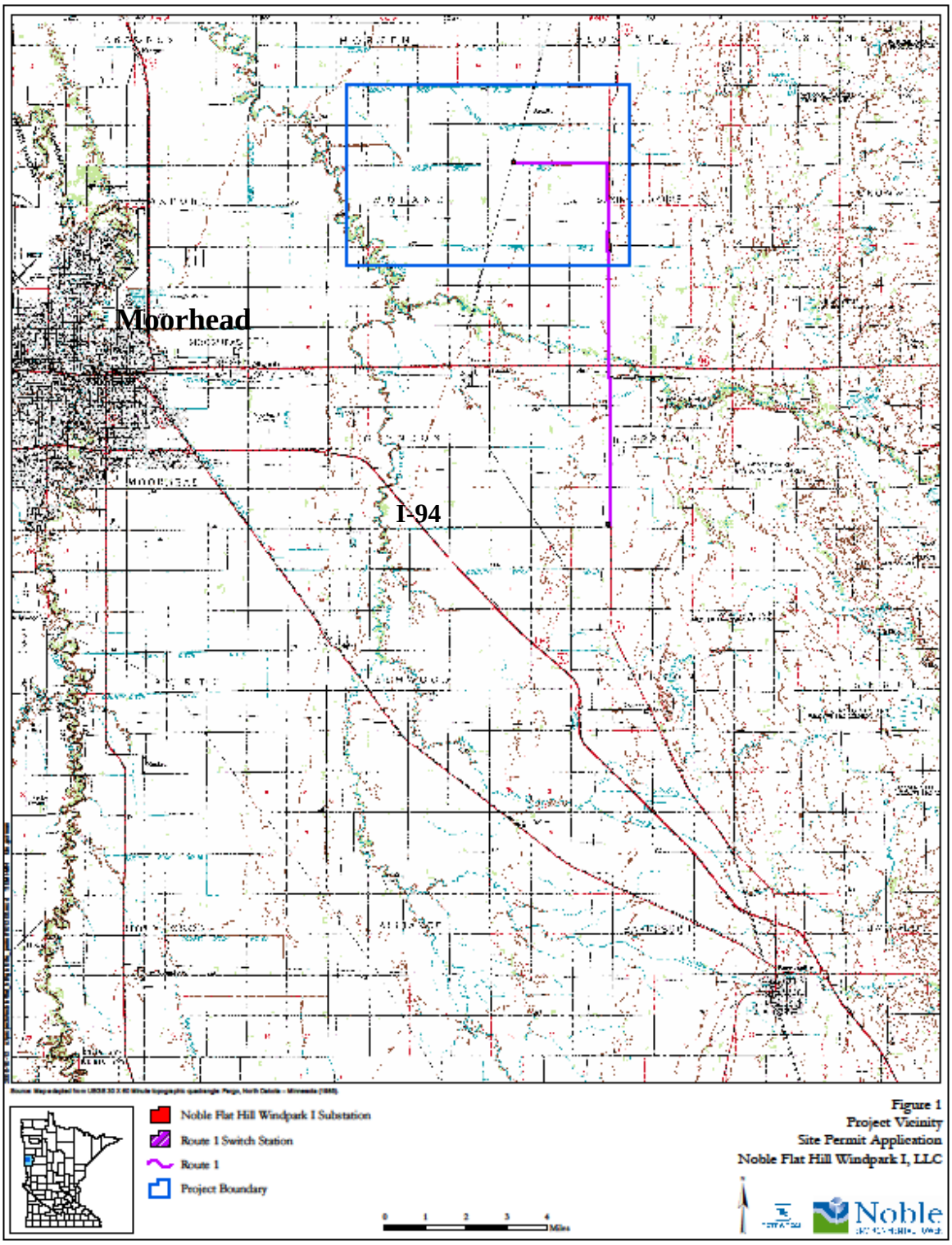


Figure 3: Noble Flat Hill Wind Park, Clay, Becker, Ottertail Counties



B. Health Issues

The National Research Council of the National Academies (NRC, 2007) has reviewed impacts of wind energy projects on human health and well-being. The NRC begins by observing that wind projects, just as other projects, create benefits and burdens, and that concern about impacts is natural when the source is near one's home. Further, the NRC notes that different people have different values and levels of sensitivity. Impacts noted by the NRC that may have the most effect on health include noise and low frequency vibration, and shadow flicker. While noise and vibration are the main focus of this paper, shadow flicker (casting of moving shadows on the ground as wind turbine blades rotate) will also be briefly discussed.

Noise originates from mechanical equipment inside the nacelles of the turbines (gears, generators, etc.) and from interaction of turbine blades with wind. Newer wind turbines generate minimal noise from mechanical equipment. The most problematic wind turbine noise is a broadband "whooshing" sound produced by interaction of turbine blades with the wind. Newer turbines have upwind rotor blades, minimizing low frequency "infrasound" (i.e., air pressure changes at frequencies below 20-100 Hz that are inaudible). However, the NRC notes that during quiet conditions at night, low frequency modulation of higher frequency sounds, such as are produced by turbine blades, is possible. The NRC also notes that effects of low frequency (infrasound) vibration (less than 20 Hz) on humans are not well understood, but have been asserted to disturb some people.

Finally, the NRC concludes that noise produced by wind turbines is generally not a major concern beyond a half mile. Issues raised by the NRC report and factors that may affect distances within which wind turbine noise may be problematic are discussed more extensively below.

II. Elementary Characteristics of Sensory Systems and Sound

A. Sensory Systems

1. Hearing

Sensory systems respond to a huge dynamic range of physical stimuli within a relatively narrow dynamic range of mechanical, chemical and/or neuronal (electrophysiological) output. Compression of the dynamic range is accomplished by systems that respond to logarithmic increases in intensity of physical stimuli with arithmetically increasing sensory responses. This general property is true for hearing, and has been recognized since at least the mid-19th century (see e.g., Woodworth and Schlosberg, 1964). "Loudness" is the sensory/perceptual correlate of the physical intensity of air pressure changes to which the electro-mechanical transducers in the ear and associated neuronal pathways are sensitive. Loudness increases as the logarithm of air pressure, and it is convenient to relate loudness to a reference air pressure (in dyne/cm^2 or pascals) in tenths of logarithmic units (decibels; dB). Further, the ear is sensitive to only a relatively narrow frequency range of air pressure changes: those between approximately 20 and 20,000 cycles per second or Herz (Hz). In fact, sensitivity varies within this range, so that the sound pressure level relative to a reference value that is audible in the middle of the range

(near 1,000 Hz) is about 4 orders of magnitude smaller than it is at 20 Hz and about 2 orders of magnitude smaller than at 20,000 Hz (Fig. 3). Accordingly, measurements of loudness in dB generally employ filters to equalize the loudness of sounds at different frequencies or "pitch." To approximate the sensitivity of the ear, A-weighted filters weigh sound pressure changes at frequencies in the mid-range more than those at higher or lower frequencies. When an A-weighted filter is used, loudness is measured in dB(A). This is explained in greater detail in Section B below.

The ear accomplishes transduction of sound through a series of complex mechanisms (Guyton, 1991). Briefly, sound waves move the eardrum (tympanic membrane), which is in turn connected to 2 small bones (ossicles) in the middle ear (the malleus and incus). A muscle connected to the malleus keeps the tympanic membrane tensed, allowing efficient transmission to the malleus of vibrations on the membrane. Ossicle muscles can also relax tension and attenuate transmission. Relaxation of muscle tension on the tympanic membrane protects the ear from very loud sounds and also masks low frequency sounds, or much background noise. The malleus and incus move a third bone (stapes). The stapes in turn applies pressure to the fluid of the cochlea, a snail-shaped structure imbedded in temporal bone. The cochlea is a complex structure, but for present purposes it is sufficient to note that pressure changes or waves of different frequencies in cochlear fluid result in bending of specialized hair cells in regions of the cochlea most sensitive to different frequencies or pitch. Hair cells are directly connected to nerve fibers in the vestibulocochlear nerve (VIII cranial nerve).

Transmission of sound can also occur directly through bone to the cochlea. This is a very inefficient means of sound transmission, unless a device (e.g. a tuning fork or hearing aid) is directly applied to bone (Guyton, 1991).

2. Vestibular System

The vestibular system reacts to changes in head and body orientation in space, and is necessary for maintenance of equilibrium and postural reflexes, for performance of rapid and intricate body movements, and for stabilizing visual images (via the vestibulo-ocular reflex) as the direction of movement changes (Guyton, 1991).

The vestibular apparatus, like the cochlea, is imbedded in temporal bone, and also like the cochlea, hair cells, bathed in vestibular gels, react to pressure changes and transmit signals to nerve fibers in the vestibulocochlear nerve. Two organs, the utricle and saccule, called otolith organs, integrate information about the orientation of the head with respect to gravity. Otoliths are tiny stone-like crystals, embedded in the gels of the utricle and saccule, that float as the head changes position within the gravitational field. This movement is translated to hair cells. Three semi-circular canals, oriented at right angles to each other, detect head rotation. Stimulation of the vestibular apparatus is not directly detected, but results in activation of motor reflexes as noted above (Guyton, 1991).

Like the cochlea, the vestibular apparatus reacts to pressure changes at a range of frequencies; optimal frequencies are lower than for hearing. These pressure changes can be caused by body movements, or by direct bone conduction (as for hearing, above) when vibration is applied directly to the temporal bone (Todd et al., 2008). These investigators

found maximal sensitivity at 100 Hz, with some sensitivity down to 12.5 Hz. The saccule, located in temporal bone just under the footplate of the stapes, is the most sound-sensitive of the vestibular organs (Halmagyi et al., 2004). It is known that brief loud clicks (90-95 dB) are detected by the vestibular system, even in deaf people. However, we do not know what the sensitivity of this system is through the entire range of sound stimuli.

While vestibular system activation is not directly felt, activation may give rise to a variety of sensations: vertigo, as the eye muscles make compensatory adjustments to rapid angular motion, and a variety of unpleasant sensations related to internal organs. In fact, the vestibular system interacts extensively with the "autonomic" nervous system, which regulates internal body organs (Balaban and Yates, 2004). Sensations and effects correlated with intense vestibular activation include nausea and vomiting and cardiac arrhythmia, blood pressure changes and breathing changes.

While these effects are induced by relatively intense stimulation, it is also true that A-weighted sound measurements attuned to auditory sensitivity, will underweight low frequencies for which the vestibular system is much more sensitive (Todd et al., 2008). Nevertheless, activation of the vestibular system *per se* obviously need not give rise to unpleasant sensations. It is not known what stimulus intensities are generally required for for autonomic activation at relatively low frequencies, and it is likely that there is considerable human variability and capacity to adapt to vestibular challenges.

B. Sound

1. Introduction

Sound is carried through air in compression waves of measurable frequency and amplitude. Sound can be tonal, predominating at a few frequencies, or it can contain a random mix of a broad range of frequencies and lack any tonal quality (white noise). Sound that is unwanted is called noise.

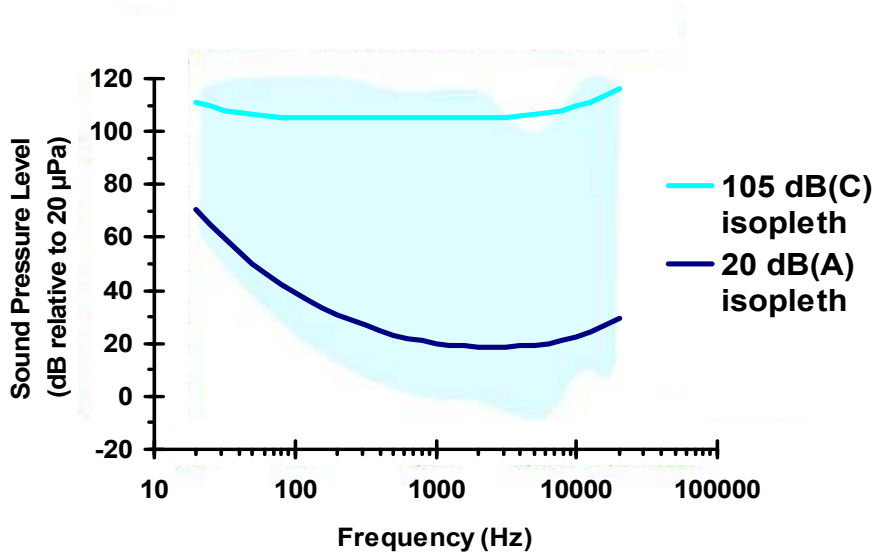
Audible Frequency Sound

Besides frequency sensitivity (between 20 and 20,000 Hz), humans are also sensitive to changes in the amplitude of the signal (compression waves) within this audible range of frequencies. Increasing amplitude, or increasing sound pressure, is perceived as increasing volume or loudness. The sound pressure level in air (SPL) is measured in micro Pascals (μPa). SPLs are typically converted in measuring instruments and reported as decibels (dB) which is a log scale, relative unit (see above). When used as the unit for sound, dBs are reported relative to a SPL of 20 μPa. Twenty μPa is used because it is the approximate threshold of human hearing sensitivity at about 1000 Hz. Decibels relative to 20 μPa are calculated from the following equation:

$$\text{Loudness (dB)} = \text{Log}\left(\left(\text{SPL} / 20\ \mu\text{Pa}\right)^2\right) * 10$$

Figure 4 shows the audible range of normal human hearing. Note that while the threshold sensitivity varies over the frequency range, at high SPLs sensitivity is relatively consistent over audible frequencies.

Figure 4: Audible Range of Human Hearing



Equivalence curves for different frequencies, when sound meter readings in dB are taken with A or C-weighting filters. (Adapted from EPD Hong Kong SAR, 2009)

Sub-Audible Frequency Sound

Sub-audible frequency sound is often called infrasound. It may be sensed by people, similar to audible sound, in the cochlear apparatus in the ear; it may be sensed by the vestibular system which is responsible for balance and physical equilibrium; or it may be sensed as vibration.

Resonance and modulation

Sound can be attenuated as it passes through a physical structure. However, because the wavelength of low frequency sound is very long (the wavelength of 40 Hz in air at sea level and room temperature is 8.6 meters or 28 ft), low frequencies are not effectively attenuated by walls and windows of most homes or vehicles. (For example, one can typically hear the bass, low frequency music from a neighboring car at a stoplight, but not the higher frequencies.) In fact, it is possible that there are rooms within buildings exposed to low frequency sound or noise where some frequencies may be amplified by resonance (e.g. ½ wavelength, ¼ wavelength) within the structure. In addition, low frequency sound can cause vibrations within a building at higher, more audible frequencies as well as throbbing or rumbling.

Sounds that we hear generally are a mixture of different frequencies. In most instances these frequencies are added together. However, if the source of the sound is not constant, but changes over time, the effect can be re-occurring pulses of sound or low frequency modulation of sound. This is the type of sound that occurs from a steam engine, a jack hammer, music and motor vehicle traffic. Rhythmic, low frequency pulsing of higher frequency noise (like the sound of an amplified heart beat) is one type of sound that can be caused by wind turbine blades under some conditions.

2. Human Response to Low Frequency Stimulation

There is no consensus whether sensitivity below 20 Hz is by a similar or different mechanism than sensitivity and hearing above 20 Hz (Reviewed by Møller and Pedersen, 2004). Possible mechanisms of sensation caused by low frequencies include bone conduction at the applied frequencies, as well as amplification of the base frequency and/or harmonics by the auditory apparatus (eardrum and ossicles) in the ear. Sensory thresholds are relatively continuous, suggesting (but not proving) a similar mechanism above and below 20 Hz. However, it is clear that cochlear sensitivity to infrasound (< 20 Hz) is considerably less than cochlear sensitivity to audible frequencies.

Møller and Pedersen (2004) reviewed human sensitivity at low and infrasonic frequencies. The following findings are of interest:

- When whole-body pressure-field sensitivity is compared with ear-only (earphone) sensitivity, the results are very similar. These data suggest that the threshold sensitivity for low frequency is through the ear and not vestibular.
- Some individuals have extraordinary sensitivity at low frequencies, up to 25 dB more sensitive than the presumed thresholds at some low frequencies.
- While population average sensitivity over the low frequency range is smooth, sound pressure thresholds of response for individuals do not vary smoothly but are inconsistent, with peaks and valleys or "microstructures". Therefore the sensitivity response of individuals to different low frequency stimulation may be difficult to predict.
- Studies of equal-loudness-levels demonstrate that as stimulus frequency decreases through the low frequencies, equal-loudness lines compress in the dB scale. (See Figure 4 as an example of the relatively small difference in auditory SPL range between soft and loud sound at low frequencies).
- The hearing threshold for pure tones is different than the hearing threshold for white noise at the same total sound pressure.

3. Sound Measurements

Sound measurements are taken by instruments that record sound pressure or the pressure of the compression wave in the air. Because the loudness of a sound to people is usually the primary interest in measuring sound, normalization schemes or filters have been applied to absolute measurements. dB(A) scaling of sound pressure measurements was intended to normalize readings to equal loudness over the audible range of frequencies at low loudness. For example, a 5,000 Hz (5 kHz) and 20 dB(A) tone is expected to have the same intensity or loudness as a 100 Hz, 20 dB(A) tone. However, note that the absolute sound pressures would be about 20,000 μPa and 40,000 μPa, respectively, or about a difference of 20 dB (relative to 20 μPa), or as it is sometimes written 20 dB(linear).

Most sound is not a single tone, but is a mixture of frequencies within the audible range. A sound meter can add the total SPLs for all frequencies; in other words, the dB readings over the entire spectrum of audible sound can be added to give a single loudness metric. If sound is reported as A-weighted, or dB(A), it is a summation of the dB(A) scaled sound pressure from 20 Hz to 20 kHz.

In conjunction with the dB(A) scale, the dB(B) scale was developed to approximate equal loudness to people across audible frequencies at medium loudness, and dB(C) was developed to approximate equal-loudness for loud environments. Figure 4 shows isopleths for 20 dB(A) and 105 dB(C). While dB(A), dB(B), dB(C) were developed from empirical data at the middle frequencies, at the ends of the curves these scales were extrapolated, or sketched in, and are not based on experimental or observational data (Berglund et al., 1996). As a result, data in the low frequency range (and probably the highest audible frequencies as well) cannot be reliably interpreted using these scales. The World Health Organization (WHO, 1999) suggests that A-weighting noise that has a large low frequency component is not reliable assessment of loudness.

The source of the noise, or the noise signature, may be important in developing equal-loudness schemes at low frequencies. C-weighting has been recommended for artillery noise, but a linear, unweighted scale may be even better at predicting a reaction (Berglund et al., 1996). A linear or equal energy rating also appears to be the most effective predictor of reaction to low frequency noise in other situations, including blast noise from mining. The implication of the analysis presented by Berglund et al. (1996) is that annoyance from non-tonal noise should not be estimated from a dB(A) scale, but may be better evaluated using dB(C), or a linear non-transformed scale.

However, as will be discussed below, a number of schemes use a modified dB(A) scale to evaluate low frequency noise. These schemes differ from a typical use of the dB(A) scale by addressing a limited frequency range below 250 Hz, where auditory sensitivity is rapidly changing as a function of frequency (see Figure 4).

III. Exposures of Interest

A. Noise From Wind Turbines

1. Mechanical noise

Mechanical noise from a wind turbine is sound that originates in the generator, gearbox, yaw motors (that intermittently turn the nacelle and blades to face the wind), tower ventilation system and transformer. Generally, these sounds are controlled in newer wind turbines so that they are a fraction of the aerodynamic noise. Mechanical noise from the turbine or gearbox should only be heard above aerodynamic noise when they are not functioning properly.

2. Aerodynamic noise

Aerodynamic noise is caused by wind passing over the blade of the wind turbine. The tip of a 40-50 meter blade travels at speeds of over 140 miles per hour under normal operating conditions. As the wind passes over the moving blade, the blade interrupts the laminar flow of air, causing turbulence and noise. Current blade designs minimize the amount of turbulence and noise caused by wind, but it is not possible to eliminate turbulence or noise.

Aerodynamic noise from a wind turbine may be underestimated during planning. One source of error is that most meteorological wind speed measurements noted in wind farm literature are taken at 10 meters above the ground. Wind speed above this elevation, in

the area of the wind turbine rotor, is then calculated using established modeling relationships. In one study (van den Berg, 2004) it was determined that the wind speeds at the hub at night were up to 2.6 times higher than modeled. Subsequently, it was found that noise levels were 15 dB higher than anticipated.

Unexpectedly high aerodynamic noise can also be caused by improper blade angle or improper alignment of the rotor to the wind. These are correctable and are usually adjusted during the turbine break-in period.

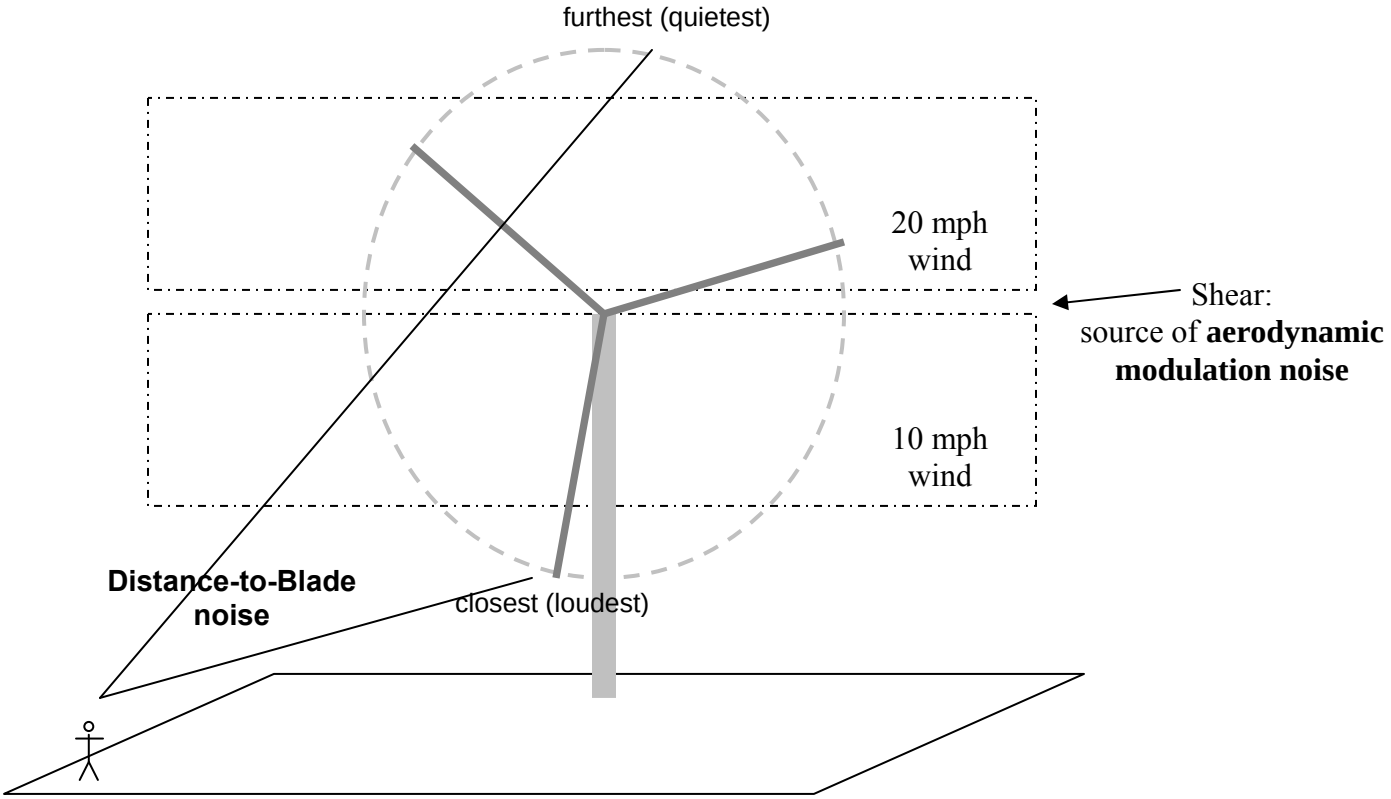
3. Modulation of aerodynamic noise

Rhythmic modulation of noise, especially low frequency noise, has been found to be more annoying than steady noise (Bradley, 1994; Holmberg et al., 1997). One form of rhythmic modulation of aerodynamic noise that can be noticeable very near to a wind turbine is a distance-to-blade effect. To a receptor on the ground in front of the wind turbine, the detected blade noise is loudest as the blade passes, and quietest when the blade is at the top of its rotation. For a modern 3-blade turbine, this distance-to-blade effect can cause a pulsing of the blade noise at about once per second (1 Hz). On the ground, about 500 feet directly downwind from the turbine, the distance-to-blade can cause a difference in sound pressure of about 2 dB between the *tip* of the blade at its farthest point and the *tip* of the blade at its nearest point (48 meter blades, 70 meter tower). Figure 5 demonstrates why the loudness of blade noise (aerodynamic noise) pulses as the distance-to-blade varies for individuals close to a turbine.

If the receptor is 500 feet from the turbine base, in line with the blade rotation or up to 60° off line, the difference in sound pressure from the *tip* of the blade at its farthest and nearest point can be about 4-5 dB, an audible difference. The tip travels faster than the rest of the blade and is closer to (and then farther away from) the receptor than other parts of the blade. As a result, noise from other parts of the blade will be modulated less than noise from the tip. Further, blade design can also affect the noise signature of a blade. The distance-to-blade effect diminishes as receptor distance increases because the relative difference in distance from the receptor to the top or to the bottom of the blade becomes smaller. Thus, moving away from the tower, distance-to-blade noise gradually appears to be more steady.

Another source of rhythmic modulation may occur if the wind through the rotor is not uniform. Blade angle, or pitch, is adjusted for different wind speeds to maximize power and to minimize noise. A blade angle that is not properly tuned to the wind speed (or wind direction) will make more noise than a properly tuned blade. Horizontal layers with different wind speeds or directions can form in the atmosphere. This wind condition is called shear. If the winds at the top and bottom of the blade rotation are different, blade noise will vary between the top and bottom of blade rotation, causing modulation of aerodynamic noise. This noise, associated with the blades passing through areas of different air-wind speeds, has been called aerodynamic modulation and is demonstrated in Figure 5.

Figure 5: Sources of noise modulation or pulsing



In some terrains and under some atmospheric conditions wind aloft, near the top of the wind turbine, can be moving faster than wind near the ground. Wind turbulence or even wakes from adjacent turbines can create non-uniform wind conditions as well. As a result of aerodynamic modulation a rhythmic noise pattern or pulsing will occur as each blade passes through areas with different wind speed. Furthermore, additional noise, or thumping, may occur as each blade passes through the transition between different wind speed (or wind direction) areas.

Wind shear caused by terrain or structures on the ground (e.g. trees, buildings) can be modeled relatively easily. Wind shear in areas of flat terrain is not as easily understood. During the daytime wind in the lower atmosphere is strongly affected by thermal convection which causes mixing of layers. Distinct layers do not easily form. However, in the nighttime the atmosphere can stabilize (vertically), and layers form. A paper by G.P. van den Berg (2008) included data from a study on wind shear at Cabauw, The Netherlands (flat terrain). Annual average wind speeds at different elevations above ground was reported. The annual average wind speed at noon was about 5.75 meters per second (m/s; approximately 12.9 miles per hour(mph)) at 20 m above ground, and about 7.6 m/s (17 mph) at 140 m. At midnight, the annual averages were about 4.3 m/s (9.6 mph) and 8.8 m/s (19.7 mph) for 20m and 140 m, respectively, above ground. The data show that while the average windspeed (between 20m and 140m) is very similar at noon and midnight at Cabauw, the windspeed difference between elevations during the day is

much less than the difference at night (1.85 m/s (4.1 mph) and 4.5 m/s (10 mph), respectively). As a result one would expect that the blade angle can be better tuned to the wind speed during the daytime. Consequently, blade noise would be greater at night.

A number of reports have included discussion of aerodynamic modulation (van den Berg, 2005; UK Department of Transport and Industry, 2006; UK Department for Business Enterprise and Regulatory Reform, 2007; van den Berg, 2008). They suggest that aerodynamic modulation is typically underestimated when noise estimates are calculated. In addition, they suggest that detailed modeling of wind, terrain, land use and structures may be used to predict whether modulation of aerodynamic noise will be a problem at a proposed wind turbine site.

4. Wind farm noise

The noise from multiple turbines similarly distant from a residence can be noticeably louder than a lone turbine simply through the addition of multiple noise sources. Under steady wind conditions noise from a wind turbine farm may be greater than noise from the nearest turbine due to synchrony between noise from more than one turbine (van den Berg, 2005). Furthermore, if the dominant frequencies (including aerodynamic modulation) of different turbines vary by small amounts, an audible beat or dissonance may be heard when wind conditions are stable.

B. Shadow Flicker

Rhythmic light flicker from the blades of a wind turbine casting intermittent shadows has been reported to be annoying in many locations (NRC, 2007; Large Wind Turbine Citizens Committee, 2008). (Note: Flashing light at frequencies around 1 Hz is too slow to trigger an epileptic response.)

Modeling conducted by the Minnesota Department of Health suggests that a receptor 300 meters perpendicular to, and in the shadow of the blades of a wind turbine, can be in the flicker shadow of the rotating blade for almost 1½ hour a day. At this distance a blade may completely obscure the sun each time it passes between the receptor and the sun. With current wind turbine designs, flicker should not be an issue at distances over 10 rotational diameters (~1000 meters or 1 km (0.6 mi) for most current wind turbines). This distance has been recommended by the Wind Energy Handbook (Burton et al., 2001) as a minimum setback distance in directions that flicker may occur, and has been noted in the Bent Tree Permit Application (WPL, 2008).

Shadow flicker is a potential issue in the mornings and evenings, when turbine noise may be masked by ambient sounds. While low frequency noise is typically an issue indoors, shadow flicker can be an issue both indoors and outdoors when the sun is low in the sky. Therefore, shadow flicker may be an issue in locations other than the home.

Ireland recommends wind turbines setbacks of at least 300 meters from a road to decrease driver distraction (Michigan State University, 2004). The NRC (2007) recommends that shadow flicker is addressed during the preliminary planning stages of a wind turbine project.

IV. Impacts of Wind Turbine Noise

A. Potential Adverse Reaction to Sound

Human sensitivity to sound, especially to low frequency sound, is variable. Individuals have different ranges of frequency sensitivity to audible sound; different thresholds for each frequency of audible sound; different vestibular sensitivities and reactions to vestibular activation; and different sensitivity to vibration.

Further, sounds, such as repetitive but low intensity noise, can evoke different responses from individuals. People will exhibit variable levels of annoyance and tolerance for different frequencies. Some people can dismiss and ignore the signal, while for others, the signal will grow and become more apparent and unpleasant over time (Moreira and Bryan, 1972; Bryan and Tempest, 1973). These reactions may have little relationship to will or intent, and more to do with previous exposure history and personality.

Stress and annoyance from noise often do not correlate with loudness. This may suggest, in some circumstances, other factors impact an individual's reaction to noise. A number of reports, cited in Staples (1997), suggest that individuals with an interest in a project and individuals who have some control over an environmental noise are less likely to find a noise annoying or stressful.

Berglund et al. (1996) reviewed reported health effects from low frequency noise. Loud noise from any source can interfere with verbal communication and possibly with the development of language skills. Noise may also impact mental health. However, there are no studies that have looked specifically at the impact of low frequency noise on communication, development of language skills and mental health. Cardiovascular and endocrine effects have been demonstrated in studies that have looked at exposures to airplane and highway noise. In addition, possible effects of noise on performance and cognition have also been investigated, but these health studies have not generally looked at impacts specifically from low frequency noise. Noise has also been shown to impact sleep and sleep patterns, and one study demonstrated impacts from low frequency noise in the range of 72 to 85 dB(A) on chronic insomnia (Nagai et al., 1989 as reported in Berglund et al., 1996).

Case studies have suggested that health can be impacted by relatively low levels of low frequency noise. But it is difficult to draw general conclusions from case studies. Feldmann and Pitten (2004)) describe a family exposed during the winter to low frequency noise from a nearby heating plant. Reported health impacts were: "indisposition, decrease in performance, sleep disturbance, headache, ear pressure, crawl parästhesy [crawling, tingling or numbness sensation on the skin] or shortness of breath."

Annoyance, unpleasant sounds, and complaints

Reported health effects from low frequency stimulation are closely associated with annoyance from audible noise. "There is no reliable evidence that infrasounds below the hearing threshold produce physiological or psychological effects" (WHO, 1999). It has not been shown whether annoyance is a symptom or an accessory in the causation of

health impacts from low frequency noise. Studies have been conducted on some aspects of low frequency noise that can cause annoyance.

Noise complaints are usually a reasonable measure of annoyance with low frequency environmental noise. Leventhall (2004) has reviewed noise complaints and offers the following conclusions:

> " The problems arose in quiet rural or suburban environments
> The noise was often close to inaudibility and heard by a minority of people
> The noise was typically audible indoors and not outdoors
> The noise was more audible at night than day
> The noise had a throb or rumble characteristic
> The main complaints came from the 55-70 years age group
> The complainants had normal hearing.
> Medical examination excluded tinnitus.
>
> " These are now recognised as classic descriptors of low frequency noise problems."

These observations are consistent with what we know about the propagation of low intensity, low frequency noise. Some people are more sensitive to low frequency noise. The difference, in dB, between soft (acceptable) and loud (annoying) noise is much less at low frequency (see Figure 4 audible range compression). Furthermore, during the daytime, and especially outdoors, annoying low frequency noise can be masked by high frequency noise.

The observation that "the noise was typically audible indoors and not outdoors" is not particularly intuitive. However, as noted in a previous section, low frequencies are not well attenuated when they pass through walls and windows. Higher frequencies (especially above 1000 Hz) can be efficiently attenuated by walls and windows. In addition, low frequency sounds may be amplified by resonance within rooms and halls of a building. Resonance is often characterized by a throbbing or a rumbling, which has also been associated with many low frequency noise complaints.

Low frequency noise, unlike higher frequency noise, can also be accompanied by shaking, vibration and rattling. In addition, throbbing and rumbling may be apparent in some low frequency noise. While these noise features may not be easily characterized, numerous studies have shown that their presence dramatically lowers tolerance for low frequency noise (Berglund et al., 1996).

As reviewed in Leventhall (2003), a study of industrial exposure to low frequency noise found that fluctuations in total noise averaged over 0.5, 1.0 and 2.0 seconds correlated with annoyance (Holmberg et al., 1997). This association was noted elsewhere and led (Broner and Leventhall, 1983) to propose a 3dB "penalty" be added to evaluations of annoyance in cases where low frequency noise fluctuated.

In another laboratory study with test subjects controlling loudness, 0.5 – 4 Hz modulation of low frequency noise was found to be more annoying than non-modulated low

frequency noise. On average test subjects found modulated noise to be similarly annoying as a constant tone 12.9 dB louder (Bradley, 1994).

B. Studies of Wind Turbine Noise Impacts on People

1. Swedish Studies

Two studies in Sweden collected information by questionnaires from 341 and 754 individuals (representing response rates of 68% and 58%, respectively), and correlated responses to calculated exposure to noise from wind farms (Pedersen and Waye, 2004; Pedersen, 2007; Pedersen and Persson, 2007). Both studies showed that the number of respondents perceiving the noise from the wind turbines increased as the calculated noise levels at their homes increased from less than 32.5 dB(A) to greater than 40 dB(A). Annoyance appeared to correlate or trend with calculated noise levels. Combining the data from the two studies, when noise measurements were greater than 40 dB(A), about 50% of the people surveyed (22 of 45 people) reported annoyance. When noise measurements were between 35 and 40 dB(A) about 24% reported annoyance (67 of 276 people). Noise annoyance was more likely in areas that were rated as quiet and in areas where turbines were visible. In one of the studies, 64% respondents who reported noise annoyance also reported sleep disturbance; 15% of respondents reported sleep disturbance without annoyance.

2. United Kingdom Study

Moorhouse et al. (UK Department for Business Enterprise and Regulatory Reform, 2007) evaluated complaints about wind farms. They found that 27 of 133 operating wind farms in the UK received formal complaints between 1991 and 2007. There were a total of 53 complainants for 16 of the sites for which good records were available. The authors of the report considered that many complaints in the early years were for generator and gearbox noise. However, subjective analyses of reports about noise ("like a train that never gets there", "distant helicopter", "thumping", "thudding", "pulsating", "thumping", "rhythmical beating", and "beating") suggested that aerodynamic modulation was the likely cause of complaints at 4 wind farms. The complaints from 8 other wind farms may have had "marginal" association with aerodynamic modulation noise.

Four wind farms that generated complaints possibly associated with aerodynamic modulation were evaluated further. These wind farms were commissioned between 1999 and 2002. Wind direction, speed and times of complaints were associated for 2 of the sites and suggested that aerodynamic modulation noise may be a problem between 7% and 25% of the time. Complaints at 2 of the farms have stopped and at one farm steps to mitigate aerodynamic modulation (operational shutdown under certain meteorological conditions) have been instituted.

3. Netherlands Study

F. van den Berg et al. (2008) conducted a postal survey of a group selected from all residents in the Netherlands within 2.5 kilometers (km) of a wind turbine. In all, 725 residents responded (37%). Respondents were exposed to sound between 24 and 54 dB(A). The percentage of respondents annoyed by sound increased from 2% at levels of 30 dB(A) or less, up to 25% at between 40 and 45 dB. Annoyance decreased above 45 dB. Most residents exposed above 45 dB(A) reported economic benefits from the

turbines. However, at greater than 45 dB(A) more respondents reported sleep interruption. Respondents tended to report more annoyance when they also noted a negative effect on landscape, and ability to see the turbines was strongly related to the probability of annoyance.

4. Case Reports

A number of un-reviewed reports have catalogued complaints of annoyance and some more severe health impacts associated with wind farms. These reports do not contain measurements of noise levels, and do not represent random samples of people living near wind turbines, so they cannot assess prevalence of complaints. They do generally show that in the people surveyed, complaints are more likely the closer people are to the turbines. The most common complaint is decreased quality of life, followed by sleep loss and headache. Complaints seem to be either from individuals with homes quite close to turbines, or individuals who live in areas subject to aerodynamic modulation and, possibly, enhanced sound propagation which can occur in hilly or mountainous terrain. In some of the cases described, people with noise complaints also mention aesthetic issues, concern for ecological effects, and shadow flicker concerns. Not all complaints are primarily about health.

Harry (2007) describes a meeting with a couple in Cornwall, U.K. who live 400 meters from a wind turbine, and complained of poor sleep, headaches, stress and anxiety. Harry subsequently investigated 42 people in various locations in the U.K. living between 300 meters and 2 kilometers (1000 feet to 1.2 miles) from the nearest wind turbine. The most frequent complaint (39 of 42 people) was that their quality of life was affected. Headaches were reported by 27 people and sleep disturbance by 28 people. Some people complained of palpitations, migraines, tinnitus, anxiety and depression. She also mentions correspondence and complaints from people in New Zealand, Australia, France, Germany, Netherlands and the U.S.

Phipps (2007) discusses a survey of 619 households living up to 10 kilometers (km; 6 miles) from wind farms in mountainous areas of New Zealand. Most respondents lived between 2 and 2.5 km from the turbines (over 350 households). Most respondents (519) said they could see the turbines from their homes, and 80% of these considered the turbines intrusive, and 73% considered them unattractive. Nine percent said they were affected by flicker. Over 50% of households located between 2 and 2.5 km and between 5 and 9.5 km reported being able to hear the turbines. In contrast, fewer people living between 3 and 4.5 km away could hear the turbines. Ninety-two households said that their quality of life was affected by turbine noise. Sixty-eight households reported sleep disturbances: 42 of the households reported occasional sleep disturbances, 21 reported frequent sleep disturbances and 5 reported sleep disturbances most of the time.

The Large Wind Turbine Citizens Committee for the Town of Union (2008) documents complaints from people living near wind turbines in Wisconsin communities and other places in the U.S. and U.K. Contained in this report is an older report prepared by the Wisconsin Public Service Corporation in 2001 in response to complaints in Lincoln County, Wisconsin. The report found essentially no exceedances of the 50 dB(A) requirement in the conditional use permit. The report did measure spectral data

accumulated over very short intervals (1 minute) in 1/3 octave bands at several sites while the wind turbines were functioning, and it is of interest that at these sites the sound pressure level at the lower frequencies (below 125 Hz) were at or near 50 dB(A).

Pierpont (2009) postulates wind turbine syndrome, consisting of a constellation of symptoms including headache, tinnitus, ear pressure, vertigo, nausea, visual blurring, tachycardia, irritability, cognitive problems and panic episodes associated with sensations of internal pulsation. She studied 38 people in 10 families living between 1000 feet and slightly under 1 mile from newer wind turbines. She proposes that the mechanism for these effects is disturbance of balance due to "discordant" stimulation of the vestibular system, along with visceral sensations, sensations of vibration in the chest and other locations in the body, and stimulation of the visual system by moving shadows. Pierpont does report that her study subjects maintain that their problems are caused by noise and vibration, and the most common symptoms reported are sleep disturbances and headache. However, 16 of the people she studied report symptoms consistent with (but not necessarily caused by) disturbance of equilibrium.

V. Noise Assessment and Regulation

1. Minnesota noise regulation

The Minnesota Noise Pollution Control Rule is accessible online at: https://www.revisor.leg.state.mn.us/rules/?id=7030 . A summary of the Minnesota Pollution Control Agency (MPCA) noise guidance can be found online at: http://www.pca.state.mn.us/programs/noise.html . The MPCA standards require A-weighting measurements of noise; background noise must be at least 10 dB lower than the noise source being measured. Different standards are specified for day and night, as well as standards that may not be exceeded for more than 10 percent of the time during any hour (L10) and 50 percent of the time during any hour (L50). Household units, including farm houses, are Classification 1 land use. The following are the Class 1 noise limits:

Table 1: Minnesota Class 1 Land Use Noise Limits

Daytime		Nighttime	
L50	L10	L50	L10
60 dB(A)	65 dB(A)	50 dB(A)	55 dB(A)

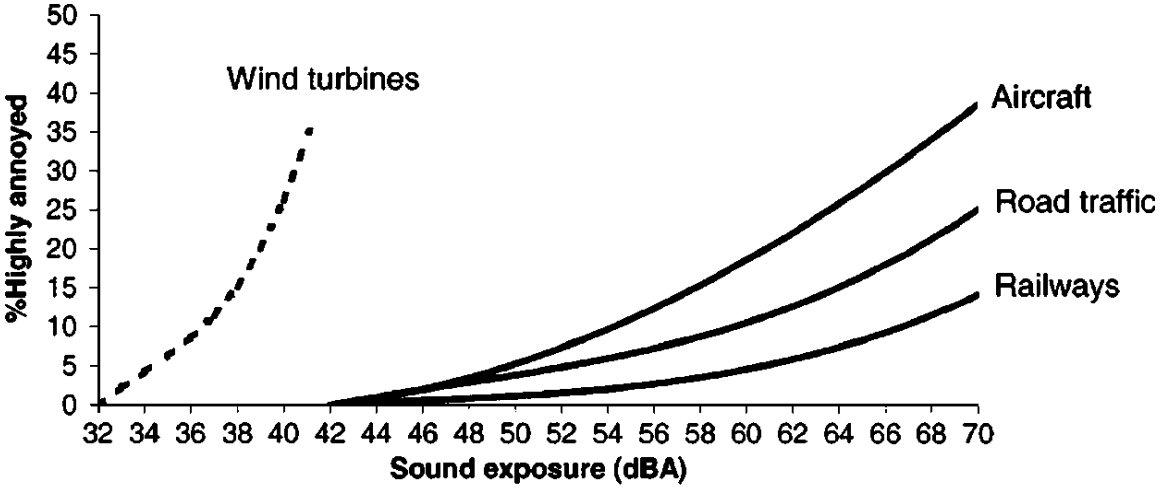
These noise limits are single number limits that rely on the measuring instrument to apply an A-weighting filter over the entire presumed audible spectrum of frequencies (20 Hz to 20 KHz) and then integrating that signal. The result is a single number that characterizes the audible spectrum noise intensity.

2. Low frequency noise assessment and regulation

Pedersen and Waye (2004) looked at the relationship between total dB(A) sound pressure and the annoyance of those who are environmentally exposed to noise from different sources. Figure 6 demonstrates the difficulty in using total dB(A) to evaluate annoyance. Note how lower noise levels (dB(A)) from wind turbines engenders annoyance similar to

much higher levels of noise exposure from aircraft, road traffic and railroads. Sound impulsiveness, low frequency noise and persistence of the noise, as well as demographic characteristics may explain some of the difference.

Figure 6: Annoyance associated with exposure to different environmental noises



Reprinted with permission from Pedersen, E. and K.P. Waye (2004). Perception and annoyance due to wind turbine noise—a dose–response relationship. The Journal of the Acoustical Society of America 116: 3460. Copyright 2004, Acoustical Society of America.

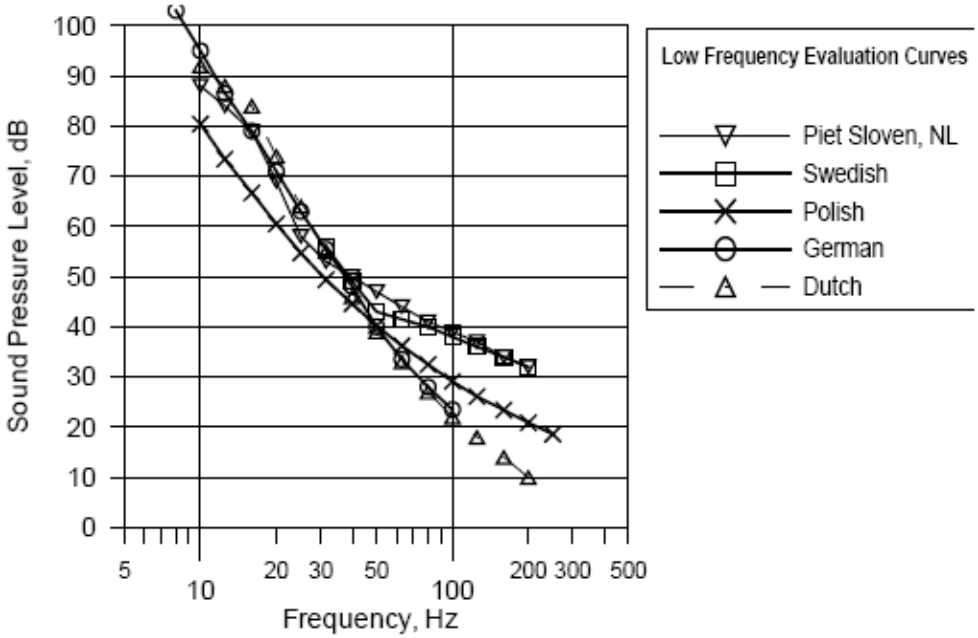
Kjellberg et al. (1997) looked at the ability of different full spectrum weighting schemes to predict annoyance caused by low frequency audio noise. They found that dB(A) is the worst predictor of annoyance of available scales. However, if 6 dB ("penalty") is added to dB(A) when dB(C) – dB(A) is greater than 15 dB, about 71% of the predictions of annoyance are correct. It is important to remember that integrated, transformed measurements of SPL (e.g. dB(A), dB(C)) do not measure frequencies below 20 Hz. While people detect stimuli below 20 Hz, as discussed in above sections, these frequencies are not measured using an A-weighted or C-weighted meter.

The World Health Organization (WHO) recommends that if dB(C) is greater than 10 dB more than dB(A), the low frequency components of the noise may be important and should be evaluated separately. In addition, WHO says "[i]t should be noted that a large proportion of low-frequency components in noise may increase considerably the adverse effects on health." (WHO, 1999)

Many governments that regulate low frequency noise look at noise within bands of frequencies instead of summing the entire spectrum. A study by Poulsen and Mortensen (Danish Environmental Protection Agency, 2002) included a summary of low frequency noise guidelines. German, Swedish, Polish, and Dutch low frequency evaluation curves were compared (see Figure 7). While there are distinctions in how the evaluation curves are described, generally, these curves are sound pressure criterion levels for 1/3 octaves from about 8 Hz to 250 Hz. Exceedance in any 1/3 octave measurement suggests that the noise may be annoying. However, note that regulations associated with low frequency

noise can be quite complex and the regulatory evaluations associated with individual curves can be somewhat different.

Figure 7: 1/3 Octave Sound Pressure Level Low frequency Noise Evaluation Curves



(Danish Environmental Protection Agency, 2002)

The Danish low frequency evaluation requires measuring noise indoors with windows closed; SPL measurements are obtained in 1/3 octave bands and transformed using the A-weighting algorithm for all frequencies between 10 and 160 Hz. These values are then summed into a single metric called $L_{pA,LF}$. A 5 dB "penalty" is added to any noise that is "impulsive". Danish regulations require that 20 dB $L_{pA,LF}$ is not exceeded during the evening and night, and that 25 dB $L_{pA,LF}$ is not exceeded during the day.

Swedish guidance recommends analyzing 1/3 octave bands between 31.5 and 200 Hz inside a home, and comparing the values to a Swedish assessment curve. The Swedish curve is equal to the United Kingdom (UK) Department of Environment, Food and Rural Affairs (DEFRA) low frequency noise criterion curve for overlapping frequencies (31.5 – 160 Hz).

The German "A-level" method sums the A-weighted equivalent levels of 1/3 octave bands that exceed the hearing threshold from 10 – 80 Hz. If the noise is not tonal, the measurements are added. The total cannot exceed 25 dB at night and 35 dB during the day. A frequency-dependent adjustment is applied if the noise is tonal.

In the Poulsen and Mortensen, Danish EPA study (2002), 18 individuals reported annoyance levels when they were exposed through earphones in a controlled environment to a wide range of low frequency environmental noises, all attenuated down to 35 dB, as depicted in Table 2. Noise was simulated as if being heard indoors, filtering out noise at

higher frequencies and effectively eliminating all frequencies above 1600 Hz. Noise levels in 1/3 octave SPLs from 8 Hz to 1600 Hz were measured and low frequencies (below 250 Hz) were used to predict annoyance using 7 different methods (Danish, German A-level, German tonal, Swedish, Polish, Sloven, and C-level). Predictions of annoyance were compared with the subjective annoyance evaluations. Correlation coefficients for these analyses ranged from 0.64 to 0.94, with the best correlation in comparison with the Danish low frequency noise evaluation methods.

As would be expected, at 35 dB nominal (full spectrum) loudness, every low frequency noise source tested exceeded all of the regulatory standards noted in the Danish EPA report. Table 2 shows the Danish and Swedish regulatory exceedances of the different 35 dB nominal (full spectrum) noise.

Table 2: 35 dB(A) (nominal, 8 Hz-20KHz) Indoor Noise from Various Outdoor Environmental Sources

	Traffic Noise	Drop Forge	Gas Turbine	Fast Ferry	Steel Factory	Generator	Cooling Compressor	Discotheque
Noise	67.6 dB(lin)	71.1 dB(lin)	78.4 dB(lin)	64.5 dB(lin)	72.7 dB(lin)	60.2 dB(lin)	60.3 dB(lin)	67.0 dB(lin)
Noise ≥ 20 Hz	35.2 dB(A)	36.6 dB(A)	35.0 dB(A)	35.1 dB(A)	33.6 dB(A)	36.2 dB(A)	36.6 dB(A)	33.6 dB(A)
	62.9 dB(C)	67.3 dB(C)	73.7 dB(C)	61.7 dB(C)	66.0 dB(C)	58.6 dB(C)	59.0 dB(C)	57.8 dB(C)
Danish Environmental Protection Agency	14.5 dB	21.5 dB *	14.8 dB	15.0 dB	13.1 dB	16.1 dB	14.0 dB	18.0 dB *
Swedish National Board of Health and Welfare	14.1 dB	19.7 dB	15.9 dB	16.8 dB	15.5 dB	18.3 dB	16.0 dB	10.0 dB
* includes 5 dB "penalty"								

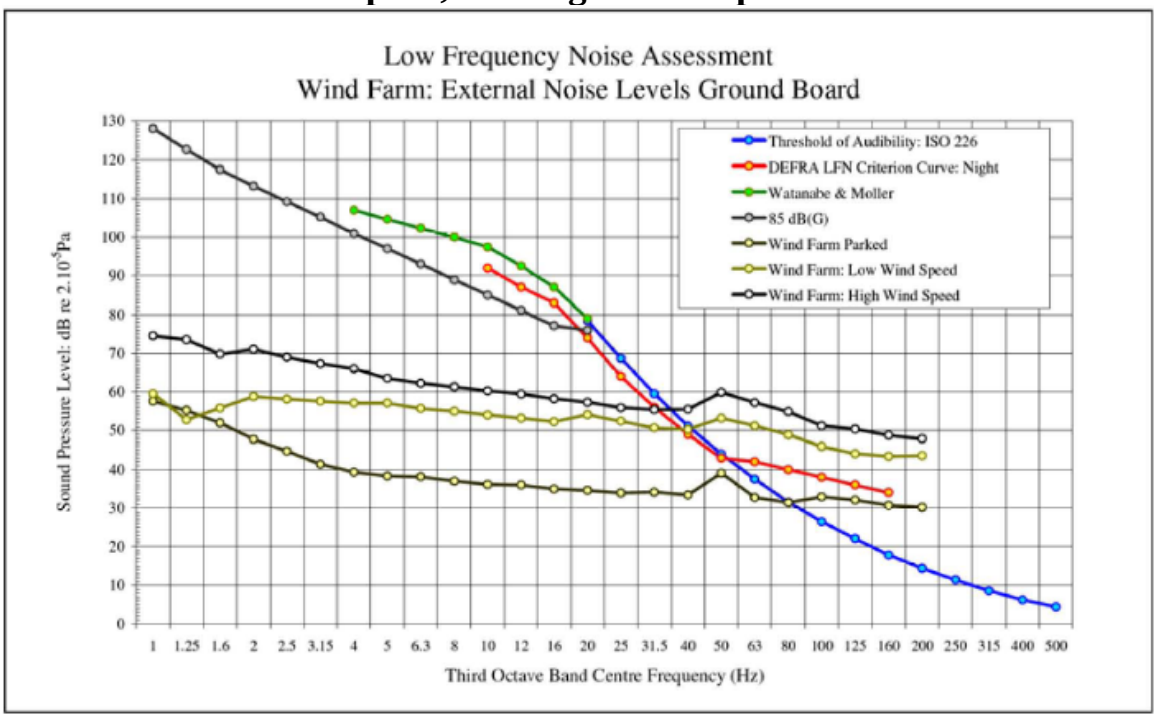
Noise adjusted to dB(lin), dB(A), dB(C) scales. Calculated exceedances of Danish and Swedish indoor criteria. (data from Danish Environmental Protection Agency, 2002)

In their noise guidance, the WHO (1999) recommends 30 dB(A) as a limit for "a good night's sleep". However, they also suggest that guidance for noise with predominating low frequencies be less than 30 dB(A).

3. Wind turbine sound measurements

Figure 8 shows examples of the SPLs at different frequencies from a representative wind turbine in the United Kingdom. Sound pressure level measurements are reported for a Nordex N-80 turbine at 200 meters (UK Department of Transport and Industry, 2006) when parked, at low wind speeds, and at high wind speeds. Figure 8 also includes, for reference, 3 sound threshold curves (ISO 226, Watanabe & Moller, 85 dB(G)) and the DEFRA Low Frequency Noise Criterion Curve (nighttime).

Figure 8: Low Frequency Noise from Wind Farm: Parked, Low Wind Speed, and High Wind Speed

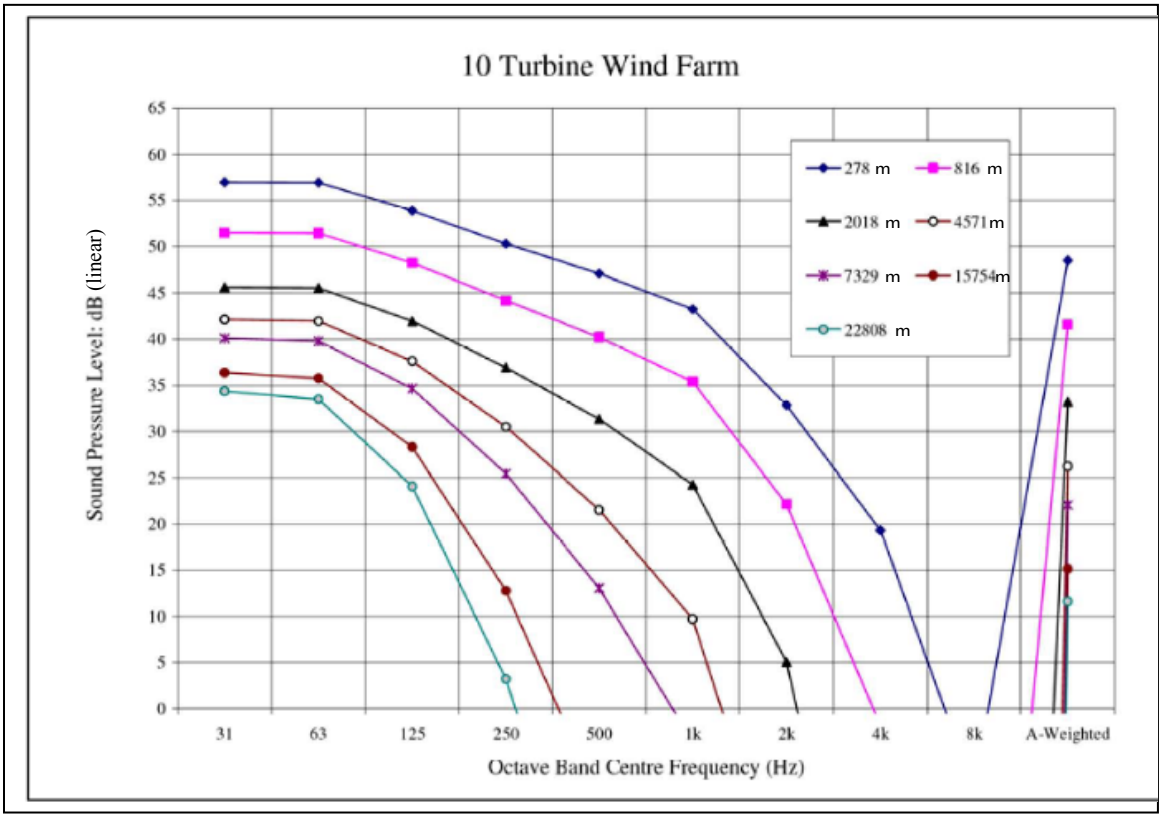


(UK Department of Transport and Industry, 2006)

In general, sound tends to propagate as if by spherical dispersion. This creates amplitude decay at a rate of about -6 dB per doubling of distance. However, low frequency noise from a wind turbine has been shown to follow more of a cylindrical decay at long distances, about -3 dB per doubling of distance in the downwind direction (Shepherd and Hubbard, 1991). This is thought to be the result of the lack of attenuation of low frequency sound waves by air and the atmospheric refraction of the low frequency sound waves over medium to long distances (Hawkins, 1987).

Figure 9 shows the calculated change in spectrum for a wind farm from 278 meters to 22,808 meters distant. As one moves away from the noise source, loudness at higher frequencies decreases more rapidly (and extinguishes faster) than at lower frequencies. Measurement of A-weighted decibels, shown at the right of the figure, obscures this finding.

Figure 9: Change in Noise Spectrum as Distance from Wind Farm Changes



(UK Department of Transport and Industry, 2006)

Thus, although noise from an upwind blade wind turbine is generally broad spectrum, without a tonal quality, high frequencies are efficiently attenuated by both the atmosphere, and by walls and windows of structures, as noted above. As a result, as one moves away from a wind turbine, the low frequency component of the noise becomes more pronounced.

Kamperman and James (2008) modeled indoor noise from outdoor wind turbine noise measurements, assuming a typical vinyl siding covered 2X4 wood frame construction. The wind turbine noise inside was calculated to be 5 dB less than the noise outside. Model data suggested that the sound of a single 2.5 MW wind turbine at 1000 feet will likely be heard in a house with the windows sealed. They note that models used for siting turbines often incorporate structure attenuation of 15dB. In addition, Kamperman and James demonstrate that sound from 10 2.5 MW turbines (acoustically) centered 2 km (1¼ mile) away and with the nearest turbine 1 mile away will only be 6.3 dB below the sound of a single turbine at 1000 feet (0.19 mile).

4. Wind turbine regulatory noise limits

Ramakrishnan (2007) has reported different noise criteria developed for wind farm planning. These criteria include common practices (if available) within each jurisdiction for estimating background SPLs, turbine SPLs, minimum setbacks and methods used to

assess impacts. Reported US wind turbine noise criteria range from: ambient + 10 dB(A) where ambient is assumed to be 26 dB(A) (Oregon); to 55 dB(A) or "background" + 5 dB(A) (Michigan). European criteria range from 35 dB(A) to 45 dB(A), at the property. US setbacks range from 1.1 times the full height of the turbine (consenting) and 5 times the hub height (non-consenting; Pennsylvania); to 350 m (consenting) and 1000 m (non-consenting; Oregon). European minimum setbacks are not noted.

VI. Conclusions

Wind turbines generate a broad spectrum of low-intensity noise. At typical setback distances higher frequencies are attenuated. In addition, walls and windows of homes attenuate high frequencies, but their effect on low frequencies is limited. Low frequency noise is primarily a problem that may affect some people in their homes, especially at night. It is not generally a problem for businesses, public buildings, or for people outdoors.

The most common complaint in various studies of wind turbine effects on people is annoyance or an impact on quality of life. Sleeplessness and headache are the most common health complaints and are highly correlated (but not perfectly correlated) with annoyance complaints. Complaints are more likely when turbines are visible or when shadow flicker occurs. Most available evidence suggests that reported health effects are related to audible low frequency noise. Complaints appear to rise with increasing outside noise levels above 35 dB(A). It has been hypothesized that direct activation of the vestibular and autonomic nervous system may be responsible for less common complaints, but evidence is scant.

The Minnesota nighttime standard of 50 dB(A) not to be exceeded more than 50% of the time in a given hour, appears to underweight penetration of low frequency noise into dwellings. Different schemes for evaluating low frequency noise, and/or lower noise standards, have been developed in a number of countries.

For some projects, wind velocity for a wind turbine project is measured at 10 m and then modeled to the height of the rotor. These models may under-predict wind speed that will be encountered when the turbine is erected. Higher wind speed will result in noise exceeding model predictions.

Low frequency noise from a wind turbine is generally not easily perceived beyond ½ mile. However, if a turbine is subject to aerodynamic modulation because of shear caused by terrain (mountains, trees, buildings) or different wind conditions through the rotor plane, turbine noise may be heard at greater distances.

Unlike low frequency noise, shadow flicker can affect individuals outdoors as well as indoors, and may be noticeable inside any building. Flicker can be eliminated by placement of wind turbines outside of the path of the sun as viewed from areas of concern, or by appropriate setbacks.

Prediction of complaint likelihood during project planning depends on: 1) good noise modeling including characterization of potential sources of aerodynamic modulation noise and characterization of nighttime wind conditions and noise; 2) shadow flicker modeling; 3) visibility of the wind turbines; and 4) interests of nearby residents and community.

VII. Recommendations

To assure informed decisions:

- Wind turbine noise estimates should include cumulative impacts (40-50 dB(A) isopleths) of all wind turbines.
- Isopleths for dB(C) - dB(A) greater than 10 dB should also be determined to evaluate the low frequency noise component.
- Potential impacts from shadow flicker and turbine visibility should be evaluated.

Any noise criteria beyond current state standards used for placement of wind turbines should reflect priorities and attitudes of the community.

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