The Oklahoma Wind Power Assessment Initiative

A proposed plan for stimulating economic development through wind power production in Oklahoma

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I. Introduction and Project Summary

Photo courtesy American Wind Energy Association

Oklahoma has a long history of harnessing the winds to provide water for the needs of ranchers and farmers, but now we are on the threshold of a profound transformation. While efforts in past decades to utilize wind for energy production were noble, they have seldom been cost-effective. Wind generators were limited to small systems for use where electricity was scarce or unavailable, or to large systems in California, a state with vigorous population and economic growth and the political will to invest in the technology. In recent years, however, improvements in wind turbine technology, restructuring of electricity markets across the US, and the growing popularity of "green" energy (that from renewable sources) have culminated in markets where power from the wind is no longer just a neat idea. It is now also a profitable thing to do.

There are many factors that underscore the potential wind power has as a growth industry in Oklahoma. The following are just a few of the most noteworthy.

- Oklahoma is ranked number 8 among all states for estimated wind energy potential [Table 1], with a potential annual production of 725 billion kilowatt-hours (Kwh), an amount equal to 8.8% of the total use of electricity in the contiguous U.S. in 1990 [Elliott and Schwartz, 1993].
- Four states bordering Oklahoma - Colorado, Kansas, New Mexico, and Texas - have existing or planned wind power programs, so it is clear these states find such programs worthwhile. Yet of the four, only Kansas and Texas lead Oklahoma in potential gains from this renewable resource.
- Minnesota and Iowa have each invested in hundreds of megawatts of wind power generating capacity even while lagging Oklahoma in wind power potential. Iowa's wind industry currently employs about 40 workers, and it hired 200 during the intense construction phase. Counties receive $2 million per year in taxes while 115 landowners share $640,000 in lease payments.
- Texas has set its renewable energy target to an additional 2000 MW capacity by the year 2009.
- The U.S. Department of Energy has set a target for wind power to meet 5% of the nation's electricity needs by the year 2020. This equates to 80,000 MW of wind turbine capacity, or about 32 times the current installed capacity.

(Note: a more comprehensive report on wind power in the U.S. and abroad can be found in the January/February 2000 issue of Solar Today [Real de Azua, 2000], included with this proposal.)

Clearly, these kinds of investments, initiatives, and returns would not be realized if the economical and environmental returns were not positive. The time is right for Oklahoma to take measures to catch up with other states and attract investors from the wind power industry, due to the factors above and also to the confluence of the following developments.

- Technological improvements have brought the cost of energy production by wind turbines down from 38 cents per Kwh in 1980, to 3.0 - 6.0 cents per Kwh in 2000, with projections of 2.5 to 3.5 cents/Kwh by 2005.
- Electric industry restructuring has already occurred in 22 states and Washington, D.C., with regulatory orders issued or pending activities in the majority of the remaining states [Figure 1]. Deregulation will allow competition to select the most efficient means of energy production, and it will also open the doors for interstate trading of green power and green credits. This will foster the growth of wind-generated power by market-mediated and regulatory factors that will favor continued improvement in turbine technology. Growth will also be fostered by the economic benefits likely to accrue from an expanded market for electric power sales and by the growing demand for emissions trading, pollution offsets, and related environmental quality activities.
- The demand for green power is growing daily. As of late March, 2000, 27 utilities in 14 states, including Texas, have installed new renewables capacity specifically for green pricing programs. In total across the U.S., 156 utilities offer customers the green power option.
- Renewables Portfolio Standards (RPS) have been approved in eight states [Figure 2]. These programs set target standards that mandate certain percentages of energy consumption be satisfied with renewable sources (wind, solar, biomass, landfill gas, etc.) by given dates. While the programs vary in degree, these states and others that follow will create a demand for green energy that will place Oklahoma in an enviable position as a supplier of power from the wind. Furthermore, should a federal RPS be enacted, or should federal tax incentives encourage development of RPS programs in more states, the demand for green power will skyrocket.
- There are improvements in other technologies such as solar collection and energy storage (e.g.: fuel cells) that complement wind power. As these technologies come into their own, much of the resources developed for a wind power program will transfer to studies and/or implementation of these other facets.

Currently, power generation by wind turbines is the most cost-effective of all the renewable energy sources. Though long-term operation and maintenance costs are low due to the improved technology and to the free and inexhaustible "fuel", wind power plants are capital intensive on installation. Hence, it is critical to prove areas in Oklahoma do provide profitable wind conditions, and that these conditions exist in reasonable proximity to infrastructure needs (transmission lines, roads, etc.). In order to reach the point of attracting investors in a timeframe that maximizes benefits, the following program must be implemented soon and carried out over the next two to three years.

1.) Use existing Oklahoma Mesonet data to determine a preliminary estimate of the wind power resource potential in Oklahoma, and to narrow down the region for further study.
2.) Use Geographic Information Systems (GIS) data to study physical and demographic characteristics for the study region.
3.) Locate prime areas for placement of tall towers (40 meter or more) outfitted with industry-standard wind measuring instruments, and develop a data-collection and study plan.
4.) Install tall towers and collect data for 1 to 2 years.
5.) Evaluate data and make results available to potential investors in wind farms. Also, evaluate data and perform economic benefit analyses so that landowners in areas of future wind farm development may reap the full benefit of their resource.
6.) Study and pursue spin-off programs that will enhance or provide profound economic and environmental benefits for our state in the near term and in years to come.
7.) Assess the policy instruments (e.g., state and federal incentives) deployed in states such as Wisconsin, Iowa, and Texas to motivate the wider use of wind power, in order to enhance the potential for wind power development in Oklahoma.

Also, the following activities should be initiated in order to foster the long-term success of a renewable energy program in Oklahoma.

1.) Educational outreach initiatives must be kindled to promote the understanding and need for renewable energy sources and energy efficiency. Such initiatives should be considered for all levels - from K12 through college and on up to the level of policy makers.
2.) The development of technical skills needed to service wind turbines and other renewable technologies (e.g.: solar panels) should be enhanced in areas of the state where these resources are in abundance.
3.) A renewable energy information center should be established.

This proposal will detail a plan for a first-year study and activities, and will outline the plan for continued activities in years 2 and 3. Furthermore, anticipated long-term spin-off studies and benefits are discussed.

II. Problem Definition

Oklahoma is ranked number 8 among all states for estimated wind energy potential [Table 1]. Four states bordering Oklahoma - Colorado, Kansas, New Mexico, and Texas - have existing or planned wind power programs. These states clearly find such programs worthwhile, yet of the four, only Kansas and Texas lead Oklahoma in potential gains from this renewable resource. Furthermore, Minnesota and Iowa are each investing in hundreds of megawatts(MW) of wind power generating capacity even while lagging Oklahoma in wind power potential. Incentives for green power, many of them national scale programs, signal a market that is ready to explode with growth. If Oklahoma is to benefit from this coming market, a catalyst for action is needed. The Oklahoma Wind Power Assessment Initiative (OWPAI) can provide such a catalyst.

Wind power poses significant sources of income for Oklahomans, as in the case of large-scale wind power farms. *Everyone* knows that it is windy in Oklahoma, but because of the large up-front investment that large-scale wind-farms require (~$1 million per megawatt of rated capacity), there are many factors that must be considered to determine potential profitability with the aim toward attracting investors. Evaluating the wind resource itself is critical, but that is just part of a larger plan that is needed. The work entailed is not trivial, but the long-term payoffs have the potential to be enormous.

The investigators propose that the following approach will address the above issues and implementation of this program will help demonstrate to investors a commitment to pursue this area of development in our state.

III. Approach and Products

A strategy is needed for building a program that will initiate and strengthen opportunities for long-term economic benefits from wind power in our state. The following are considered the key elements of that strategy for year 1.

- Evaluate the wind resource.
- Evaluate the land use and economics of the regions with good wind resources.
- Evaluate the infrastructure components (transmission lines, roads, etc.) needed for construction and maintenance of wind farms and for getting the power to markets where the demand resides.
- Study federal and states' incentives for renewable energy; study programs in states that have a successful track record in making renewable programs work.
- Estimate the value of this resource in the coming energy market
- Grow wind power educational resource programs
- Plant seeds to build technical programs to provide skilled workers in regions with good wind resources by initiating contacts with technical training centers.
- Plan for activities in year 2 and the longer term.

A comprehensive statement of work and schedule of deliverables by quarter in FY2001 are presented in Appendix F. This section will provide an overview of the approach and a summary of the products that will be made available at the end of FY2001.

<u>1.) Evaluating the Oklahoma wind resource</u>

When evaluating potential wind resources, the Wind Power Density (WPD) term is a useful quantity that only depends on available wind and other meteorological factors, and is independent of type or size of wind turbine to be used. The calculation for WPD takes into account the density of the air, the frequency distribution of wind speeds, and the dependence of power on the cube of the velocity. More information on WPD and how it relates to **wind power classes** is given in Appendix C, as is a more complete explanation of the process by which WPD is calculated from Mesonet wind data. The results of a preliminary estimation of wind power are shown in Figure 3 (Oklahoma's Potential Wind Class Rankings). While the process used to obtain this result needs improvement to better locate regions with high potential for wind power, this graphic clearly shows there are significant regions in Oklahoma's western half with the potential for wind power class ranking of 4 or better, the ranking preferred for large-scale wind farms.

There are 3 main steps to this program's wind evaluation process:

- Improve the process for wind power mapping
- Zoom in to find prime areas
- Prepare data layers for GIS study

<u>Improving the process for wind power mapping</u>

Improvements to the process that will be employed as part of this program are as follows.

- ➢ Increase study period to use 6 years of Oklahoma Mesonet wind data.
- ➢ Produce Oklahoma wind power maps with seasonal breakdown.
- ➢ Provide climatological average wind and wind power products (regular wind rose and wind energy rose combination), annual and by season, for OK Mesonet stations in optimal regions, to provide baselines against which tall tower data may later be compared. With such baselines established to prove whether the period of study showed low, average, or high wind energy conditions with respect to the longer-term average, data-collection periods could be kept shorter. This will lower maintenance costs and will free equipment sooner for use in evaluating other locations.
- ➢ Improve landcover determination, thereby improving estimates of wind speeds (and energy) at 50 meters, using wind data from 10 meters. [More on the process for estimating winds at 50 meters using data at 10 meters may be found in Appendix C.].
- ➢ Improve the estimate for the air density term in the WPD equation by using Mesonet temperature and pressure data.

<u>Zoom in on prime areas for wind power</u>

While the study of Oklahoma Mesonet data as described above is quite valuable, it should be noted that Mesonet stations were located so as to provide data that is representative of a large area. Hence, most stations are NOT found in the best locations for high mean wind energy, and local terrain features can cause mean wind energy to vary considerably over short distances [Elliott et al, 1987, p. 2]. A careful study of terrain and fetch conditions surrounding the stations will help locate the best spots and minimize the quantity of towers needed later. Software that uses wind, landcover, and terrain data will be employed to model the regional wind flow.

<u>Prepare data layers for GIS study</u>

The results from the above studies will be placed in a format for use with GIS software in the subsequent work with data layers showing infrastructure components, demographics and economics, areas to avoid, etc.
[More background on the processes described above may be found under "A Description of GIS and Key Data Components" in Appendix C. (Fact Sheets and Other Information).]

2.) Evaluating the economics of regions with good wind resources

GIS data sources contain data layers that can be used to answer the following questions, therefore providing important information to both potential investors and to key state and regional policy makers.

- What are the main land-use activities in these regions and what could wind power investors expect to pay for lease-rights? This component is important to attracting investors.
- What are the economics of these regions and how will wind power farms contribute to the general economic well-being and growth of the areas?

3.) Evaluating infrastructure components

Several landscape features in the form of GIS data layers will be used for siting turbines and large wind farms in combination with the data prepared in Part 1. Other features are involved in the assessment of the infrastructure vital for the continuance of wind power generation and marketing. The construction and maintenance of wind farms, for instance, may require building new roads which, in turn, requires knowledge of property ownership, right-of-ways, erodability of soils by wind and water, roadside drainage potential, source of road materials, and cost of construction.

Getting the power to markets can be a very complex issue. Single turbines for domestic electricity may require simple wiring and storage facilities unless the owner decides to sell electricity in excess of domestic needs. Then information about the power grid, line capacities, market demands and locations, pricing, and other physical, economic, and regulatory factors must be available. This is especially necessary for large wind farms.

Data about the infrastructure components will be acquired and mapped as GIS data layers compatible with the other landscape GIS data layers. In particular, transmission lines and grid characteristics will be focused on initially. Considering the future development of co-generation facilities and improvement in fuel cell technology, GIS data layers of existing and planned pipelines and storage facilities will also be acquired.

By way of example, Figure 4 shows a GIS case-study in which many data layers of locations, streams and roads are buffered, merged and overlaid on a relief map.

4.) Study federal incentives and programs in other states

A program for wind power development in Oklahoma will benefit by a better understanding of how well state and federal incentives have performed. In order to provide policy makers with the best information available, the team will conduct a detailed analysis and assessment of the policy instruments that have been deployed in states such as Wisconsin, Iowa, and Texas to motivate the wider use of wind power. This part of the study will provide Oklahoma policy makers with a comparative basis for selecting the most effective and efficient measures to adopt in the state. Particular attention will be paid to public and private sector investment criteria, state renewable energy planning and management goals and strategies, and the standards by which state activities in wind power development have been evaluated.

5.) Estimating the value of this resource in the coming energy market

This project will address issues that predict the value of wind power to Oklahoma in the near future. These issues include, but are not limited to, the following.

- *Utility deregulation:* how will an open market affect power production costs and retail prices?
- *Renewable Portfolio Standards:* as federal and regional incentives or mandates for RPS programs proliferate, what will happen to the demand for green energy, and where will the supplies likely be found?
- *The growing popularity of green energy:* what is the current trend for utilities offering green power and what growth is expected for this demand?
- *Coming restrictions on greenhouse gases and pollutants:* what is expected with regard to future tighter restrictions on carbon dioxide and sulphur and nitrogen compound emissions, and how will these restrictions benefit Oklahoma if we are a wind power producing state?
- *Activities in renewables in the surrounding region:* what wind power programs are active in Texas, Colorado, New Mexico, and Kansas and how will their competition affect Oklahoma?

6.) Growing wind power information/education programs in state

This project will initiate the growth of wind power information resources and educational programs by taking the following actions.

- Build a library at EVAC of appropriate publications, manuals, etc. (hardcopy and electronic versions) addressing wind power technology, policy, educational tools, and more.
- Develop a brochure with general information on wind power and its benefits.
- Plant seeds for educational outreach programs by approaching key professional educators at OU and other schools in Oklahoma with opportunities to share tutorials and ideas for further development. Some potential contacts are:
  - The Department of Education at OU;
  - The State's Department of Education's 7 regional Professional Development Centers;
  - the NASA Oklahoma Space Grant Consortium (OSGC), which yearly holds summer workshops for middle to high school level teachers;
  - the Associate Director for OSGC at Cameron University in Lawton; and more.
- Plant seeds to build programs to provide workers skilled in related technologies by initiating contacts with technical training centers, in regions with good wind resources.

- Plant seeds to grow resource programs for other renewable technologies, by investigating a series of studies that fit with, or naturally follow from, wind power studies.

7.) Building toward future activities

The following activities in the 3rd and 4th quarters of FY2001, will help build momentum toward continued efforts in FY2002 and beyond.

- Sources of funds, such as those provided by the DOE SEP 2000 program for "Wind Energy Case Studies" will be researched and applied for, as appropriate. Sources of funds to match or leverage against DOE or Oklahoma funds will also be investigated.
- The PI will attend training classes at the Alternative Energy Institute in Canyon, Texas, to better familiarize himself with software, hardware, and other technical issues involved in measuring winds for prospective wind farms.
- One 40 meter tower, with wind instruments at the industry-standard 10, 25 and 40 meters, will be installed and data will be collected and analyzed. The benefits from this activity will be twofold for investigators:
  - they will gain experience with the equipment and software used by the wind power industry - this will strengthen their position for gaining year 2 funding; and
  - they will have data from one site early on, to validate (or not) the prediction for winds at this site so that corrections may be made if needed before more towers are installed.
- A data collection, analysis, and dissemination plan will be prepared for a potential network of tall towers.
- Hughes, Meo, Salisbury and Stadler will attend the WindPower2001 conference in Washington, D.C. in June of 2001. A poster presentation showing the program's results will be presented and brochures on wind power activities in Oklahoma may be distributed. Hence, Oklahoma's activity in wind power field will be well advertised to the industry.

Summary of Products

The following is a summary of the products that will become available upon completion of OWPAI's first year.

- Oklahoma wind power map - annual average wind power available at 10 meters.
- Oklahoma wind power map - annual average wind power available at 50 meters.
- Four Oklahoma wind power maps, with estimated seasonal average wind power available at 50 meters (one map for each of these periods: Jan.-Mar.; Apr.-June; July-Sept., Oct.-Dec.)
- Results of study using GIS data layers (wind power, roads, transmission lines, etc.) to find optimal regions for wind power farms and areas to avoid (wildlife refuges, populated areas, etc.)
- Climatological average wind and wind power products - regular wind rose (see Figure 5 for a sample) and wind energy rose combination - for Oklahoma Mesonet stations in optimal regions.
- Maps, graphs and tables showing solar energy available at Mesonet sites, averaged over 6 years.

- Report on renewable energy policies in other states and how they might be applied to Oklahoma's wind power policy implementation and incentives for development.
- Report on long-term potential spin-off projects and strategies for leading into them.
- Web-pages that teach about wind power and Oklahoma's potential for this resource, and which display selected output from this study.
- Report on ties formed for potential K12 and post-secondary educational outreach programs and strategies for future programs.
- Report on installation of one tall tower.
- Plan for tall-tower data collection and analysis plan for FY 2002 activities.
- Report on sources of potential funds (e.g.: USDOE, DOE/EPSCoR) for FY2002 activities.
- Poster presentation of results from this project for display at WindPower 2001 conference in Washington, D.C.
- Presentation of results from this project, in appropriate format, for the wind-power workshop hosted by the Oklahoma Department of Commerce at the end of FY2001 or beginning of FY2002.

IV. Program benefits

The primary benefit of OWPAI is to help the state manage and utilize its natural resource endowment strategically with respect to generating economic development, enhancing environmental quality, and serving as the basis for longer term resource development and research inquiries.

Economic development benefits

Harnessing wind energy affords Oklahoma several opportunities to advance its economic prospects. These include:

- sizing and locating large-scale wind farms that can meet power needs for large communities and/or provide power for export to other states;
- facilitating distributed smaller scale power plants that can meet some rural electric needs; and
- providing clean technology that complements more conventional power plants.

Economic development benefits can accrue as affordable, clean, reliable energy, royalty or lease payments to landowners, and development of technical expertise in clean energy supply systems.

The use of Iowa's wind power program as a model will give a more tangible idea of the economic benefits Oklahomans can realize. Iowa's 354 wind turbines produce about 646 million kilowatt-hours every year. Wind farms pay 115 landowners about $2000 per turbine for lease-rights, totaling $640,000 per year. The wind farms also pay $2 million per year in taxes to counties - money that is used for schools, roads, health care and other needs. To build the wind farms, 200 jobs were created over 6 months, and there are 40 ongoing jobs for operation and maintenance. Furthermore, Iowa's wind turbines displace about 382,000 tons of coal each year, preventing $6.2 million from leaving the state to pay for that fuel, annually.

While Iowa is a good model to cite for short-term benefits, there are two important factors to keep in mind, in order to appreciate how much more value wind power can have for Oklahoma in the long-term.

- Oklahoma has significantly more potential wind resource than Iowa (725 vs. 551 Billion kilowatt-hours annually) [Table 1].
- Oklahoma will achieve similar benefits by just **meeting** current Iowa wind farms' 246 MW rated capacity. If the Department of Energy's goal of 80,000 MW total capacity by 2020 is reached, and if Oklahoma has captured a fair portion of that capacity, lease rights could easily reach many millions of dollars for landowners, with state and local taxes benefiting from many tens of millions additional revenue.

Note that while only Iowa is referenced here, OWPAI will also study other states' programs to achieve a better assessment of potential economic benefits to Oklahoma.

Environmental benefits

Of the many health-threatening pollutants that are by-products of coal generated electricity - compounds of nitrogen and sulphur, particulates and ozone - *none* are produced when generating power using the wind. Furthermore, there are no carbon dioxide (CO_2) emissions, as there are with coal and gas-fired generators. These benefits to the environment are clearly attractive, even standing alone. When one considers that these benefits will also spawn economic gains by attracting investors, they are even better. To understand why investors will be attracted, consider these factors.

- EPA regulatory uncertainties are eliminated, since there are no pollutants.
- Investors may benefit from the opportunity to participate in CO_2 emissions trading should a national or regional market for emissions trading develop in the future.

Technical skills resource development

OWPAI will act as a catalyst to stimulate the development of the technical skills needed in the areas where wind farms are placed. Once technical programs are in place to enhance these skills, other technological programs that need similar skills will follow.

Long-term spin-offs for related economic and research programs

The following are just some of the long-term programs that may be spawned by this program.

With the informational infrastructure that OWPAI will build, there will exist:

1) an improved potential to demonstrate the comparative advantages that Oklahoma has over other Great Plains states in renewable resources;

2) the opportunity to develop more completely the total mix of renewable energy resources and to study the economic feasibility of renewable energy technologies, to possibly include solar energy (active and passive), biomass derived fuels, and others;
3) the potential for coupling of wind power technology with hydrogen production, gas-fired turbines, solar power systems, and other technologies.

Furthermore, this program can lead to university research, service, and curriculum additions that will in turn enhance the attractiveness of the state to innovators and investors. A system with such positive feedback can ultimately lead to the development of a renewable energy technology manufacturing base.

V. Investigators' Backgrounds and Qualifications

The following are summary reviews of the investigators' backgrounds and qualifications, in relation to the work they will perform. For more background, biographical sketches can be found for each in Appendix G.

Tim Hughes

Mr. Hughes has had an interest in renewable energy sources, especially wind power, for over 20 years. Seeing an opportunity to build upon the tremendous value of Oklahoma Mesonet's wind data resource, he proposed the Oklahoma Wind Power Assessment Initiative in the fall of 1999 as a long-term joint effort between OU and OSU. At that time, he produced the first map of estimated wind power in Oklahoma (Figure 3) using the available Mesonet wind summaries.

Mr. Hughes's background is in math, physics, computers, meteorology, and instrumentation, with recent forays into GIS applications. He is currently a Research Associate at the Environmental Verification and Analysis Center (EVAC), at OU. Before joining EVAC in 1999, he was Assistant Project Manager and Project Manager for the Oklahoma Mesonet for eight years and thus is very knowledgeable about Mesonet data, station sites, and hardware installation. He will use his technical and management experience to act as project director for OWPAI . Specifically, he will:

- set evaluation criteria for the assessment of wind power at 10m and 50m levels;
- review quality control on the assessment inputs;
- contribute educational outreach materials, including tutorials on wind power calculations, proper siting of small wind power generators, and factors to consider in siting of large-scale wind power farms;
- initiate contacts with professional educators;
- research funding sources for continued wind power studies;
- oversee wind instrumentation issues; and
- act as editor on documents and a poster presentation for the WindPower 2001 conference.

Mark Meo

Mark Meo is a Research Fellow in the Science and Public Policy Program and a Professor of Civil Engineering and Environmental Science at the University of Oklahoma. One of his areas of expertise and interest is alternative energy policy. Dr. Meo's task will be to address the policy options for motivating wind power development in the state of Oklahoma with specific attention to:

- economic feasibility;
- effects of institutional and financial incentives;
- existing impediments and/or barriers to wind power development; and
- market potential for the wind power industry under a deregulated electric power regime.

In his analysis, he will draw upon current and planned activities in the states that currently produce wind power (e.g.: California, Texas, Iowa, and Minnesota), and he will address the potential value of wind-generated electricity as an input to cleaner fuels production in Oklahoma. His contributions will ensure that this work will provide the focus, base-line data, and results for subsequent research efforts.

Jayne Salisbury

Dr. Salisbury is Director of the Oklahoma Spatial and Environmental Information Clearinghouse (SEIC), Research Scientist in the Environmental Institute, and Adjunct Assistant Professor in the Department of Geography at Oklahoma State University. She completed a joint Ph.D. in Civil Engineering and Geosciences at OU in 1992 with research on incorporating GIS and Remote Sensing into hydrologic modeling. After that, she worked as a research scientist at OU on several GIS projects, then was employed as a research hydrologist with the USDA Agricultural Research Service creating GIS data sets for research watersheds.

Salisbury has been on staff at OSU since 1996. As Director of SEIC, she oversees the acquisition, metadata documentation, and cataloging of GIS and other geospatial data for Oklahoma and the distribution of these data via the Internet. Salisbury will be responsible for acquiring and standardizing GIS data and creating the digital maps of wind power density, landscape features, and other research data and results. Using her experience in modeling with GIS and other geospatial data, she will also perform the test of the WindFlow™ model using Mesonet wind data and GIS terrain data. Other GIS landscape data (e.g.: roads, bodies of water, municipal areas) will be mapped along with wind flow speed and direction for identifying areas with the highest potential for large wind farms. She will also design and maintain the Web site for OWPAI on the SEIC Internet server. The wind-power assessment results will be accessible from this Web site. Educational outreach materials and tutorials about wind power will also be maintained on the Web site. The site will be publicly accessible and advertised as a source for information about wind power in Oklahoma.

Mark Shafer

Mark Shafer is a Staff Climatologist with the Oklahoma Climatological Survey (OCS), where he has been employed since 1990. He holds a B.S. degree in Atmospheric Sciences from the

University of Illinois and an M.S. Degree in Meteorology from the University of Oklahoma. In addition to his full-time work at the Climatological Survey, he is completing a Ph.D. in Political Science at the University of Oklahoma.

Mr. Shafer presently works in the service side of OCS, principally in data management and product development. During his tenure at OCS, he has been involved in several aspects of developing the Oklahoma Mesonet. During 1992, he coordinated the site-selection process, and personally surveyed most sites across Western Oklahoma, an area expected to be rich in wind resources**.** In 1995 he developed automated quality-assurance procedures for the data recorded by the Mesonet [Shafer et al, 2000]. Mr. Shafer currently works with a variety of clients to produce tailored products from Mesonet and other data archives to meet applied research needs.

Because of his background in Mesonet site selection, quality-assurance, and product development, Mr. Shafer will contribute to the quality of wind products developed in support of this project. In particular, he will be able to identify local conditions or instrument problems that may affect the quality of the product, before it is used in additional analyses. His experience at working with a diverse range of clients will ensure that the products developed for this project are easily imported into GIS applications.

Mr. Shafer began the Ph.D. program in Political Science in 1995. His focus is on the areas of public policy and management and the utilization of technical information in policy decisions, especially those relating to natural hazards management. With this background, he is well qualified to contribute to the needs assessments, benefits, and policy feasibility aspects of this project.

Steve Stadler

Dr. Stadler is a professor of Geography at Oklahoma State University and has been at the university since 1980. His Ph.D. is in Physical Geography and he specializes in applied climatology. His research has emphasized interactions between the atmosphere and society and the atmosphere and landscape. Currently, he is working on NASA-funded projects on evapotranspiration and evaluation of satellite algorithms with *in-situ* data. Also in progress is a co-authored applied climatology book for Prentice-Hall. He has been a member of the Steering Committee of the Oklahoma Mesonetwork since its inception. He is knowledgeable about uses, limitations, and analyses of Mesonet data. In particular, he has had considerable experience in the spatial interpolation of Mesonet data. For the proposed work he will provide expertise in the application of Mesonet data to the WindMap™ software and in the climatological characterization of Oklahoma.

May Yuan

Dr. Yuan has been actively involved in studying geographic information representation and analysis since 1994. Her doctoral research is on GIS representation and modeling, the presentation of which received the best student paper award from the GIS specialty group in the

1994 American Association of Geographers annual meeting. Subsequent papers on geographic representation and information management and analysis have been published in various scientific journals and book collections. Through these studies, Dr. Yuan has developed GIS methods to assess spatial and temporal relationships among geographic features and processes. Her recent work involves analysis of severe weather impacts in human environments. She is interested in examining severe weather climatologies, such as heavy winds and lightning strikes and their influences on wind farm planning and future operations. Her expertise in mapping and relating environmental and socio-economic variables in space and time will directly apply to the analysis of wind farm siting, wind power forecasting, and socio-economic impacts.

VI. Conclusion

The 3 key components needed to attract wind power investors to Oklahoma, and hence to begin the process leading to economic development through wind power, are as follows.

- Evaluate and advertise Oklahoma's wind resource
- Build an educational and technological infrastructure to enhance development
- Implement a state policy that encourages wind power development

While these are efforts that will take some years to fully develop, this proposal has set out a plan to initiate development in all three areas, with the OU/OSU team in a strong position to provide a leading role. The investigators have access to a unique resource for wind evaluation - the Oklahoma Mesonet - and they have the skills and background (meteorological, climatological, geospatial, political, and more) to do a thorough job.

With the results from this study, Oklahoma will strengthen its position to garner funds from other sources for further studies in the second year - principally the installation and collection of data from tall towers for micro-site assessment at prime locations.

Section VII. Appendices

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Appendix A - Tables

Table 1. The top twenty states for wind energy potential, as measured by annual energy potential in the billions of kilowatt-hours, factoring in environmental and land effects.

1	North Dakota	1,210	11	Colorado	481
2	Texas	1,190	12	New Mexico	435
3	Kansas	1,070	13	Idaho	73
4	South Dakota	1,030	14	Michigan	65
5	Montana	1,020	15	New York	62
6	Nebraska	868	16	Illinois	61
7	Wyoming	747	17	California	59
8	**Oklahoma**	**725**	18	Wisconsin	58
9	Minnesota	657	19	Maine	56
10	Iowa	551	20	Missouri	52

Source: *An Assessment of the Available Windy Land Area and Wind Energy Potential in the Contiguous United States*, Pacific Northwest Laboratory, 1991. (10)

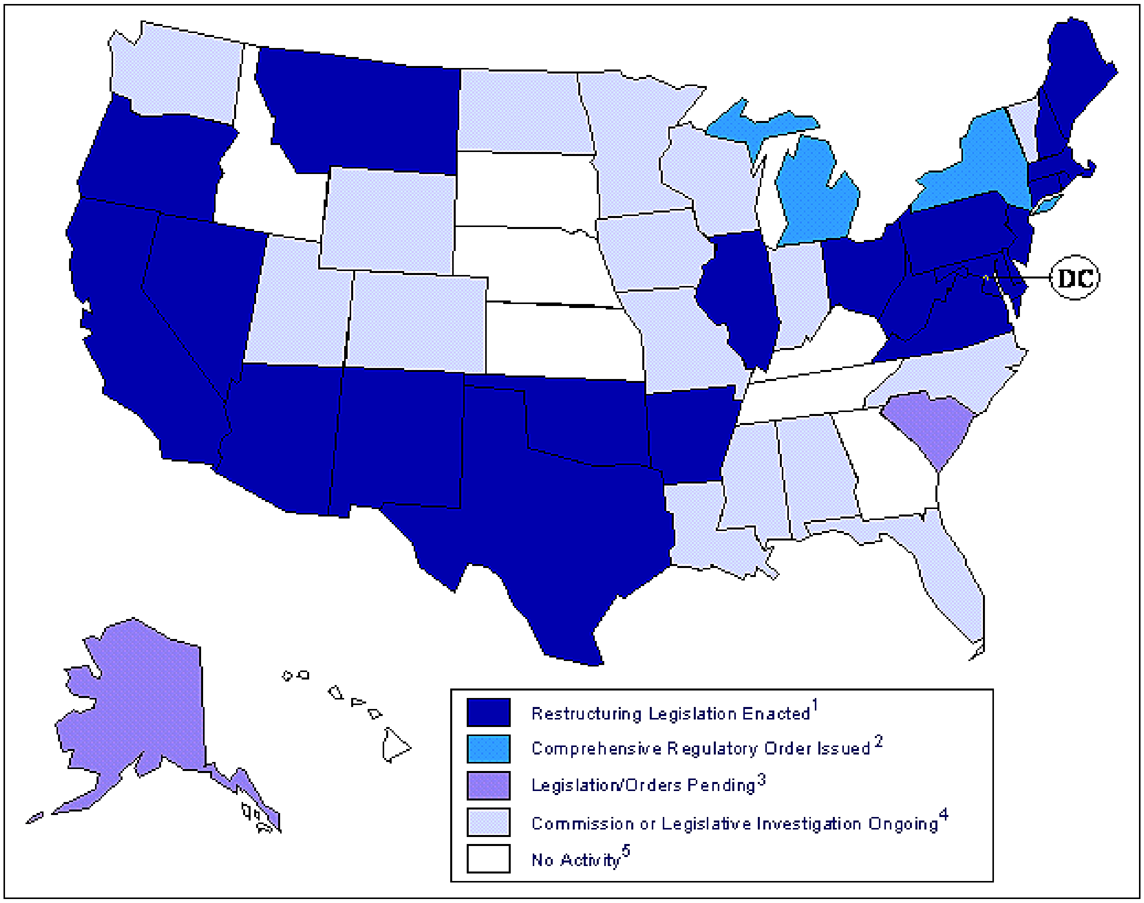
Table 2. Sample of Wind Data Summary

This table summarizes wind data for one Mesonet station for a five year period (1994-1998). The speed classes (far left column) and frequency distribution (far right column) are the critical components used in the preliminary study by Hughes. Also shown are direction classes (top row) and their associated frequency distribution (5th row from bottom), and other summary data which may be used for further studies.

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
1- 5 mph	1.1	1.2	1.0	0.8	0.8	1.1	1.9	1.9	1.0	0.6	0.5	0.4	0.5	0.7	0.9	0.9	**15.3 %**
6-10 mph	2.0	2.9	2.0	1.7	1.6	2.0	4.2	5.5	3.4	1.8	1.0	0.6	0.3	0.7	1.0	1.1	**31.7 %**
11-15 mph	2.8	2.7	1.1	0.5	0.5	0.5	2.1	4.7	5.8	2.7	1.2	0.5	0.2	0.3	0.6	1.1	**27.1 %**
16-20 mph	2.1	1.5	0.3	0.1	0.1	0.1	0.4	2.3	4.5	2.0	0.6	0.2	0.1	0.1	0.3	0.7	**15.5 %**
21-25 mph	1.0	0.6	0.1	0.0	0.0	0.0	0.1	0.8	2.2	1.0	0.2	0.1	0.0	0.0	0.1	0.3	**6.3 %**
26-30 mph	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.6	0.3	0.0	0.0	0.0	0.0	0.0	0.1	**1.6 %**
31-35 mph	0.1	0.0	0.0	0.0	-	-	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.2 %**
35+ mph	0.0	0.0	0.0	0.0	-	-	-	0.0	0.0	0.0	0.0	0.0	0.0	-	-	0.0	**0.0 %**
CALM	**N**	**NNE**	**NE**	**ENE**	**E**	**ESE**	**SE**	**SSE**	**S**	**SSW**	**SW**	**WSW**	**W**	**WNW**	**NW**	**NNW**	**# Obs**
2.2%	**9.4 %**	**8.9 %**	**4.5 %**	**3.1 %**	**3.0 %**	**3.7 %**	**8.7 %**	**15.3 %**	**17.6 %**	**8.4 %**	**3.4 %**	**1.8 %**	**1.1 %**	**1.8 %**	**2.9 %**	**4.2 %**	**516900**

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
Max Gust	55	62	59	56	46	38	43	61	76	65	56	50	52	48	49	78	77.5
Max 5 Min	42	42	38	36	27	26	33	44	55	50	37	37	36	32	32	54	**55.0**
Avg Speed	12.7	10.8	8.1	6.8	6.7	6.4	7.7	10.4	13.6	13.2	10.7	9.1	6.7	6.8	8.2	10.5	**10.3**

Appendix B - Figures



Status of State Electric Industry Restructuring Activities as of May 2000

1) Arizona, Arkansas, California, Connecticut, Delaware, District of Columbia, Illinois, Maine, Maryland, Massachusetts, Montana, Nevada, New Hampshire, New Jersey, New Mexico, Ohio, Oklahoma, Oregon, Pennsylvania, Rhode Island, Texas, Virginia, and West Virginia.
2) Michigan and New York.
3) Alaska and South Carolina.
4) Alabama, Colorado, Florida, Indiana, Iowa, Louisiana, Minnesota, Mississippi, Missouri, North Carolina, North Dakota, Utah, Vermont, Washington, Wisconsin, and Wyoming.
5) Georgia, Hawaii, Idaho, Kansas, Kentucky, Nebraska, South Dakota, and Tennessee.

Source: Energy Information Administration.

Figure 1.

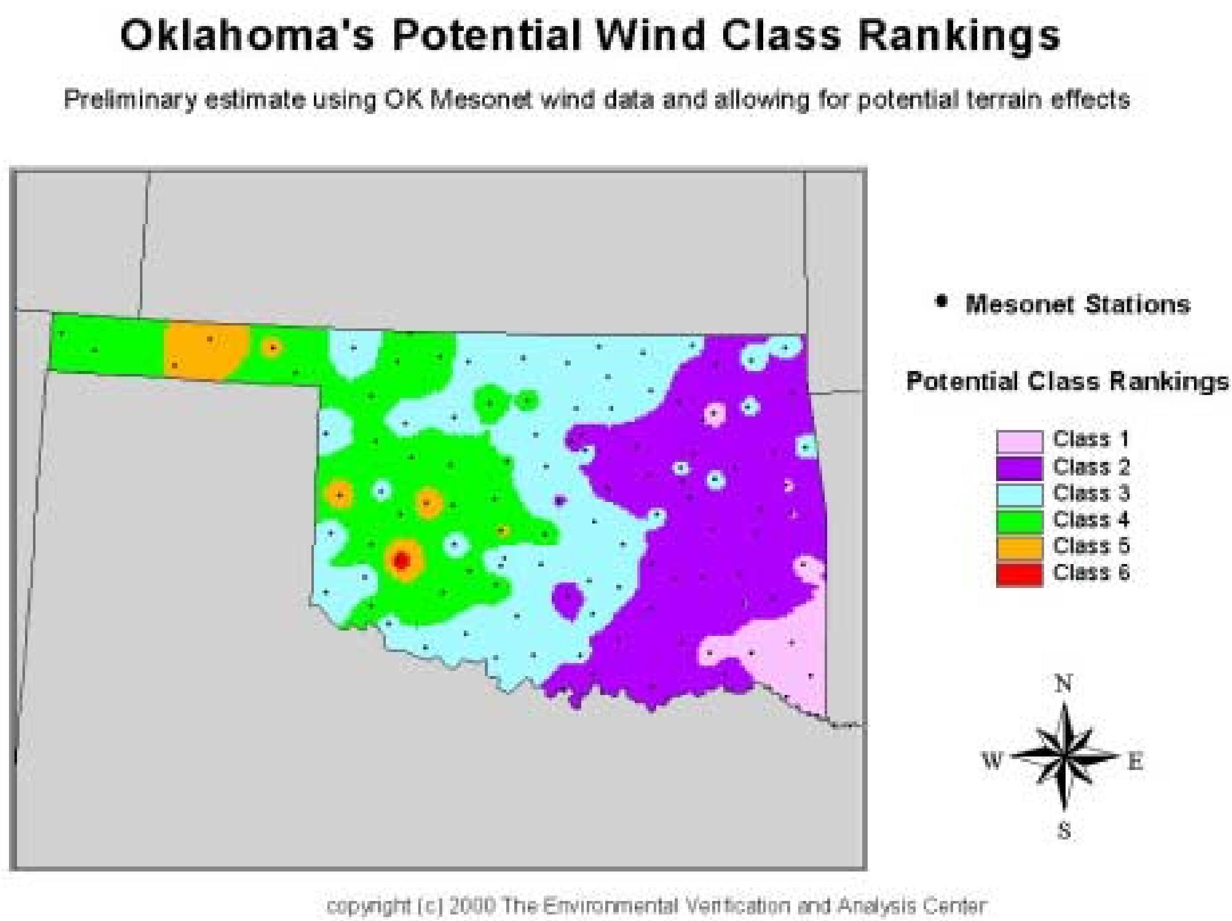


Figure 3. Preliminary wind power assessment and Mesonet station locations.

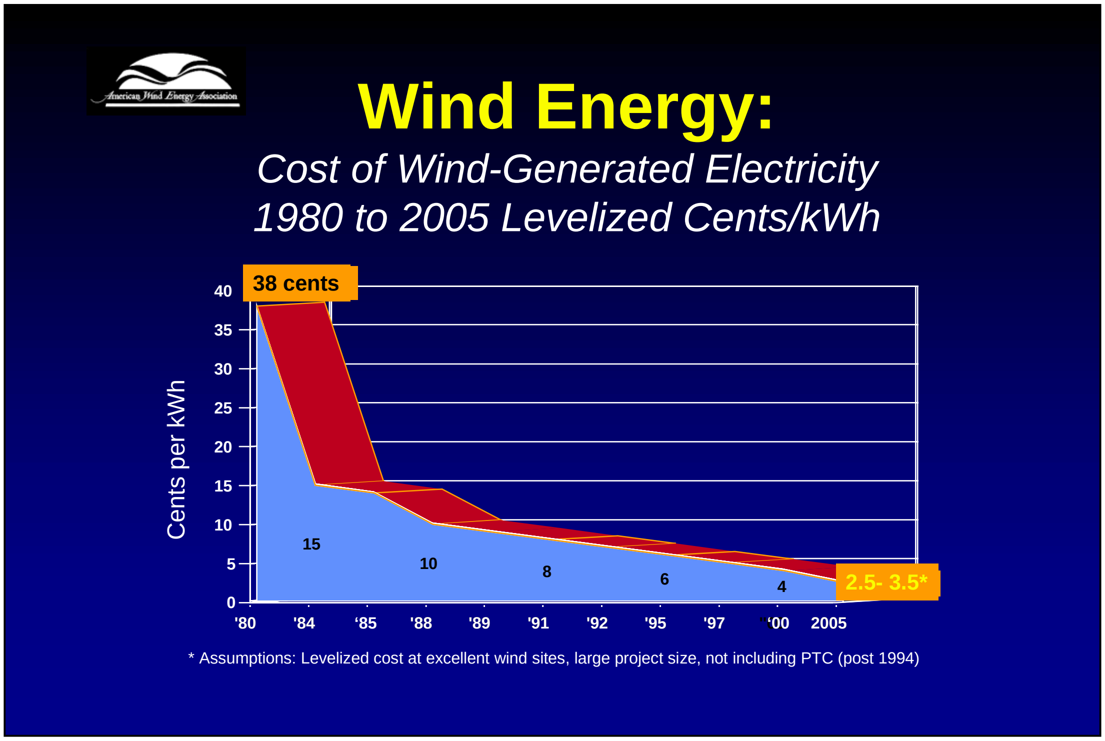


Figure ___:

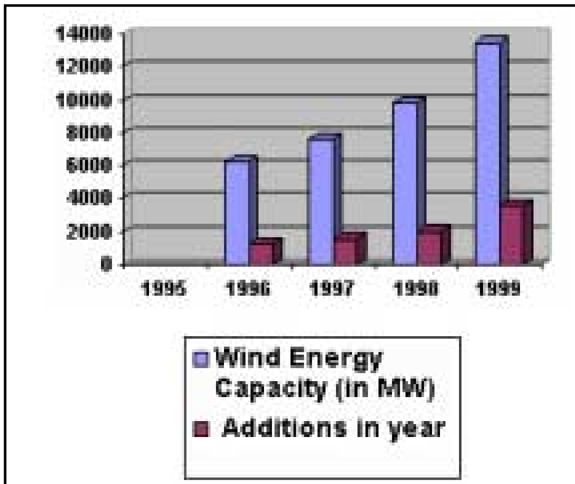


Figure courtesy of American Wind Energy Association

Figure???

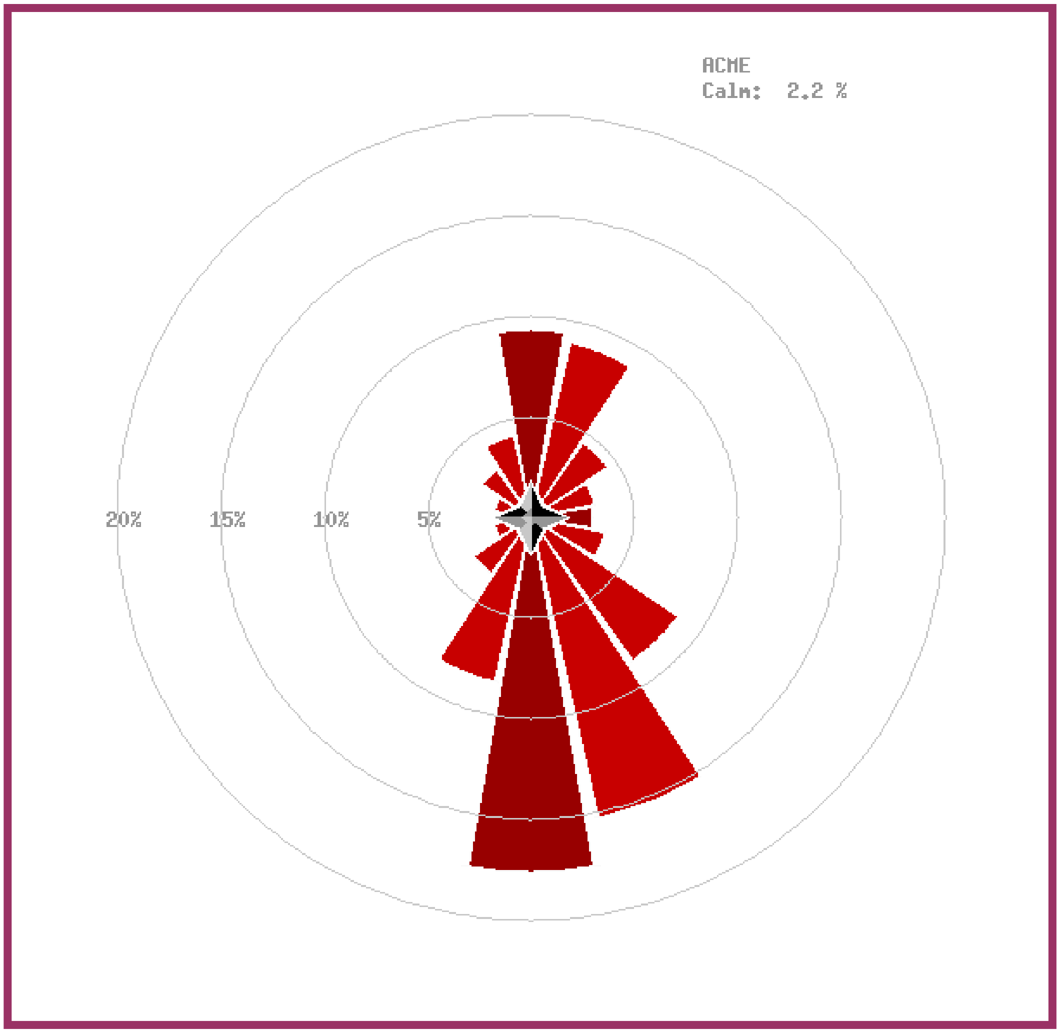


Figure 5. Sample Mesonet wind rose product.

Appendix C

Fact Sheets and Other Information

Evaluating and using Mesonet climatological wind data summaries

Table 2 shows the format for the wind data summary used for the preliminary study reflected by Figure 3. For all but 3 of the 114 Mesonet stations, this summary represents the distillation of 5 years of data (the 3 have about 2.5 years of data that went into the process). Wind data are classified in bins according to both wind-speed and wind-direction classes. For the purposes of the preliminary study, only the wind-speed classes were used.

As depicted in this table, there are 9 classes of wind speed, including 'calm'.

Calculation of Wind-power Density

For a given air parcel of mass **m**, density ρ, length **l**, cross-sectional area **A,** and velocity **v**, the energy contained in that parcel is given by the expression:

$$\text{Energy} = 0.5 * \mathbf{m} * \mathbf{V}^2 = 0.5 * \rho * (\text{Volume}) * \mathbf{v}^2 = 0.5 * \rho * (\mathbf{A} * \mathbf{l}) * \mathbf{v}^2$$

Since power is energy per unit time, we will assume a time Δt for this parcel to pass through a given plane so that the parcel's length can be expressed as $\mathbf{l} = \mathbf{v} * \Delta \mathbf{t}$. Then the power generated can be expressed as:

$$\text{Power} = \text{Energy}/\Delta\mathbf{t} = \{ 0.5 * \rho * [\mathbf{A} * (\mathbf{v} * \Delta\mathbf{t})] * \mathbf{v}^2 \} / \Delta\mathbf{t}$$

or $$\text{Power} = 0.5 * \rho * \mathbf{A} * \mathbf{v}^3$$

The power generated by a constant stream of air parcels (i.e.: "wind"), which pass through a wind turbine with a rotor-swept area A, can be expressed as "power-flux" by:

$$\text{Power} / A = 0.5 * \rho * \mathbf{v}^3$$

The Wind Power Density (WPD) is a term defined to take into account the density of the air, the frequency distribution of wind speeds, and the dependence of power on the cube of the velocity. WPD is defined as:

$$\mathbf{WPD} = 0.5 * \sum_{j=1}^{n} [\rho * (\text{median } \mathbf{v}^3 \text{ in class j}) * (\text{frequency of occurrence in class j})]$$

where n is the number of frequency classes. The larger the value for n, the closer one gets to the true theoretical WPD. For this study, this number of classes is 9 (including 0, or 'calm'). For coarser classes, it is important to use cube-root of the median of the cubed endpoints, and not the simple median of the endpoints, in the above formula, as the latter will result in underestimating WPD.

Calculation of air density (ρ)

The following formula approximates the US Standard Atmosphere profile for air density, using only a function of elevation:

$$\rho \approx 1.225 - (1.194 * 10^{-4}) * \mathbf{Z} \quad \text{(where } \mathbf{Z} \text{ = station's elevation in meters)}$$

Note that at sea level, ρ would be 1.225 kg/m^3. Each increase of 1000m corresponds to an approximate decrease of 0.12 kg/m^3. This means a difference in air density of about 10% from the state's lowest location in the SE, to its highest point in the NW. The change with elevation was considered worth accounting for in the preliminary study.

If ρ is assumed to not change over time, it can be pulled out of the summation to give:

$$\text{WPD} = 0.5 * \rho * \sum_{j=1}^{n} [\ (\text{median } \mathbf{v}^3 \text{ for class j }) * (\text{frequency of occurrence in class j }) \ ]$$

This assumption introduces some error (+/- 5% over full range of conditions), and was acceptable for the preliminary project in order to avoid rigorous considerations of effects of temperature and air pressure over time.

Estimation of winds at 50 m using data at 10m

When evaluating wind resources for large wind turbines, the industry standard level for taking (or deducing) such data is at 50 meters. Because Mesonet wind data is taken at 10 meters, an extrapolation must be made. The following approximation is used for this process.

$$V_2 \approx V_1 * [\ \log(Z_2) - \log(Z_0)\ ] / [\ \log(Z_1) - \log(Z_0)] \qquad (1)$$

where: V_2 is the estimated wind speed at height Z_2 (50 meters in this case)
V_1 is the observed wind speed at height of instrument, Z_1 (10 meters in this case)
and Z_0 is the surface roughness value.

Substituting in the known quantities, equation (1) reduces to the following:

$$V_{50} \approx \text{WSPD} * [\ 1.70 - \log(Z_0)\ ] / [\ 1 - \log(Z_0)] \qquad (2)$$

The roughness value, Z_0, is approximated for each Mesonet station using a landuse/landcover dataset. An assumption will be made that the frequency distribution of wind speeds at 10 m. can be translated to 50 m. In reality, some difference can be expected, but will make a small difference in the overall WPD.

A Description of GIS and Key Data Components

The OU/OSU team is in position to assess wind power potential in Oklahoma in a manner that would be uniquely Oklahoman. We feel four major factors are in place and it is the intent of this proposal to coordinate these factors into an objective assessment of wind power potential. These factors came into place in the last part of the 1990s and we wish to capitalize upon them.

First, Oklahoma is known to possess considerable potential for wind power generation vis-à-vis other states. For instance, general sources such as Visher (1954), NOAA (1983), and Elliott et. al. (1987) contain small-scale maps of wind produced from interpolation of data from National Weather Service (NWS) observation sites. It is well appreciated that mean wind speeds increase to the west in Oklahoma, but there has been no statewide Oklahoma work objectively relating topography, land cover, and the wind resource.

Second, the state's atmosphere is sampled by the country's premiere atmospheric measurement system – the Oklahoma Mesonetwork. The Mesonetwork sites are spaced around the state with at least one site in each of Oklahoma's seventy-seven counties (Figure 3) and an average spacing of 35 km. The proposed work will make heavy use of the wind speed and direction data. The archived Mesonetwork wind observations are approximately ten times denser in space and twelve times denser in time than the archived observations of the NWS. Existing wind and wind power potential maps such as those cited in the paragraph above are based on data from hourly reporting stations located at airports. Airports are sited on cleared, flattish terrain and, without a detailed assessment of surrounding vegetation/terrain combinations, it is uncertain as to how representative the sites are of wind in their surroundings. The Mesonetwork sites (other than two purposely co-located at airports with NWS automated sites) have been located to be representative of their landscape surrounding while meeting all World Meteorological Organization siting criteria. Existing NWS sites provide reasonable first approximations of wind, but much more could be learned. For instance, there are no NWS sites in Oklahoma to the south and east of McAlester nor are there any sites in the Panhandle. It is anticipated the use of Oklahoma Mesonetwork data will provide a fresh perspective on the mesoscale characteristics of the wind resource.

The third salient factor is the wealth of existing coverages (electronic data layers) and point data (e.g. Mesonetwork data) that can be interpolated into statewide coverages. Statewide data layers became abundant in the late 1990s and each represents a large investment of work. The proposed work will manipulate these coverages and spatially relate them without having to "reinvent" the coverages. Given the size of Oklahoma and the thoroughness with which we intend to study siting, the goal of identifying the "best" areas of wind power potential suggests the use of Geographic Information System (GIS) methodology. Crisman (1997) has labeled a GIS as a "convergence of many technologies." GIS technology is now running on PCs whereas before a decade ago it was the sole realm of mainframe and expensive workstations.

Basically, a GIS is a set of electronic maps and associated metadata. The most vital concern is being able to align the individual electronic maps while minimizing spatial errors. When co-considering the landscape with the atmosphere and social variables, a GIS allows the user to pose many questions and produce plentiful map and tabular output. The proposed project would build a database to be queried for assorted purposes. A sense of the various data layers can be gained from Figure 4 (Gould quadrangle). The maps of Figure 4 are not end products, but examples of data layers from which the "best" potential wind farm sites will be defined. Parameters such as distance to transmission lines and land ownership will be laid over physical factors such as topography, vegetation and wind potential. Such a mesoscale analysis would take years via manual means, but can be accomplished objectively within months using GIS technology.

Longley et. al. (1999) have provided the most comprehensive explanation of GIS techniques and applications and show GIS is well-suited for coordinating environmental and social elements within projects. It is also plain that there is now a user group for electronic wind data coverages. For instance, Brower and Company of Andover, MA vend a wind energy prediction program that runs on a PC and produces coverages that can be used directly in a GIS. While there is no "off the shelf" software to accomplish the goals of the proposed project, minor modifications in extant software will allow us to produce the deliverables outlined elsewhere.

Caveats

Oklahoma-relevant GIS coverages are abundant and GIS analysis software is already running at the Clearinghouse, but the creation of a GIS database for wind power potential assessment is not a trivial matter. Data coverages have had various origins and purposes of creation so they each have their own quirks and, importantly, exist in various map projections. A good deal of care must be used to align the data into a database. The incorporation of Mesonetwork data into the GIS database is ostensibly simple. That is, quality-controlled data are available for 100+ sites starting 1 January 1994. The ability to estimate wind over mesoscale area is a key need of this project. Although the Mesonetwork is spatially extensive and offers the best hope for characterization of Oklahoma's atmosphere, the Mesonetwork sites are sampling only a tiny fraction of the wind. Winds can be interpolated via various horizontal and vertical algorithms, yet we will need to exert caution concerning wind-causing and –altering mesoscale phenomena such as surface-forced convection and flow around topographic obstructions. The incorporation of vegetation and terrain phenomena with the wind data for a statewide mesoscale GIS analysis is a fresh approach and will require some learning as to what will work and what will not.

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Final vers.: 5/24/00

Appendix F: Statement of work and deliverables for OWPAI activities for July 1, 2000 to June 30, 2001

Summary of goals for FY2001

1. Using 6 years of Oklahoma Mesonet wind data (10 meters):
- produce an Oklahoma wind power map, with estimated annual average wind power available at 10 meters;
- produce an OK wind power map, with estimated annual average wind power available at 50 meters; and
- produce four OK wind power maps, with estimated seasonal average wind power available at 50 meters (one map for each of these periods: Jan.-Mar.; Apr.-June; July-Sept., Oct.-Dec.)
2. Show results of study using GIS data layers (wind power, roads, transmission lines, etc.) to find optimal regions for wind power farms and areas to avoid (wildlife refuges, populated areas, etc.)
3. Provide climatological average wind and wind power products (regular wind rose and wind energy rose combination), annual and by season, for OK Mesonet stations in optimal regions, to provide baselines against which tall tower data may later be compared.
4. Provide maps and/or tables showing solar energy available at Mesonet sites, averaged over 6 years.
5. Provide report on renewables policies in other states and how they might be applied to Oklahoma's wind power policy implementation and incentives for development.
6. Provide report on long-term potential spin-off projects and strategies for leading into them.
7. Develop web-pages which teach about wind power and Oklahoma's potential for this resource, and which display selected output from this study.
8. Form ties for potential K12 and post-secondary educational outreach programs.
9. Begin contacts with landowners in optimal regions.
10. Install one tall tower (40 meters or more) instrumented with wind-sensors at industry-standard heights (eg: 10, 25 and 40 meters).
11. Document tall-tower data collection and analysis plan for FY 2002 activities.
12. Investigate sources of funds (eg: USDOE, DOE/EPSCoR) for FY2002 activities.
13. Provide and present results from this project, in appropriate format, for the wind-power workshop hosted by the Oklahoma Department of Commerce at the end of FY2001 or beginning of FY2002.

Goals by quarter

The items in the following quarterly work statements are annotated with the initials of the person(s) primarily responsible for the work (TH=Tim Hughes; MM=Mark Meo; MS=Mark Shafer; MY=May Yuan; JS=Jayne Salisbury; SS=Steve Stadler)

First Quarter (July 1 to September 30, 2000)

1) Send wind-power study plan to Elliott and/or Schwartz at NREL for external review. They will propose changes if needed to improve plan. [TH]
2) Review Mesonet sites' surrounding conditions to place quality indicator flags on wind data, by 16 compass-point directions, where needed to indicate compromises in fetch. Build flag array (115 stations x 16 flags) for use in programs. [TH, MS]
3) Oversee modification and running of Oklahoma Climate Survey's wind-rose program, to produce standard wind-rose graphics and wind power tables for each Mesonet station. [MS, TH]. Modify existing program to:
   - use 1 meter/second wind speed classes
   - add calculation to integrate wind energy for each station, with division by 16 compass points (add use of air temperature and pressure data to improve estimates)
   - run using Mesonet data from January 1, 1994 to December 31, 1999
4) Assemble output products from 3), to include: [TH, MS]
   - standard GIF format graphical output of wind rose product (see attached example)
   - ASCII formatted table files (one for each station) with breakdown of wind speed/direction frequencies - same basic structure as attached example, but reflecting wind speed divisions of 1 m/s.
   - ASCII formatted table files (one for each station) with wind energy integrated for each of 16 compass point direction bins.
   - as time and resources allow, graphical representation (HTML or other format) of tables as produced in (3).
5) Using results from (4), produce map of estimated annual average wind power available at 10-meter level, for entire state. [JS, SS, TH]
6) Write report on wind power (and renewables) policy implementation in other states, and how these policies may transfer to Oklahoma. [MM]
7) Implement web-pages to include: [all JS unless otherwise noted]

- some tutorials on calculating wind power density [TH will provide text and graphics]
- maps showing available GIS data layers (transmission lines, Mesonet sites, terrain, other data layers as available)
- results from 10m wind power map (availability of this web-page limited until later)
- other information as appropriate

8) Procure WindMap software, begin testing with sample Mesonet and terrain data. Prepare preliminary report with sample output. [JS, SS]
9) Research best method for 50 meter wind power approximation (using results from 10 meter wind speed data and land-cover and other data). [TH, MS]
10) Attend Kansas windpower workshop for updates on activities in area, and input on issues to address at the ODOC workshop later. [TH, MM]

Summary of deliverables due at end of 1st quarter:

- ♦ Map for Oklahoma's estimated annual average wind power at 10 meters [JS, SS]
- ♦ Summary of Mesonet sites' surrounding conditions & potential impact on wind data and wind power estimates [TH]

- ♦ Oklahoma wind power web-site and available results to date [JS]
- ♦ First report on policies in other states and how they might be applied to Oklahoma's wind power policy implementation and incentives for development [MM]
- ♦ Quarterly status report to ODOC (to include all the above) [TH, MM]

Second Quarter (October 1 to December 31, 2000)

1) Produce comprehensive wind-speed and energy distribution tables for 50 meter height, based on 10 meter product files in first quarter.
2) Oversee modification and running of wind-rose program to produce ***seasonal*** average wind product results for 10 meter winds (outputs from this part are analogous to those in first-quarter - but tables and wind-roses will be broken down by four seasons).
3) Document procedure of no. 1. and 2. as basis for descriptions on web-pages and for poster presentation. [TH, MS]
4) Produce array of 50m wind power estimates from no. 1, by Mesonet station. [TH]
5) Analyze and grid array of wind power values in (4) - produce map [JS, SS].
6) Study terrain to look for likely areas of terrain modified wind. [JS, SS, TH]
7) Use sample Mesonet wind data (from conditions reflecting prevailing winds for sites involved) and terrain data to look for areas with terrain accentuated wind-flow [JS, SS, TH].
8) Compare results of 5. and 6. and report. [JS, SS, TH]
9) Continue to assemble GIS data layers (trans. lines, etc.) [JS, SS]
10) Investigate and acquire severe weather information (e.g.: severe winds, lightning) as may be appropriate to study for effects on wind farm locations. Also, investigate prospects for wind energy forecasting and potential applications of GIS to such. [MY]
11) Update web-site [JS]
12) Internal review of above results [MM]

Summary of deliverables due at end of 2nd quarter:

- ♦ Tables of annual and seasonal OK 50m wind power estimates [TH, MS]
- ♦ Maps of annual and seasonal averages for OK 50m wind power estimates [JS, SS]
- ♦ Metadata for tables [TH]
- ♦ Metadata for maps [JS]
- ♦ Updates to web-pages to reflect new maps [JS]
- ♦ Quarterly status report to ODOC [TH]

Third Quarter (January 1 to March 31, 2001)

1) Attend Alternative Energy Institute for one week of training (tower setup, software use, data evaluation, etc.) [TH]

2) Evaluate how terrain data affects prime areas with varying wind [JS, SS, TH]
3) Finalize assembly of GIS data layers. [JS, SS, TH]
4) Determine prime areas for installation of tall towers. [TH, JS, SS]
5) Investigate educational outreach partnerships in or near optimal areas (say, with Cameron, Lawton area vo-tech) [TH]
6) Produce tables of average daily and average monthly solar energy available at Mesonet sites, for 6-year period. [TH, MS]
7) Produce maps for average monthly solar energy available at Mesonet sites [JS, SS]
8) Add demographic and economic study in and around areas with minimum wind power conditions needed for large wind farms [MY, MM]
9) Contribute to conference poster presentation [ALL]

Summary of deliverables due during or at end of 3rd quarter:

- ♦ Proposal for USDOE State Energy Program, if *Wind Power Case Studies* program is available; proposals may go to other fund sources if available [TH, MM]
- ♦ Maps showing optimal areas for wind (with buffering for parks, towns, habitats, etc.) and proximity to transmission lines and roads. [JS, SS]
- ♦ Maps and/or tables showing solar energy available at Mesonet sites [JS, TH]
- ♦ Maps/reports on demographics and economics of regions [MY]
- ♦ Metadata on appropriate products [JS, TH]
- ♦ Updates to web-pages to reflect new maps [JS]
- ♦ Quarterly status report to ODOC [TH]
- ♦ Plan for continued work in FY 2002 (placement of towers, collection of data, etc.) and preliminary proposal and budget. [TH, MS]

Fourth Quarter (April 1 to June 30, 2001)

1) Update report on renewables policies and wind power programs in other states (part 1. provided in first quarter) [MM]
2) Select good location prospects for placement of tall instrumented towers [TH]
3) Finalize poster for presentation at WindPower 2001 [TH lead, all help]
4) Install 1 tall tower and instruments; collect and display data. [TH]
5) Attend WindPower 2001 in Washington DC. [TH, MM, JS, SS]
6) NREL's Elliott and/or Schwartz provide external review final report draft, conference poster, and plan for data collection in FY2002 and provide feedback as needed. [TH]
7) Compile materials for comprehensive FY2001 report; provide to printers [TH, JS]

Summary of deliverables due by end of 4th quarter:

- ♦ Updates to web-pages to reflect new maps, reports, and links [JS]

- ♦ Metadata for any new products, as needed [JS, TH]
- ♦ Summary report on prime regions [TH, JS, SS]
- ♦ Report on 1 installed tower and data collection progress [TH]
- ♦ Poster for presentation at WindPower 2001 [TH, JS, SS]
- ♦ Quarterly status report to ODOC [TH]
- ♦ Plan for tall-tower network data collection, evaluation, and quality checks [TH]
- ♦ Recommendation for continued work, work plan, budget, external funding sources. [TH]
- ♦ Comprehensive report (text, maps and tables) in professionally bound form. [TH, JS]

Appendix G: Biographical Sketches

Tim Hughes - Principal Investigator
Research Associate
The Environmental Verification and Analysis Center
University of Oklahoma
710 Asp Ave., Suite 8
Norman, OK 73069
Phone: (405) 447-8412
Email: Thughes@ou.edu

Education:

1982-1984	Graduate Studies	Oregon State University Penn State University
B.S. 1981	Mathematics, Physics	Beloit College, Beloit, Wisconsin

Past Professional Experience:

1994-1999	Project Manager, Oklahoma Mesonetwork, Oklahoma Climate Survey
1991-1994	Ass't Proj. Mgr., Oklahoma Mesonetwork, Oklahoma Climate Survey
1988-1991	Computer Resource Mgr., School of Meteorology, University of Oklahoma
1986-1988	Teacher of Math, Science and Computer Sci., Casady School, Oklahoma City
1985-1986	Assistant Computer Services Director, Beloit College, Beloit, WI
1982-1984	Graduate Studies in Meteorology, Oregon State and Penn State Universities
1981-1982	Technical Associate, Science Division, Beloit College, Beloit, WI

Professional Interests:
Alternative Energy Sources, Automated Weather Networks, Educational Outreach Initiatives

Workshops/Course Labs Conducted:
Contributed to preparation and presentation of hands-on instrument and data-logging lab components for the OU School of Meteorology course "Meteorological Measurements".

Led University of Oklahoma NASA Space Grant Consortium (NASA/SGC) courses for students and teachers for the following projects:

- Altitude Tracking Devices (devices constructed from basic components to demonstrate principles of trigonometric altitude determination)
- Principles of Model Rocketry
- Model rocket construction and launch

These courses were part of the following summer programs (1993 to present):

- NASA/SGC "Aerospace Education: Above and Beyond"
- NASA/SGC "Mission To Planet Earth - MTPE"
- NASA/SGC "New Horizons: Gifted and Talented Students (Grades 5-9)"
- NASA/SGC "Aerospace Studies"

- Oklahoma Aeronautics Commission: "Aerospace Education - A View from Above"

Funded Projects:

PI for " **Mesonet, Jr.:A prototype weather station for K12 education in Alva, OK**", Oklahoma NSF-EPSCoR, 4/1/98 - 7/31/98

PI for "**ARM/NSA/Sheba Training**", Sandia Labs, 2/10/98 - 2/14/98

Co-PI for **"Training in Oklahoma Mesonet Quality Assurance for the South African ISCW**", US Department of Agriculture, 9/15/98 - 9/30/99

Co-PI for **"Environmental Monitoring Station Installation and First-Year Operation",** Kerr Environmental Research, Environmental Protection Agency, 6/1/98 - 6/30/99

Co-PI for "**The OK-FIRST! Project**", funded for the period October 1, 1996 to September 30, 1998 by the U.S. Department of Commerce.

Relevant Publications:

Crawford, K.C., D.A. Morris, R.A. McPherson, H.L. Johnson, M.A. Shafer, J.M. Wolfinbarger, and T.W. Hughes. 1998. **OK-FIRST: A Decision-Support System for Public Safety Agencies.** 14th International Conference on Interactive Information Processing Systems for Meteorology, Oceanography, and Hydrology; American Meteorological Society, Phoenix, Arizona, January 11-16.

Hughes, T.W., M.A. Shafer and W.G. McPherson, Jr. 1994. **Sharing Oklahoma Mesonet Data via Public Display Terminals**. 10th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology; American Meteorological Society, Nashville, Tennessee, January 23-28.

Shafer, M.A., T. Hughes, and J.D. Carlson. 1993. **The Oklahoma Mesonet: Site Selection and Layout.** 8th Symposium on Meteorological Observations and Instrumentation; American Meteorological Society, Anaheim, California, January 17-22.

Shafer, M.A. and T.W. Hughes, 1996, **Automated Quality Assurance of Data from the Oklahoma Mesonetwork**, 12th International Conference on Interactive Information Processing Systems for Meteorology, Oceanography, and Hydrology; American Meteorological Society, Atlanta, Georgia, January 28-February 2.

Shafer, Mark, Christopher Fiebrich, Derek Arndt, Sherman Fredrickson, and Timothy Hughes, 2000, **Quality assurance procedures in the Oklahoma Mesonetwork,** Journal of Atmospheric and Oceanic Technology, Vol. 17, No. 4, pp. 474-494.

Mark Meo
Research Fellow, Science and Public Policy Program
Professor, Civil Engineering and Environmental Science
University of Oklahoma

100 E. Boyd St., Room S-202
Norman, OK 73719
Tel: (405) 325-2272 or 325-2554
Fax: (405) 325-7695
email: mmeo@ou.edu

Education:

Ph.D. 1983, University of California, Davis Ecology and Policy Analysis
M.S. 1974, Louisiana State University, Marine Sciences
B.A. 1971, Northeastern University, Biology

Professional Employment History:

1985 - Present University of Oklahoma. Joint appointment in the Science and Public Policy Program and the School of Civil Engineering and Environmental Science.

2000 - Present, Research Fellow, Science and Public Policy Program.
1995 - 2000, Director, Science and Public Policy Program.
1985 -1995, Research Fellow, Science and Public Policy Program.

1999 - Present, Professor of Civil Engineering and Environmental Science.
1991 - 1999 Associate Professor of Civil Engineering and Environmental Science.
1985 - 1991 Assistant Professor of Civil Engineering and Environmental Science.
1983 - 1985 Postdoctoral Fellow, Marine Policy Center, Woods Hole Oceanographic Institution.

Research Interests:

Prof. Meo's research has been focused on the intersection of science and technology issues and their effect on public policy. In the last two decades, he has conducted research of a variety of environmental topics including the use of natural ecological systems for waste recycling, renewable energy and clean fuel technologies (including biomass-based alcohol fuels and natural gas power production), the use of scientific and technical information in decision making, environmental planning and management, global change, and sustainable development policy.

Research Funding:

$3.37 million in external research awards as principal or co-principal investigator; 26 projects. Research sponsors include the Electric Power Research Institute, the National Oceanic and Atmospheric Administration, the National Science Foundation, the State of Oklahoma, the U.S. Department of Energy, and the U.S. Environmental Protection Agency.

Publications: 68 academic publications:

51 journal and proceedings publications; 35 peer-reviewed.
17 reports.
34 professional presentations.

Representative Publications:

Mark Meo and Mark Sharfman (eds.) *Green Technology and Public Policy*, **American Behavioral Scientist**, Vol. 44, No. 2, (forthcoming).

Mark Sharfman, Rex Ellington, and Mark Meo, "DuPont, Conoco, and the Biodegradable Grease Project: Using Innovation to Turn Chemical By-Products into a New Product," **Corporate Environmental Strategy**, Vol. 7, No. 1, pp. 62-71, 2000.

Mark Sharfman, Rex Ellington, Mark Meo, "Conoco and the Vapor Recovery Project: Using Innovation to Preserve Autonomy," **Journal of Industrial Ecology**, Vol. 3, No. 1, pp. 93-110, 1999.

Mark Meo, Kenneth Johnson, and Kenneth Luza, "Forest and Nonfuel Mineral Resources," in **Oklahoma Resources for Economic Development**, Hans Spaeth, Gary Thompson, and Henry Eisenhart (eds.) OGS Special Publication 98-4, pp. 157-176, Norman, OK: Oklahoma Geological Survey, 1998.

Rex Ellington, Mark Meo, and Dawlat El-Sayed, "The Net Greenhouse Warming Forcing of Methanol Produced From Biomass," **Biomass and Bioenergy**, Vol. 4, No. 6, pp. 405-418, 1993.

Student Advising: 10 Ph.D. committees; chair of 3.
11 M.S. committees; chair of 5.

Mark Shafer
Staff Climatologist, Oklahoma Climatological Survey
100 E. Boyd St., Suite 1210
Norman, OK 73019
Tel: (405) 325-3044
Fax: (405) 325-2550
email: mshafer@ou.edu

Education:

M.S.	1990, University of Oklahoma	Meteorology
B.A.	1987, University of Illinois	Atmospheric Sciences

Professional Employment History:

1990 - Present	Staff Climatologist, Oklahoma Climatological Survey
1987 - 1990	Graduate Research Assistant, University of Oklahoma
1983 – 1987	Undergraduate Research Assistant, University of Illinois, Urbana-Champaign

Research Interests:

Mr. Shafer is presently pursing a Ph.D. in political science at The University of Oklahoma, with an emphasis in policy. His research interests are in the utilization of technical information in the policy making process. In addition to his doctoral studies, Mr. Shafer works with data management and product development. His interests focus upon broadening the use of weather and climate information to include state agencies that previously have under-utilized these resources. He has also worked extensively with quality-assurance measures for data and educational outreach programs.

Research Funding:

$549,910 external funding award from the U.S. Department of Commerce as co-principal investigator for the OK-FIRST program. The OK-FIRST program received an additional award of $20,000 as a finalist in Harvard's Innovations in American Government awards program for 1999.

Representative Publications:

Mark Shafer, Christopher Fiebrich, Derek Arndt, Sherman Fredrickson, and Timothy Hughes, "Quality assurance procedures in the Oklahoma Mesonetwork," **Journal of Atmospheric and Oceanic Technology**, Vol. 17, No. 4, pp. 474-494, 2000.

Mark Shafer, Donald MacGorman, and Frederick Carr, "Cloud-to-ground lightning throughout the lifetime of a severe storm system in Oklahoma," **Monthly Weather Review**, 2000 (in press).

William Easterling, Scott Isard, Pamala Warren, Patrick Guinan, and Mark Shafer, "Improving the Detection of Agricultural Drought: A Case Study of Illinois Corn Production," **Agricultural and Forest Meteorology**, Vol. 43, No. 1, pp. 37-47, 1988.

Thomas James, Paula Long, and Mark Shafer, "An independent evaluation of the OK-FIRST decision-support system," *Preprints, 2nd Symposium on Environmental Applications*, American Meteorological Society, January 9-14, 2000.

Mark Shafer and Mark Morrissey, "Design of a Pacific Rainfall Database," *Preprints, Ninth Conference on Applied Climatology,* American Meteorological Society, January 15-20, 1995.

J.D. Carlson, Gerrit Cuperus, Ron Elliott, Steve Stadler, and Mark Shafer, "Using The Oklahoma Mesonet as an Agricultural Management Tool," *Preprints, 21st Conference on Agricultural and Forest Meteorology,* American Meteorological Society, March 7-11, 1994.

J.D. Carlson, David Engle, and Mark Shafer, "Using the Oklahoma Mesonet as a Fire Management Tool," *Preprints, Twelfth International Conference of Fire and Forest Meteorology,* American Meteorological Society, October 26-28, 1993.

Mark Shafer, Timothy Hughes, and J.D. Carlson, "The Oklahoma Mesonet: Site Selection and Layout," *Preprints, Eighth Symposium on Meteorological Observations and Instrumentation,* American Meteorological Society, January 17-21, 1993.

Jayne M. Salisbury
Director, Spatial and Environmental Information Clearinghouse
Oklahoma State University
Tel: 405-744-843
Fax: 405-744-7008
Email: jsalis@www.seic.okstate.edu

Education

Ph.D. 1992 Interdisciplinary/Engineering/Geosciences, University of Oklahoma, Norman, OK.
M. A. 1979 Geography, University of Iowa, Iowa City, IA.
B. S. 1972 Geography, University of Iowa, Iowa City, IA.
1969 Naval Photography School, U.S. Navy, Pensacola, FL.
1964 - 1967 Briar Cliff College, Sioux City, IA.

Professional Experience

1996-present; Research Scientist, Environmental Institute; Director, Spatial and Environmental Information Clearinghouse (SEIC); Adjunct Assistant Professor, Department of Geography, Oklahoma State University, Stillwater, OK.
1994-1996; Hydrologist, GS-12, U. S. Department of Agriculture, Agricultural Research Service, National Agricultural Water Quality Laboratory, Durant, OK.
1991-1994; Research Scientist, Oklahoma Climatological Survey, Norman, OK.
1987-1991; Research Assistant, NASA International Studies of Land Surface Climatology Project, School of Meteorology, University of Oklahoma, Norman, OK.
1986-1987; Research Associate, Coop. Center for Mesoscale Meteorological Studies, Norman
1981; Consultant, Amos Eddy, Inc., Norman, OK.
1980-1982; Research Assistant, Oklahoma Climatological Survey, Norman, OK.
1979; Research Assistant, National Center for Ground Water Research, Norman, OK.
1976-1979; Research Geologist, Water Resources Division, Iowa Geological Survey, Iowa City.
1974-1977; Instructor and Graduate Research and Teaching Assistant, Geography, University of Iowa, Iowa City, IA.

Professional Memberships and Activities

Member of the Graduate Faculty, Oklahoma State University.
Member of American Water Resources Association.
President, Oklahoma Section of American Water Resources Association, 1997-2000.
Member of Association for Women Geoscientists
UCOWR representative for Oklahoma State University.
Vice Chair for Geography, Oklahoma Academy of Science.
Chairperson of Technical Working Group on Geographical Information Systems and Remote Sensing, American Water Resources Association, 1992-present.
Chairperson of Conference on “Water Resources and the Energy Industry,” Oklahoma Section, American Water Resources Association, in planning for Spring, 2001.
Chairperson of “The Great Plains Symposium 1999: The Ogallala Aquifer, Steps to Sustainability,” sponsored by Great Plains Foundation, Oklahoma City, OK, April, 1999.
Chairperson of the “Water Quality and Animal Wastes Conference, Workshops, and Field Trip,” March 2-4, 1998, Oklahoma City, OK, March, 1998.
General Chairperson of the National Symposium on “GIS and Water Resources,” American Water Resources Association, Ft. Lauderdale, FL, September, 1996.

Selected Publications –GIS papers and presentations

Salisbury, Jayne M. and Hsuan-Tsung Hsieh, in progress, "Download topography and soils data with a click of a button," American Society of Agricultural Engineers, 2000 ASAE Annual International Meeting, July, 2000, Milwaukee, WI.

Chaubey, Indrajeet, C.T. Haan, J.M. Salisbury, and S. Grunwald, in progress, "Effects of spatial variability of land use and land cover on modeling hydrologic/water quality processes."

Salisbury, Jayne M. and Thomas A. Wikle, 1999, "GIS and Water Resources: NSF Research Experiences for Undergraduates at Oklahoma State University," *Symposium on Water Resources on the Internet,* American Water Resources Assoc., Dec. 5-9, 1999, Seattle, WA.

Salisbury, Jayne M., 1999, "The Oklahoma Spatial and Environmental Information Clearinghouse," Inter-Tribal Environmental Council Forth Annual Conference, June 1-2, 1999, Tulsa, OK.

Salisbury, Jayne M., 1999, "I never metadata I didn't like," South Central ARC User Conference, Feb. 22-26, 1999, Fort Worth, TX.

Salisbury, Jayne M., 1998, "Water Quality Standards GIS for Oklahoma," Inter-Tribal Environmental Council Third Annual Conference, June 9-10, 1998, Oklahoma City, OK.

Starks, Patrick J., Jurgen Garbrecht, Frank R. Schiebe, Jayne M. Salisbury, David A. Waits, 1996, "Issues related to the development and use of GIS coverages for the Little Washita River Watershed," *GIS and Water Resources*, Ann Arbor Press, Ann Arbor, MI.

Starks, Patrick J., Jurgen Garbrecht, Frank R. Schiebe, Jayne M. Salisbury, David A. Waits, 1996. "Issues Relating to the Development and Use of GIS Coverages for the Little Washita River Watershed." *Proceedings*, Symposium on GIS and Water Resources, AWRA, September 22-26, 1996, Fort Lauderdale, FL, pp. 47-56.

Hallam, Cheryl A. and Jayne M. Salisbury, 1994. "Geographic Information Systems (GIS) Applications in Water Resources Research: American Water Resources Association Annual Meeting, Chicago, Illinois, November 6-10, 1994." USGS Open-File Report 94-700, 31 pp.

Recent GIS and Web Grants and Contracts

Real-time access to Harn map, Certified Corner Registrations, and GPS base station readings for field surveyors; funding: Oklahoma Land Surveyors Association.

Easy download of Oklahoma 1:24,000 digital data: Soils, DOQs, DEMs, DRGs, and DLGs, funding: Oklahoma Conservation Commission.

Oklahoma Digital Water Atlas, Web-based archive, documentation, and access to water data and GIS maps; 2000; funding: Arican Water Resources Assoc., Oklahoma Section.

OWQMC Web site and data clearinghouse development and maintenance, 1999- open date; funding: Oklahoma Water Quality Monitoring Council.

Don't Duck Metadata, 1999-2000, public workshops across state; funding:FGDC/USGS.

GIS and metadata training American Indian Tribes in Oklahoma, funding:FGDC/USGS.

Locating and documenting water-related, geospatial data in Oklahoma; funding: USGS. OSU Environmental Institute, Oklahoma EPSCoR, and Oklahoma Conservation Commission.

Sustained Undergraduate/Mentor Research Collaboration: Applying GIS to Hydrology and Water Resources, 1999-2001; with Geography; funding: NSF.

Land use maps & statistics for Lake Arcadia Watershed, 1998; funding: Ok Water Res. Board.

Water Quality Standards GIS for Oklahoma, 1997-1998; funding: Ok. Water Res. Board & EPA.

Building the water rights GIS database for Oklahoma, 1997-1998; USGS.

Multiple GIS coverages: Blaine aquifer characteristics in southwestern Oklahoma, 1997; OWRB.

Stephen J. Stadler
Professor, Geography Department
Oklahoma State University
Stillwater, OK 74078-4073
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E-mail: rroh69@okstate.edu

Education
Ph.D. Physical Geography, 1979, Indiana State University
M.A. Geography, 1976, Miami University
B.S.Ed. Social Studies Education (cum laude), 1973, Miami University

Professional Experience
Professor, Geography Department, Oklahoma State University, 1993-present
Steering Committee, Oklahoma Mesonetwork, 1988-present
Faculty Supervisor, Oklahoma State University Center for Applications of Remote Sensing, 1991-1994.
Associate Professor (1985-1992) and Assistant Professor (1980-1985) Department of Geography, Oklahoma State University.
Temporary Assistant Professor, Department of Geography, Michigan State University, 1979-1980.
University Fellow, Department of Geography and Geology, Indiana State University, 1975-1979
Graduate Assistant, Department of Geography, Miami University, 1973-1975

Research Interests
Applied climatology, landscape/atmosphere interactions, remote sensing

Professional Affiliations
Association of American Geographers
American Meteorological Society
American Society of Photogrammetry
Oklahoma Academy of Science

Honors and Award:
The Honor Society of Phi Kappa Phi
President, Southwest Association of American Geographers
Chair, Geography Section, Oklahoma Academy of Science

Selected Publications
Oliver, J.E. and Stadler, S.J. Applied Climatology . Prentice-Hall (In preparation for 2001).

Czajkowski, K.P., Goward, S.N., Stadler, S.J., and Walz, A. (forthcoming) Thermal Remote Sensing of Near Surface Environmental Variables: Application Over the Oklahoma Mesonet. The Professional Geographer.

Stadler, S.J., “Aridity Indices” In: Encyclopedia of Hydrology and Water Resources, R.W. Herschy and R.W. Fairbridge eds. (Dordrecht, Netherlands: Kluwer Academic Publishers,

1998), pp. 78-82. [Reprinted from The Encyclopedia of Climatology]

Stadler, S.J., F.Brock, J.D. Carlson, G. Cuerus, K. Crawford, J. Duthie, C. Doswell III, M. Eilts, T. Hughes, and H. Johnson. 1997. “Climatic Geography and the Oklahoma Mesonetwork. In Geographic Perspectives on the Texas Region, D. Lyons and P. Hudak eds. (Washington, D.C.: Association of American Geographers), pp. 107-114

Brock, F.V., K.C. Crawford, R.L. Elliott, G.W. Cuperus, S.J. Stadler, H.L. Johnson and M.D. Eilts. 1995. The Oklahoma Mesonet: A Technical Overview. Journal of Atmospheric and Oceanic Technology , Vol 12 no 1, pp. 5-19

Kessler, E. and S.J. Stadler. 1993. Some Warm-Season Singularities in the Precipitation of Central Oklahoma. (Norman: Oklahoma Climatological Survey), 54 pages.

Rabin, R.M., S.J. Stadler, P.J. Wetzel, D.J. Stensrud, and M. Gregory. 1994. Observed Effects of Landscape Variability on Convective Clouds. Bulletin of the American Meteorological Society, Vol. 71, No. 3, cover and pp. 272-280.

Funding History - Grants Since 1990
NASA EOS
NASA EPSCoR
NSF EPSCOR
NSF ILI
NOAA Global Change
Oklahoma State Regents for Higher Education

Funding History - Current:
(through 2000) NASA EPSCoR Quantification of Regional Evapotranspiration[2]
(through 2001) NASA TERRESTRIAL BIOSPHERE DYNAMICS “Terrestrial Environmental Variables Derived from EOS Platform Sensors”[1]

Funding History - Since 1990
NSF EPSCoR Landscape/Atmosphere Interactions[1]
NOAA Global Change[1]
[2]USDOE Atmospheric Radiation Measurement Program Educational Outreach[2]
OKLAHOMA STATE REGENTS FOR HIGHER EDUCATION Telecommunications[2]
NSF ILI Undergraduate simulations laboratory[2]
NSF STI Renovation of research space[2]

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EDUCATION

1994 **Ph.D.** (Geography) the State University of New York at Buffalo.

1992 M. A. (Geography) the State University of New York at Buffalo

1988-1990 Graduate Study in the University of Georgia.

1987 **B. S.** (Geography) the National Taiwan University

EMPLOYMENT

1994-date Assistant Professor of Geography, University of Oklahoma, Norman, OK

1990-1994 Graduate assistant and graduate teaching assistant, Department of Geography, the State University of New York at Buffalo, Buffalo, NY and the National Center for Geographic Information and Analysis.

1989-1990 Graduate teaching assistant, the University of Georgia, Athens, GA.

1987-1988 Research Assistant (Full Time), the National Taiwan University, Taipei, Taiwan.

Refereed Publications (last three years)

Yuan, M. In press. Modeling geographic information to support spatiotemporal queries. In *Life and Motion of Socio-Economic Units* edited by A. U. Frank, J. Raper, and J. P. Cheyland. European Science Foundation (ESF) Series (London: Taylor and Francis).

Yuan, M. In press. Integration of raster and vector data to represent dynamic geographic phenomena based on hierarchical theory. *Proceedings: 9th International Symposium on Spatial Data Handling Spatial Data Handling*, edited by Pip Forer.

Yuan, M., D. Mark, M. Egenhofer, and D. Peuquet, 2000. Extensions to Geographic Representations. To be included in *Research Challenges in Geographic Information Science*. R. McMaster Eds. (New York: John Wiley & Sons).

Mass, D. S. and M. Yuan. 1999. Analyzing Dispersal Dynamics of Golden-cheeked Warblers (*Dendroica chrysoparia*) Using Remote Sensing, Global Positioning System, and Geographic Information System Technologies. *Applied Geographic Studies*. Volume 3 (2): 77-95.

Yuan, M. 1999. Representing Geographic Information to enhance GIS support for complex spatiotemporal queries. *Transactions in GIS*, 3(2):137-160.

Yuan, M. 1998. Representing Spatiotemporal Processes to Support Knowledge Discovery in GIS databases. *Proceedings: 8th International Symposium on Spatial Data Handling Spatial Data Handling*, edited by T. K. Poiker and N. Chrisman, Pp. 431-440.

Yuan, M. and D. R. Perault. 1998. Measuring the Fractal Dimensions of a Temporal Forest Landscape. *Applied Geographic Studies*, 2(2): 131-144.

Yuan, M., 1997. Knowledge acquisition for building wildfire representation in Geographic Information Systems. *The International Journal of Geographic Information Systems, 11(8):723-745.*

RECENT GRANTS AND CONTRACTS (LAST THREE YEARS)

1998-1999 National Geographic Society Education Foundation. *Windows on the World: Using ArcView GIS to Enhance Geography Curricula.* **Co-Investigator** with Julie Parker (Principal Investigator). Total award: $12,710.

1997 NASA/MTPE, Oklahoma Center of Excellence for Applications of Remote Sensing, Co-Investigator: **Co-Investigator** with Dr. Karen Humes (Principal Investigator) with 12 Co-Investigators (equipment grant, Total award $340,000)

1997-2002 Department of Defense, National Imagery and Mapping Agency, *Development of an Intelligent GIS to Support Spatiotemporal Queries, Analysis, and Modeling in Hydrology*. **Principal Investigator**. Co-Investigators: Drs. David Legates, John Canning, and Mark Morrissey. $600,000 for the first 3 years and $400,000 for the last two years.

1997 The Oklahoma Department of Wildlife and Fisheries. *Use of Geographic Information Systems (GIS) to Model the Effects of Reservoir Operations on Fisheries in Hugo Lake, Oklahoma.* **Principal Investigator**, Total award: $4,480.

1996-98 NASA-Experimental Program to Stimulate Competitive Research (EPSCoR). *Research on the Fluxes of Water and Energy at the Land Surface, Element#7: Development of a HydroGIS based on Oklahoma Mesonet*. **Principal Investigator**, Total award: $243,000 for three years.

1996-0 NASA-Sponsored Cooperative University-based Program in Earth System Science Education. *Educational Explorations of the Earth System*. **Co-Investigator** with Drs. John Snow (Principal Investigator), Mark Morrissey, William Beasley, James Kimpel, Susan Postawko, and Linda Wallace, Total award: $ 200,000 for 5 years.

PROFESSIONAL RECOGNITION AND DEVELOPMENT

2000 Invited participant to USGS/LASULGC workshop on Future Science Directions of the U.S. Geological Survey: Opportunities for a Federal-University Partnership in the Natural Sciences. June 5-6, 2000. Washington, D.C.

1998 Invited specialist to NSF Varenius specialist meeting on Cognitive Models of Dynamic Geographic Phenomena and Representations. October 29-31, 1998. Pittsburgh, PA.

1998 Team Member of Extensions to Geographic Representation University Consortium for Geographic Information Science (UCGIS), Team leader: Dr. D. Peuquet.

1997 Coordinator and Delegate, University Consortium for Geographic Information Science (UCGIS) at the University of Oklahoma.

1997 Nominee for Amoco Good Teaching Award.

1997 Invited specialist to NCGIA-I20 workshop on Interoperating GIS, sponsored by NSF and OpenGIS. December 5-6, 1997. Santa Barbara, CA.

1997 Invited instructor to GIS workshop in UNIDATA training workshops, June 22-27. Boulder, Co.

1996 Invited specialist to NCGIA-I21 workshop on *Formalizing Common Sense Geographic Worlds* sponsored by NSF. October 30 - November 3, 1996, San Marcos, TX.

1996 Invited Speaker on *GIS Data Schemata for Spatiotemporal Information* in The Third International Conference in Integrating GIS and Environmental Modeling. Santa Fe, New Mexico. January 21-25, 1996.

1995 **International Young Scholar** in Geographic Information Science. National Science Foundation and European Science Foundation. 1995.

1994 **First Prize of the Student Paper Competition** conducted by GIS Specialty Group of the Association of American Geographers for papers presented at the 1994 annual meeting of the Association. The paper presented was entitled *Knowledge acquisition for building wildfire representation in geographic information systems*.

1989 The Graduate School at the University of Georgia. **University-wide Graduate School Scholarship**.

1986 The National Council of Science, Taiwan. **Natural Science Scholarship**.