United States Environmental Protection Agency
Office of Solid Waste and Emergency Response
Innovations Work Group
Specific Innovation Pilot Final Report (Rev. 0)

GROUNDWATER REMEDIATION POWERED BY A RENEWABLE ENERGY SOURCE

Curt Elmore, Ph.D., P.E.
Ron Gallagher, M.S., P.E.
University of Missouri-Rolla
Geological Engineering

UMR

In collaboration with U.S. Environmental Protection Agency Region 7, U.S. Army Corps of Engineers Kansas City District, and Bergey Wind Systems.

September 2005

UNIVERSITY OF MISSOURI-ROLLA

GEOLOGICAL ENGINEERING
125 McNutt Hall
1870 Miner Circle
Rolla, MO 65409-0420
Phone: 573.341.6784
Fax: 573.341.6935
elmoreac@umr.edu
www.umr.edu/~elmoreac

September 23, 2005

Mr. David Drake, R.G.
Remediation Project Manager
Region VII
901 North 5th Street
Kansas City, KS 66101

Subject: Final Report (Rev. 0), Groundwater Remediation Powered by a Renewable Energy Source, Former Nebraska Ordnance Plant, Mead, Nebraska

Dear Mr. Drake;

We are pleased to transmit three paper copies and two electronic copies of the subject document. We have enjoyed working on the wind turbine project, and we hope that we will have the opportunity to collaborate with you again in the near future.

Please call me at 573-341-6784 with your questions.

Very truly yours;

Signature Not Verified

Curt Elmore

Digitally signed by Curt Elmore
DN: cn=Curt Elmore, o=University of Missouri-Rolla, ou=Geological Engineering, c=US
Date: 2005.09.22 14:01:55 -06'00'

Curt Elmore, Ph.D., P.E.
Assistant Professor

Tables

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Appendixes

A commercially-available wind turbine rated by the manufacturer at 10 kW was installed at a groundwater circulation well called GCW-1 at the former Nebraska Ordnance Plant Superfund site. The wind turbine system was configured to operate in grid inter tie mode which means that the wind turbine supplemented the power supplied by the local utility company. In the event that there was excess electricity generated by the turbine during high wind periods, the excess was transmitted back to the utility grid for other customers to use. Several challenges were identified during the implementation of the technology. One of the major challenges was that the wind turbine performance was significantly below the predicted performance because the vendor-supplied performance curve for the wind turbine was for a newer generation of air foils (or blades) that were not supplied with the subject wind turbine.

Analysis of historical electricity usage at the GCW-1 indicated that there was little correlation between either the quantity of water treated or the mass of contaminant removed and the quantity of electricity consumed. Treating electricity cost as a random variable, there is a 90 percent likelihood that the GCW-1 monthly electric bill would be less than or equal to $250. Assuming a 3 percent interest rate, a 20 year project lifetime, and an initial cost of $8,000 for installing the electric utility grid connection, the present value of the utility electricity costs is more than $52,000. This significantly exceed the approximately $40,000 cost of procuring and installing the wind turbine system. The wind turbine did not produce sufficient energy to power all of the primary electrical components of GCW-1, but the energy production was estimated to be sufficient to power the submersible pump as a part of an off-grid active remediation system.

The environmental value of the system was considerable. The GCW removed 52 kg of trichloroethylene from more than 24 million gallons of groundwater during the study without any net loss of water to the aquifer. The wind turbine generated 13,335 kWh of electricity. If the same quantity of electricity had been generated by the utility industry, it is estimated that 17,882 lb of carbon dioxide would have been released to the atmosphere.

The wind turbine application is transferable to approximately 14 percent of the contiguous U.S. based on wind resource availability. The wind turbine application is transferable to several relatively small scale active remediation technologies including pump and treat, soil vapor extraction, and air sparging systems.

One refereed journal article, three conference presentations, two invited lectures, and twelve general interest or trade articles have been published or presented to date. In addition, the project has provided opportunities for student involvement for two university classes as well as graduate studies. The project has also resulted in the acquisition of almost $60,000 in related and follow-on funding. At a minimum, it is expected that three additional papers will be submitted to refereed journals in the future.

Three important topics have been identified for follow-on study:

- How much energy is consumed at active remediation systems compared to the energy consumption estimated during the remedial design?
- Can renewable energy be used for active remediation off-grid?
- How can the use of renewable energy systems applied to the protection of human health and the environment be used for outreach to under-represented groups in science and engineering studies at the K-12 and higher education levels?

1.1 PURPOSE OF REPORT

The purpose of this report is to satisfy the reporting requirements associated with the subject project. This report has been prepared under the direction of Dr. Curt Elmore, Assistant Professor of Geological Engineering, University of Missouri – Rolla (UMR) for Mr. Dave Drake, U.S. Environmental Protection Agency Region 7, Kansas City, Kansas.

The following is the brief project description:

- Project Name: Groundwater remediation powered by a renewable energy source
- Project Location: Former Nebraska Ordnance Plant (FNOP) Superfund Site, Mead, Nebraska
- Project Period: October 1, 2003 through September 30, 2004 with an extension through September 30, 2005
- Name of EPA Employee & Office Sponsoring Project including mailcode: Mr. Craig W. Smith, Region 7 OSWER Pilot Representative, Superfund Division, and Mr. Dave Drake, Region 7 Federal Facilities and Special Emphasis Branch, Superfund Division
- Cooperative Partners, if any: UMR, Dr. Curt Elmore. Additional collaborators include the U.S. Army Corps of Engineers Kansas City District and Bergey Wind Systems, Inc.
- Recipient of Funds, if Funds Requested: UMR
- Project Topic and Priority Area: The project addressed the energy recovery priority area by using wind power to generate electricity used by a groundwater remediation system

1.2 PROBLEM STATEMENT & PROJECT OVERVIEW

Energy conservation is recognized as an important issue both in terms of preserving fossil fuel resources and in reducing harmful emissions during fossil fuel combustion. Major initiatives have been successful at reducing energy consumption by automobiles, electrical fixtures, building heating and cooling systems, and industrial processes. The U.S. Environmental Protection Agency has implemented ENERGY STAR which is a government-backed program helping businesses and individuals protect the environment through superior energy efficiency. The Conservation and Energy Reserve Acid Rain Program rewards utilities which undertake renewable energy measures, and Title IV of the Clean Air Act provide additional incentives for energy conservation. However, there are few, if any, instances of directly applying renewable energy to power groundwater remediation systems. A proven groundwater remedial innovative technology known as groundwater circulation wells (GCWs) is a good candidate for the use of renewable energy because GCWs are stand-alone systems with relatively small power requirements. Therefore, commercially available domestic wind turbine generators may be appropriate for powering a GCW system. Finally, GCWs conserve the groundwater resource because contaminated water is extracted through one interval of a well, the water is treated, and the treated water is recharged through a separate interval in the same well. Therefore, using a wind turbine will help preserve our clean air resource while restoring and conserving the groundwater resource.

The overall objective of the project is the demonstration of the use of a renewable energy source, specifically wind power, to power a groundwater remediation system. Specific objectives included the characterization of the reduction in the consumption of utility power by comparing the quantity of wind power consumed during the demonstration to historical energy consumption by GCWs systems at the demonstration site. Another specific objective was the characterization of the mass of target contaminant, TCE, removed from the groundwater during the demonstration period.

A 10 kilowatt (kW) wind turbine was procured from Bergey Wind Systems, Inc., and was installed at an existing GCW designated GCW-1 at the FNOP site. A schematic of GCW-1 is shown on **Figure 1-1**. Since the system had been operated using utility power purchased from the Omaha Public Power District (OPPD), the grid inter-tie option was selected for the wind turbine. Grid inter-tie is a system which permits the use of both utility power and wind turbine power. When there are insufficient wind resources to power the GCW, utility power is used. In the even that the wind turbine generates more power than is being consumed by the GCW, the excess power is available for other OPPD users connected to the utility grid.

The project was funded in September 2003, and the installation design for the wind turbine was completed so that construction began in November 2003. The wind turbine went into operation in January 2004. The wind turbine was taken out of service in August 2005 so that new wind turbine equipment could be installed for further research. As of the writing of this report, mid-September 2005, the GCW remains out of service while work related to a reconfiguration of the GCW components is completed. **Appendix 1-1** contains the quarterly reports for the project.

Generally the implementation of the technology was straight-forward. The Bergey Excel S wind turbine system is designed for domestic use, and the connection of the grid inter-tie system requires the installation of a new circuit breaker in the electrical distribution box used for the GCW. Thus the wind turbine acts as an appliance which produces power instead of consuming power. **Appendix 1-2** includes a refereed article (Elmore, et al., 2004) which presents the initial findings for the project.

The following challenges were encountered during the project:

- A direct generation permit was required from OPPD to connect the wind turbine system to the utility grid. The grid inter-tie system must be connected to a utility grid to function, and the direct generation application process is primarily intended for diesel-powered generators intended to supply critical power needs during utility blackout periods. Thus specific assistance from OPPD was required to complete the direct generation permit application because of the different type of power generation.
- OPPD provided metering for both the utility power consumed by the GCW as well as the wind-generated power which was returned to the utility grid during low consumption/high wind generation periods. UMR installed additional power metering equipment, and the readings from the OPPD export meter were erroneous throughout the study. Requests for service from OPPD's metering department did not result in a correction of the faulty metering system. Finally, the OPPD billing department initially charged the project owners for the power which the export meter indicated that the wind turbine was returning to the utility grid. The billing issue was eventually resolved satisfactorily.
- The wind turbine output was approximately 30 percent below that predicted by the vendor's wind turbine production model given the wind data collected at the site. Investigation showed that the vendor's power rating curve was for a newer generation of wind turbine airfoils which are more efficient. An additional anemometer was installed on the wind turbine tower with the intent to collect more wind data to convince the vendor to upgrade the airfoils. That data collection effort is still on-going.
- The wind turbine power center failed and was returned for warranty repair in August 2005. The contractors who operate the FNOP remediation system report that electrical and electronic equipment at the site fail with an unquantified regularity because of issues related to the quality of the utility power available in the rural area. The power center was repaired and returned to the site in September 2005.

3.1 SYSTEM COSTS

Table 3-1 summarizes the costs incurred in procuring and installing the wind turbine system.

3.2 ENERGY COSTS COMPARISON

The OPPD utility bills were provided by the FNOP operators for GCW-1, and those data were analyzed in Elmore, et al. (2004). Exhibits 5 through 9 in **Appendix 2-1** show that there is little correlation between the quantity of water treated by GCW-1 and the quantity of energy consumed by the remediation system.

The Nebraska Energy Office (NEO) maintains an online database of Nebraska's electricity rates (NEO, 2005). The following analysis was performed for the most recent data available in the database. The average rate was $0.0652/kWh with a minimum of $0.0133 and a maximum of $0.0994. **Figure 3-1** shows the cumulative distribution of the database rates.

The NEO database listed the average OPPD electric rate as $0.0546/kWh. According to the **Figure 3-1**, there is an 80 percent probability that another utility company would charge a higher rate in Nebraska. This means that there is a high likelihood that the energy costs discussed below are lower than the costs which would be encountered at other Nebraska sites. If the energy costs were higher, the following economic analysis would be even more favorable for wind turbine.

The data from Elmore et al. (2004) show that the average monthly cost of power when GCW-1 was operating was $150 with a minimum of $32 and a maximum exceeding $350. The energy costs were not well-correlated to the quantity of water treated or the mass of contamination removed. In fact, the energy cost may be treated as a random variable because it cannot be predicted in advance based on the analysis presented in Elmore et al. (2004). The uncertainty about costs caused by this random phenomenon can be accounted for using the **Figure 3-2** histogram analysis of the cost data. This analysis shows that there is a 90 percent likelihood that the monthly electric cost would be less than or equal to $250. Please note that these costs do not include monthly service charges and other fees. The $250 monthly cost is equivalent to an annual cost of $3,000. It is estimated that the cost of installing utility service to the GCW was approximately $8,000. Assuming a 3 percent interest rate, the present value of the installation cost and the annual electric costs is more than $52,000 for a 20 year project life time. This cost exceeds the estimated cost for purchasing and installing a 10 kW off-grid wind turbine system which was estimated as $45,000 by Elmore et al. (2004). **Figure 3-1** shows that there is a 90 percent probability that the average electric rate in Nebraska will be less than or equal to $0.08/kWh. This value is approximately 50 percent higher than the OPPD average rate. Thus, if the FNOP costs are escalated approximately 50 percent to account for electric costs at other localities, the annual cost may be estimated as $4,500. The present value then becomes $75,000 for a 20 year project life. This amount substantially exceeds the **Table 3-1** cost of approximately $40,000 for purchasing and installing the system.

3.3 ENERGY GENERATION

A wind turbine's energy production is a random variable because it cannot be predicted in advance. Wind turbine vendor's use proprietary models which incorporate a mathematical distribution of wind speeds and the power rating for a specific wind turbine model to predict energy production. The total energy output for a wind turbine is found by calculating discrete probabilities of wind speed across a range of values. The Bergey model, called Windcad, uses the Weibull probability density function given as Equation 1 in **Appendix 1-2**. The product of the wind speeds, probabilities, and discrete values from the specific wind turbine power curve are summed to estimate the energy output.

One of the occupants of the FNOP property is the University of Nebraska Agricultural Research and Development Center (ARDC), and there are three weather stations on the site associated with ARDC research. The wind data from these three stations are included in the High Plains Regional Climate Center (HPRCC) online database. Average wind speed data from the ARDC station designated MEADAGROFARM are presented in **Table 3-2**. Those data were used as input to the Bergey Windcad model to generate the power predictions shown on **Table 3-2**. The wind turbine output was significantly lower than the predicted performance, so a NRG No. 40 anemometer and associated Wind Explorer datalogger were installed at a height of approximately 82 ft on the wind turbine tower on March 17, 2005. The anemometer provides more accurate wind speed data at the GCW site compared to the offsite 3 m anemometer data obtained from the HPRCC database. The wind turbine performance remains below the predicted performance. Conversations with the vendor indicated that the power curve used in the Windcad model was developed for the newest generation of Bergey airfoils which were released after the procurement of the subject wind turbine. A power curve for the existing airfoils was not available from Bergey.

Table 3-2 also includes two columns for the measured output of the wind turbine. Initially electronic datalogging was used to measure both the wind turbine output and GCW energy consumption. Exhibit 4 of Elmore et al., (2004) is a schematic drawing for the power consumption data collection. The Campbell Scientific Instruments (CSI) 21X datalogger electronically collected power measurements on a 1 minute interval, and the 20 minute interval was recorded. Sensors used to measure the instantaneous power consumption were Ohio Semitronics, Inc. (OSI) PC-5 transducers. These transducers are very similar to the equipment used by the U.S. Department of Energy (USDOE) National Renewable Energy Laboratory (NREL) for field verification of wind turbine performance. The NREL follows the International Electrotechnical Commission (IEC) Standard IECWT01-IEC for the testing and certification of wind turbines. The strict use of this standard for the subject study was cost prohibitive.

Additional metering using a General Electric watt hour meter Type 1-70-S-2, Cat. No. 720X070001 was performed in order to confirm the wind turbine power generation. **Table 3-2** indicates that there were discrepancies between the two metering methods. A study was performed during Spring 2005 in the UMR Electrical Engineering laboratory to confirm the accuracy of the CSI datalogging system. **Appendix 3-1** presents a summary of that study which concluded that the CSI system was accurate within approximately 5 percent.

3.4 ENERGY CONSUMPTION

Table 3-3 presents the energy consumption measured at GCW-1. The energy consumed by the submersible pump and the air stripper blower were measured using the datalogging equipment. The period of operation of the pump was identical to the period of operation of the air stripper blower recorded by the datalogger. So the discharge pump energy consumption was indirectly measured by multiplying the period of operation for the centrifugal pump by the product of the pump's rating (1 hp) and dividing by an assumed efficiency of 75 percent.

As described in Section 1, the OPPD export metering system did not collect accurate data regarding the quantity of excess energy exported by the wind turbine system to the utility grid. Thus data regarding the quantity of energy exported from the wind turbine to the utility grid were not obtained, nor was it possible to accurately measure the total energy consumption of the GCW system including incidental loads such as heating and ventilation.

The data presented in **Table 3-3** indicate that the wind turbine energy production was not sufficient to operate the primary GCW components without supplemental energy from OPPD. However the data indicate that there is sufficient wind turbine energy to operate the submersible pump intermittently. **Table 3-4** presents the percentage of time that GCW-1 was in operation on a monthly basis. The GCW was originally designed as a pilot system, and as such it did not include an auto restart feature. The contractors who operate the FNOP remediation systems report that electrical and electronic equipment at the site shut down with an unquantified regularity because of issues related to the quality of the utility power available in the rural area. Thus GCW-1 does not automatically restart if there is a system shut down due to an electricity dropout or any other reason.

Table 3-4 also presents the percentage of time that the submersible pump could have been operated using solely energy generated by the wind turbine assuming:

- All of the energy generated by the wind turbine presented in **Table 3-2** in the datalogger column was available for use by the submersible pump
- The submersible pump operated at the same flowrate and efficiency so that the unit energy consumption did not change from that measured during the study

3.5 ENERGY COST IMPLICATIONS

The primary implication of the energy and energy cost data collected during this study is that it suggests that it may economically feasible to operate a GCW intermittently solely using wind-generated electricity assuming:

- The GCW could be constructed so that energy was not required to heat or cool the system. Of primary importance at the study site would be the need to have a self-draining system that would be resistant to freeze damage.
- An energy-passive technology such as zero valent iron could be used to treat the groundwater

Figure 3-3 shows a capital cost recovery analysis based on a 3 percent interest rate. The graph includes several plots for varying net costs associated with using a wind turbine to power a groundwater remediation system. The net cost could be estimated by summing the cost of the wind turbine system, energy-passive treatment system minus a typical treatment system such as an air stripper, and any system modifications such as self-draining systems. The cost of installing utility power to the system would then be subtracted from the sum to arrive at the net cost. The time required to recover the net cost associated with installing the wind turbine system is then a function of the estimated monthly cost for operating an equivalent system using utility power. For example, if the net cost of installing a wind turbine system was $35,000 and the estimated monthly cost of operating an equivalent system using utility power was $250/month, it would take approximately 15 years to recover the wind turbine investment.

3.6 ENVIRONMENTAL VALUE – TCE

The conservation of groundwater at the FNOP site has been of great public interest because the local agricultural activities rely on groundwater for irrigation. Elmore & Graff (2001) documented the process used at the FNOP to identify means of conserving groundwater during the groundwater remediation. Eventually, groundwater circulation wells were selected for focused remediation at the FNOP site to reduce the quantity of groundwater surface discharged during remediation. Elmore & Graff (2002) presented the preliminary performance of GCW-1 as well as a second GCW pilot system at the site. During the wind turbine project documented in this report, GCW-1 continued to remove TCE from the groundwater with no net loss of groundwater to the aquifer. **Table 3-5** presents the quantity of water treated during the current project, the TCE concentration measured at the GCW prior to air stripping which is called the influent TCE concentration, the effluent TCE concentration which is the concentration of TCE in the water after air stripping and immediately prior to recharge to the aquifer, as well as the total mass of TCE removed from the aquifer.

3.7 ENVIRONMENTAL VALUE – AIR EMISSIONS

One of the motivating factors for using wind turbines to power groundwater remediation systems is that the power plant emissions are reduced. In recent years, greenhouse gasses, especially carbon dioxide, have been of interest when discussing power plant emissions. USDOE/USEPA (2000) cites the 1999 national average output rate as 1.341 lb of CO_2 per kWh generated. **Table 3-6** uses that value to estimate the equivalent carbon dioxide mass mitigated through the use of the wind turbine at the FNOP.

4.1 GEOGRAPHIC

The U.S. Department of Energy categorizes wind resources using wind power classes ranging from Class 1 to Class 7. Areas designated as Class 3 or higher are suitable for power generation using wind turbine technology. **Appendix 1-2** contains additional discussion of wind power classes.

There is a great potential for the development of wind energy in the U.S. In 1993, the USDOE estimated that a group of 12 states in the midsection of the country had enough wind energy potential to produce nearly four times the amount of energy consumed by the nation in 1990. More than 14 percent of the land area in the contiguous U.S. is rated as Wind Power Class 3 or higher. The knowledge gained from the Nebraska Class 3 area could be readily applied to groundwater remediation projects across the country. **Figure 3-4** shows the areas of the country where the Wind Power Class is 3 or greater. Remediation sites in located in the **Figure 3-4** areas are general candidates for wind turbine applications. For rural sites where the cost of installing a utility power connection is in excess of $5,000, a wind turbine application may be especially economically attractive. There may be other benefits to installing wind turbines at sites where utility connections are cost competitive including, but not limited to:

- Public interest in using renewable energy resources
- K-12 outreach

4.2 REMEDIATION TECHNOLOGY

Gill & Mahutova (2004) cited Presidential Executive Order 13123, "Greening the Government through Efficient Energy Management" as motivation for considering energy conservation and production at waste clean up projects. This reference demonstrates the use of motor horsepower ratings to estimate power consumption of groundwater cleanup system. However, Elmore et al. (2004) provided a case study analysis which showed that the volume of water treated at GCW-1 was relatively insensitive to the quantity of energy purchased and that the use of motor ratings to predict energy consumption was unreliable. For example, monthly data indicated that the quantity of groundwater treated could range from 0 to 2,000,000 gallons for approximately the same quantity of energy (roughly 5,000 kWh). The sources of the variability included the percentage of time that the system operated and the efficiency of the power-consuming devices associated with the system, and treatment building heating and ventilation. The monthly averages for energy costs ranged from approximately $0.05 to $0.35 per 1,000 gallons of water treated. Total monthly energy costs ranged from $32 to $350. Therefore, one of the major lessons learned from this project is that there is significant room for improving the energy efficiency of the groundwater cleanup system. The use of renewable energy, which may have a more limited availability relative to the virtually continuous supply of utility power in the U.S., provides strong motivation for developing more inherently energy efficient remediation systems. This concept of energy efficiency could readily be transferred to virtually any treatment technology system regardless of the electrical power source.

In terms of transferring the wind turbine application to remediation systems other than GCWs using air stripping, candidate systems would include virtually any treatment technology that required approximately the same energy requirements as a small domestic residence and/or which could be effectively operated intermittently. For example, a pump and treat system which operated intermittently would be good candidate for a wind turbine application if the treatment component did not require relatively large energy requirements. Granular activated carbon would be a good candidate treatment technology to couple with a wind turbine system. Another candidate remediation system might be a soil vapor extraction/air sparging system applied to a relatively shallow aquifer system and operated intermittently.

5.1 CURRENT OPPORTUNITIES

The project has provided several opportunities to publish and otherwise communicate information to the regulatory community, the technical community, and the general public.

5.1.1 Refereed Publications

The project has provided the opportunity to publish the following paper:

- Elmore, A.C., R. Gallagher, & K.D. Drake. 2004. Using wind to power a groundwater circulation well – preliminary results. Remediation. 14(4), 49-65.

5.1.2 Conference Participation

The project has provided the following opportunities to present project-related material via poster or podium presentation:

- Elmore, A.C., J. W. Cable, R.A. Dilly, R.E. Gallagher, R. Seabaugh. 2005. Ground water remediation powered with renewable energy. U.S. Environmental Protection Agency, People, Prosperity, Plant (P3) student design competition. Washington, D.C. May 16 & 17.
- Elmore, A.C. & K. D. Drake. 2005. Using wind energy to power groundwater remediation. U.S. Environmental Protection Agency National Association of Remedial Project Managers 15th Annual Training Conference, Phoenix, Arizona. May 23 – 27.
- Drake, K.D & A.C. Elmore. 2004. Groundwater remediation powered by renewable energy. Abstract 36 (5) 245-6. Geological Society of America Annual Meeting, Denver, Colorado. November 7-10.

5.1.3 Invited Lectures

The project has provided the opportunity for the following invited lectures:

- Elmore, A.C. 2004. Groundwater remediation powered by a renewable energy source-preliminary results. U.S. Environmental Protection Agency Region 7 Seminar. March 12.
- Elmore, A.C. 2004. Groundwater remediation powered by a renewable energy source-preliminary results. URS Group, Inc., Overland Park, Kansas Brown Bag Seminar. March 12.

5.1.4 Grant Proposals

The project has provided the opportunity to pursue grant funding for follow-on or otherwise related research. Dr. Elmore is the principal investigator for the grant proposals listed in this section unless otherwise noted.

<u>Funded proposals</u>

- U.S. Army Corps of Engineers, Kansas City District. Evaluation of off-grid wind energy to power GCW submersible pump. $24,511. June 2005.
- Missouri Research Board. Using wind energy to power groundwater remediation. $24,600. December 2004.
- U.S. EPA. P3 Award: A National Student Design Competition for Sustainability Focusing on People, Prosperity, and the Planet. $10,000. September, 2004.

Proposals not funded

- South Carolina Energy Office/U.S. Department of Energy. Wind powered water supply. $30,673. Submitted May 6, 2005.
- Nebraska Energy Office/U.S. Department of Energy. Using wind-generated energy to remediate contaminated groundwater. $54,081. Submitted April 27, 2005.
- National Science Foundation CAREER. $400,752. Transfer of sustainable groundwater remediation to international water supply applications. Submitted July 21, 2004.
- Shaw Environment & Infrastructure. R3: Renewable energy, recycled material, and remediation of groundwater. $102,155. Submitted April 11, 2005.
- USEPA R3: Renewable energy, recycled material, and remediation of groundwater. $74,130. Submitted April 11, 2005

5.1.5 Student Involvement

The Fall Semester 2003 UMR Geological Engineering Senior (Capstone) Design class performed the design of the wind turbine installation at the FNOP, and the class included a field trip to the FNOP site.

The Fall Semester 2004 UMR International Engineering & Design class developed a wind turbine-based remedial design which was presented at the USEPA People, Prosperity, and Planet (P3) design competition in Washington, D.C. in May 2004.

The project and follow-on grants have provided the opportunity for a UMR Geological Engineering graduate student to develop a Ph.D. program.

In addition to university students, the project has provided outreach opportunities for high school students participating in summer camps at UMR including students participating in the UMR Women's Leadership Institute Summer Solutions program.

Attempts to provide outreach to K-12 students in towns near the FNOP were unsuccessful.

5.1.6 Other Publications/Communications

The project has provided the following opportunities for publication in trade or general interest publications/seminars:

- Elmore, A.C. 2004. Groundwater remediation powered by a renewable energy source-preliminary results. U.S. Environmental Protection Agency Region 7 Seminar. March 12.

- Elmore, A.C. 2004. Groundwater remediation powered by a renewable energy source-preliminary results. URS Group, Inc., Overland Park, Kansas Brown Bag Seminar. March 12.
- Elmore, A.C. (contributor). 2004. Wind turbine powers groundwater-circulation well. Technology News and Trends. U.S. Environmental Protection Agency Technology Innovation Program. September.
- Elmore, A.C. (contributor). 2004. Plugging into the wind. Environmental Protection. January. 12.
- Elmore, A.C. (contributor). 2004. Contamination is gone with the wind. Wahoo (Nebraska) Newspaper. January 15, 2004.
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- Elmore, A.C. (contributor). 2003. UMR researcher and students to use wind power to clean up groundwater at munitions site. UMR Missouri Miner. October 30.
- Elmore, A.C. (contributor). 2003. Students to use wind power to clean up groundwater at munitions site. Science Daily Online (http://www.sciencedaily.com/releases/2003/10/031028061125.htm), October 28.
- Elmore, A.C. (contributor). 2003. Wind power to clean up munitions site water. washingtontimes.com (http://washingtontimes.com/upi-breaking/20031027-052019-5504r.htm), October 28.
- Elmore, A.C. (contributor). 2003. UMR researcher and students to use wind power to clean up groundwater at munitions site. UMR Research News. October 23.

5.2 POTENTIAL FUTURE OPPORTUNITIES

5.2.1 Refereed Publications

It is expected that three manuscripts will be developed as a part as the previously mentioned graduate research associated with this project. The following is a preliminary list of the anticipated titles and target journals. Given the nature of Ph.D. research, this list is subject to change:

- Predicting small scale wind turbine performance using data readily available to the environmental practitioner – Journal of Renewable Energy

- Comparison of continuous and intermittent GCW operation using a wind turbine – American Society of Civil Engineering Practice Periodical for HTRW Management
- Decision tree analysis of GCW alternatives with wind turbine applications – Ground Water Monitoring & Remediation

It is anticipated that these manuscripts will be submitted during the first nine months of 2006.

5.2.2 Conference Participation

The following poster presentation has accepted for the Partners in Environmental Technology Technical Symposium and Workshop sponsored by SERDP/ESTCP to be held in Washington, D.C. in December 2005:

- Practical Applications of Renewable Energy to Remediation

It is also expected that a presentation will be proposed for a special session at the 2006 Annual Meeting of the American Association of Petroleum Geologists to be held in Houston, Texas in April 2006.

Additional conference opportunities will be identified in the future.

6.1 ENERGY AUDIT

One of the unexpected results of the study was the identification of the power cost as a random variable. A limited literature review did not find any work which has systematically identified energy use at remediation sites. **An important question that remains to be answered is: "How much energy is consumed at active remediation systems compared to the energy consumption estimated during the remedial design?"**

Date to be collected:

- Historical records of energy consumed at active remediation sites throughout USEPA Region 7
- Corresponding data for the quantity of water treated, the estimated energy required based on the horsepower ratings of the equipment and the period of operation, and the mass of contaminant removed

6.2 OFF GRID ACTIVE REMEDIATION

In January 2005, the University of Missouri Research Board funded the procurement of the equipment necessary to convert the wind turbine system from grid inter-tie to off grid operation using wet cell batteries for energy storage. In July 2005, the U.S. Army Corps of Engineers, Kansas City District (CENWK) provided additional funding to UMR to demonstrate that renewable energy can be used to sustain active groundwater remediation at the FNOP. The CENWK project is currently on-going, and work has been initiated to convert the operation of the GCW-1 submersible pump from operation using utility power to intermittent operation using power generated by the wind turbine. While the CENWK project will provide important data concerning an incremental application of wind turbine technology, the current project will still require the use of utility power for the treatment of the groundwater using the existing air stripper.

One of the important questions that remains to be answered is "Can renewable energy be used for active remediation off-grid?" Additional pilot study could answer this important question by providing for a low energy treatment component to replace the more energy intensive air stripper currently in use.

Zero valent iron (ZVI) has been used extensively to treat contaminated groundwater. USEPA (1998) listed 22 organic compounds and 16 inorganic compounds that have been treated, and research activities have continued to identify more treatable compounds. The design of a ZVI system is based on the contact, or residence, time between the contaminants and the iron. Envirometal Technologies, Inc. (ETI) is the license holder for ZVI systems applied to groundwater cleanup, and ETI maintains an extensive performance database of more than 100 ZVI applications world-wide. ETI provided **Table 6-1** which gives TCE treatment versus residence time where cDCE and VC are intermediate degradation products associated with the abiotic reductive dechlorination process. **Table 3-5** shows that the air stripper that is currently being used at GCW-1 does not reduce TCE concentrations to the groundwater drinking water standard of 5 ug/L. In addition, the GCW creates a circulation cell in the subsurface so that a portion of the water is extracted from the aquifer and treated more than one time. The purpose of the system is to remove contaminant mass, and the Nebraska and Federal EPAs allow the recharge of treated water in excess of the standard because the net water quality at the point of recharge is improved due to the mass of contaminant that is removed. The regulation of this system, like the regulation of bioremediation and other in-situ technologies, varies from state to state, but it is allowed under Federal regulation. Most state regulators acknowledge and accept the utility of such in-situ systems.

The removal efficiency is not dependent on the influent concentration, so **Table 6-1** can be used for other influent concentrations. For example, if the original TCE concentration is 500 ug/L, approximately 80 percent of that concentration will be treated in 10 hours resulting in a final concentration of 89 ug/L TCE.

Given that granular ZVI has a porosity of 50 percent, or that the water capacity of a tank is reduced by one-half when the tank is filled with ZVI, a 600 gallon tank filled with ZVI would have a water capacity of 300 gal. Given that water is pumped through the tank at a rate of 0.5 gallons per minute (gpm), the residence time of the tank would be 10 hours. Thus the design treatment efficiency of such a system is 80 percent according to **Table 6-1**. The ZVI-filled tank could be installed at GCW-1 to replace the treatment currently provided by the air stripper. The wind turbine would provide the energy for the pumps, and utility power would not be needed to operate GCW-1.

This system has the potential to be much more energy efficient relative to the current air stripper-based system which includes an additional 5 hp air blower motor. The potential exists to construct a ZVI-based system in the future that includes a submersible pump in the well which operates at high efficiency and which requires no environmental controls for heating and/or ventilation. Finally, Moon et al. (2005) have recently published research which indicates that the residence time required for TCE treatment may be reduced significantly by applying direct current to the ZVI. This suggests that there may be the potential to reduce the residence time thereby increasing the flowrate which could be treated by applying a direct current to the proposed treatment vessel.

The following data will be collected:

- Wind velocity using the existing NRG No. 40 anemometer and associated Wind Explorer datalogger. These data will be used for two purposes: 1) to characterize the wind resource available at the site through comparison with data from three nearby weather stations operated by the High Plains Regional Climate Center; and 2) to characterize the actual energy generation performance of the wind turbine relative to the estimate predicted by the manufacturer's performance model
- Energy data using the existing Campbell Scientific Datalogger CR-1000 which is powered using a solar cell. These data will be used for the following purposes: 1) Measuring the energy generated by the wind turbine; 2) Measuring the energy used by the submersible pump in the well; 3) Measuring the energy consumed by the 0.5 gpm transfer pump.
- Groundwater flow data using the existing solar-powered datalogger. These data will be used for the following purposes: 1) Estimating the quantity of water treated and the mass of contaminant removed from the aquifer; 2) Estimating the capture zone created by the intermittent pumping of the aquifer. The pulsed operation of the GCW using renewable power is of particular interest to engineers and scientists involved with aquifer cleanup.

Lui et al. (2000) presented a study for optimizing contaminant mass by operating an extraction pump in an intermittent manner instead of continuous pumping. Musa & Kemblowski (1996) provided a procedure for estimating the area of aquifer which contributes water when a well is pumped intermittently. The datalogger and associated flow meter will provide a time record of the well operation which will be used to address the data objectives described above.

Groundwater concentration data using Quick Test® Water Analysis for Volatile Organic Halides which is a field method described by Elmore et al. (2002). These data will be used to estimate the mass of TCE removed from the aquifer by calculating the TCE concentration differences between samples collected before the ZVI treatment vessel and samples collected after the treatment vessel. The groundwater samples will be collected on a weekly basis while the system is operating, and duplicate samples will be collected monthly. The duplicate samples will be transmitted to an offsite laboratory for analysis using EPA Standard Method 8260 (GC/MS for VOCs).

6.3 OUTREACH

One of today's important societal issues is **how can members of under-represented groups be recruited for careers with an emphasis in science and/or engineering?** Research at the University of Michigan has shown that some under-represented groups, including women, are attracted to fields of study which are person-oriented. That is, disciplines where it is perceived that the practitioners care about people such as the medical field. There are relatively high percentages of under-represented groups in fields such as environmental science because of the focus on protecting human health and the environment.

The wind turbine project provides an important technical knowledge base which can be applied to K-12 outreach targeting under-represented groups in science and engineering. The outreach can be divided into two categories. The first category includes in service outreach which would involve collaboration between the university researchers and K-12 math and science teachers during the regular school year. Specific collaborations could include preparation for local K-12 science fairs and/or assistance with extra-curricular regional math and science competitions. The second category would include the development of a summer program for students in grades 9-12.

The following data will be collected:

- The ratio of students from under-represented groups who participate in the programs compared to existing programs for traditional engineering and science disciplines
- The effectiveness of extra-curricular programs conducted during the school year for recruiting under-represented students compared to the summer programs
- A yield study to identify the percentage of students who participated in either the extra-curricular or the summer programs who ultimately select a science and/or engineering field of study at a university

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U.S. Environmental Protection Agency (USEPA). 1998. Permeable reactive barrier technologies for contaminant remediation. EPA/600/4-98/125. September.

Table 3-1
Wind Turbine One Time Costs

Item	**Cost**	**Procurement date**	**Notes**
Bergey Excel S wind turbine system with 100 ft guyed lattice tower	$30,510	Dec-03	The procurement included on site installation support by experienced Bergey personnel and cost sharing by Bergey.
Installation subcontract	$5,882	Dec-03	
Miscellaneous installation supplies	$1,447	Dec-03	This line item consisted primarily of electrical supplies.
Datalogging sensors	$552	Dec-05	Ohio Semitronics provided cost sharing for the datalogger sensors, and an existing datalogger was initially used at no cost to the project.
TOTAL	**$38,391**		
Approximately $7,000 in UMR funding was used to purchase a new datalogging system in Spring 2005. Additional costs were incurred for travel and graduate student stipends.			

Table 3-2
Wind Turbine Power Generation

Month	HPRCC Average Wind Speed @ 3 m (m/s)	GCW-1 Average Wind Speed @ 82 ft (m/s)	WindCad Predication (kWh)	Wind Turbine Output 1 (kWh)	Wind Turbine Output 2 (kWh)
Jan 2004 (10 days)	3.83	Not available (N/A)	366	N/A	400
Feb 2004	4.00	N/A	1,218	N/A	771
Mar 2004	4.65	N/A	1,675	N/A	1,148
Apr 2004	4.37	N/A	1,482	N/A	934
May 2004	4.67	N/A	1,688	N/A	1,023
Jun 2004	3.13	N/A	630	402	423
Jul 2004	2.20	N/A	183	219	288
Aug 2004	2.49	N/A	295	317	373
Sep 2004	3.03	N/A	570	516	737
Oct 2004	3.53	N/A	888	674	743
Nov 2004	3.40	N/A	801	617	613
Dec 2004	3.67	N/A	985	627	798
Jan 2005	3.62	N/A	950	565	605
Feb 2005	3.08	N/A	600	412	483
Mar 2005	4.01	6.27	1,661	793	921
Apr 2005	4.29	6.10	1,575	935	975
May 2005	3.99	5.83	1,435	896	934
Jun 2005	3.73	5.29	1,151	526	670
Jul 2005	3.06	4.68	838	478	496
Totals			**18,991**		**13,335**

Notes:
1. Output measured using General Electric Watthour Meter Type 1-70-S-2, Cat. No. 720X070001.
2. Output Measured using CSI datalogging system described in text.
The HPRCC station designated "MEADAGROFARM" was used for the average wind speeds.
N/A indicates that the data were not available because the instrument had not been installed.
The Windcad model which was posted on the Bergey website on the afternoon of February 8, 2005 was used for the calculations with the following parameters through March 2005:
The HPRCC data were used for the average wind speed until the anemometer was installed at on the wind turbine tower at GCW-1.
Weibull K=2
Site altitude=356 m
Wind shear exp=0.143
Anem. Height=3 m
Tower Height=30.48 m
Turbulence factor=10.0%
Beginning in March 2005, the anemometer height was changed to 82 ft.

Table 3-3
Comparison of Energy Production and Energy Consumption

Month	Submersible Pump (kWh)	Air Stripper (kWh)	Discharge Pump (kWh)	Total System Consumption (kWh)	Wind Turbine Generation (kWh)
Jan 2004 (10 days)	279	370	172	821	400
Feb 2004	823	1,116	461	2,400	771
Mar 2004	813	1,159	457	2,429	1,148
Apr 2004	917	1,302	511	2,730	934
May 2004	1,001	1,415	564	2,980	1,023
Jun 2004	290	423	166	879	423
Jul 2004	964	1,388	543	2,895	288
Aug 2004	1,154	1,660	650	3,464	373
Sep 2004	1,091	1,567	636	3,294	737
Oct 2004	1,043	1,505	607	3,155	743
Nov 2004	1,107	1,619	622	3,348	613
Dec 2004	604	879	342	1,825	798
Jan 2005	1,198	1,752	678	3,628	605
Feb 2005	1,026	1,485	581	3,092	483
Mar 2005	1,202	1,722	679	3,603	921
Apr 2005	1,160	1,667	657	3,484	975
May 2005	1,057	1,516	629	3,202	934
Jun 2005	684	978	415	2,077	670
Jul 2005	913	1,319	550	2,782	496
Totals	**17,326**	**24,842**	**9,920**	**52,088**	**13,335**

Table 3-4
GCW-1 Operational Time

Month	Percent of operating time for month	Estimated kWh for continuous submersible pump operation	Submersible pump operation potential (percent)
Jan 2004 (10 days)	68	411	97
Feb 2004	69	1,193	65
Mar 2004	64	1,271	90
Apr 2004	74	1,239	75
May 2004	79	1,267	81
Jun 2004	24	1,209	35
Jul 2004	76	1,269	23
Aug 2004	91	1,268	29
Sep 2004	89	1,225	60
Oct 2004	85	1,226	61
Nov 2004	90	1,230	50
Dec 2004	48	1,258	63
Jan 2005	95	1,261	48
Feb 2005	90	1,140	42
Mar 2005	95	1,265	73
Apr 2005	95	1,221	80
May 2005	88	1,201	78
Jun 2005	60	1,140	59
Jul 2005	77	1,186	42
Average	**77**	**1,183**	**61**

Table 3-5
TCE Removal

Month	Volume of water treated (1,000 gal)	TCE influent concentration (ug/L)	TCE effluent concentration (ug/L)
Jan 2004 (10 days)	202	N/A	N/A
Feb 2004	1,133	950	113
Mar 2004	N/A	195	52
Apr 2004	905	1,050	73
May 2004	1,739	910	58
Jun 2004	325	N/A	N/A
Jul 2004	N/A	N/A	N/A
Aug 2004	2,427	510	24
Sep 2004	1,410	920	44
Oct 2004	1,221	730	18
Nov 2004	1,655	650	131
Dec 2004	824	680	18
Jan 2005	1,845	1,120	30
Feb 2005	1,315	520	48
Mar 2005	1,289	620	40
Apr 2005	1,488	910	38
May 2005	1,825	370	30
Jun 2005	815	460	30
Jul 2005	1,508	N/A	N/A

N/A indicates that the data were not available. This typically occurred when the system was not in operation when the researchers were on their monthly site visit.

Month	Volume of water treated (1,000 gal)	TCE influent concentration (ug/L)	TCE effluent concentration (ug/L)	Treatment efficiency (percent)	Mass of TCE removed (kg)
Jan 2004 (10 days)	202	**648**	**42**	94	0.40
Feb 2004	1,133	950	113	88	3.13
Mar 2004	**1,290**	195	52	73	0.61
Apr 2004	905	1,050	73	93	2.92
May 2004	1,739	910	58	94	4.89
Jun 2004	325	**648**	**42**	94	0.65
Jul 2004	**1,290**	**648**	**42**	94	2.58
Aug 2004	2,427	510	24	95	3.89
Sep 2004	1,410	920	44	95	4.08
Oct 2004	1,221	730	18	98	2.87
Nov 2004	1,655	650	131	80	2.84
Dec 2004	824	680	18	97	1.80
Jan 2005	1,845	1,120	30	97	6.64
Feb 2005	1,215	520	48	91	1.89
Mar 2005	1,289	620	40	94	2.47
Apr 2005	1,488	910	38	96	4.28
May 2005	1,825	370	30	92	2.05
Jun 2005	815	460	30	93	1.16
Jul 2005	1,508	**648**	**42**	94	3.02
	24,406	648	42	91	52.16

The March and July 2004 volumes were estimated as the average of the other monthly volumes. In a similar manner, the geometric mean was used to estimate missing concentrations.

Table 3-6
Equivalent Carbon Dioxide Mass Saved

Month	Energy generated by wind turbine (kWh)	Equivalent CO_2 mass (lb)
Jan 2004 (xx days)	400	536
Feb 2004	771	1,034
Mar 2004	1,148	1,539
Apr 2004	934	1,252
May 2004	1,023	1,372
Jun 2004	423	567
Jul 2004	288	386
Aug 2004	373	500
Sep 2004	737	988
Oct 2004	743	996
Nov 2004	613	822
Dec 2004	798	1,070
Jan 2005	605	811
Feb 2005	483	648
Mar 2005	921	1,235
Apr 2005	975	1,307
May 2005	934	1,252
Jun 2005	670	898
Jul 2005	496	665
Totals	**13,335**	**17,882**

Table 6-1
ZVI Residence Times

Residence Time (hr)	Effluent Concentration (ug/L)			Percent Removal
	TCE	**cDCE**	**VC**	
0	1000.0	0.0	0.0	0.0
2	707.1	7.8	0.1	28.1
4	500.0	11.9	0.2	48.2
6	353.6	13.7	0.4	62.6
8	250.0	14.0	0.6	72.9
10	176.8	13.4	0.7	80.3
12	125.0	12.4	0.8	85.6
14	88.4	11.1	0.8	89.5
16	62.5	9.8	0.8	92.3

Figure 1-1 GCW Elements (Elmore & Graff, 2002)

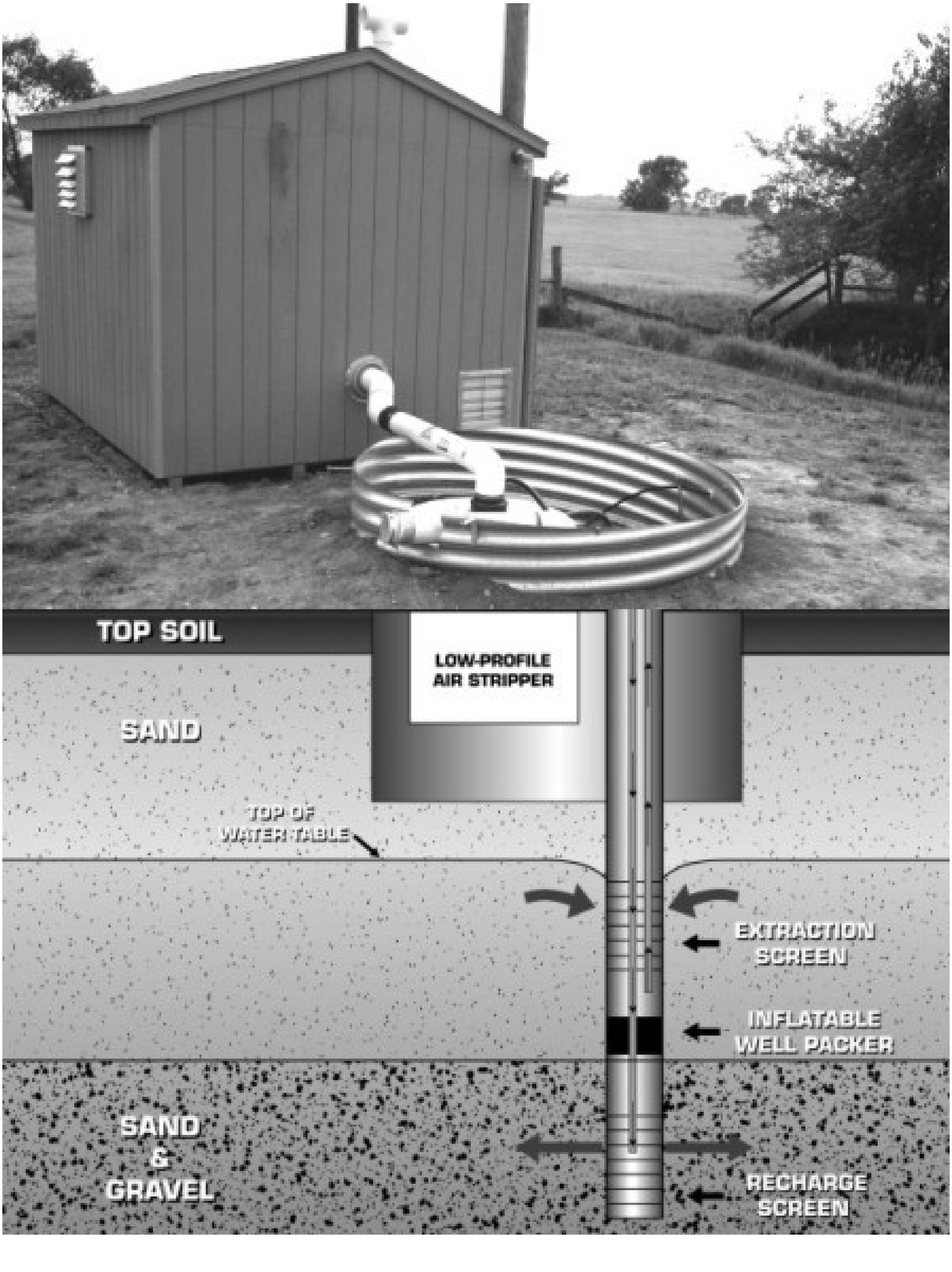


Figure 3-1. Cumulative Distribution of Nebraska Electricity Rates

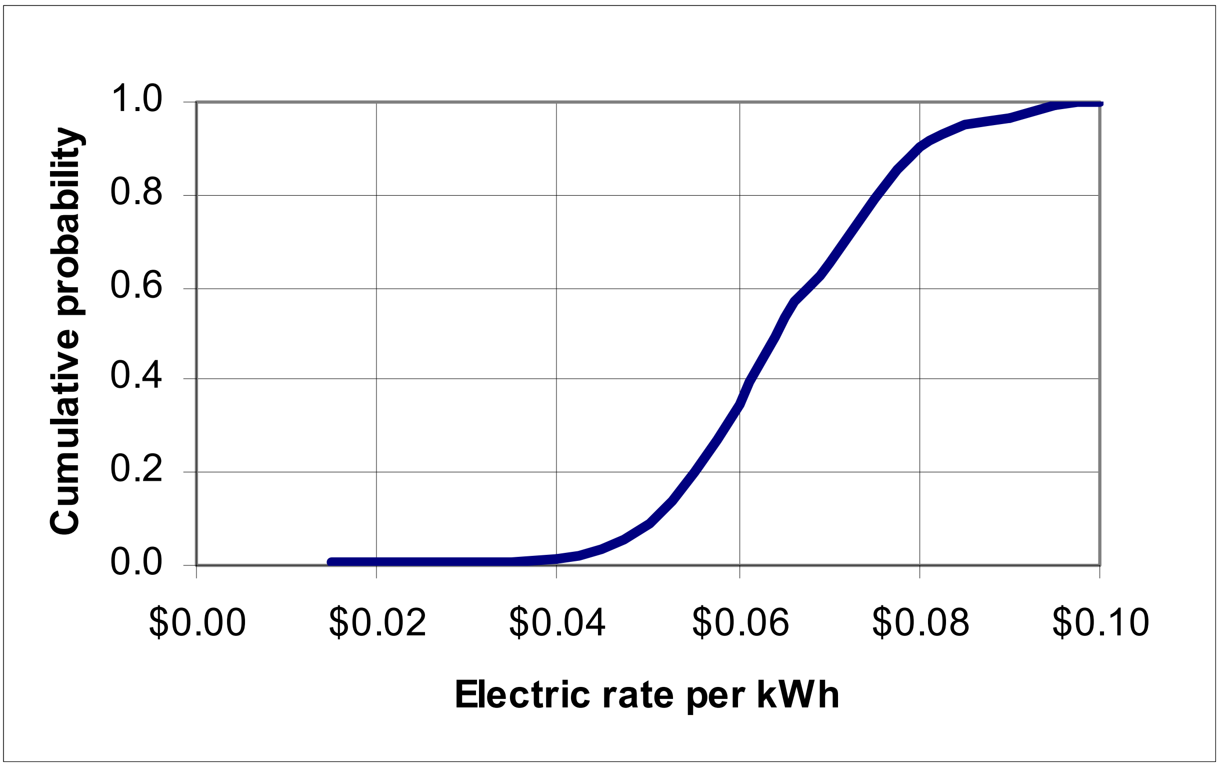


Figure 3-2. Cumulative Distribution of GCW-1 Energy Costs

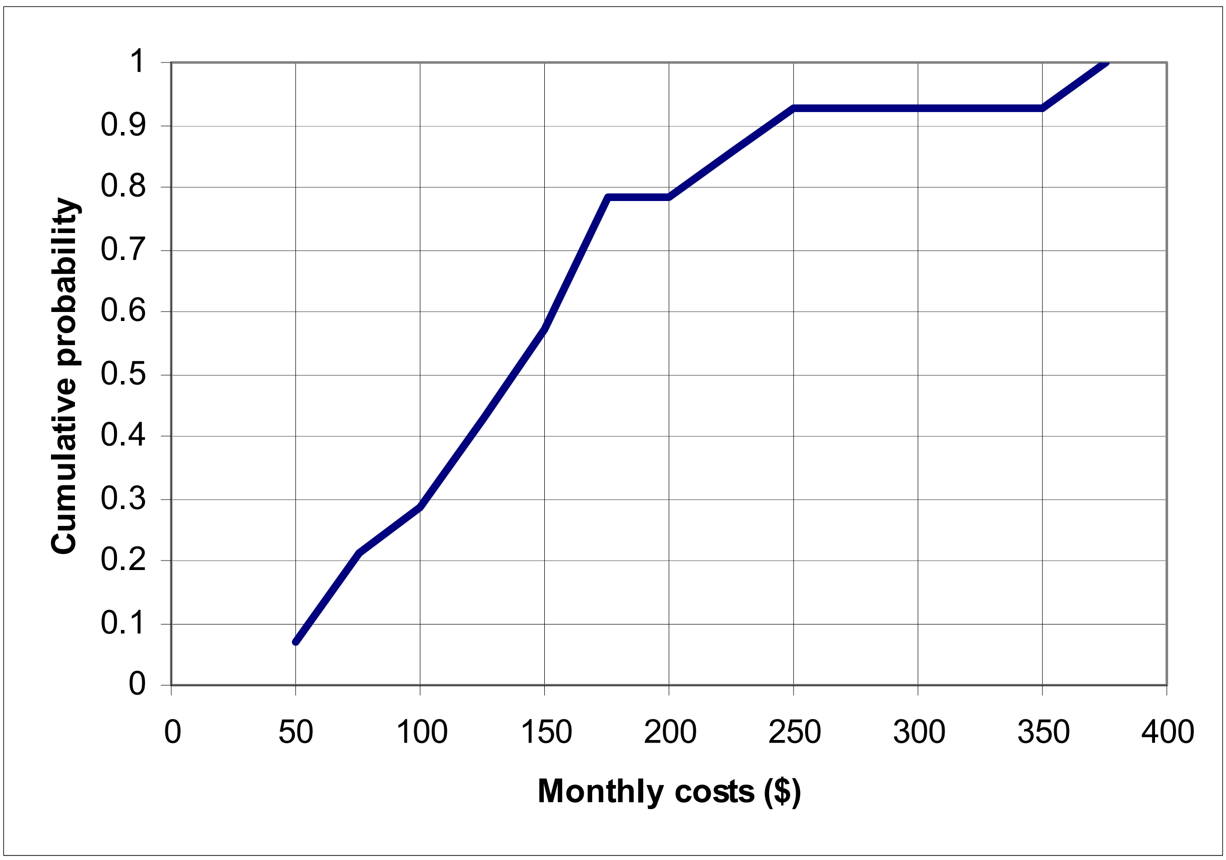


Figure 3-3. Capital Recovery Analysis

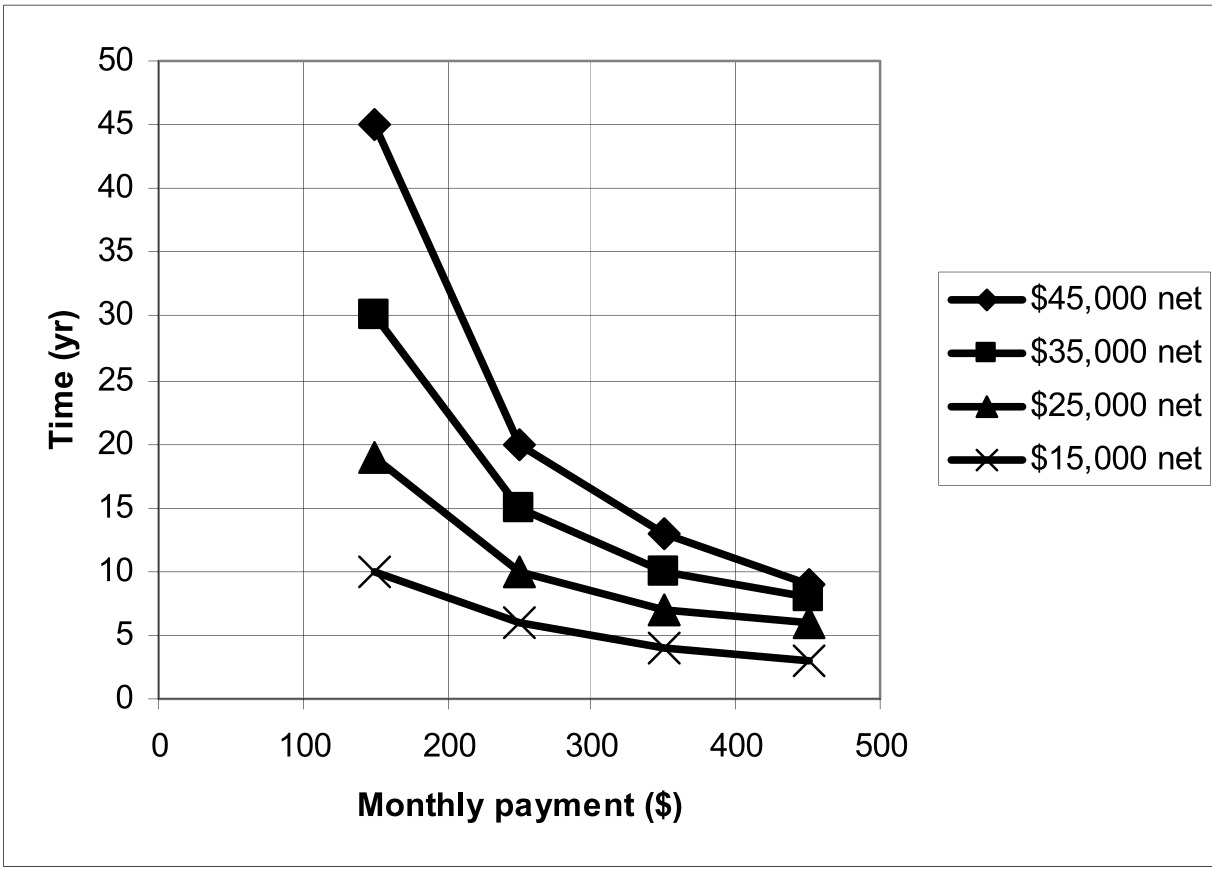
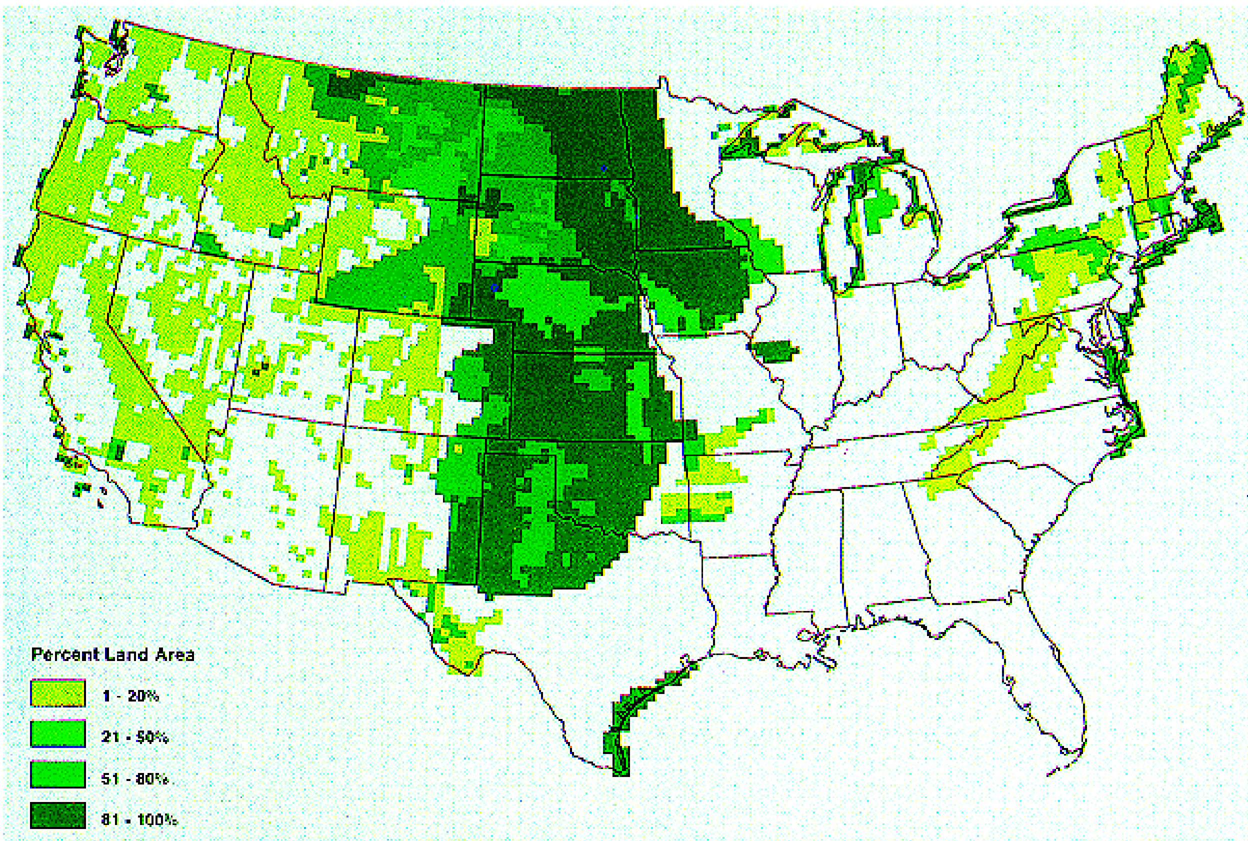


Figure 3-4. U.S. Wind Energy Potential (Elliot et al. 1986)



Appendix 1-1
Quarterly Reports

UMR
UNIVERSITY OF MISSOURI-ROLLA

GEOLOGICAL ENGINEERING
129 McNutt Hall
1870 Miner Circle
Rolla, MO 65409-0420
Phone: 573.341.6784
Fax: 573.341.6935
elmoreac@umr.edu
www.umr.edu/~elmoreac

March 7, 3004

Mr. David Drake, R.G.
Remediation Project Manager
Region VII
901 North 5th Street
Kansas City, KS 66101

Subject: Quarterly Report No. 1, Groundwater Remediation Powered by a Renewable Energy Source, Former Nebraska Ordnance Plant, Mead, Nebraska

Dear Mr. Drake;

The following is a summary of the activities associated with the subject project for the period from the beginning of the project through December 31, 2003:

- July 14, 2003: Request for grant proposal received from Mr. Craig Smith, Region 7 EPA received
- July 23, 2003: Abbreviated work plan submitted
- September 29, 2003: Preliminary Wind Power Demonstration Project Submittal
- ca October 1, 2003: Notice to proceed received
- October 10, 2003: Comments by Mr. Dave Drake, Region 7 EPA, on Preliminary Wind Power Demonstration Project Submittal received
- October 28, 2003: Responses to Comments on Preliminary Wind Power Demonstration Project Submittal transmitted
- November 11, 2003: Draft Work Plan, Groundwater Remediation Powered by a Renewable Energy Source, Former Nebraska Ordnance Plant, Mead, Nebraska transmitted
- November 19 -21 and December 8 -10, 2003: Wind turbine system construction; system not put into operation

Please call me at 573-341-6784 with your questions.

Very truly yours;

Curt Elmore, Ph.D., P.E.
Assistant Professor

UMR
UNIVERSITY OF MISSOURI-ROLLA

GEOLOGICAL ENGINEERING
129 McNutt Hall
1870 Miner Circle
Rolla, MO 65409-0420
Phone: 573.341.6784
Fax: 573.341.6935
elmoreac@umr.edu
www.umr.edu/~elmoreac

April 8, 2004

Mr. David Drake, R.G.
Remediation Project Manager
Region VII
901 North 5th Street
Kansas City, KS 66101

Subject: Quarterly Report No. 2, Groundwater Remediation Powered by a Renewable Energy Source, Former Nebraska Ordnance Plant, Mead, Nebraska

Dear Mr. Drake;

The following is a summary of the activities associated with the subject project for the period from January 1, 2004 through March 31, 2003:

- January 7, 2004: Wind turbine operation begins
- January 20 -22, 2004: Watt transducers and datalogger installed
- February 10, 2004: Datalogger downloaded, and chemical samples collected and analyzed
- February 19, 2004: Comments by Mr. Dave Drake, Region 7 EPA, on Draft Work Plan, Groundwater Remediation Powered by a Renewable Energy Source, Former Nebraska Ordnance Plant, Mead, Nebraska received
- February 27, 2004: Dr. Curt Elmore made the presentation "Groundwater remediation powered by a renewable energy source-preliminary results" at the University of Missouri-Columbia Geotechnical and Geoenvironmental Engineering graduate seminar
- March 7, 2004: Quarterly Report No. 1, Groundwater Remediation Powered by a Renewable Energy Source, Former Nebraska Ordnance Plant, Mead, Nebraska transmitted
- March 10, 2004: Datalogger downloaded, and chemical samples collected and analyzed
- March 12, 2004: Draft Final Work Plan, Groundwater Remediation Powered by a Renewable Energy Source, Former Nebraska Ordnance Plant, Mead, Nebraska transmitted; the transmittal included responses to comments on the draft work plan
- March 12, 2004: Dr. Curt Elmore made the presentation "Groundwater remediation powered by a renewable energy source-preliminary results" at the URS, Inc. offices in Overland Park, Kansas and the Region 7 headquarters in Kansas City, Kansas

GEOLOGICAL ENGINEERING
129 McNutt Hall
1870 Miner Circle
Rolla, MO 65409-0420
Phone: 573.341.6784
Fax: 573.341.6935
elmoreac@umr.edu
www.umr.edu/~elmoreac

Please call me at 573-341-6784 with your questions.

Very truly yours;

Curt Elmore, Ph.D., P.E.
Assistant Professor

UNIVERSITY OF MISSOURI-ROLLA

GEOLOGICAL ENGINEERING
129 McNutt Hall
1870 Miner Circle
Rolla, MO 65409-0420
Phone: 573.341.6784
Fax: 573.341.6935
elmoreac@umr.edu
www.umr.edu/~elmoreac

July 12, 2004

Mr. David Drake, R.G.
Remediation Project Manager
Region VII
901 North 5th Street
Kansas City, KS 66101

Subject: Quarterly Report No. 3, Groundwater Remediation Powered by a Renewable Energy Source, Former Nebraska Ordnance Plant, Mead, Nebraska

Dear Mr. Drake;

The following is a summary of the activities associated with the subject project for the period from April 1, 2004 through June 30, 2003:

- April 8, 2004: Quarterly Report No. 2, Groundwater Remediation Powered by a Renewable Energy Source, Former Nebraska Ordnance Plant, Mead, Nebraska transmitted
- April 9, 2004: Datalogger downloaded, and chemical samples collected and analyzed
- May 16, 2004: Datalogger downloaded, and chemical samples collected and analyzed. Installation of supplemental electric meter initiated.
- May 18, 2004: Installation of supplemental electric meter completed.
- May 31, 2004: Datalogger downloaded.
- June 2, 2004: TCE concentrations measured at GCW-1
- June 18, 2004: Datalogger downloaded. Chemical samples not collected because the GCW system was not operating.

Please call me at 573-341-6784 with your questions.

Very truly yours;

Curt Elmore, Ph.D., P.E.
Assistant Professor

UNIVERSITY OF MISSOURI-ROLLA

GEOLOGICAL ENGINEERING
125 McNutt Hall
1870 Miner Circle
Rolla, MO 65409-0420
Phone: 573.341.6784
Fax: 573.341.6935
elmoreac@umr.edu
www.umr.edu/~elmoreac

October 11, 2004

Mr. David Drake, R.G.
Remediation Project Manager
Region VII
901 North 5th Street
Kansas City, KS 66101

Subject: Quarterly Report No. 4, Groundwater Remediation Powered by a Renewable Energy Source, Former Nebraska Ordnance Plant, Mead, Nebraska

Dear Mr. Drake;

The following is a summary of the activities associated with the subject project for the period from July 12, 2004 through September 30, 2004:

- July 12, 2004: Quarterly Report No. 3, Groundwater Remediation Powered by a Renewable Energy Source, Former Nebraska Ordnance Plant, Mead, Nebraska transmitted
- August 11, 2004: Datalogger downloaded, and chemical samples collected and analyzed, participated in system restart training with ECC operators
- September 10, 2004: Datalogger downloaded, and chemical samples collected and analyzed.

The following publications were released during the reporting time period:

Elmore, A.C., R. Gallagher, & K.D. Drake. 2004. Using wind to power a groundwater circulation well – preliminary results. Remediation. 14(4), 49-65.

Elmore, A.C. (contributor). 2004. Wind turbine powers groundwater-circulation well. Technology News and Trends. U.S. Environmental Protection Agency Technology Innovation Program. September.

The following grant related to the wind turbine project was received:

Principal Investigator. U.S. EPA. P3 Award: A National Student Design Competition for Sustainability Focusing on People, Prosperity, and the Planet. $10,000. September, 2004.

The following proposal related to the wind turbine project was submitted:

Principal Investigator. Missouri Research Board. $25,600. Using wind energy to power groundwater remediation. Submitted September 24, 2004.

Please call me at 573-341-6784 with your questions.

Very truly yours;

Curt Elmore, Ph.D., P.E.
Assistant Professor

UMR
UNIVERSITY OF MISSOURI-ROLLA

GEOLOGICAL ENGINEERING
125 McNutt Hall
1870 Miner Circle
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Fax: 573.341.6935
elmoreac@umr.edu
www.umr.edu/~elmoreac

January 24, 2005

Mr. David Drake, R.G.
Remediation Project Manager
Region VII
901 North 5th Street
Kansas City, KS 66101

Subject: Quarterly Report No. 5, Groundwater Remediation Powered by a Renewable Energy Source, Former Nebraska Ordnance Plant, Mead, Nebraska

Dear Mr. Drake;

The following is a summary of the activities associated with the subject project for the period from October 1, 2004 through December 31, 2004:

- October 9, 2004: Chemical samples collected and analyzed; however, a computer problem prevented data downloading
- October 12, 2004: Quarterly Report No. 4, Groundwater Remediation Powered by a Renewable Energy Source, Former Nebraska Ordnance Plant, Mead, Nebraska transmitted
- October 23, 2004: Datalogger downloaded, and chemical samples collected and analyzed
- November 8, 2004: Participated in a site visit with team members from the former Blaine Naval Ammunition Depot Superfund Project
- November 13, 2004: Datalogger downloaded, and chemical samples collected and analyzed
- December 16, 2004: Datalogger downloaded, and chemical samples collected and analyzed
- January 18, 2005: Participated in project briefing at the Kansas City District Corps of Engineers
- January 22, 2005: Datalogger downloaded, and chemical samples collected and analyzed

Please call me at 573-341-6784 with your questions.

Very truly yours;

Curt Elmore, Ph.D., P.E.

UNIVERSITY OF MISSOURI-ROLLA

GEOLOGICAL ENGINEERING
125 McNutt Hall
1870 Miner Circle
Rolla, MO 65409-0420
Phone: 573.341.6784
Fax: 573.341.6935
elmoreac@umr.edu
www.umr.edu/~elmoreac

Assistant Professor

UNIVERSITY OF MISSOURI-ROLLA

GEOLOGICAL ENGINEERING
125 McNutt Hall
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Rolla, MO 65409-0420
Phone: 573.341.6784
Fax: 573.341.6935
elmoreac@umr.edu
www.umr.edu/~elmoreac

March 21, 2005

Mr. David Drake, R.G.
Remediation Project Manager
Region VII
901 North 5th Street
Kansas City, KS 66101

Subject: Quarterly Report No. 6, Groundwater Remediation Powered by a Renewable Energy Source, Former Nebraska Ordnance Plant, Mead, Nebraska

Dear Mr. Drake;

The following is a summary of the activities associated with the subject project for the period from January 1, 2005 anticipated through March 31, 2005:

- January 24, 2005: Datalogger downloaded, and chemical samples collected and analyzed
- February 8, 2005: Teleconference with Mike Bergey of BWC, Inc. regarding comparison of wind turbine performance and wind turbine performance prediction model
- February 19, 2005: Datalogger downloaded, and chemical samples collected and analyzed
- March 17, 2005: Datalogger downloaded, and chemical samples collected and analyzed. Wind anemometer and associated datalogger installed on the wind turbine tower at a height of 82 ft.
- March 21, 2005: Quarterly Report No. 6 transmitted

Please call me at 573-341-6784 with your questions.

Very truly yours;

Curt Elmore, Ph.D., P.E.
Assistant Professor

UNIVERSITY OF MISSOURI-ROLLA

GEOLOGICAL ENGINEERING
125 McNutt Hall
1870 Miner Circle
Rolla, MO 65409-0420
Phone: 573.341.6784
Fax: 573.341.6935
elmoreac@umr.edu
www.umr.edu/~elmoreac

June 27, 2005

Mr. David Drake, R.G.
Remediation Project Manager
Region VII
901 North 5th Street
Kansas City, KS 66101

Subject: Quarterly Report No. 7, Groundwater Remediation Powered by a Renewable Energy Source, Former Nebraska Ordnance Plant, Mead, Nebraska

Dear Mr. Drake;

The following is a summary of the activities associated with the subject project for the period from April 1, 2005 through June 30, 2005:

- April 16, 2005: Datalogger downloaded, and chemical samples collected and analyzed
- April 21 & 22, 2005: Participated in meetings with Mr. Dave Drake regarding the preparation of the NARPM presentation
- May 26, 2005: Datalogger downloaded, and chemical samples collected and analyzed. Solar panel and surge protection for future datalogger installed.
- May 26, 2005: Presented "Using Wind to Power a Groundwater Circulation Well – Initial Findings" with Mr. Dave Drake at the USEPA National Association of Remedial Project Managers 15th Annual Training Conference, Phoenix, Arizona
- June 25, 2005: Datalogger downloaded, and chemical samples collected and analyzed. New datalogger installed.

Please call me at 573-341-6784 with your questions.

Very truly yours;

Curt Elmore, Ph.D., P.E.
Assistant Professor

Appendix 1-2
Using Wind to Power a Groundwater Circulation Well
Preliminary Results (Elmore et al., 2004

Using Wind To Power a Groundwater Circulation Well—Preliminary Results

Andrew Curtis Elmore

Ron Gallagher

K. David Drake

In areas of the country where the U.S. Department of Energy has classified the available wind resources as Class 3 or greater, the use of wind turbines to provide power to relatively small remediation systems such as groundwater circulation wells may be technically and economically feasible. Groundwater circulation wells are a good candidate technology to couple with renewable energy, because the remediation system removes contamination from the subject aquifer with no net loss of the groundwater resource, while the wind turbine does not create potentially harmful air emissions. Wind data collected in the vicinity of the former Nebraska Ordnance Plant Superfund site were used to select a wind turbine system to provide a portion of the energy necessary to power a groundwater circulation well located in an area of high trichloroethylene groundwater contamination. Because utility power was already installed at the remediation system, a 10 kW grid inter-tie wind turbine system supplements the utility system without requiring batteries for energy storage. The historical data from the site indicate that the quantity of energy purchased correlates poorly with the quantity of groundwater treated. Preliminary data from the wind turbine system indicate that the wind turbine provides more energy than the remediation system treatment components and the well submersible pump require on a monthly average. The preliminary results indicate that the coupling of wind turbines and groundwater circulation wells may be an attractive alternative in terms of the system operation time, cost savings, and contaminant mass removal. © 2004 Wiley Periodicals, Inc.

INTRODUCTION

The general trend in groundwater remediation is to focus on resource-conservative methods, which treat contamination without reducing the quantity of groundwater available for use. Resource conservative technologies include:

- permeable reactive barriers (PRBs), which treat groundwater *in situ*, using zero-valent iron or other treatment media;
- biologically active zone enhancement, which involves the periodic introduction of an electron donor substance or other amendment to stimulate bacterial activity in the subject aquifer;
- phytoremediation, which relies on plant uptake and biotreatment of relatively shallow groundwater;
- monitored natural attenuation, which does not require supplemental treatment;
- some pump-and-treat systems, which involve the reinjection or recharge of treated groundwater to the subject aquifer; and
- other systems that do not significantly modify the preremediation water balance.

Published online in Wiley Interscience (www.interscience.wiley.com). DOI: 10.1002/rem.20021

One of the major challenges associated with the *in situ* PRB and biodegradation technologies is that significant monitoring of intermediate and final degradation products is required to manage any increase in human health-risk levels associated with the generation of toxic daughter products. Another challenge is that the effectiveness of these technologies requires a good understanding of the groundwater flow regime so that the treatment materials may be placed in the appropriate locations. These challenges are often outweighed by the typically low operation and maintenance (O&M) costs of the technologies. For example, a well-designed and constructed PRB may not require any maintenance outside of routine groundwater monitoring for several years after construction. However, accessibility may hamper the implementation of PRBs at some sites. Unlike active systems, such as pump-and-treat, which can be "offset" to accommodate land use and still be effective to some degree, PRBs require relatively precise placement.

The use of pump-and-treat systems with reinjection options may address some of the challenges associated with the *in situ* systems.

The use of pump-and-treat systems with reinjection options may address some of the challenges associated with the *in situ* systems. For example, the treatment component of such a system may be engineered to effectively treat contamination without the generation of any toxic byproducts in the treated water. Furthermore, the design of pump-and-treat systems may be somewhat more robust relative to PRBs and other *in situ* systems, because the contaminated water is actively moved to the extraction well through pumping. However, the operation costs of pump-and-treat systems may be significant due to both costs directly related to treatment and the cost of conveying groundwater from the aquifer to the treatment unit, from the treatment unit to the reinjection location, and back into the aquifer. The Underground Injection Control (UIC) regulations may require that the groundwater undergo treatment for the project contaminants of concern and any other unacceptable chemicals prior to reinjection. Additionally, wells require periodic maintenance and eventual replacement in order to maintain design production levels.

The combination of a groundwater circulation well (GCW) with a renewable energy source may present a combination of benefits that will be attractive at sites where:

- the aquifer will support a GCW system and
- sufficient renewable energy resources are available.

The GCW/wind turbine system may be especially attractive at sites where the cost of installing and/or the purchasing of utility power are high.

A GCW is a quasi-*in situ* treatment technology that uses a single well with hydraulic isolated multiple-screened sections to extract and recharge groundwater. The systems include a component to treat the groundwater prior to recharge. A GCW variant includes the use of pairs of multiple screen wells to set up horizontal circulation wells instead of the vertical circulation cells associated with single GCW systems. Typically, the systems are exempt from UIC regulation, or a UIC waiver may be obtained, because the intent of the system is to improve the groundwater quality at the GCW location. The treatment component may be designed for virtually any contaminant, while PRBs and biodegradation systems may be limited to specific contaminants. For example, Elmore and Graff (2002) describe the application of best-available technology design applied to a GCW located in an area of trichloroethylene (TCE) contamination and a GCW system located in an area of contamination by the explosive compound hexhydro-1,3,5-trinitro-

1,3,5-triazine, known as RDX. Groundwater monitoring and modeling may also be used to characterize the area of the aquifer treated by a GCW as described in Elmore and DeAngelis (2004) and Elmore and Hellman (2001).

The operation and maintenance costs for a GCW should be lower compared to a comparable pump-and-treat system with remote reinjection simply because energy is not required to transfer groundwater from the extraction wells to the treatment facilities to the recharge wells. GCWs still require periodic well rehabilitation, as with any well, and the overall O&M cost of a GCW system should be expected to be higher relative to a well-designed and -constructed PRB system. However, the use of a renewable energy source has the potential to significantly reduce the annual O&M cost of a GCW system while potentially reducing air emissions associated with the generation of fossil fuel–based power. Gipe (1995) summarizes emissions offset associated with the use of renewable energy in the place of fossil fuel energy. That summary gives a range of average emissions for power generation in the United States as 0.07 to 4 g/kWh of nitrogen oxides and 487 to 940 g/kWh for carbon dioxide.

PROJECT BACKGROUND

The former Nebraska Ordnance Plant (NOP) occupied more than 17,000 acres in east-central Nebraska near the village of Mead in Saunders County. The facility produced ordnance from 1942 to 1956 during World War II and the Korean Conflict. The plant was used for munitions storage and ammonium nitrate production. The prevalent explosive compound released into the environment is RDX. In 1959 and 1964, the facility was used to construct and maintain Atlas missiles. TCE was used as a degreaser during the missile construction. Spent TCE was released to the ground and entered the unconfined groundwater aquifer, which is used regionally for water supply. The former NOP site was included on the National Priorities List under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or Superfund) on August 30, 1990. Since then, investigations have identified two RDX groundwater contamination plumes and two TCE plumes (United States Environmental Protection Agency [US EPA], 1990). In April 1997, a pump-and-treat groundwater remedy was selected for the site. Currently, 11 groundwater extraction wells have been constructed along the leading edge of the plumes. The purpose of these wells is to use hydraulic containment to prevent contamination from migrating to uncontaminated areas. The combined design flow from these wells is 2,650 gallons per minute (gpm). The groundwater Record of Decision included focused remediation with the hydraulic containment to balance the objective of decreasing remediation time with the needs of the local community to use groundwater for agricultural irrigation, domestic, and other uses. The community interest in groundwater conservation, as described by Elmore and Graff (2001), led to the pilot-testing of two GCW systems, beginning in May 2000.

The operation and maintenance costs for a GCW should be lower compared to a comparable pump-and-treat system with remote reinjection. . .

One of the pilot GCWs, known as GCW-1, was installed in an area where there were TCE concentrations in the groundwater on the order of 5,000 μg/L or greater and there are no other contaminants present. The former NOP site cleanup goal for TCE is 5 μg/L. The GCW-1 pilot study results are described in Elmore and Graff (2002). GCW-1 was left in service after the completion of the pilot study, and it currently remains in service.

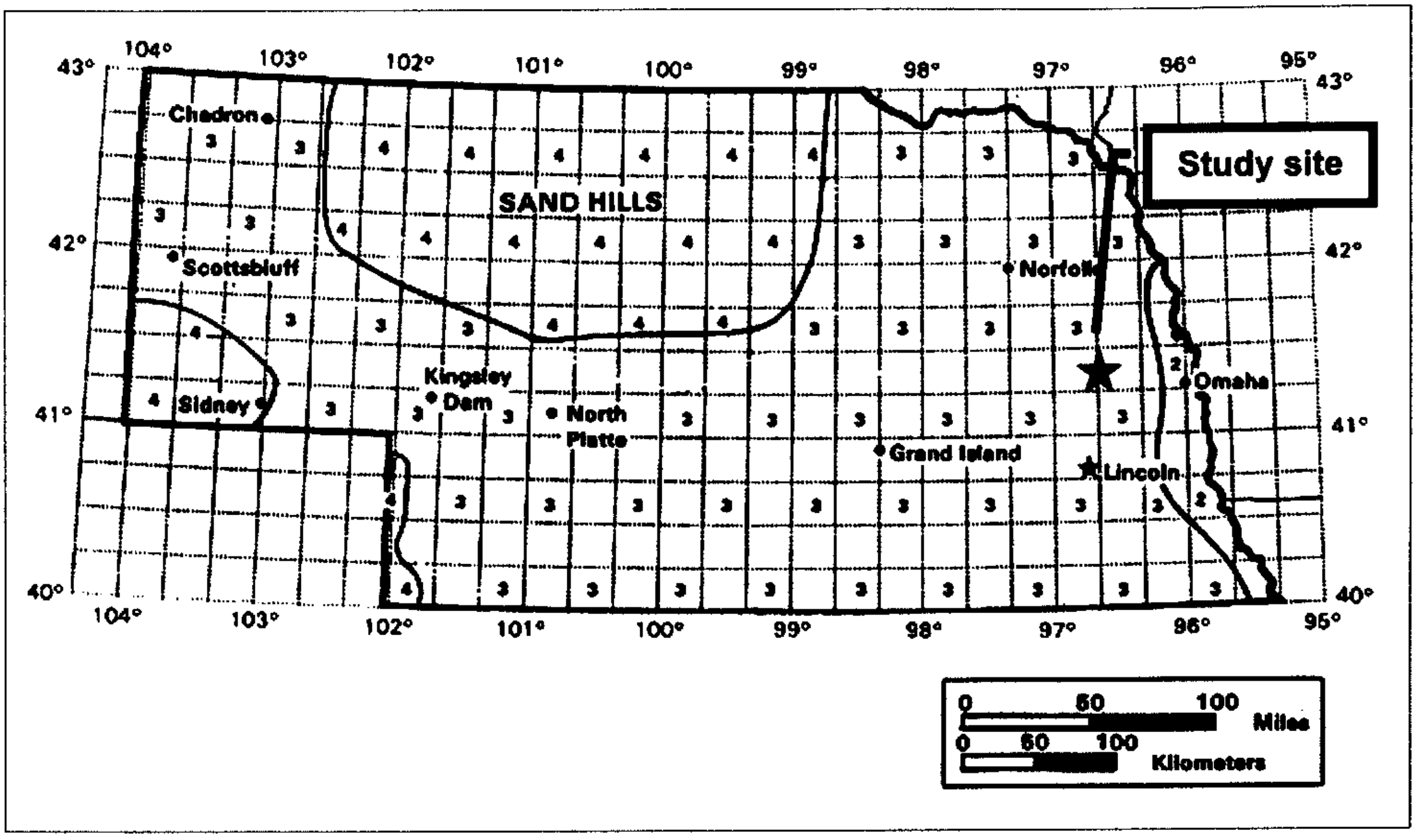

Exhibit 1. Nebraska average annual wind power classes (after Elliott et al., 1986)

SYSTEM DESIGN AND CONSTRUCTION

In 2003, work was initiated to demonstrate the use of wind power using GCW-1 at the former NOP site. Specific project objectives include:

- characterization of the reduction in the consumption of utility power by comparing the quantity of wind power consumed during the demonstration to the historical energy consumption and
- characterization of the mass quantity of TCE removed from groundwater during the demonstration period.

The University of Missouri–Rolla (UMR) Geological Engineering Capstone Design class performed the system design during the fall 2003 semester.

The U.S. Department of Energy (DOE) categorizes wind resources using wind power classes ranging from Class 1 to Class 7 (Elliott et al., 1986). Each class represents a range of mean wind power density (in units of W/m^2) or equivalent mean wind speed at a specified height(s) above ground. Areas designated Class 3 or greater are suitable for most wind turbine applications, whereas Class 2 areas are deemed marginal by Elliott et. al. (1986). The study site location shown in Exhibit 1 was classified as a Class 3 area by Elliott et al. (1986). The Class 3 wind power density range is 150 to 200 W/m^2 at a height of 10 m, and the range of mean wind speeds is 5.1 to

5[illegible]m/s (or 11.5 to 12.5 mph). The Class 3 wind power designation for the study site indicated that the site was an appropriate candidate for a wind turbine installation. In fact, the Lincoln (Nebraska) Electric System operates two 750 kW wind turbines approximately 30 miles from the study site as a part of the utility's Renewable Energy Program.

The GCW system consists of the following primary electrical machinery:

- a 1.5 hp submersible well pump used to extract water from the aquifer to the air stripper;
- a 5 hp blower used to circulate air through the stripper; and
- a 1 hp centrifugal pump used to return treated water from the stripper sump to the well.

Additional equipment includes an electrical control panel and small chemical feed pump to add a buffering agent to the groundwater after treatment. The electrical loads created by this equipment are assumed to be negligible relative to the equipment listed above, which has an aggregate power rating of 7.5 hp or 5.6 kW. In addition to the treatment-related electrical equipment, GCW-1 includes additional equipment for climate control. The original purpose of GCW-1 was to serve as a pilot system to generate data to be used for the design of additional systems at the site. The pilot system included a thermostat-controlled ventilation fan to provide cooling of the building that housed the air stripper blower, the control panel, and the chemical feed system. An electric radiant heater was subsequently added to the vault containing the air stripper and the centrifugal pump, and a second heater was installed in the GCW-1 building.

The GCW was designed to operate continuously, and neglecting the heating and cooling energy demands, the maximum monthly demand for the treatment system was estimated to be the product of 6 kW (7 hp) and 720 hr/month, or approximately 4,000 kWh/month. This estimate does not include any energy costs associated with heating and cooling. During the period of June 2000 through December 2000, a total of 19,032 kWh of electricity were purchased from the local utility resulting in an average monthly consumption of 2,718 kWh/month. Based on the maximum monthly demand estimated for the treatment system calculated above, the seven-month maximum demand was estimated as 30,000 kWh. Assuming that all other electrical demands are negligible, it was estimated that the system operated approximately 60 percent of the time based on the quantity of electricity consumed. During this same period, 12,120,000 gallons of water were treated by the system. Assuming that the system operated at an average flowrate of 50 gpm, the system was in operation approximately 80 percent of the time, based on the quantity of water treated. The GWC-1 flowmeter readings were manually recorded between 48.9 and 50.1 gpm (Elmore & Graff, 2002); thus, the operation time estimate of 80 percent appears to be reliable. The practice of using motor power ratings and utility power consumption records to estimate operation time appears to be less reliable.

The practice of using motor power ratings and utility power consumption records to estimate operation time appears to be less reliable.

The Nebraska Power Association conducted a four-year study to identify potential locations for wind energy development from 1995 to 1999 as described by Global Energy Concepts, Inc. (GEC; 1999). The study consisted of the monitoring of eight stations across Nebraska including a station at Wahoo, Nebraska, that is approximately 11 miles from the former NOP site. Over the four-year monitoring period associated with the GEC (1999) study, the following data were collected using a 40 m anemometer at the Wahoo station:

- average wind speed—6.4 m/s
- wind shear exponent—0.27
- turbulence intensity—0.17 to 0.21

Seasonal data showed that the highest wind speeds occurred during the fall and winter, with the lowest winds in July and August. The diurnal wind pattern indicated that the wind speeds decreased slightly in the early morning and evening hours.

Seasonal data showed that the highest wind speeds occurred during the fall and winter, with the lowest winds in July and August.

Several wind turbine performance models are available on the Internet, including a spreadsheet model at www.bergey.com/Technical/ExcelS.xls. The models use a modified version of the Weibull probability density function to estimate the probability *f* that a given wind speed *x* will occur given the average turbine hub wind speed *u* and *a* Weibull shape factor *K* according to the following equation:

$$f(x) = \frac{0.89 \cdot K}{u} \cdot \left(\frac{0.89 \cdot x}{u}\right)^{k-1} \exp\left[-\left(\frac{0.89x}{u}\right)^{K}\right] \qquad [1]$$

The total energy output for a wind turbine is found by calculating discrete probabilities of wind speed across a range of values, such as 1 to 20 m/s. The product of those probabilities and discrete values from the specific wind turbine power curve are summed to estimate the energy output. The wind shear exponent is used to correct for height differences between the anemometer and the wind turbine. The spreadsheet at the Web site given above was used to estimate the total average annual energy output of a Bergey Windpower Company Excel S 10kW wind turbine using the Wahoo data with the following results:

- 15,600 kWh for a 30.48 m (100 ft) tower
- 18,100 kWh for a 40 m (130 ft) tower

GEC (1999) estimated energy production using the wind speed distribution at the Wahoo monitoring site and the power curve for a 750 kW wind turbine on a 40 m tower as 6,134 MWh per year. Assuming that the power curve is proportional according to the wind turbine ratings, the corresponding annual value for a 10 kW system would be 20,500 kWh, which is about 12 percent more than the value estimated above using the modified Weibull model.

Exhibit 2 summarizes the energy supply-and-demand estimates calculated during the system design. A 10 kW wind turbine would supply approximately 50 percent of the energy needs of the GCW system. Exhibit 2 also provides estimates of the cost savings associated with using the 10 kW wind turbine system. The wind turbine could be operated in two manners:

- Independent of any other power source—In this configuration, the GCW system would only operate using the energy generated by the wind turbine system. This configuration would probably require intermittent operation of the GCW sys-

Estimated Annual Supply from Wind Turbine	Estimate from Modified Weibull Model	Estimate from GEC (1999) Production Estimate
kWh	15,600	20,500
Potential Annual Energy Value ($0.07/kWh)	$1,092	$1,435
Energy Present Value ($0.07/kWh) for 20 years at 5 percent interest	$13,609	$17,883
Estimated Annual Demand	**Estimate from Motor Ratings**	**Estimate from Utility Meter Readings**
kWh	49,000	33,000
Potential Annual Energy Value	$3,430	$2,310
Present Value ($0.07/kWh) for 20 years at 5 percent interest	$42,745	$28,788

Exhibit 2. Estimated annual energy values

tem. The potential present value energy cost savings would be between $29,000 and $43,000 for 20 years at a 5 percent interest rate.

Inter-tied with an existing utility energy supply—This would operate the system when there were insufficient wind resources. The potential present value energy cost savings would be between $14,000 and $18,000 for 20 years at a 5 percent interest rate.

The cost of an independent 10 kW wind turbine system is approximately $45,000, including installation. This cost appears to be very competitive given the power savings estimated above. The wind turbine costs may be more competitive for rural sites where the installation of utility lines to a GCW may range from $5,000 to $10,000.

The cost analysis appears less attractive for the grid inter-tie system, considering the wind turbine system estimated installed cost of $35,000.

The wind turbine project at the former NOP site was originally scoped for an installation independent of utility energy connections at a GCW system designed to be energy-efficient. However, administrative delays in constructing new GCW systems resulted in the installation of a Bergey Windpower Company 10 kW Excel S Gridtek 10 system on a 100-foot guyed lattice tower for connection to GCW-1. The system is a grid inter-tie system, which means that energy is supplied by the local utility company as well as the wind turbine system. In the event that the wind turbine generates more energy than required by the GCW, the excess energy is transmitted back to the utility grid. Typically, the GCW is operated using a combination of utility and wind turbine energy, but the system is operated only by utility power during periods of low wind. In the event that there is an outage of utility power, the wind turbine system is automatically taken off-line as required by utility company regulations. Therefore, the wind turbine is a supplement to the utility system as opposed to being a replacement during blackout conditions.

The wind turbine tower was erected in December 2003, and the system was put into service in January 2004 (Exhibit 3). Exhibit 4 provides details of the electronic monitoring system used to collect power generation and power consumption data. It is important to note that the centrifugal pump, which returns water from the air stripper sump to the recharge screen in the well, is not monitored. It is also assumed that the period of operation of this pump is equal to the period of operation of the submersible pump and the air stripper blower, and that the power demand is equivalent to the motor rating, which is 1 hp.

Water samples are collected before and after the air stripper on a monthly basis to estimate the mass of TCE removed from the groundwater.

. . .electrical demands such as system heating and cooling apparently contribute to significant energy costs.

HISTORICAL PERFORMANCE

Utility billing records were reviewed to develop Exhibit 5, which shows the quantity of energy purchased for the GCW. Operational records provided the treated groundwater data. Exhibit 6 summarizes the monthly energy purchases. Inspection of the data suggests that the quantity of energy purchased is not closely correlated to the quantity of water treated by the system. For example, the second highest quantity of energy was purchased in February 2003 when the treatment system was inoperable. Therefore, electrical demands such as system heating and cooling apparently contribute to significant energy costs. Exhibit 7 shows the energy purchased versus the water treated. The best-fit line through the origin shows a relatively poor correlation between energy purchase and water treated with an R^2 value of 0.29.

Exhibit 8 shows the energy cost for the system. The unit cost for energy ranged from $0.06/kWh to $0.08/kWh, and service charges were not included in the costs shown on the exhibit. Again, there is poor correlation between energy costs and the quantity of groundwater treated.

Exhibit 9 presents the history of the system flowrate and percentage of system operation time. During the first two years, the system operated 65 to 100 percent of the time on a monthly basis. Operational records indicate that a common reason for system shutdown was related to irregular power supply events associated with the energy purchased from the local utility. Other causes of shutdowns included declining well yields, recharge pump failures, system imbalances, and other events. The system operated at approximately 50 gpm for two years before there was an indication that well efficiency was declining. In November 2002, the system was temporarily taken out of service so that the rehabilitation of the well-extraction screen could be evaluated. The system was put back on line in December 2003 after the rehabilitation of both the extraction and recharge screens, but the original yield could not be restored, and the yield began to decline almost immediately.

Exhibit 10 summarizes the estimated mass of TCE removed by the GCW system. Inspection of the graph shows that there is a wide range of removal rates from less than 2 mg/kWh to almost 16 mg/kWh. This wide range of removal rates is the result of varying influent concentrations entering the GCW and the widely variable energy consumption rates.

The overall conclusion drawn from the historical data is that there is little correlation between the quantity of energy purchased and the mass of contaminant removed from the aquifer. Furthermore, the GCW was designed to operate continuously, and the data indicate that the system typically operates between 65 and 100 percent of the time.

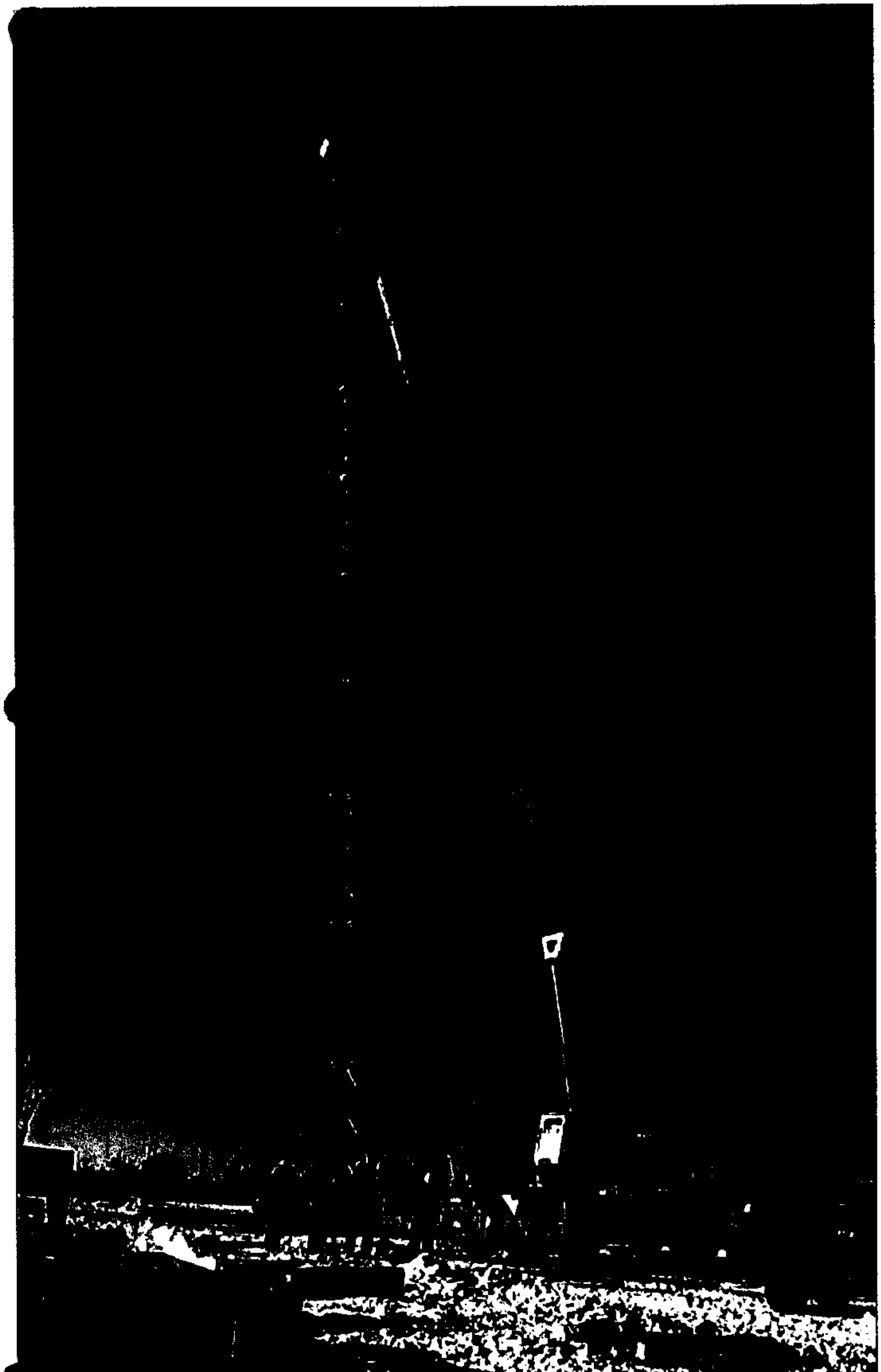

Exhibit 3. Erection of the wind turbine in December 2003

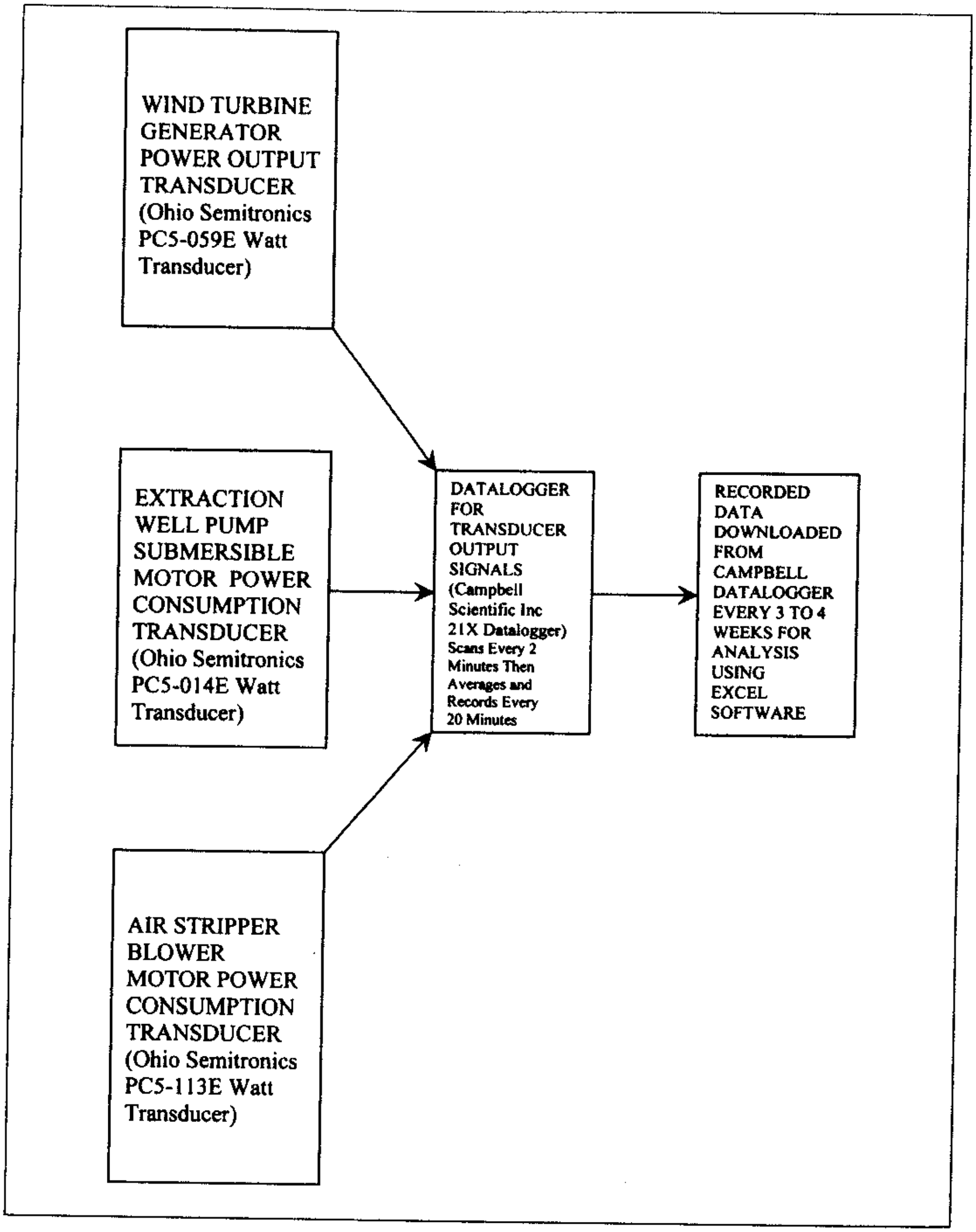

Exhibit 4. Power generation and consumption monitoring schematic

WIND TURBINE PERFORMANCE

Data regarding power generation by the wind turbine system and power consumption by the GCW treatment components have been collected continuously since January 21, 2004. Exhibit 11 shows the energy generated and energy consumed in March 2004. The energy curves for the other months are relatively similar. Exhibit 12 summarizes the energy data as well as the contaminant mass removal data for the time period beginning with the initiation of wind turbine service.

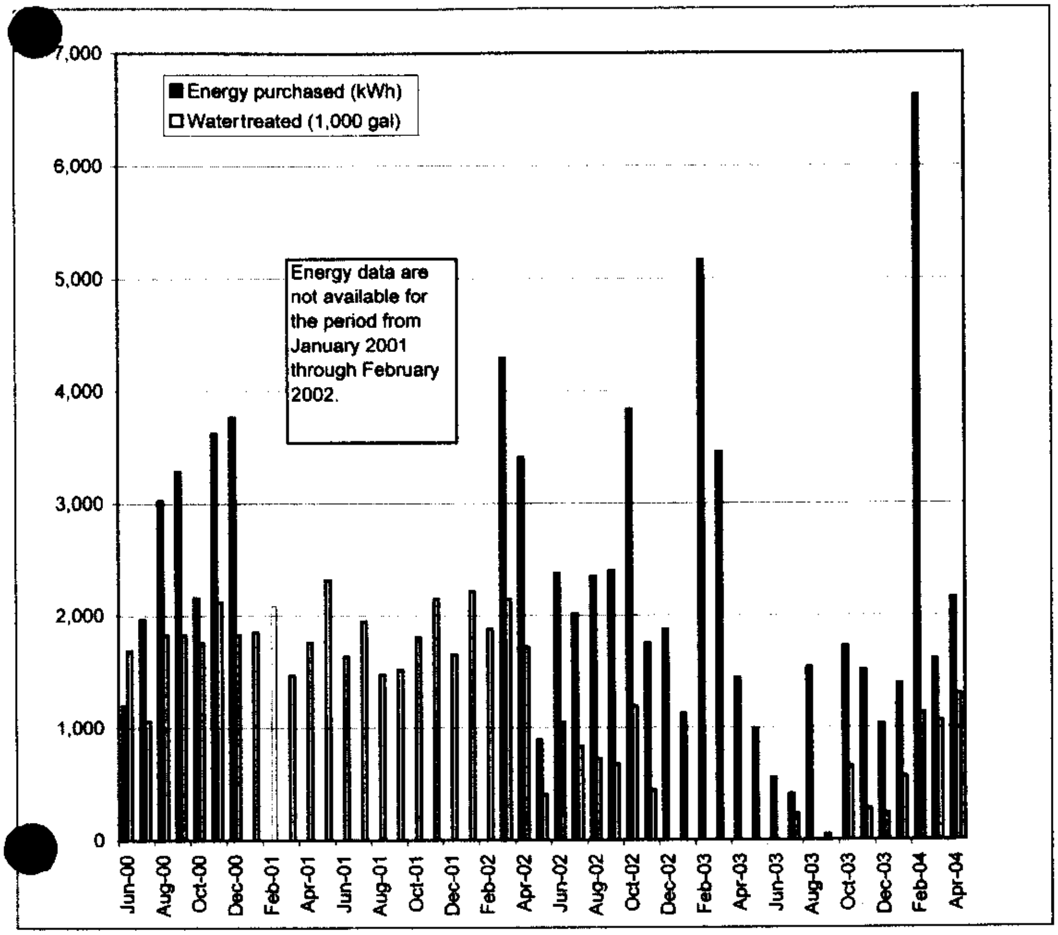

Exhibit 5. Historic purchase of energy and volume of water treated

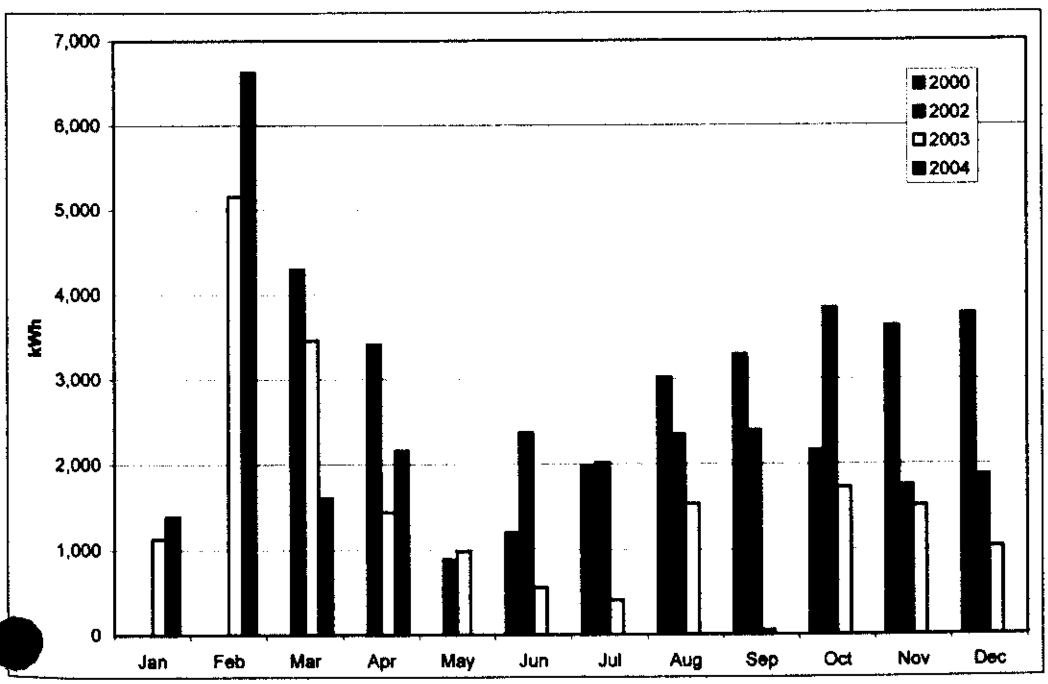

Exhibit 6. Monthly summary of purchased energy

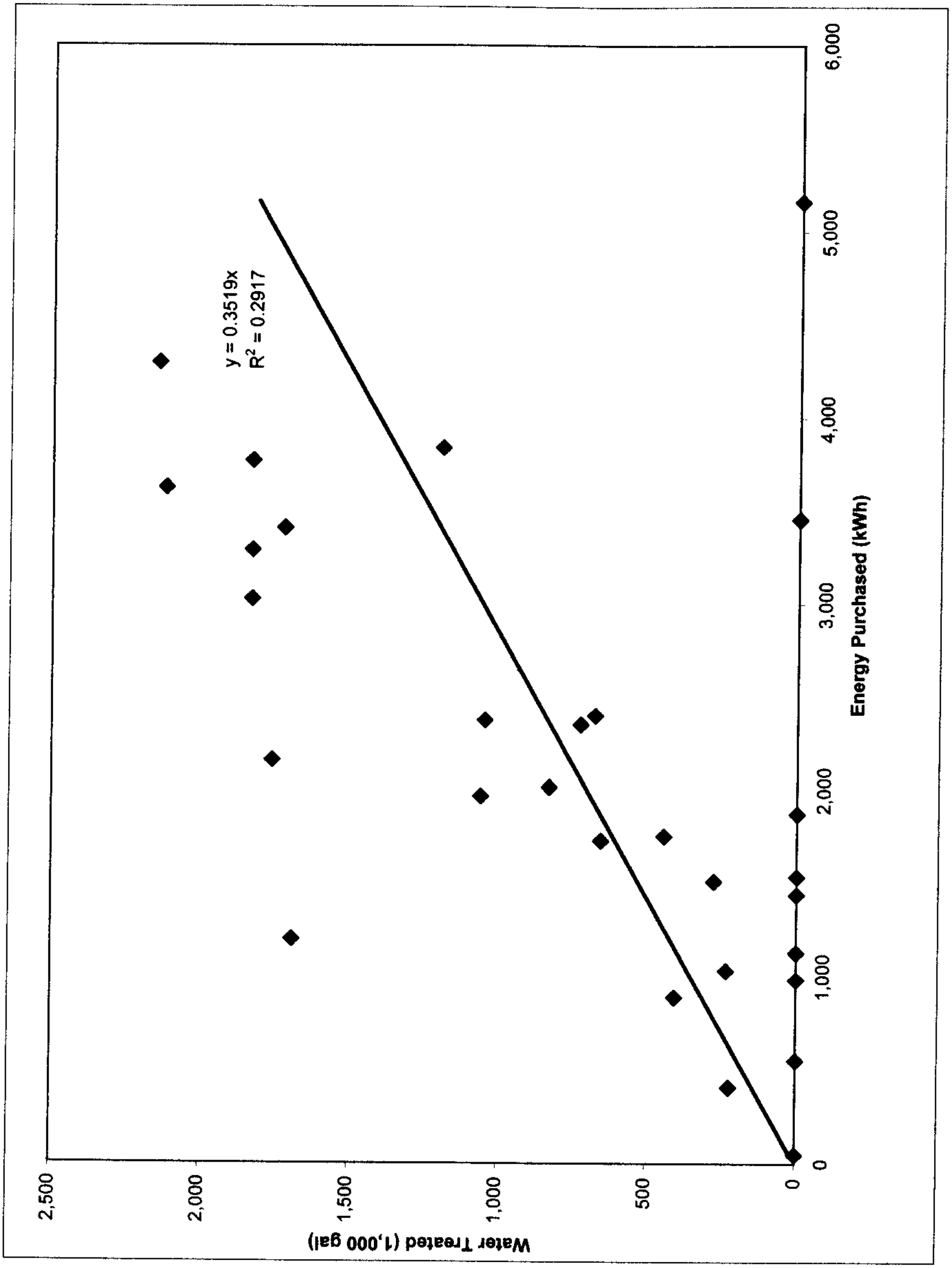

Exhibit 7. Correlation analysis of energy purchased versus volume of water treated

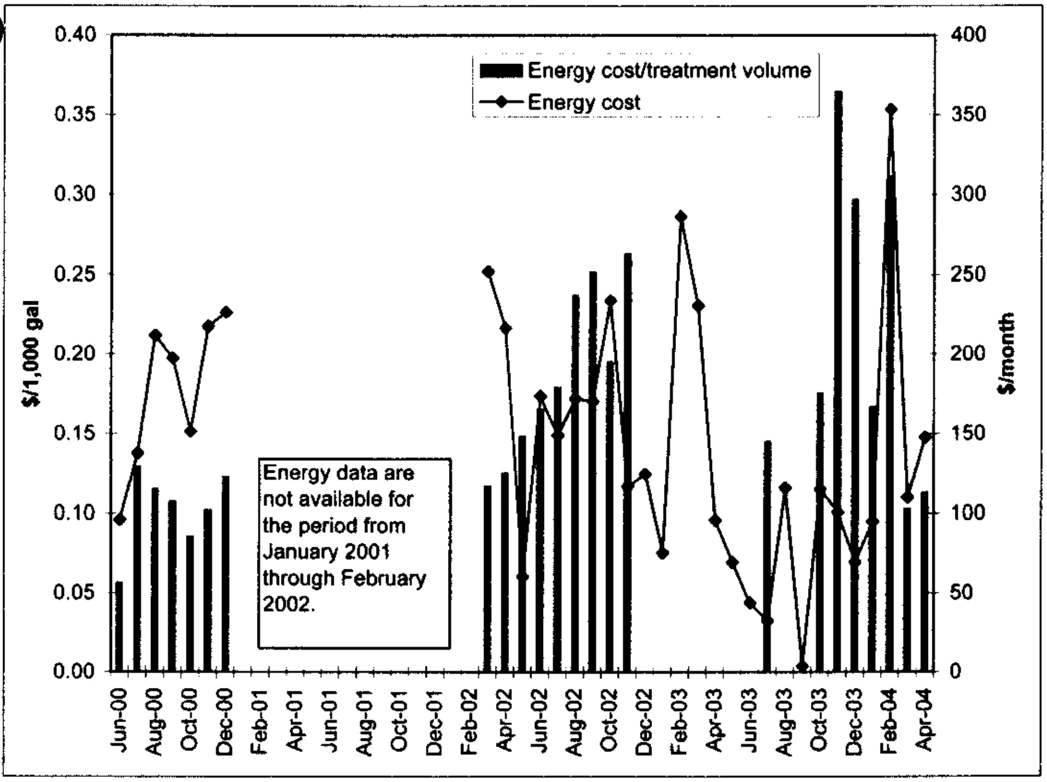

Exhibit 8. System energy costs

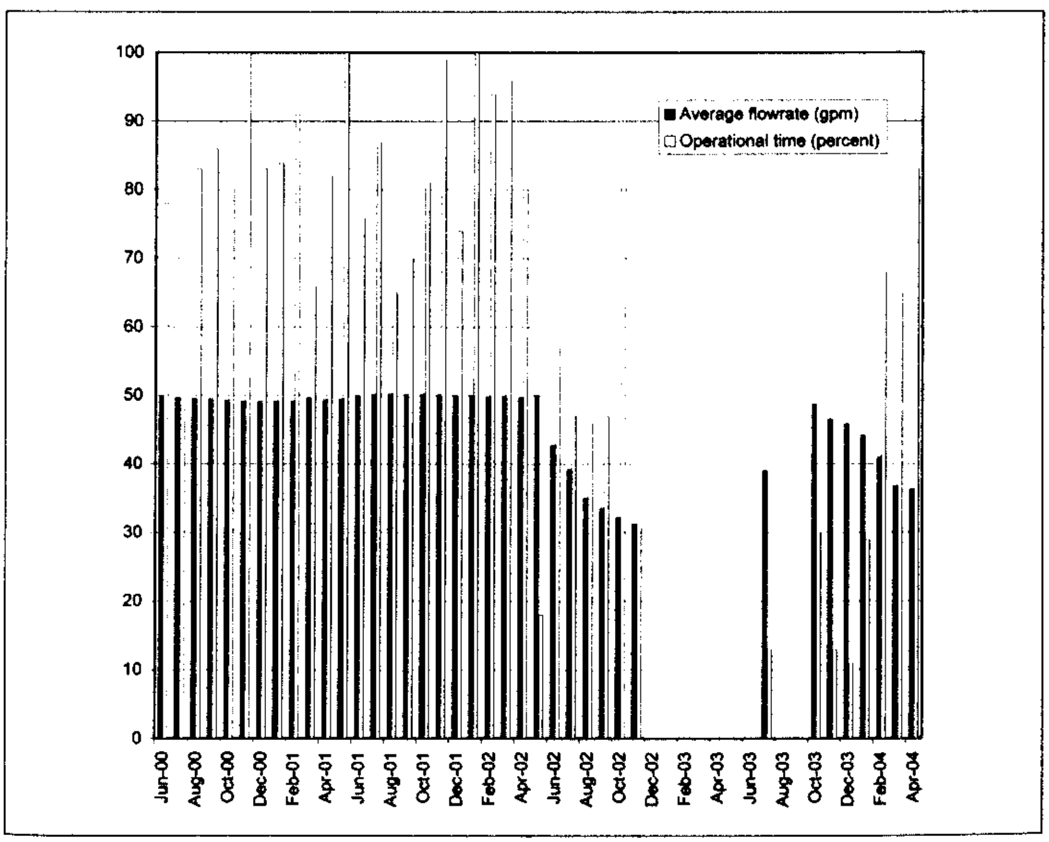

Exhibit 9. System operational time

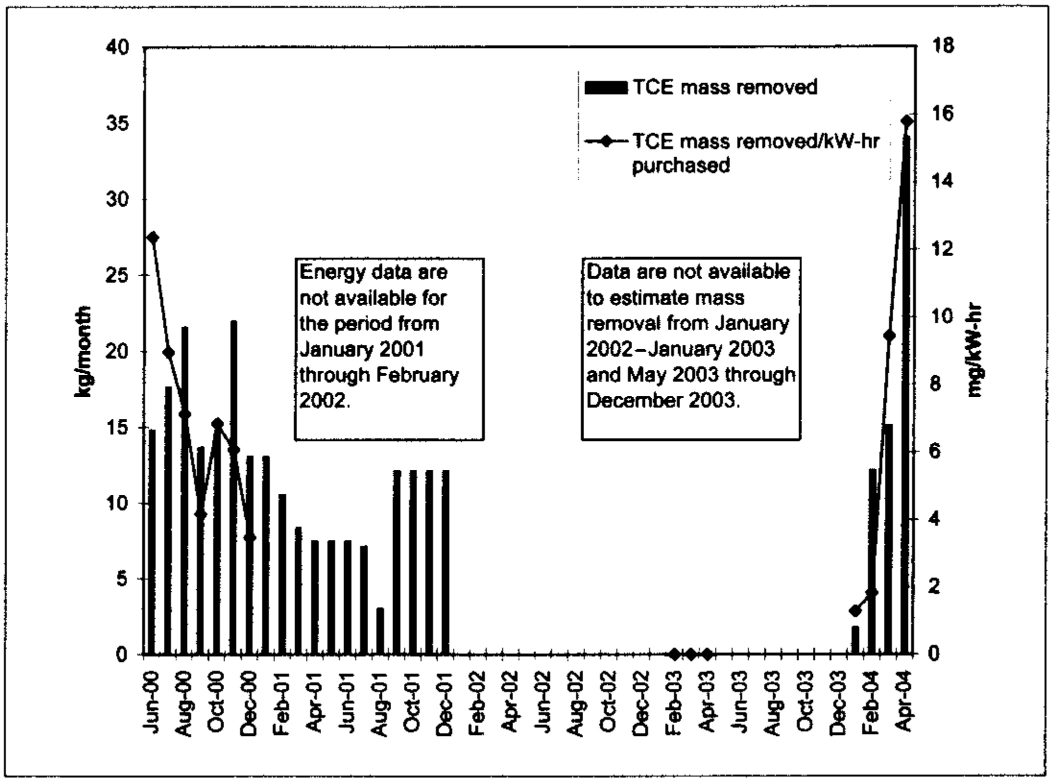

Exhibit 10. Estimated TCE mass removal

The average monthly energy production can be estimated from the annual value estimated from the modified Weibull model value of 1,300 kWh (Exhibit 2). This is almost double the average monthly value presented in Exhibit 12 for the first four months of wind turbine operation. Although the actual production is significantly lower than the design estimate, the estimated energy consumption is much less than that estimated in Exhibit 2. In terms of the overall energy balance, the preliminary results indicate that the wind turbine energy production exceeds the treatment system demand.

The Exhibit 12 summary indicates that the system is removing approximately 21 mg of TCE per kWh of energy generated by the wind turbine. Examination of the flowrate data presented in Exhibit 9 shows that the average flowrate of the system has been declining since October 2003. Therefore, if the mass of TCE is proportional to the flowrate, the current operational status of the system at flowrates less than 50 gpm depresses the rate of TCE mass removal per unit of energy generated by the wind turbine.

Exhibit 11 shows that energy production is a highly variable, random event, while the energy consumption is relatively constant. Although the treatment system operational period is a random variable because it cannot be predicted a priori, the magnitude of the treatment power demand is relatively constant at 4.7 kW. The Exhibit 12 energy balance indicates that the wind turbine generates more energy than that required by the treatment system during the preliminary months of the project. However, timing of the energy delivery does not match the energy demand. For the grid inter-tie system, other electrical processes for the GCW system either use the excess energy or, if the supply exceeds the total GCW demand, the excess enters the utility grid. Net metering refers to the practice of giving utility customers who deliver

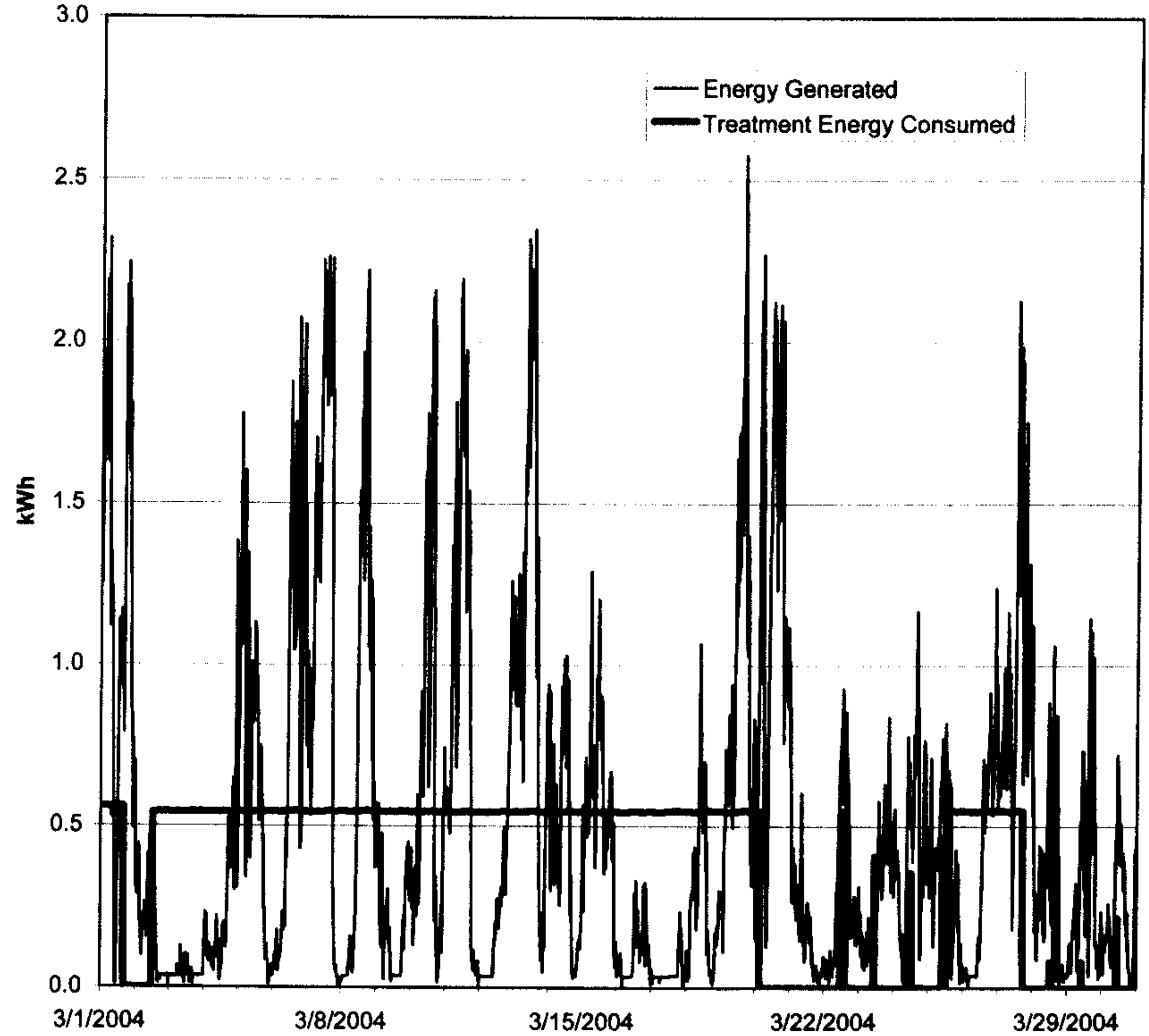

Exhibit 11. Energy curves for March 2004

generated power in excess of demand to the utility compensation for that power. This practice makes the grid inter-tie systems more economically attractive. Unfortunately, net metering is not practiced in Nebraska. Given an estimated price of $0.07/kWh, the average monthly value of the wind-generated energy is $57/month. In theory, this should represent a cost savings for the system. However, a reduction in energy consumption is not obvious from an inspection of the data presented in Exhibit 5. In fact, more than 6,500 kWh of electricity were purchased during February 2003, which is the maximum monthly use given the available data. The wind turbine system contributed an additional 770 kWh during the same period.

The GCW continues to remove contaminant mass from the aquifer without removing water from the aquifer. Estimated monthly mass removal quantities of 10 kg are not unusual, and almost 21 mg of TCE are being removed with each kWh of energy generated by the wind turbine system.

Month	Energy Generated (kWh) (a)	Energy Consumed by Treatment System (kWh) (b)	Difference kWh (a)-(b)	Operational Time	TCE Removed per kWh Generated (mg/kWh)
Jan-04	209	279	-70	75%	8.6
Feb-04	771	824	-53	72%	15.8
Mar-04	1,148	814	335	67%	13.2
Apr-04	935	917	17	78%	36.5
May-04	1,024	1,001	23	82%	-
Total	4,087	3,835	252	-	-
Monthly Average	817	767	50	75%	20.7

Notes:
1. System monitoring was initiated on January 21, 2004.
2. Data were not available at submittal time to estimate the mass of TCE removed in May 2004.

Exhibit 12. Wind turbine performance summary

CONCLUSIONS AND RECOMMENDATIONS

To the best of our knowledge, this is the first application of a wind turbine to power a groundwater remediation system. The system was well received by the public, and efforts are underway to provide an outreach program with local schoolchildren. The wind turbine has no known negative impact on wildlife, the environment, or land use. The historical data collected for the system indicate that there is a poor correlation between the quantity of energy purchased and the quantity of water treated at the GCW system. The subject GCW system was constructed as a prototype for the collection of data to be used during the design of subsequent systems. This subject system may be relatively inefficient in terms of energy used to heat and cool the treatment system components. Although the wind system generates sufficient energy to satisfy the needs of the treatment system, including the submersible well pump, the wind energy supply falls far short of matching the quantity of energy purchased for the system. It is concluded that the cost efficiency of future systems would greatly benefit if one of the bases of design was energy efficiency. Furthermore, the preliminary results indicate that it may be possible to operate the GCW system using solely wind power if the only energy demands were those required for circulating and treating groundwater.

The data indicate that the GCW, which was designed for "continuous" operation, operates, on average, approximately 75 percent of the time. It may be concluded that this time period would be appropriate for the design of an off-grid renewable energy system. That is, it would only be necessary to specify energy storage capabilities, which would result in system operation 75 percent of the time instead of 100 percent of the time.

The preliminary data collected from this study also encourage the development of a remedial system that uses wind energy without storage. A significant quantity of groundwater could be pumped if a variable frequency drive pump matched to the wind turbine was employed at the study site or a site with similar or greater wind resources.

ACKNOWLEDGMENTS

The wind turbine project was funded by a grant from the U.S. Environmental Protection Agency Office of Solid Waste and Emergency Response Innovative Work Groups program. The U.S. Army Corps of Engineers, Kansas City District, their contractors, the University of Missouri–Rolla, Bergey Windpower Company, Inc., and Ohio Semitronics, Inc. provided additional support.

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Andrew Curtis Elmore is an assistant professor of geological engineering at the University of Missouri–Rolla. His areas of expertise include design and analysis of groundwater circulation wells, sustainable groundwater design, and characterization of water supply sources in Guatemala.

Ron Gallagher is a PhD student in the University of Missouri–Rolla geological engineering program, where he is studying the application of renewable energy to groundwater remediation systems.

K. David Drake is a remediation project manager in the Federal Facilities Section of Region 7, U.S. Environmental Protection Agency. He provides technical leadership for the remediation of Superfund sites throughout Region 7.

Appendix 3-1
Energy Datalogging Accuracy Study

University of Missouri-Rolla
Geological Engineering Program

Calibration Test Results

1.0 Purpose

The purpose of this report is to document the calibration data of 3 Ohio Semitronics Inc. (OSI) watt – hour transducers. Models W-113E, W-014E and W-059E OSI transducers were purchased by the Geological Engineering Department of the University of Missouri-Rolla (UMR) from OSI in April 2005.

2.0 Calibration Procedure

The above devices were calibrated in the UMR Emerson Electric Power Laboratory during June 2005. The calibration process consisted of the following steps:

a) After the OSI device was clamped to the table, the 3 phase power cables were connected to the power source panel and then connected to 3 load resistance boxes. The load boxes consisted of 39 ohm resistors that can be chained together to provide the required resistance for the desired kilowatt power load.
b) One leg of the 3 phase power was then measured using a Techtronic TDS420A Digital Oscilloscope (S/N B030419) and Techtronic AM503B Current Probe Amplifier (S/N B045369).
c) A Fluke 79III VOM meter G12#3 (S/N 7880404) was also used to measure the voltage output of the OSI rate terminals and as a general setup checking device.
d) After the correct load box setting were switched the OSI transducer was then tested from 7 to 91 minutes (depending on the transducer) and final reading taken at the end of the test. Various testing times were necessary due to availability of lab space, number of students in the lab, hours of other lab classes, and amount of heat generated by the load boxes.

3.0 Test Results

Some test results were wide ranging due principally to the use of normal line current. The results of the 8 tests calibration tests are shown below.

a) OSI – Model W-014E
   Calibration testing ranged from 0.01% to 2.6% of the laboratory measured values and an average of all W-014E test values of 1.03%.
b) OSI – Model W-059E
   Calibration testing ranged from 0.4% to 6.8% of the laboratory measured values with an average of all W- 059E test values of 3.13%
c) OSI – Model W-113E
   Calibration testing ranged from 0.0% to 15.6% of laboratory measured values with and average of all W-113E test values of 5.08 %

University of Missouri Rolla
Geological Engineering Department

Calibration Test Results

Sheet 1 of 2
Device: Watt hour transducer
Manufacturer: Ohio Semitronics Inc.
Model: **W-014E**
S/N: 2395
Calibration Date: OSI Calibration 2/05
UMR Calibration 6/05

Run A
Input Volts = 225.7VAC
Input Power = 3.116 kw
Input Power Quantity = 3.116kwh
Length of Test = 60 minutes

Measured power rate = 3.131 (pulsed) Percentage Difference = 0.5%
Measured power rate = 3.088 (rate) Percentage Difference = 0.9%
Measured power rate = 3.138 (integration) Percentage Difference = 0.7%
Measured power quantity = 3.131 (pulsed) Percentage Difference = 0.5%
Measured power quantity = 3.088 (rate) Percentage Difference = 0.9%
Measured power quantity = 3.138 (integration) Percentage Differ = 0.7%

Run B
Input Volts = 224.6VAC
Input Power = 3.14kw
Input Power Quantity = 0.419kwh
Length of Test = 8 Minutes

Measured power rate = 3.06 (pulsed) Percentage Difference = 2.6%
Measured power rate = 3.09 (rate) Percentage Difference = 1.5%
Measured power rate = 3.137 (integration) Percentage Difference = 0.01%
Measured power quantity = 0.408 (pulsed) Percentage Difference = 2.6%
Measured power quantity = 0.412 (rate) Percentage Difference = 1.7%
Measured power quantity = 0.418 (integration) Percentage Differ = 0.2%

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Geological Engineering Department

Calibration Test Results

Sheet 2 of 2
Device: Watt hour transducer
Manufacturer: Ohio Semitronics Inc.
Model: **W-014E**
S/N: 2395
Calibration Date: OSI Calibration 2/05
UMR Calibration 6/05

Run C
Input Volts = 223.5VAC
Input Power = 2.09kw
Input Power Quantity = 3.169kwh
Length of Test = 91 Minutes

Measured power rate = 2.09 (pulsed) Percentage Difference = 0.0%
Measured power rate = 2.04 (rate) Percentage Difference = 2.4%
Measured power rate = 2.084 (integration) Percentage Difference = 0.3%
Measured power quantity = 3.164 (pulsed) Percentage Difference = 0.2%
Measured power quantity = 3.094 (rate) Percentage Difference = 2.4%
Measured power quantity = 3.161 (integration) Percentage Differ = 0.3%

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Geological Engineering Department

Calibration Test Results

Sheet 1 of 2
Device: Watt hour transducer
Manufacturer: Ohio Semitronics Inc.
Model: **W-059E**
S/N: 87445
Calibration Date: OSI Calibration 2/05
UMR Calibration 6/05

Run A
Input Volts = 220.6VAC
Input Power = 2.97kw
Input Power Quantity = 0.446kwh
Length of Test = 9 Minutes

- Measured power rate = 3.00 (pulsed) Percentage Difference = 1.0%
- Measured power rate = 2.82 (rate) Percentage Difference = 5.0%
- Measured power rate = 2.90 (integration) Percentage Difference = 2.3%
- Measured power quantity = 0.45 (pulsed) Percentage Difference = 0.9%
- Measured power quantity = 0.423 (rate) Percentage Difference = 5.0%
- Measured power quantity = 0.435 (integration) Percentage Differ = 2.4%

Run B
Input Volts = 217VAC
Input Power = 10.39kw
Input Power Quantity = 2.08kwh
Length of Test = 12 Minutes

- Measured power rate = 11.1 (pulsed) Percentage Difference = 6.8%
- Measured power rate = 10.0 (rate) Percentage Difference = 3.7%
- Measured power rate = 10.35 (integration) Percentage Difference = 0.4%
- Measured power quantity = 2.22 (pulsed) Percentage Difference = 6.7%
- Measured power quantity = 2.00 (rate) Percentage Difference = 3.8%
- Measured power quantity = 2.07 (integration) Percentage Differ = 0.4%

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Geological Engineering Department

Calibration Test Results

Sheet 2 of 2
Device: Watt hour transducer
Manufacturer: Ohio Semitronics Inc.
Model: **W-059E**
S/N: 87445
Calibration Date: OSI Calibration 2/05
UMR Calibration 6/05

Run C
Input Volts = 218.3VAC
Input Power = 6.83kw
Input Power Quantity = 6.49kwh
Length of Test = 61 Minutes

Measured power rate = 6.435 (pulsed) Percentage Difference = 0.9%
Measured power rate = 6.16 (rate) Percentage Difference = 3.4%
Measured power rate = 6.14 (integration) Percentage Difference = 3.8%
Measured power quantity = 6.33 (pulsed) Percentage Difference = 2.5%
Measured power quantity = 6.26 (rate) Percentage Difference = 3.5%
Measured power quantity = 6.241 (integration) Percentage Differ = 3.8%

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Calibration Test Results

Sheet 1 of 1
Device: Watt hour transducer
Manufacturer: Ohio Semitronics Inc.
Model: **W-113E**
S/N: 12876
Calibration Date: OSI Calibration 2/05
UMR Calibration 6/05

Run A
Input Volts = 227.4VAC
Input Power = 6.22 kw
Input Power Quantity = 1.451kwh
Length of Test = 14 minutes

- Measured power rate = 6.381 (pulsed) Percentage Difference = 2.5%
- Measured power rate = 6.002 (rate) Percentage Difference = 3.5%
- Measured power rate = 6.22 (integration) Percentage Difference = 0.0%
- Measured power quantity = 1.489 (pulsed) Percentage Difference = 2.6%
- Measured power quantity = 1.400 (rate) Percentage Difference = 3.5%
- Measured power quantity = 1.459 (integration) Percentage Differ = 0.6%

Run B
Input Volts = 227.2VAC
Input Power = 2.162kw
Input Power Quantity = 0.249kwh
Length of Test = 7 Minutes

- Measured power rate = 2.331 (pulsed) Percentage Difference = 7.0%
- Measured power rate = 2.136 (rate) Percentage Difference = 1.2%
- Measured power rate = 2.465 (integration) Percentage Difference = 14%
- Measured power quantity = 0.272 (pulsed) Percentage Difference = 9.2
- Measured power quantity = 0.288 (rate) Percentage Difference = 15.6%
- Measured power quantity = 0.252 (integration) Percentage Differ = 1.2%