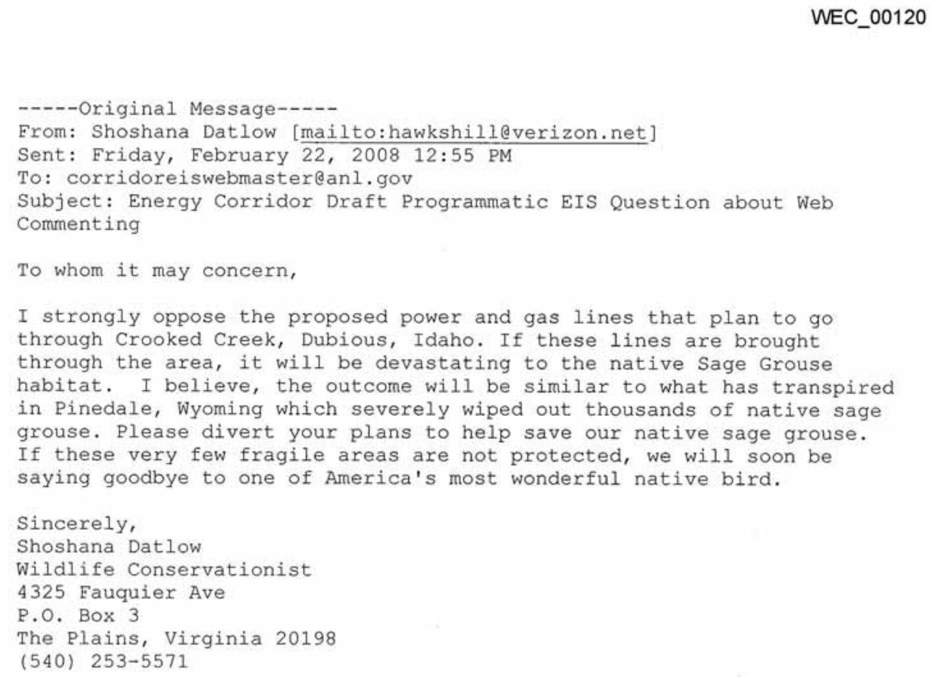


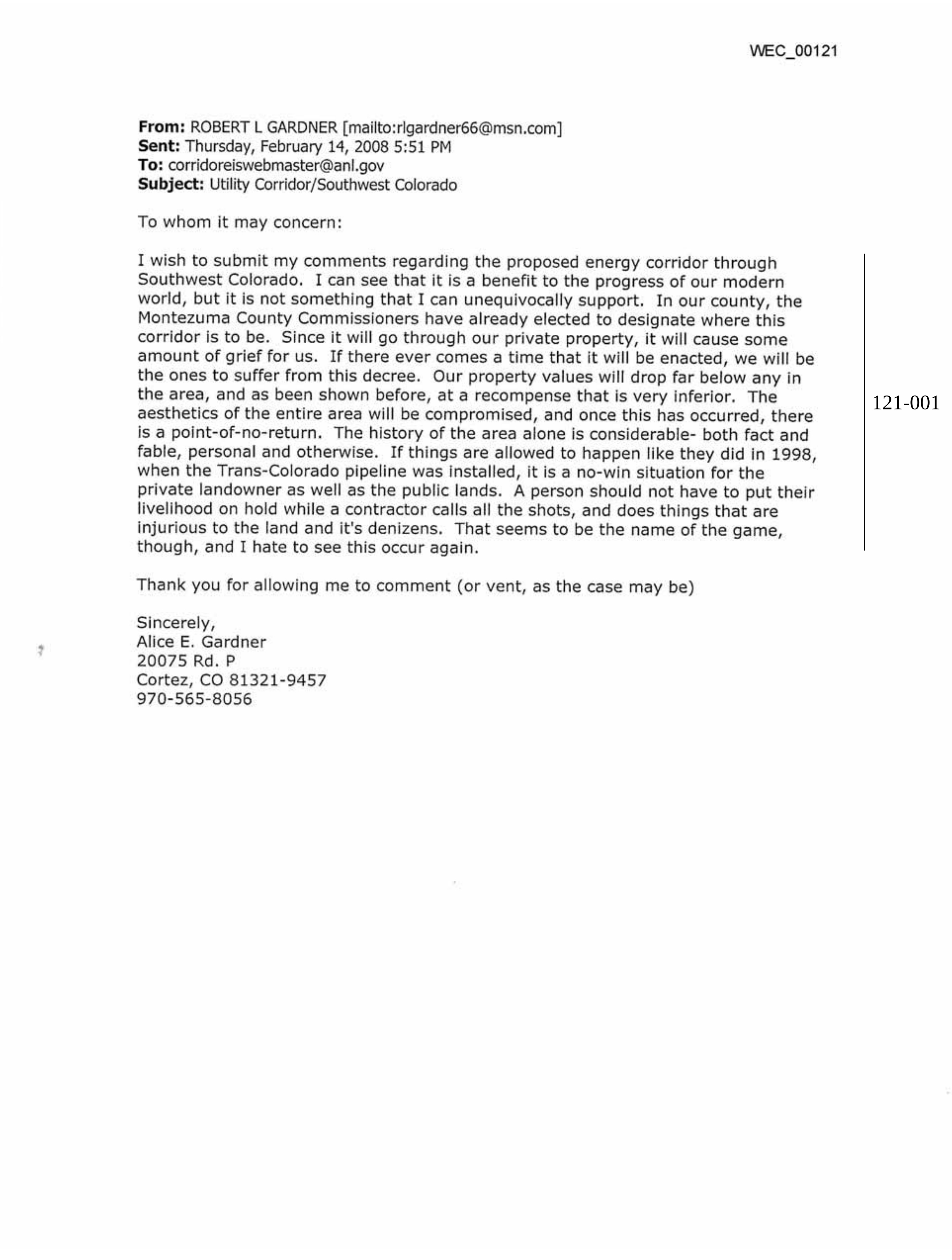
WEC_00120

-----Original Message-----
From: Shoshana Datlow [mailto:hawkshill@verizon.net]
Sent: Friday, February 22, 2008 12:55 PM
To: corridoreiswebmaster@anl.gov
Subject: Energy Corridor Draft Programmatic EIS Question about Web Commenting

To whom it may concern,

I strongly oppose the proposed power and gas lines that plan to go through Crooked Creek, Dubious, Idaho. If these lines are brought through the area, it will be devastating to the native Sage Grouse habitat. I believe, the outcome will be similar to what has transpired in Pinedale, Wyoming which severely wiped out thousands of native sage grouse. Please divert your plans to help save our native sage grouse. If these very few fragile areas are not protected, we will soon be saying goodbye to one of America's most wonderful native bird. 120-001

Sincerely,
Shoshana Datlow
Wildlife Conservationist
4325 Fauquier Ave
P.O. Box 3
The Plains, Virginia 20198
(540) 253-5571



WEC_00121

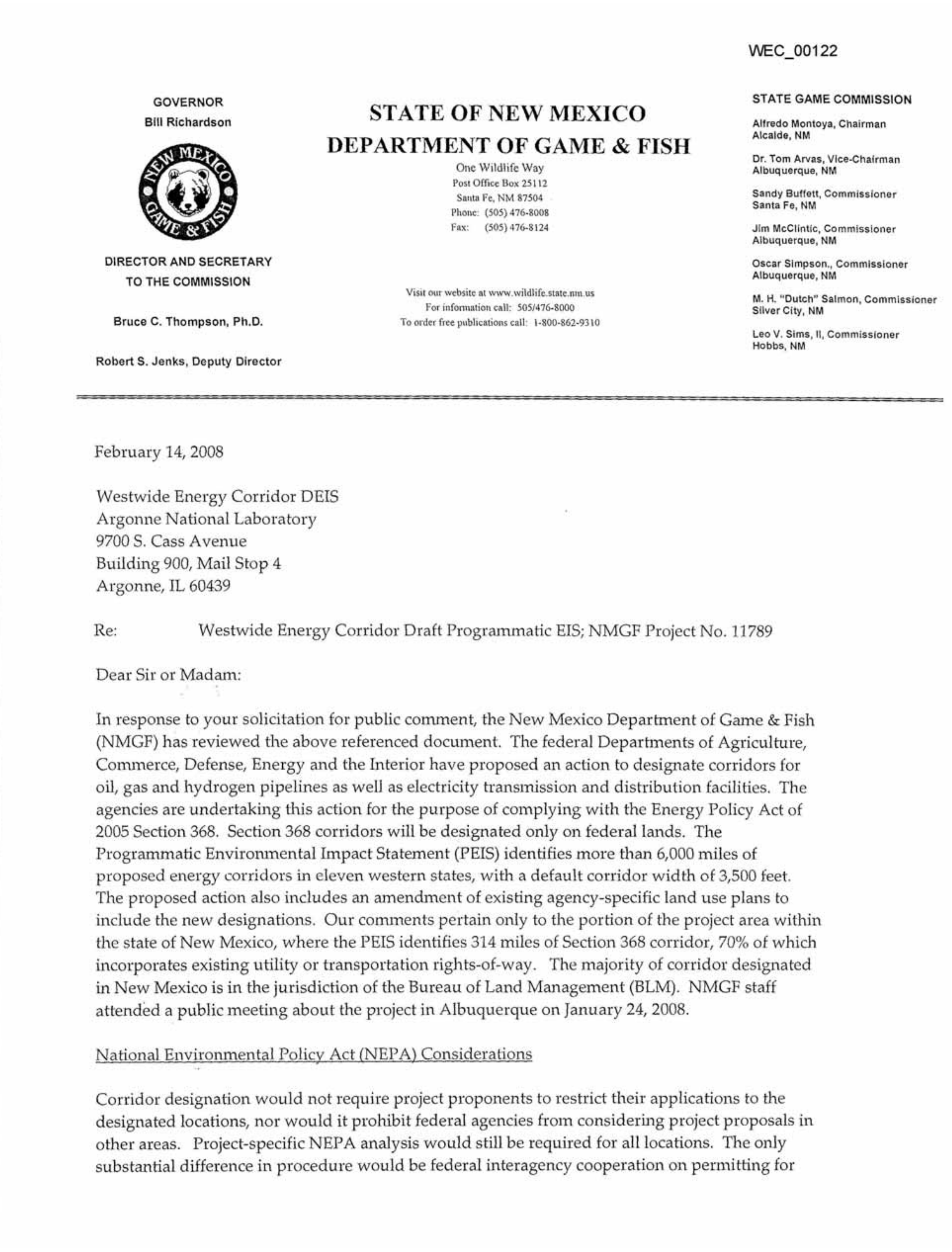
From: ROBERT L GARDNER [mailto:rlgardner66@msn.com]
Sent: Thursday, February 14, 2008 5:51 PM
To: corridoreiswebmaster@anl.gov
Subject: Utility Corridor/Southwest Colorado

To whom it may concern:

I wish to submit my comments regarding the proposed energy corridor through Southwest Colorado. I can see that it is a benefit to the progress of our modern world, but it is not something that I can unequivocally support. In our county, the Montezuma County Commissioners have already elected to designate where this corridor is to be. Since it will go through our private property, it will cause some amount of grief for us. If there ever comes a time that it will be enacted, we will be the ones to suffer from this decree. Our property values will drop far below any in the area, and as been shown before, at a recompense that is very inferior. The aesthetics of the entire area will be compromised, and once this has occurred, there is a point-of-no-return. The history of the area alone is considerable- both fact and fable, personal and otherwise. If things are allowed to happen like they did in 1998, when the Trans-Colorado pipeline was installed, it is a no-win situation for the private landowner as well as the public lands. A person should not have to put their livelihood on hold while a contractor calls all the shots, and does things that are injurious to the land and it's denizens. That seems to be the name of the game, though, and I hate to see this occur again. 121-001

Thank you for allowing me to comment (or vent, as the case may be)

Sincerely,
Alice E. Gardner
20075 Rd. P
Cortez, CO 81321-9457
970-565-8056



WEC_00122

GOVERNOR
Bill Richardson

DIRECTOR AND SECRETARY
TO THE COMMISSION

Bruce C. Thompson, Ph.D.

Robert S. Jenks, Deputy Director

STATE OF NEW MEXICO
DEPARTMENT OF GAME & FISH
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Silver City, NM

Leo V. Sims, II, Commissioner
Hobbs, NM

February 14, 2008

Westwide Energy Corridor DEIS
Argonne National Laboratory
9700 S. Cass Avenue
Building 900, Mail Stop 4
Argonne, IL 60439

Re: Westwide Energy Corridor Draft Programmatic EIS; NMGF Project No. 11789

Dear Sir or Madam:

In response to your solicitation for public comment, the New Mexico Department of Game & Fish (NMGF) has reviewed the above referenced document. The federal Departments of Agriculture, Commerce, Defense, Energy and the Interior have proposed an action to designate corridors for oil, gas and hydrogen pipelines as well as electricity transmission and distribution facilities. The agencies are undertaking this action for the purpose of complying with the Energy Policy Act of 2005 Section 368. Section 368 corridors will be designated only on federal lands. The Programmatic Environmental Impact Statement (PEIS) identifies more than 6,000 miles of proposed energy corridors in eleven western states, with a default corridor width of 3,500 feet. The proposed action also includes an amendment of existing agency-specific land use plans to include the new designations. Our comments pertain only to the portion of the project area within the state of New Mexico, where the PEIS identifies 314 miles of Section 368 corridor, 70% of which incorporates existing utility or transportation rights-of-way. The majority of corridor designated in New Mexico is in the jurisdiction of the Bureau of Land Management (BLM). NMGF staff attended a public meeting about the project in Albuquerque on January 24, 2008.

National Environmental Policy Act (NEPA) Considerations

Corridor designation would not require project proponents to restrict their applications to the designated locations, nor would it prohibit federal agencies from considering project proposals in other areas. Project-specific NEPA analysis would still be required for all locations. The only substantial difference in procedure would be federal interagency cooperation on permitting for projects within Section 368 corridors which cross more than one agency's jurisdiction, including the appointment of a project-specific federal point of contact (individual). Thus, there are no direct impacts from approving the proposed action, and the indirect impacts consist of the potential results of the approval of as yet unspecified proposals. The PEIS does not address impacts to non-federal land. However logic dictates that the ends of linear corridor segments must be joined. Therefore the PEIS should analyze both potential indirect and cumulative impacts to adjacent state and private lands, including consideration of how affected non-federal landowners will be consulted and possibly compensated. 122-001

The agencies preparing the PEIS have concluded that consultation with the Fish & Wildlife Service (FWS) under Section 7 of the Endangered Species Act is not required. This conclusion is correct because the lack of direct potential impact justifies deferral of consultation until the project-specific analysis phase. However, one of the results of Section 368 corridor designation will be an amendment of a large number of land use plans, wherein certain uses will be defined as "compatible" within the corridors. FWS consultation should therefore be conducted at the programmatic phase to determine that these particular uses are in fact compatible regarding their potential impact on listed species. 122-002

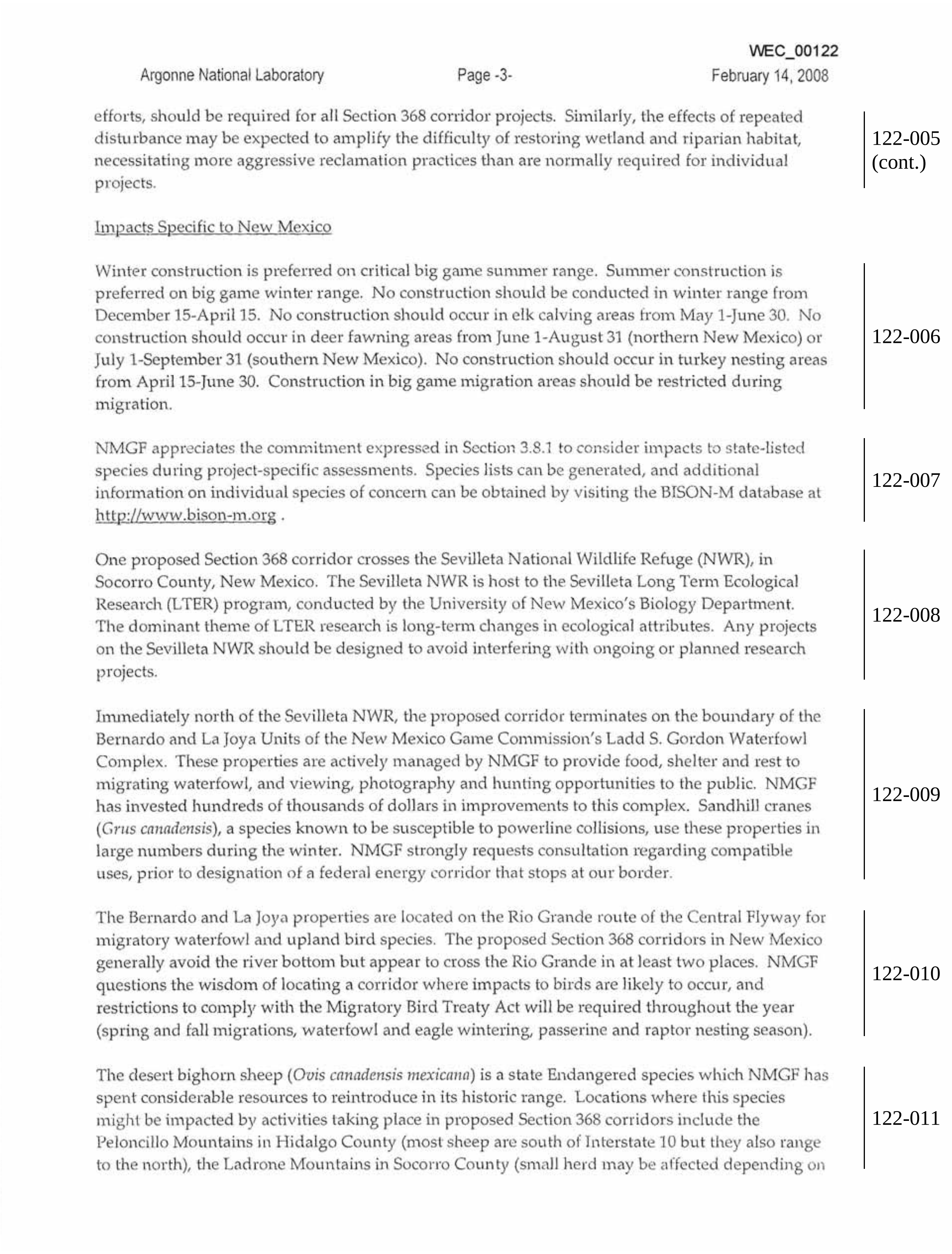
General Impacts on Wildlife and Habitat

Concentration of linear projects in corridors has the potential to reduce the footprint of ecological impact as compared to the No Action alternative of more dispersed projects. However it is also likely that the impacts within Section 368 corridors will be intensified both spatially and temporally. We are particularly concerned about the proliferation of access roads, whose use by the public will lead to increased disturbance of wildlife from noise and activity, as well as direct mortality from vehicle collisions and illegal harvest (poaching). Minimization of roads, restriction of public access (locked gates) and obliteration of obsolete roads, should be required elements of all Section 368 energy corridor projects. 122-003

Chapter 3 of the PEIS contains a detailed analysis of the potential effects on ecological resources from pipeline and powerline projects, and a list of steps to minimize or mitigate those effects. NMGF recommends that most or all of the mitigations be mandatory for applicable projects within Section 368 corridors, except where specifically exempted. This would be accomplished by changing the word "should" to "must." In particular, all trenching activities should: 122-004

1. comply with the enclosed Trenching Guidelines, and
2. all aboveground powerlines should be required to follow the Avian Power Line Interaction Committee (APLIC) *Suggested Practices for Avian Protection on Power Lines: The State of the Art in 2006* and, in locations where collision impacts are reasonably foreseeable, APLIC's *Mitigating Bird Collisions with Powerlines: The State of the Art in 1994.*

The PEIS identifies increased erosion, runoff and sedimentation as temporary impacts following construction. However the discussion of vegetation resources in Chapter 3 correctly recognizes that locations subject to repeated disturbance, especially in arid environments, may be difficult to successfully reclaim. For this reason it could be reasonably foreseen that effects to surface water and soils may persist for a longer time than is typical for similar projects in other areas. Follow-up monitoring of reclamation success, with additional erosion control mitigation for unsuccessful 122-005



efforts, should be required for all Section 368 corridor projects. Similarly, the effects of repeated disturbance may be expected to amplify the difficulty of restoring wetland and riparian habitat, necessitating more aggressive reclamation practices than are normally required for individual projects. 122-005 (cont.)

Impacts Specific to New Mexico

Winter construction is preferred on critical big game summer range. Summer construction is preferred on big game winter range. No construction should be conducted in winter range from December 15-April 15. No construction should occur in elk calving areas from May 1-June 30. No construction should occur in deer fawning areas from June 1-August 31 (northern New Mexico) or July 1-September 31 (southern New Mexico). No construction should occur in turkey nesting areas from April 15-June 30. Construction in big game migration areas should be restricted during migration. 122-006

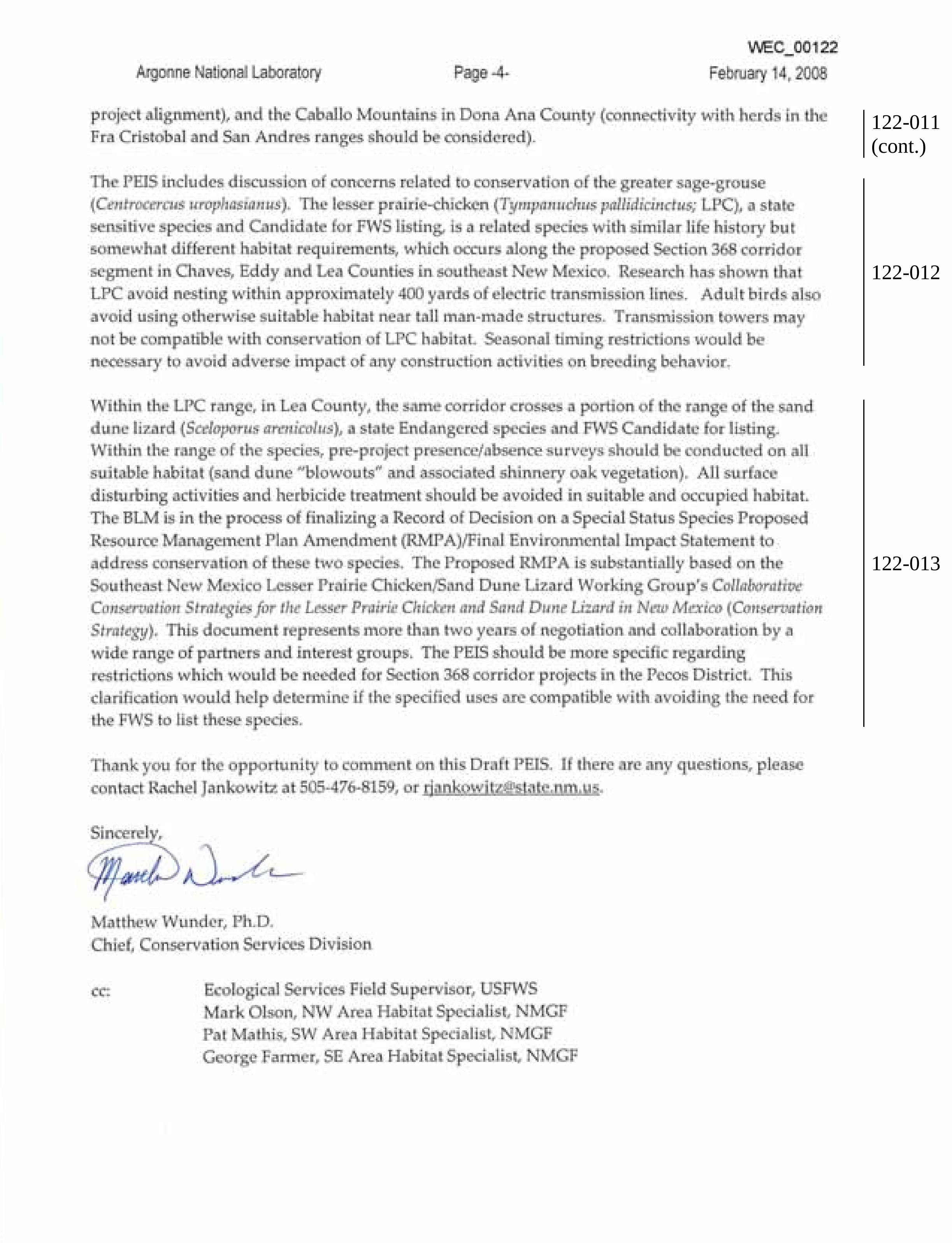
NMGF appreciates the commitment expressed in Section 3.8.1 to consider impacts to state-listed species during project-specific assessments. Species lists can be generated, and additional information on individual species of concern can be obtained by visiting the BISON-M database at http://www.bison-m.org . 122-007

One proposed Section 368 corridor crosses the Sevilleta National Wildlife Refuge (NWR), in Socorro County, New Mexico. The Sevilleta NWR is host to the Sevilleta Long Term Ecological Research (LTER) program, conducted by the University of New Mexico's Biology Department. The dominant theme of LTER research is long-term changes in ecological attributes. Any projects on the Sevilleta NWR should be designed to avoid interfering with ongoing or planned research projects. 122-008

Immediately north of the Sevilleta NWR, the proposed corridor terminates on the boundary of the Bernardo and La Joya Units of the New Mexico Game Commission's Ladd S. Gordon Waterfowl Complex. These properties are actively managed by NMGF to provide food, shelter and rest to migrating waterfowl, and viewing, photography and hunting opportunities to the public. NMGF has invested hundreds of thousands of dollars in improvements to this complex. Sandhill cranes (*Grus canadensis*), a species known to be susceptible to powerline collisions, use these properties in large numbers during the winter. NMGF strongly requests consultation regarding compatible uses, prior to designation of a federal energy corridor that stops at our border. 122-009

The Bernardo and La Joya properties are located on the Rio Grande route of the Central Flyway for migratory waterfowl and upland bird species. The proposed Section 368 corridors in New Mexico generally avoid the river bottom but appear to cross the Rio Grande in at least two places. NMGF questions the wisdom of locating a corridor where impacts to birds are likely to occur, and restrictions to comply with the Migratory Bird Treaty Act will be required throughout the year (spring and fall migrations, waterfowl and eagle wintering, passerine and raptor nesting season). 122-010

The desert bighorn sheep (*Ovis canadensis mexicana*) is a state Endangered species which NMGF has spent considerable resources to reintroduce in its historic range. Locations where this species might be impacted by activities taking place in proposed Section 368 corridors include the Peloncillo Mountains in Hidalgo County (most sheep are south of Interstate 10 but they also range to the north), the Ladrone Mountains in Socorro County (small herd may be affected depending on 122-011



project alignment), and the Caballo Mountains in Dona Ana County (connectivity with herds in the Fra Cristobal and San Andres ranges should be considered). 122-011 (cont.)

The PEIS includes discussion of concerns related to conservation of the greater sage-grouse (*Centrocercus urophasianus*). The lesser prairie-chicken (*Tympanuchus pallidicinctus;* LPC), a state sensitive species and Candidate for FWS listing, is a related species with similar life history but somewhat different habitat requirements, which occurs along the proposed Section 368 corridor segment in Chaves, Eddy and Lea Counties in southeast New Mexico. Research has shown that LPC avoid nesting within approximately 400 yards of electric transmission lines. Adult birds also avoid using otherwise suitable habitat near tall man-made structures. Transmission towers may not be compatible with conservation of LPC habitat. Seasonal timing restrictions would be necessary to avoid adverse impact of any construction activities on breeding behavior. 122-012

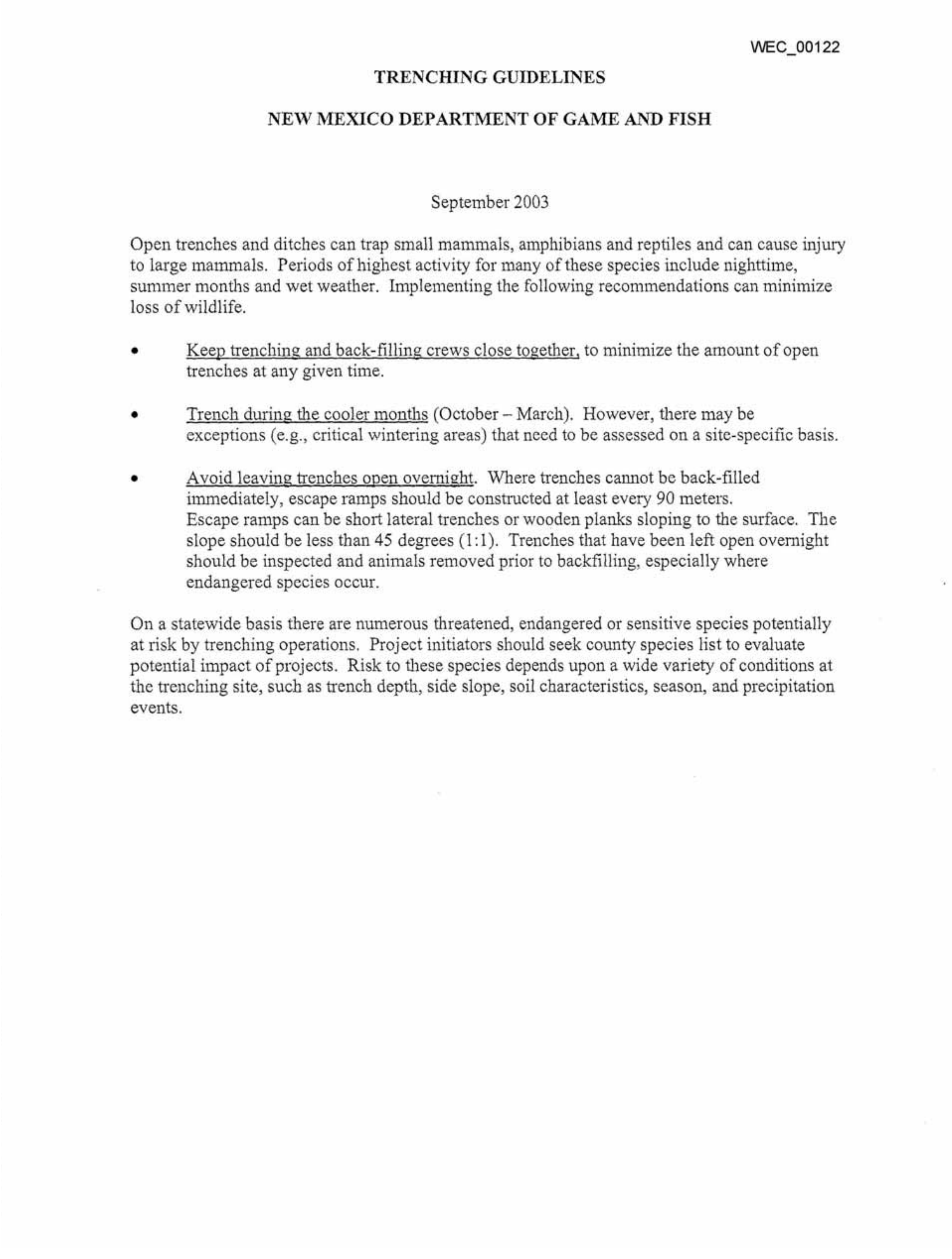
Within the LPC range, in Lea County, the same corridor crosses a portion of the range of the sand dune lizard (*Sceloporus arenicolus*), a state Endangered species and FWS Candidate for listing. Within the range of the species, pre-project presence/absence surveys should be conducted on all suitable habitat (sand dune "blowouts" and associated shinnery oak vegetation). All surface disturbing activities and herbicide treatment should be avoided in suitable and occupied habitat. The BLM is in the process of finalizing a Record of Decision on a Special Status Species Proposed Resource Management Plan Amendment (RMPA)/Final Environmental Impact Statement to address conservation of these two species. The Proposed RMPA is substantially based on the Southeast New Mexico Lesser Prairie Chicken/Sand Dune Lizard Working Group's *Collaborative Conservation Strategies for the Lesser Prairie Chicken and Sand Dune Lizard in New Mexico* (*Conservation Strategy*). This document represents more than two years of negotiation and collaboration by a wide range of partners and interest groups. The PEIS should be more specific regarding restrictions which would be needed for Section 368 corridor projects in the Pecos District. This clarification would help determine if the specified uses are compatible with avoiding the need for the FWS to list these species. 122-013

Thank you for the opportunity to comment on this Draft PEIS. If there are any questions, please contact Rachel Jankowitz at 505-476-8159, or rjankowitz@state.nm.us.

Sincerely,

Matthew Wunder, Ph.D.
Chief, Conservation Services Division

cc: Ecological Services Field Supervisor, USFWS
Mark Olson, NW Area Habitat Specialist, NMGF
Pat Mathis, SW Area Habitat Specialist, NMGF
George Farmer, SE Area Habitat Specialist, NMGF



WEC_00122

TRENCHING GUIDELINES

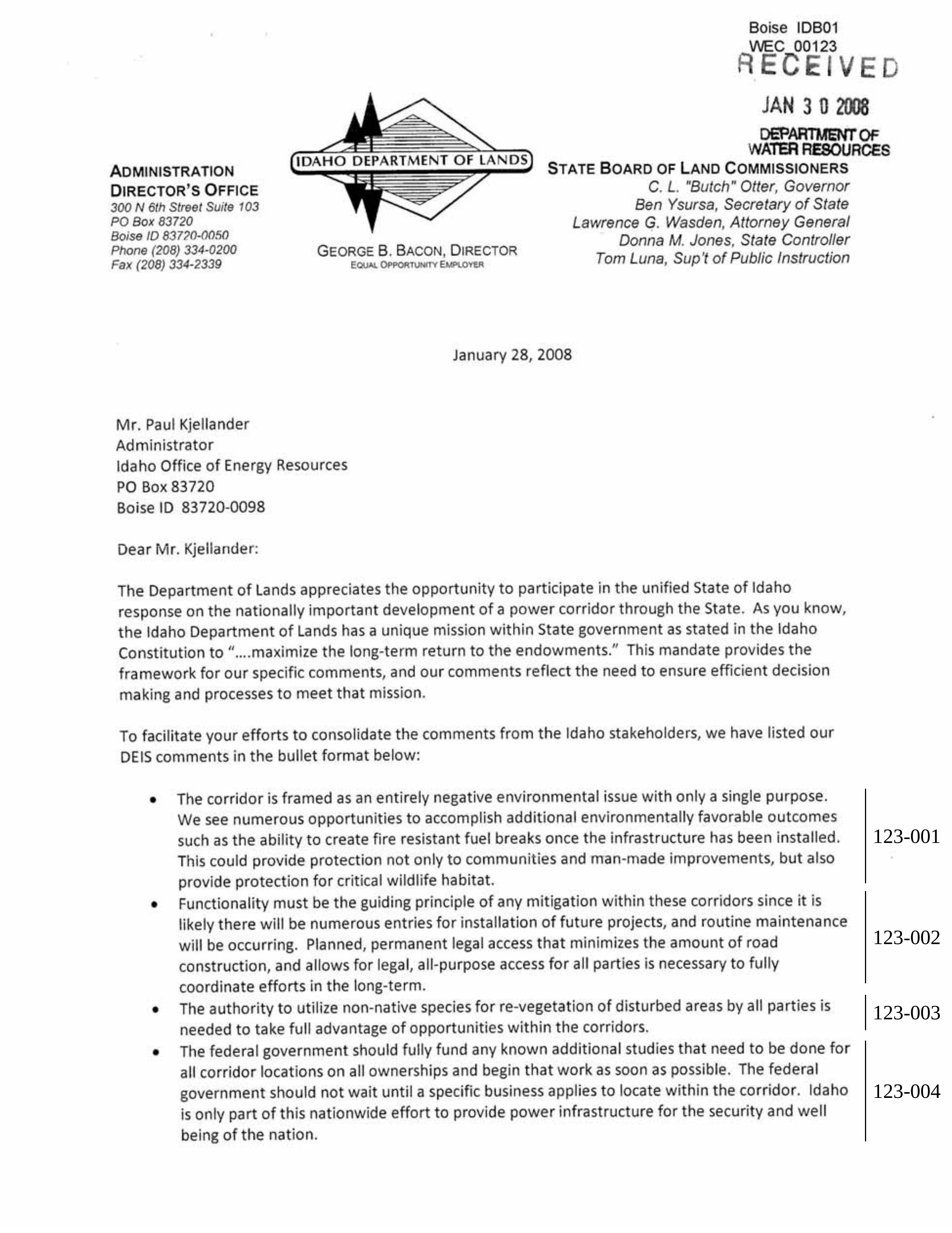
NEW MEXICO DEPARTMENT OF GAME AND FISH

September 2003

Open trenches and ditches can trap small mammals, amphibians and reptiles and can cause injury to large mammals. Periods of highest activity for many of these species include nighttime, summer months and wet weather. Implementing the following recommendations can minimize loss of wildlife.

- Keep trenching and back-filling crews close together, to minimize the amount of open trenches at any given time.
- Trench during the cooler months (October – March). However, there may be exceptions (e.g., critical wintering areas) that need to be assessed on a site-specific basis.
- Avoid leaving trenches open overnight. Where trenches cannot be back-filled immediately, escape ramps should be constructed at least every 90 meters. Escape ramps can be short lateral trenches or wooden planks sloping to the surface. The slope should be less than 45 degrees (1:1). Trenches that have been left open overnight should be inspected and animals removed prior to backfilling, especially where endangered species occur.

On a statewide basis there are numerous threatened, endangered or sensitive species potentially at risk by trenching operations. Project initiators should seek county species list to evaluate potential impact of projects. Risk to these species depends upon a wide variety of conditions at the trenching site, such as trench depth, side slope, soil characteristics, season, and precipitation events.



Boise IDB01
WEC_00123
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DEPARTMENT OF
WATER RESOURCES

IDAHO DEPARTMENT OF LANDS

ADMINISTRATION
DIRECTOR'S OFFICE
300 N 6th Street Suite 103
PO Box 83720
Boise ID 83720-0050
Phone (208) 334-0200
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GEORGE B. BACON, DIRECTOR
EQUAL OPPORTUNITY EMPLOYER

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C. L. "Butch" Otter, Governor
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Donna M. Jones, State Controller
Tom Luna, Sup't of Public Instruction

January 28, 2008

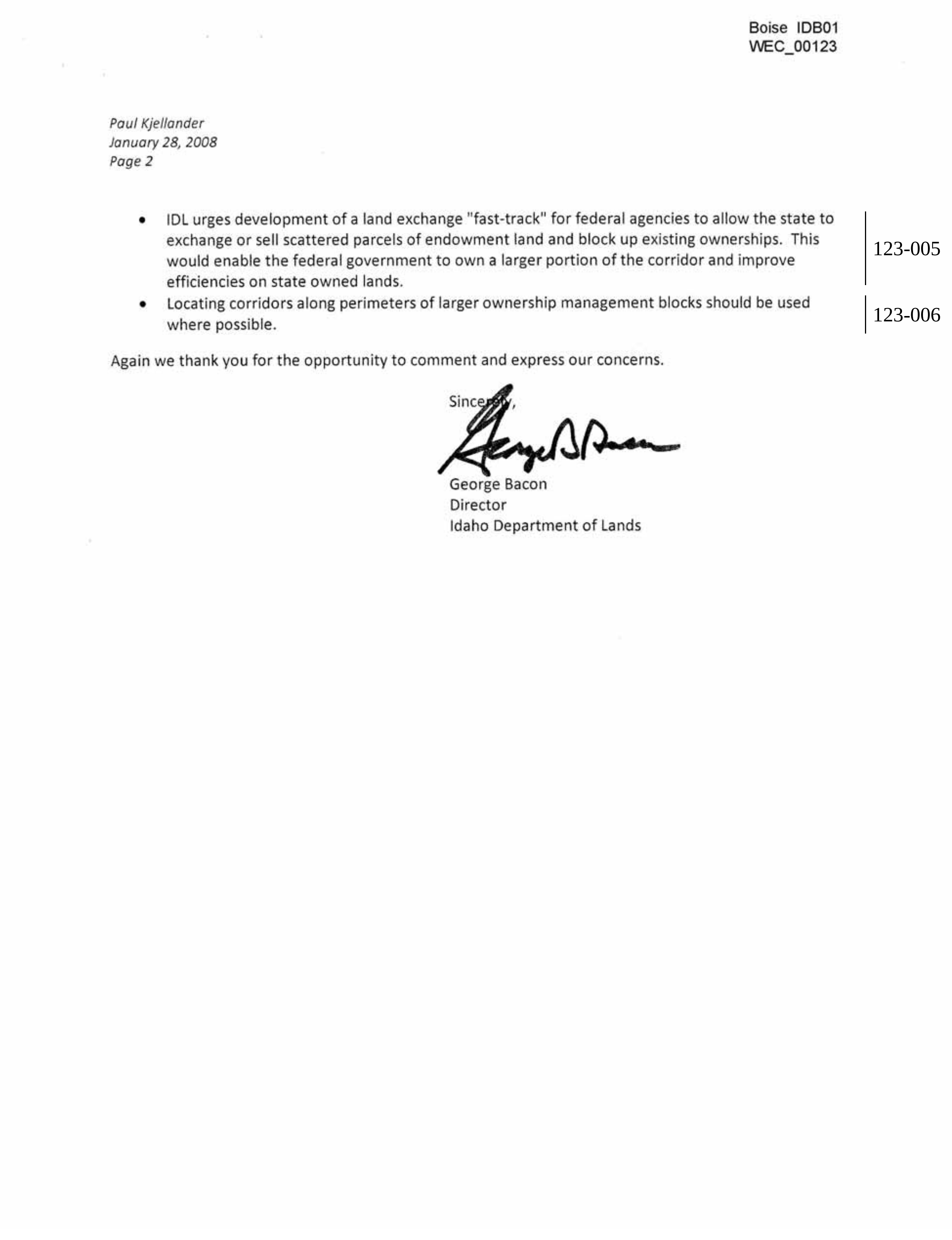
Mr. Paul Kjellander
Administrator
Idaho Office of Energy Resources
PO Box 83720
Boise ID 83720-0098

Dear Mr. Kjellander:

The Department of Lands appreciates the opportunity to participate in the unified State of Idaho response on the nationally important development of a power corridor through the State. As you know, the Idaho Department of Lands has a unique mission within State government as stated in the Idaho Constitution to "....maximize the long-term return to the endowments." This mandate provides the framework for our specific comments, and our comments reflect the need to ensure efficient decision making and processes to meet that mission.

To facilitate your efforts to consolidate the comments from the Idaho stakeholders, we have listed our DEIS comments in the bullet format below:

- The corridor is framed as an entirely negative environmental issue with only a single purpose. We see numerous opportunities to accomplish additional environmentally favorable outcomes such as the ability to create fire resistant fuel breaks once the infrastructure has been installed. This could provide protection not only to communities and man-made improvements, but also provide protection for critical wildlife habitat. 123-001
- Functionality must be the guiding principle of any mitigation within these corridors since it is likely there will be numerous entries for installation of future projects, and routine maintenance will be occurring. Planned, permanent legal access that minimizes the amount of road construction, and allows for legal, all-purpose access for all parties is necessary to fully coordinate efforts in the long-term. 123-002
- The authority to utilize non-native species for re-vegetation of disturbed areas by all parties is needed to take full advantage of opportunities within the corridors. 123-003
- The federal government should fully fund any known additional studies that need to be done for all corridor locations on all ownerships and begin that work as soon as possible. The federal government should not wait until a specific business applies to locate within the corridor. Idaho is only part of this nationwide effort to provide power infrastructure for the security and well being of the nation. 123-004



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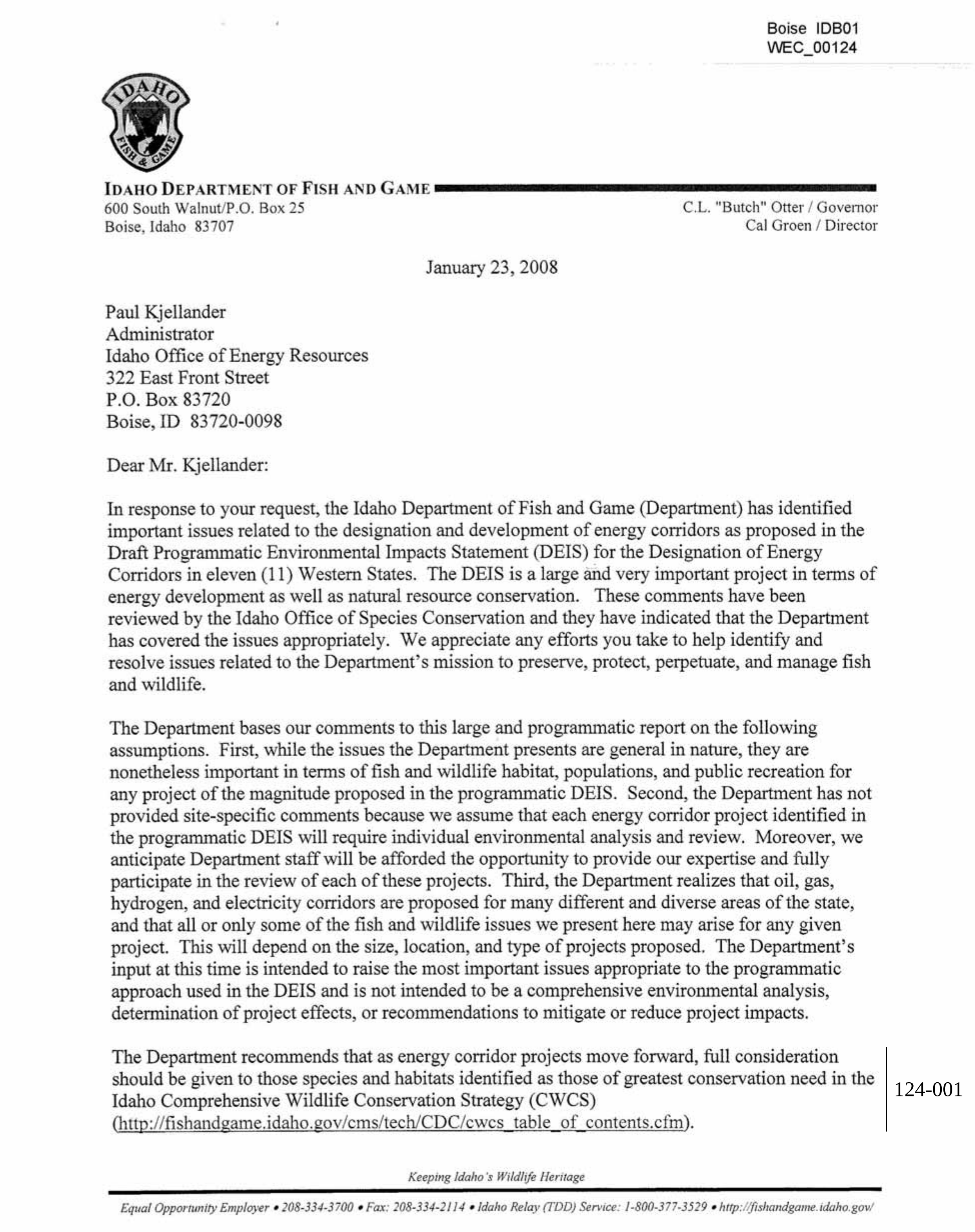
Paul Kjellander
January 28, 2008
Page 2

- IDL urges development of a land exchange "fast-track" for federal agencies to allow the state to exchange or sell scattered parcels of endowment land and block up existing ownerships. This would enable the federal government to own a larger portion of the corridor and improve efficiencies on state owned lands. 123-005
- Locating corridors along perimeters of larger ownership management blocks should be used where possible. 123-006

Again we thank you for the opportunity to comment and express our concerns.

Sincerely,

George Bacon
Director
Idaho Department of Lands



Boise IDB01
WEC_00124

IDAHO DEPARTMENT OF FISH AND GAME
600 South Walnut/P.O. Box 25
Boise, Idaho 83707

C.L. "Butch" Otter / Governor
Cal Groen / Director

January 23, 2008

Paul Kjellander
Administrator
Idaho Office of Energy Resources
322 East Front Street
P.O. Box 83720
Boise, ID 83720-0098

Dear Mr. Kjellander:

In response to your request, the Idaho Department of Fish and Game (Department) has identified important issues related to the designation and development of energy corridors as proposed in the Draft Programmatic Environmental Impacts Statement (DEIS) for the Designation of Energy Corridors in eleven (11) Western States. The DEIS is a large and very important project in terms of energy development as well as natural resource conservation. These comments have been reviewed by the Idaho Office of Species Conservation and they have indicated that the Department has covered the issues appropriately. We appreciate any efforts you take to help identify and resolve issues related to the Department's mission to preserve, protect, perpetuate, and manage fish and wildlife.

The Department bases our comments to this large and programmatic report on the following assumptions. First, while the issues the Department presents are general in nature, they are nonetheless important in terms of fish and wildlife habitat, populations, and public recreation for any project of the magnitude proposed in the programmatic DEIS. Second, the Department has not provided site-specific comments because we assume that each energy corridor project identified in the programmatic DEIS will require individual environmental analysis and review. Moreover, we anticipate Department staff will be afforded the opportunity to provide our expertise and fully participate in the review of each of these projects. Third, the Department realizes that oil, gas, hydrogen, and electricity corridors are proposed for many different and diverse areas of the state, and that all or only some of the fish and wildlife issues we present here may arise for any given project. This will depend on the size, location, and type of projects proposed. The Department's input at this time is intended to raise the most important issues appropriate to the programmatic approach used in the DEIS and is not intended to be a comprehensive environmental analysis, determination of project effects, or recommendations to mitigate or reduce project impacts.

The Department recommends that as energy corridor projects move forward, full consideration should be given to those species and habitats identified as those of greatest conservation need in the Idaho Comprehensive Wildlife Conservation Strategy (CWCS) (http://fishandgame.idaho.gov/cms/tech/CDC/cwcs_table_of_contents.cfm). 124-001

Boise IDB01
WEC_00124

Paul Kjellander
January 23, 2008
Page 2

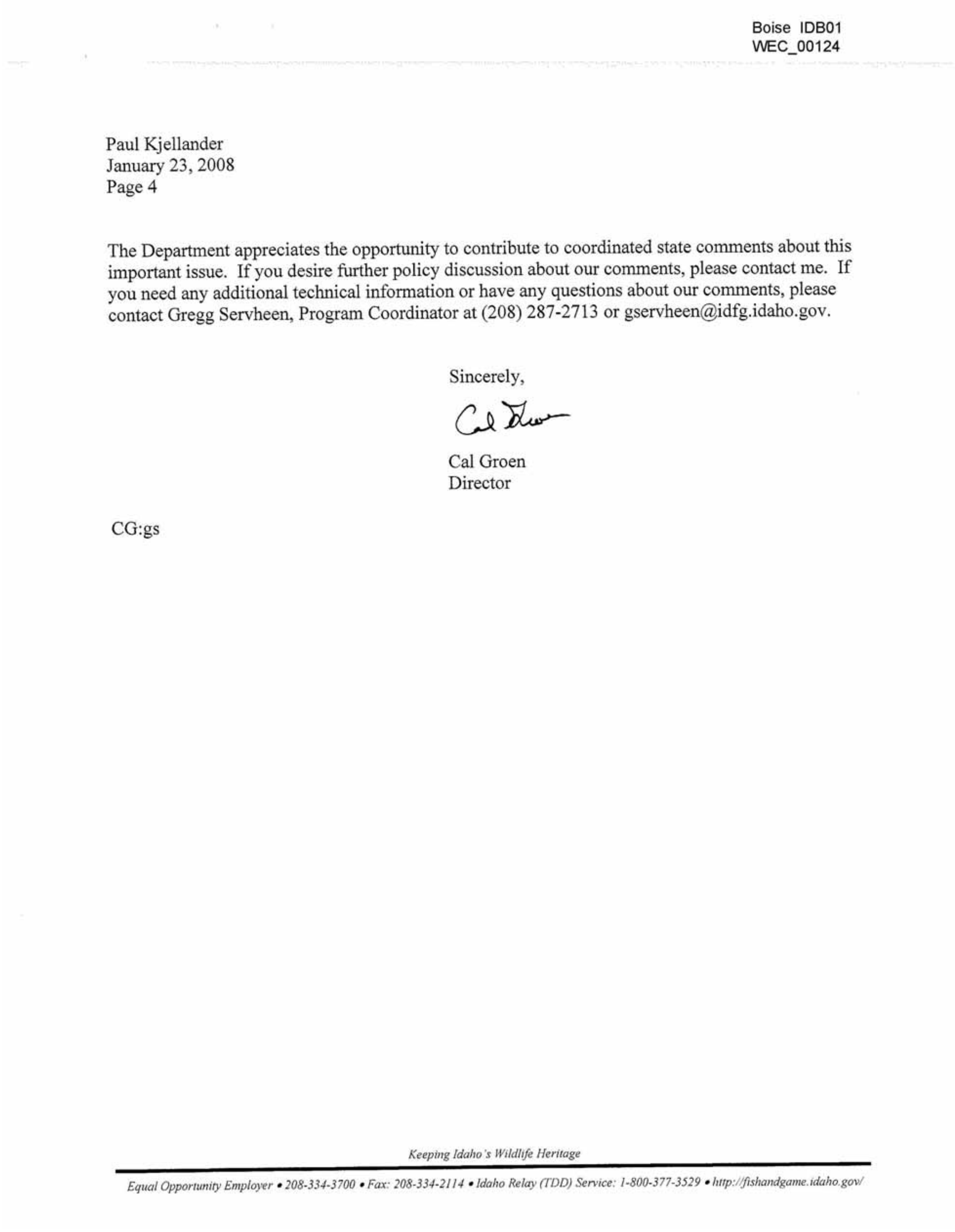
The Department offers the following list of programmatic fish and wildlife issues as considerations relevant to: 1) development of energy corridors in Idaho, 2) project specific and cumulative analyses, and 3) mitigation considerations for their effects.

1. Migration dependent species such as elk, mule deer, moose, pronghorn antelope, bighorn sheep, goats, and caribou may be impacted by development of 3,500-feet wide energy corridors and associated human disturbance within movement areas. 124-002
2. Seasonal ranges of elk, mule deer, moose, pronghorn, bighorn sheep, goats, and caribou may be lost or degraded as a result of habitat modification and human disturbance associated with energy corridor development. 124-003
3. Sage-grouse and sharp-tailed grouse populations and habitats could be affected by corridor development. Grouse may avoid or abandon otherwise suitable breeding habitat, brood areas, and other habitats near tall structures (i.e., towers) or when development within energy corridors degrades or eliminates such habitats. Towers with perching sites for raptors and nesting sites for corvids could result in reduced lek attendance and increased grouse predation and nest depredation rates. 124-004
4. Waterfowl and shorebird high-use areas, including wildlife management areas, national wildlife refuges, and areas of high and concentrated use during spring and fall migration, nesting, and brood rearing seasons, could be affected by energy corridor development. 124-005
5. Waterfowl and shorebird migration routes also may be affected. 124-006
6. Although sparsely documented, seasonal passerine bird migration routes may be affected by electrical transmission corridors, which may also increase mortality of migrating and resident birds. 124-007
7. Bat populations and habitats should be evaluated for direct and indirect impacts resulting from electric transmission corridor development. 124-008
8. Reptile and amphibian populations and habitats, particularly hibernacula, may be directly or indirectly impacted by transmission corridor construction, operation, and maintenance. Impacts to reptile and amphibian species of greatest conservation need should be assessed. 124-009
9. Direct and indirect impacts of transmission corridor construction, operation, and maintenance on resident and migratory raptor populations and habitats should be evaluated. 124-010
10. Loss and fragmentation of pygmy rabbit habitat through direct footprint effects and secondary project effects such as habitat fragmentation should be assessed. 124-011
11. Project effects on large carnivore (including grizzly bear, wolf, mountain lion, lynx, and wolverine) populations and habitats, including linkage corridors and genetic interchange, among the Greater Yellowstone Ecosystem, Central Idaho Wilderness, and grizzly bear recovery areas, should be addressed. 124-012
12. Increased motorized access to winter ranges, especially big game winter ranges, is a concern of the Department in relation to energy corridor development. 124-013
13. Road construction and the potential for increased public access resulting from construction and service roads can negatively impact wildlife and wildlife use of habitats. Road construction and maintenance (or lack thereof) can significantly impact watershed function and stability including fish and other aquatic organism habitats. 124-014

14. Best management practices are necessary to ensure water quality is maintained, disturbance caused by crossings of any perennial and fish bearing waters is minimized, and disturbed instream habitats are restored. Maintaining connectivity for populations of migratory fish is also essential both during and after construction. 124-015
15. The location of the transmission corridors in relation to rare and/or sensitive wildlife habitats including kipukas, lava tubes, caves (natural and man-made), permanent and seasonal wetlands, riparian areas, sensitive and listed plant species, and white-bark pine and old growth forest stands should be evaluated. 124-016
16. The effect of energy corridor construction and development on fire occurrence, frequency, and severity; especially as it relates to important shrub-steppe and forest habitats, should be analyzed. 124-017
17. It is important to avoid fragmentation of large contiguous blocks of wildlife habitats by transmission corridor construction, operation, and maintenance. 124-018
18. Restoration and mitigation of effects due to the project footprint are important to ensure no critical loss of habitat or fish and wildlife populations results from energy corridor development. 124-019
19. Relatively little is known about the wildlife and wildlife habitats in many areas, thus monitoring and evaluation of fish and wildlife resources and habitats is vital. Baseline information about fish and wildlife resources and recreation for any project is necessary to understand and reduce project impacts. Monitoring the effects of corridor projects is also necessary to determine long-term effects and, accordingly, to adaptively manage the design, operation, and mitigation measures of the project. 124-020

The Department recommends that analysis and evaluation of energy corridors include a cumulative effects analysis of impacts to fish and wildlife resources and associated recreation. The sum total of connected and foreseeable project impacts, especially those related to energy and existing infrastructure development may create a different scale of effect on fish and wildlife resources, than from individual projects. In particular, the Department believes a cumulative analysis should evaluate how any project relates to other proposed energy corridor developments, improvements, and facilities and how projects propose to avoid, minimize, and mitigate impacts to fish and wildlife resources and recreation. 124-021

In connection with energy corridor development, the Department recommends consideration, identification, and evaluation of indirect impacts of the project on fish and wildlife resources and associated recreation. Such an analysis might assess effects to recreation and public access, patterns of transportation and other infrastructure development, occurrence and management of noxious and invasive weeds, and occurrence and management of fire. The development and siting of other energy resources including wind, solar, hydropower, and nuclear power facilities need to be considered with this broad corridor context from the perspective of land use and development patterns, and human disturbance and activities. 124-022



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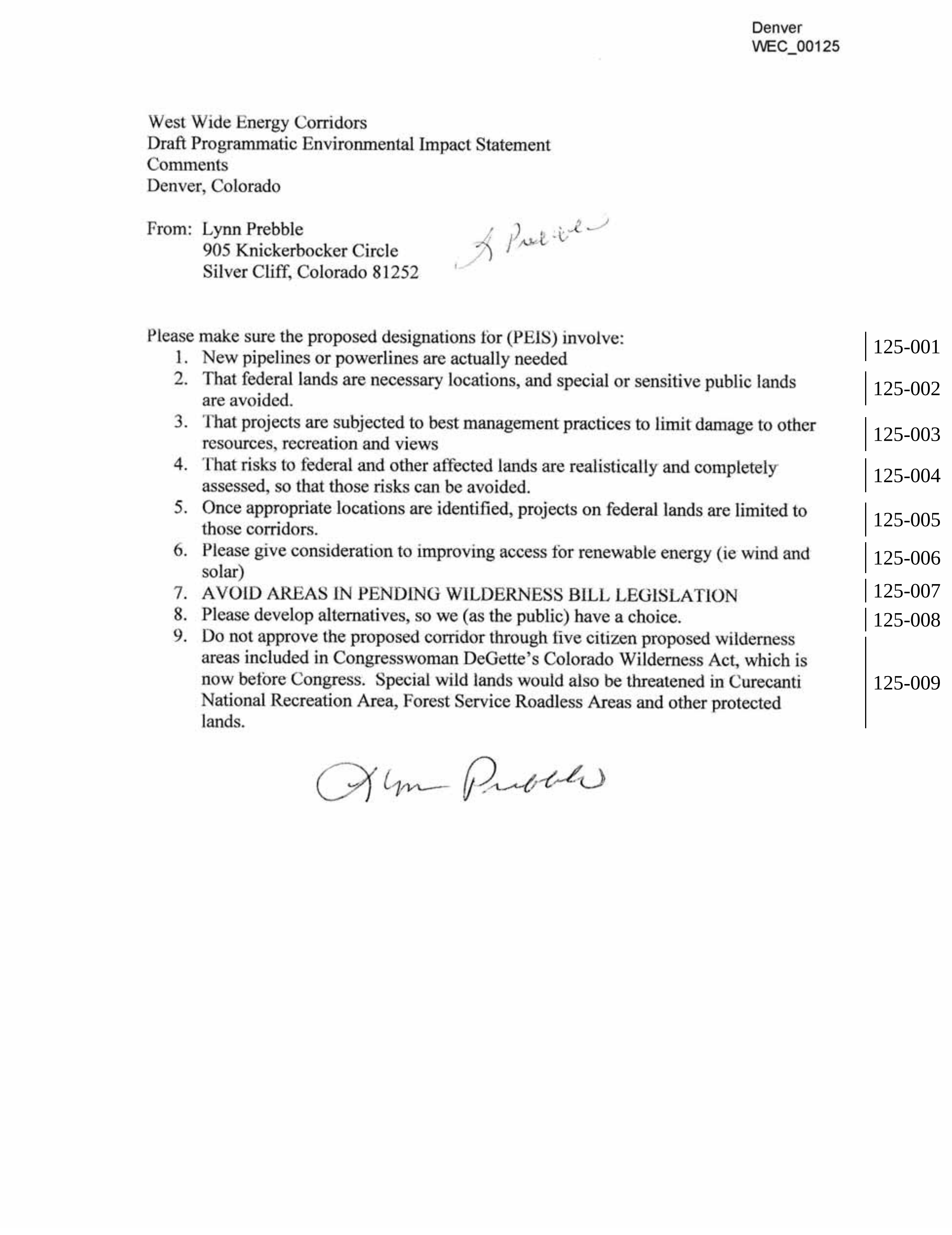
Paul Kjellander
January 23, 2008
Page 4

The Department appreciates the opportunity to contribute to coordinated state comments about this important issue. If you desire further policy discussion about our comments, please contact me. If you need any additional technical information or have any questions about our comments, please contact Gregg Servheen, Program Coordinator at (208) 287-2713 or gservheen@idfg.idaho.gov.

Sincerely,

Cal Groen
Director

CG:gs



Denver
WEC_00125

West Wide Energy Corridors
Draft Programmatic Environmental Impact Statement
Comments
Denver, Colorado

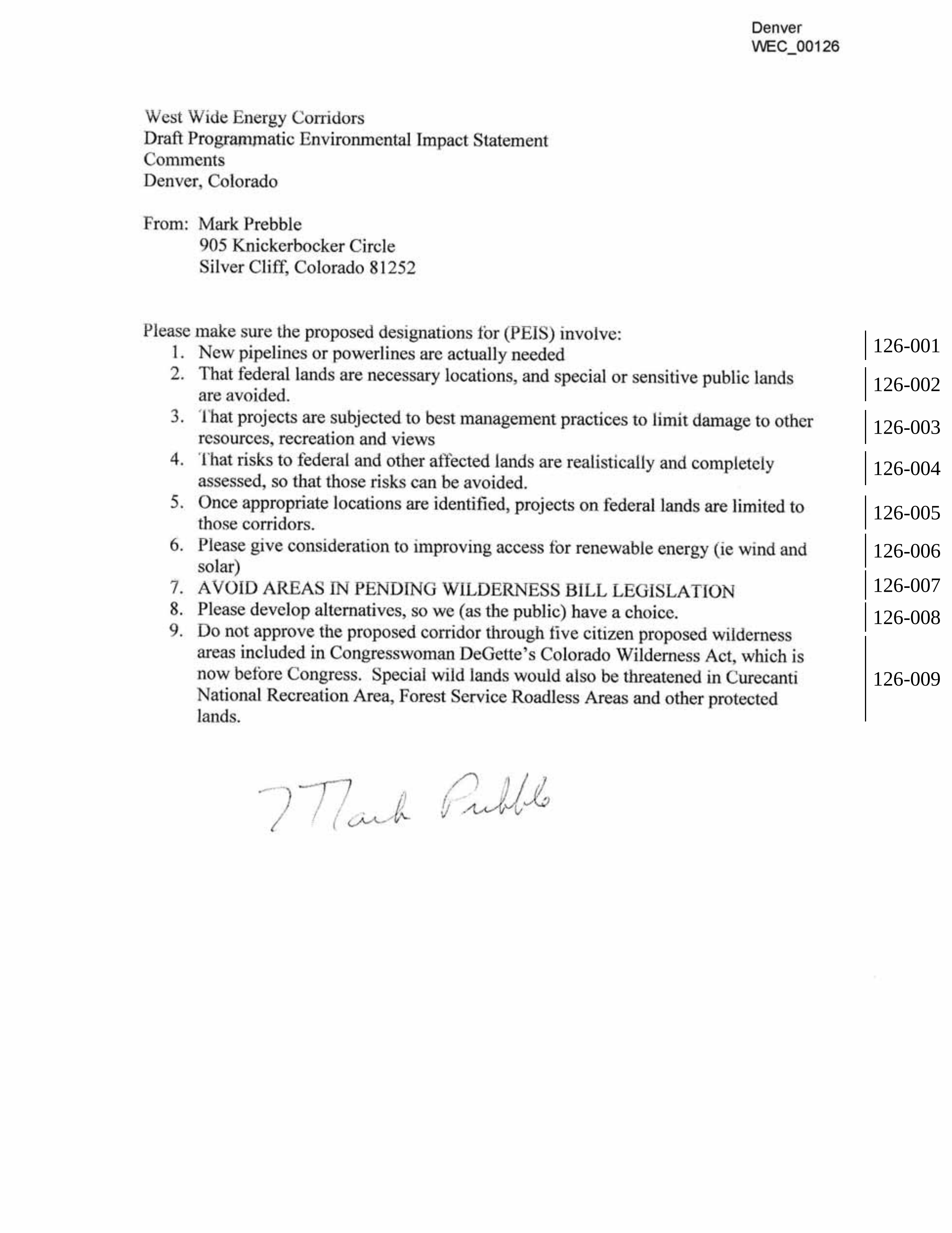
From: Lynn Prebble
905 Knickerbocker Circle
Silver Cliff, Colorado 81252

L Prebble

Please make sure the proposed designations for (PEIS) involve:

1. New pipelines or powerlines are actually needed 125-001
2. That federal lands are necessary locations, and special or sensitive public lands are avoided. 125-002
3. That projects are subjected to best management practices to limit damage to other resources, recreation and views 125-003
4. That risks to federal and other affected lands are realistically and completely assessed, so that those risks can be avoided. 125-004
5. Once appropriate locations are identified, projects on federal lands are limited to those corridors. 125-005
6. Please give consideration to improving access for renewable energy (ie wind and solar) 125-006
7. AVOID AREAS IN PENDING WILDERNESS BILL LEGISLATION 125-007
8. Please develop alternatives, so we (as the public) have a choice. 125-008
9. Do not approve the proposed corridor through five citizen proposed wilderness areas included in Congresswoman DeGette's Colorado Wilderness Act, which is now before Congress. Special wild lands would also be threatened in Curecanti National Recreation Area, Forest Service Roadless Areas and other protected lands. 125-009

Lynn Prebble



Denver
WEC_00126

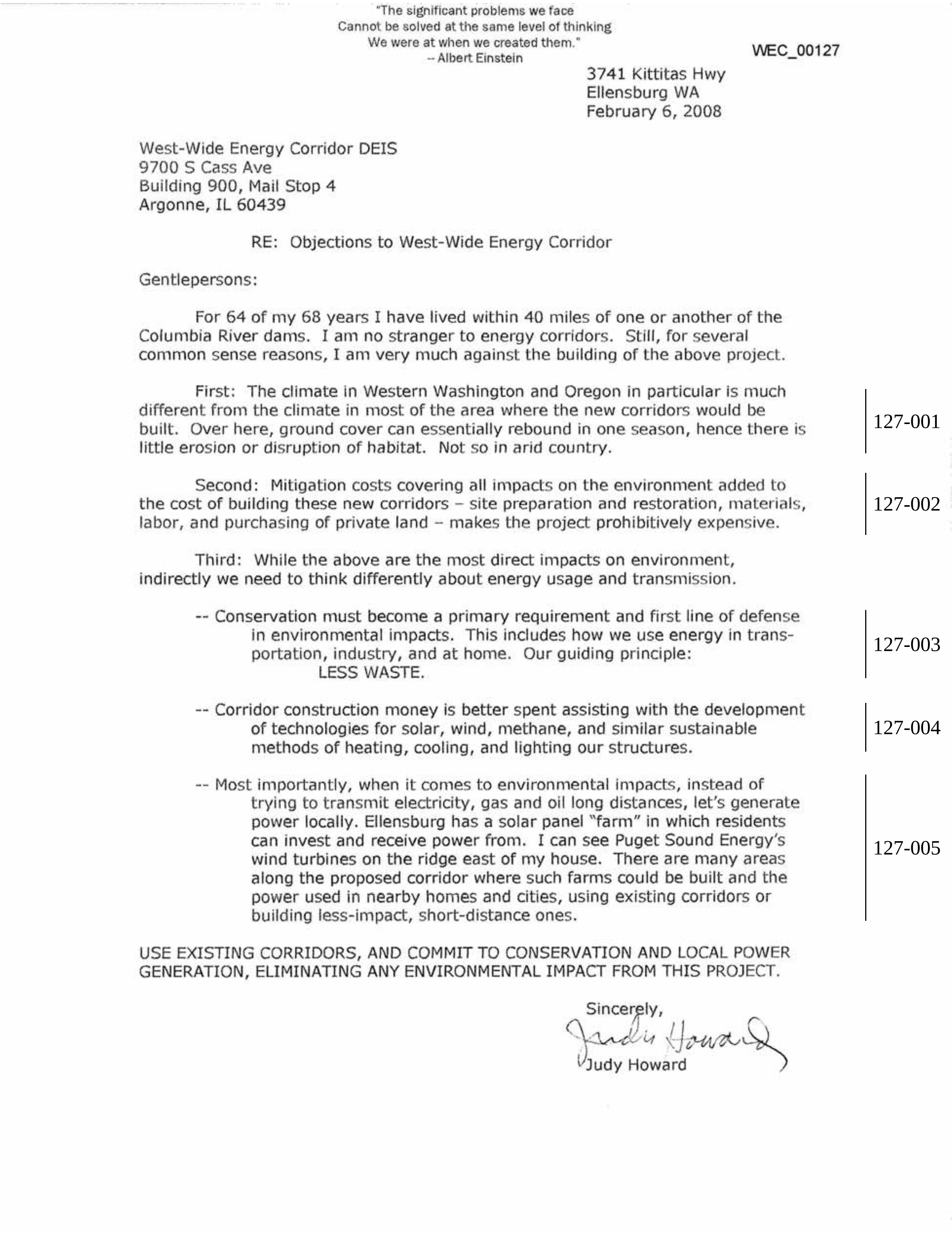
West Wide Energy Corridors
Draft Programmatic Environmental Impact Statement
Comments
Denver, Colorado

From: Mark Prebble
905 Knickerbocker Circle
Silver Cliff, Colorado 81252

Please make sure the proposed designations for (PEIS) involve:

1. New pipelines or powerlines are actually needed 126-001
2. That federal lands are necessary locations, and special or sensitive public lands are avoided. 126-002
3. That projects are subjected to best management practices to limit damage to other resources, recreation and views 126-003
4. That risks to federal and other affected lands are realistically and completely assessed, so that those risks can be avoided. 126-004
5. Once appropriate locations are identified, projects on federal lands are limited to those corridors. 126-005
6. Please give consideration to improving access for renewable energy (ie wind and solar) 126-006
7. AVOID AREAS IN PENDING WILDERNESS BILL LEGISLATION 126-007
8. Please develop alternatives, so we (as the public) have a choice. 126-008
9. Do not approve the proposed corridor through five citizen proposed wilderness areas included in Congresswoman DeGette's Colorado Wilderness Act, which is now before Congress. Special wild lands would also be threatened in Curecanti National Recreation Area, Forest Service Roadless Areas and other protected lands. 126-009

Mark Prebble



"The significant problems we face
Cannot be solved at the same level of thinking
We were at when we created them."
-- Albert Einstein

WEC_00127

3741 Kittitas Hwy
Ellensburg WA
February 6, 2008

West-Wide Energy Corridor DEIS
9700 S Cass Ave
Building 900, Mail Stop 4
Argonne, IL 60439

RE: Objections to West-Wide Energy Corridor

Gentlepersons:

For 64 of my 68 years I have lived within 40 miles of one or another of the Columbia River dams. I am no stranger to energy corridors. Still, for several common sense reasons, I am very much against the building of the above project.

First: The climate in Western Washington and Oregon in particular is much different from the climate in most of the area where the new corridors would be built. Over here, ground cover can essentially rebound in one season, hence there is little erosion or disruption of habitat. Not so in arid country. 127-001

Second: Mitigation costs covering all impacts on the environment added to the cost of building these new corridors – site preparation and restoration, materials, labor, and purchasing of private land – makes the project prohibitively expensive. 127-002

Third: While the above are the most direct impacts on environment, indirectly we need to think differently about energy usage and transmission.

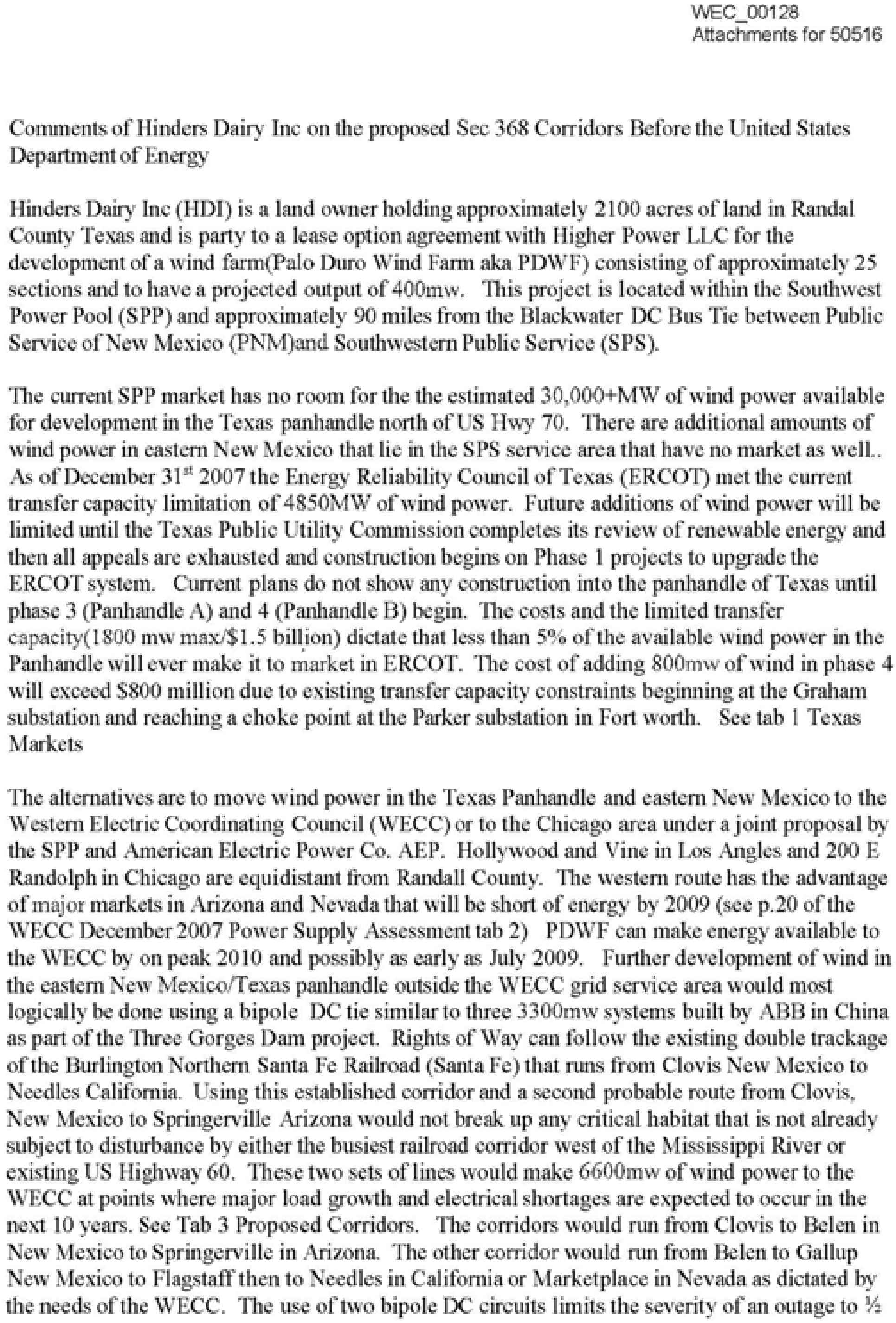
-- Conservation must become a primary requirement and first line of defense in environmental impacts. This includes how we use energy in transportation, industry, and at home. Our guiding principle:
LESS WASTE. 127-003

-- Corridor construction money is better spent assisting with the development of technologies for solar, wind, methane, and similar sustainable methods of heating, cooling, and lighting our structures. 127-004

-- Most importantly, when it comes to environmental impacts, instead of trying to transmit electricity, gas and oil long distances, let's generate power locally. Ellensburg has a solar panel "farm" in which residents can invest and receive power from. I can see Puget Sound Energy's wind turbines on the ridge east of my house. There are many areas along the proposed corridor where such farms could be built and the power used in nearby homes and cities, using existing corridors or building less-impact, short-distance ones. 127-005

USE EXISTING CORRIDORS, AND COMMIT TO CONSERVATION AND LOCAL POWER GENERATION, ELIMINATING ANY ENVIRONMENTAL IMPACT FROM THIS PROJECT.

Sincerely,
Judy Howard
Judy Howard



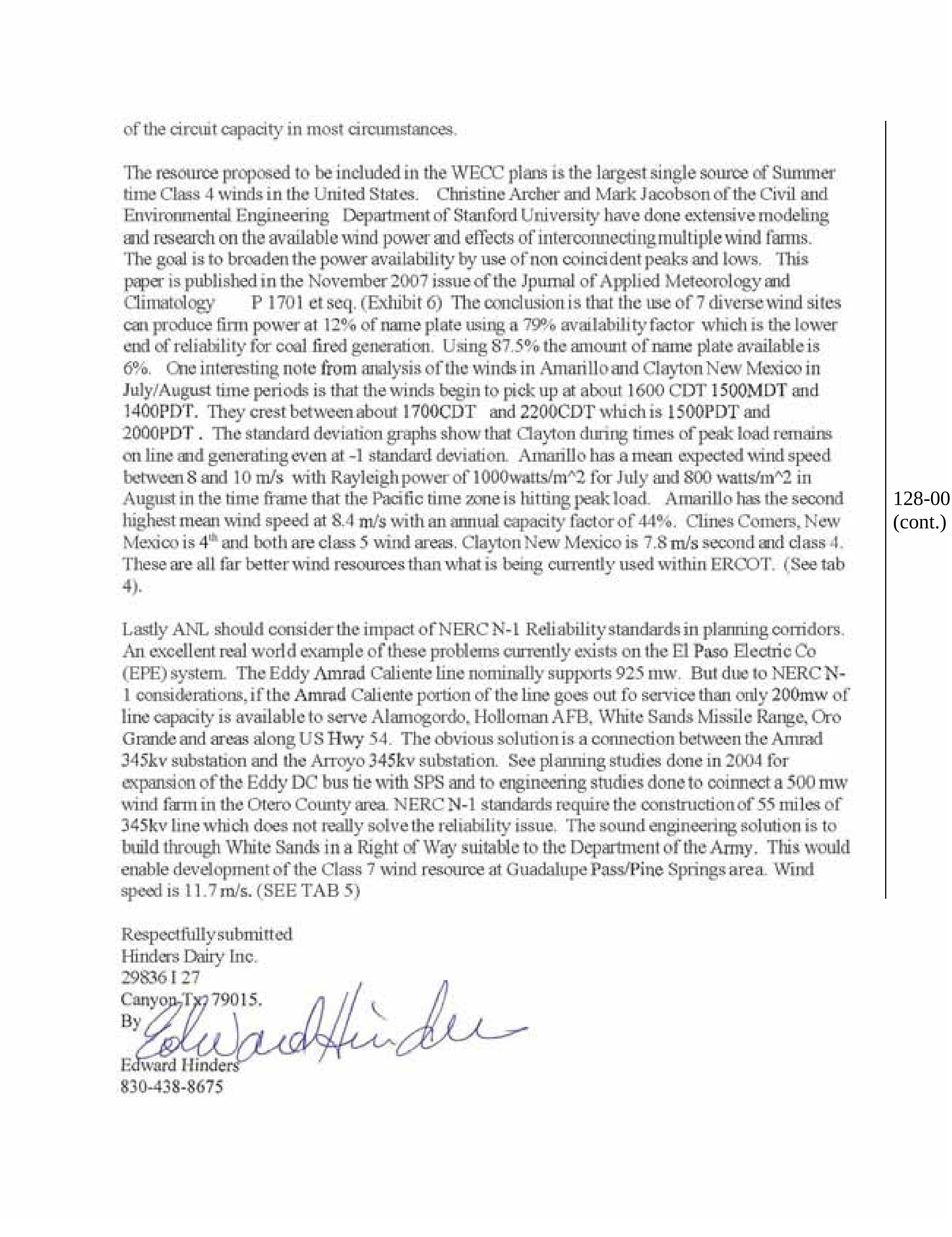
WEC_00128
Attachments for 50516

Comments of Hinders Dairy Inc on the proposed Sec 368 Corridors Before the United States Department of Energy

Hinders Dairy Inc (HDI) is a land owner holding approximately 2100 acres of land in Randal County Texas and is party to a lease option agreement with Higher Power LLC for the development of a wind farm(Palo Duro Wind Farm aka PDWF) consisting of approximately 25 sections and to have a projected output of 400mw. This project is located within the Southwest Power Pool (SPP) and approximately 90 miles from the Blackwater DC Bus Tie between Public Service of New Mexico (PNM)and Southwestern Public Service (SPS).

The current SPP market has no room for the the estimated 30,000+MW of wind power available for development in the Texas panhandle north of US Hwy 70. There are additional amounts of wind power in eastern New Mexico that lie in the SPS service area that have no market as well.. As of December 31st 2007 the Energy Reliability Council of Texas (ERCOT) met the current transfer capacity limitation of 4850MW of wind power. Future additions of wind power will be limited until the Texas Public Utility Commission completes its review of renewable energy and then all appeals are exhausted and construction begins on Phase 1 projects to upgrade the ERCOT system. Current plans do not show any construction into the panhandle of Texas until phase 3 (Panhandle A) and 4 (Panhandle B) begin. The costs and the limited transfer capacity(1800 mw max/$1.5 billion) dictate that less than 5% of the available wind power in the Panhandle will ever make it to market in ERCOT. The cost of adding 800mw of wind in phase 4 will exceed $800 million due to existing transfer capacity constraints beginning at the Graham substation and reaching a choke point at the Parker substation in Fort worth. See tab 1 Texas Markets

The alternatives are to move wind power in the Texas Panhandle and eastern New Mexico to the Western Electric Coordinating Council (WECC) or to the Chicago area under a joint proposal by the SPP and American Electric Power Co. AEP. 128-001 Hollywood and Vine in Los Angles and 200 E Randolph in Chicago are equidistant from Randall County. The western route has the advantage of major markets in Arizona and Nevada that will be short of energy by 2009 (see p.20 of the WECC December 2007 Power Supply Assessment tab 2) PDWF can make energy available to the WECC by on peak 2010 and possibly as early as July 2009. Further development of wind in the eastern New Mexico/Texas panhandle outside the WECC grid service area would most logically be done using a bipole DC tie similar to three 3300mw systems built by ABB in China as part of the Three Gorges Dam project. Rights of Way can follow the existing double trackage of the Burlington Northern Santa Fe Railroad (Santa Fe) that runs from Clovis New Mexico to Needles California. Using this established corridor and a second probable route from Clovis, New Mexico to Springerville Arizona would not break up any critical habitat that is not already subject to disturbance by either the busiest railroad corridor west of the Mississippi River or existing US Highway 60. These two sets of lines would make 6600mw of wind power to the WECC at points where major load growth and electrical shortages are expected to occur in the next 10 years. See Tab 3 Proposed Corridors. The corridors would run from Clovis to Belen in New Mexico to Springerville in Arizona. The other corridor would run from Belen to Gallup New Mexico to Flagstaff then to Needles in California or Marketplace in Nevada as dictated by the needs of the WECC. The use of two bipole DC circuits limits the severity of an outage to ½



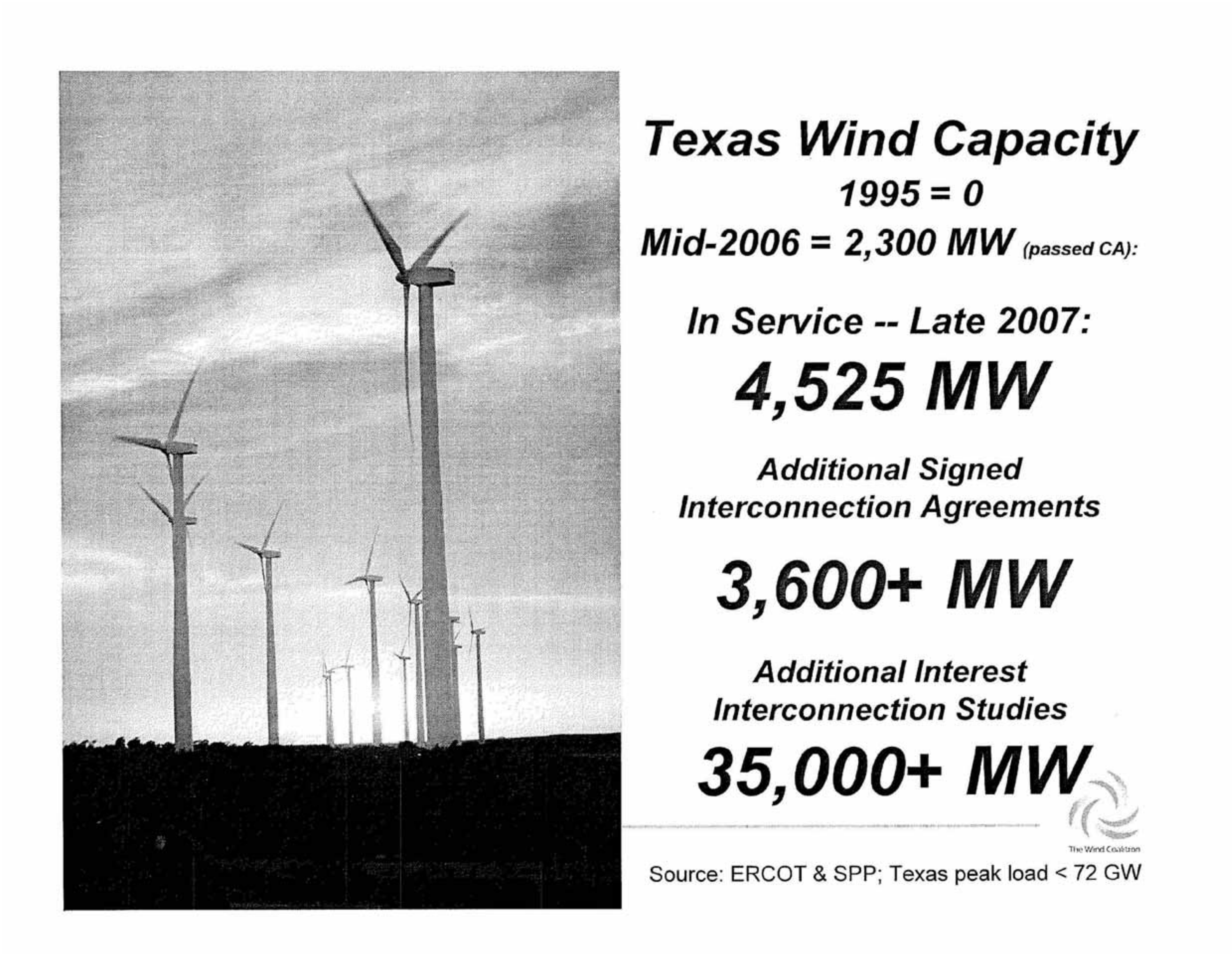
of the circuit capacity in most circumstances.

The resource proposed to be included in the WECC plans is the largest single source of Summer time Class 4 winds in the United States. Christine Archer and Mark Jacobson of the Civil and Environmental Engineering Department of Stanford University have done extensive modeling and research on the available wind power and effects of interconnecting multiple wind farms. The goal is to broaden the power availability by use of non coincident peaks and lows. This paper is published in the November 2007 issue of the Jpurnal of Applied Meteorology and Climatology P 1701 et seq. (Exhibit 6) The conclusion is that the use of 7 diverse wind sites can produce firm power at 12% of name plate using a 79% availability factor which is the lower end of reliability for coal fired generation. Using 87.5% the amount of name plate available is 6%. One interesting note from analysis of the winds in Amarillo and Clayton New Mexico in July/August time periods is that the winds begin to pick up at about 1600 CDT 1500MDT and 1400PDT. They crest between about 1700CDT and 2200CDT which is 1500PDT and 2000PDT . The standard deviation graphs show that Clayton during times of peak load remains on line and generating even at -1 standard deviation. Amarillo has a mean expected wind speed between 8 and 10 m/s with Rayleigh power of 1000watts/m^2 for July and 800 watts/m^2 in August in the time frame that the Pacific time zone is hitting peak load. Amarillo has the second highest mean wind speed at 8.4 m/s with an annual capacity factor of 44%. Clines Comers, New Mexico is 4th and both are class 5 wind areas. Clayton New Mexico is 7.8 m/s second and class 4. These are all far better wind resources than what is being currently used within ERCOT. (See tab 4).

128-001
(cont.)

Lastly ANL should consider the impact of NERC N-1 Reliability standards in planning corridors. An excellent real world example of these problems currently exists on the El Paso Electric Co (EPE) system. The Eddy Amrad Caliente line nominally supports 925 mw. But due to NERC N-1 considerations, if the Amrad Caliente portion of the line goes out fo service than only 200mw of line capacity is available to serve Alamogordo, Holloman AFB, White Sands Missile Range, Oro Grande and areas along US Hwy 54. The obvious solution is a connection between the Amrad 345kv substation and the Arroyo 345kv substation. See planning studies done in 2004 for expansion of the Eddy DC bus tie with SPS and to engineering studies done to coinnect a 500 mw wind farm in the Otero County area. NERC N-1 standards require the construction of 55 miles of 345kv line which does not really solve the reliability issue. The sound engineering solution is to build through White Sands in a Right of Way suitable to the Department of the Army. This would enable development of the Class 7 wind resource at Guadalupe Pass/Pine Springs area. Wind speed is 11.7 m/s. (SEE TAB 5)

Respectfully submitted
Hinders Dairy Inc.
29836 I 27
Canyon Tx. 79015.
By Edward Hinders
Edward Hinders
830-438-8675



Texas Wind Capacity

1995 = 0

Mid-2006 = 2,300 MW *(passed CA):*

In Service -- Late 2007:

4,525 MW

Additional Signed Interconnection Agreements

3,600+ MW

Additional Interest Interconnection Studies

35,000+ MW

The Wind Coalition

Source: ERCOT & SPP; Texas peak load < 72 GW of SPP have specified that their proposed long-range system upgrades will allow transfer of up to 600 MW from the Texas panhandle to the Sunnyside substation. Given the transmission upgrade shown in Figure 18, the ERCOT transmission system would be capable of supporting a 600 MW injection at this location.

The third level of transmission solution for Panhandle wind resources combines level 1, described above, and the Level 1 solution for Central Texas wind resources, also described above. The panhandle portion of this option is depicted in Figure 19 (the additional improvements would correspond to those depicted in Figure 12). This c[redacted]on includes all of the upgrades described as part of level 1 for the Panhandle Region, all of the upgrades included in the Level 1 alternative for Central Western Texas, as well as 70 miles of new transmission line from zone 2 to zone 10. The estimated cost of this option is $715 million.

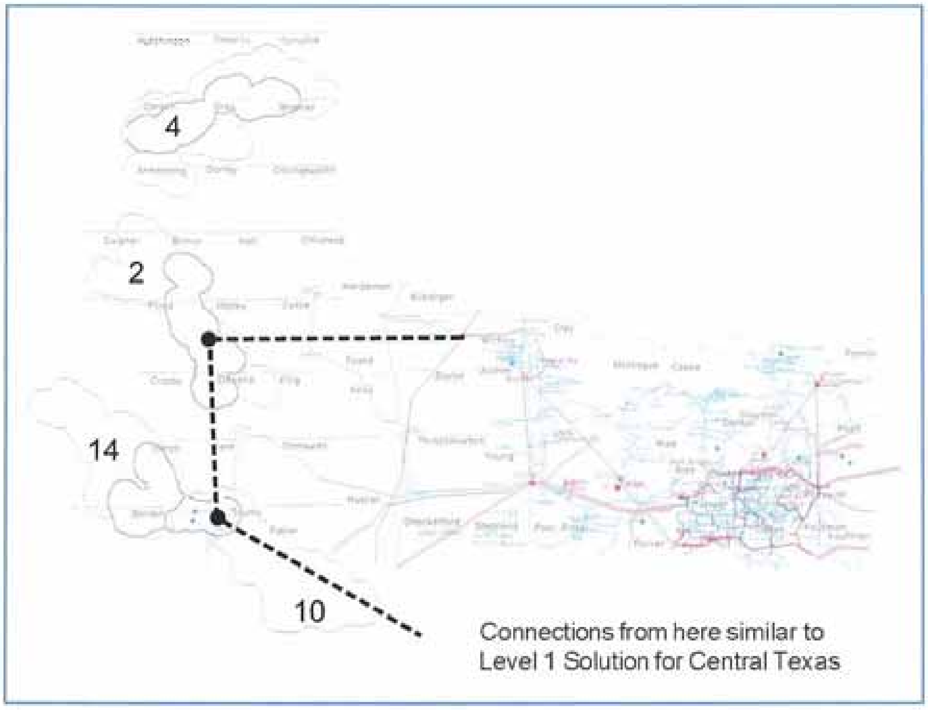
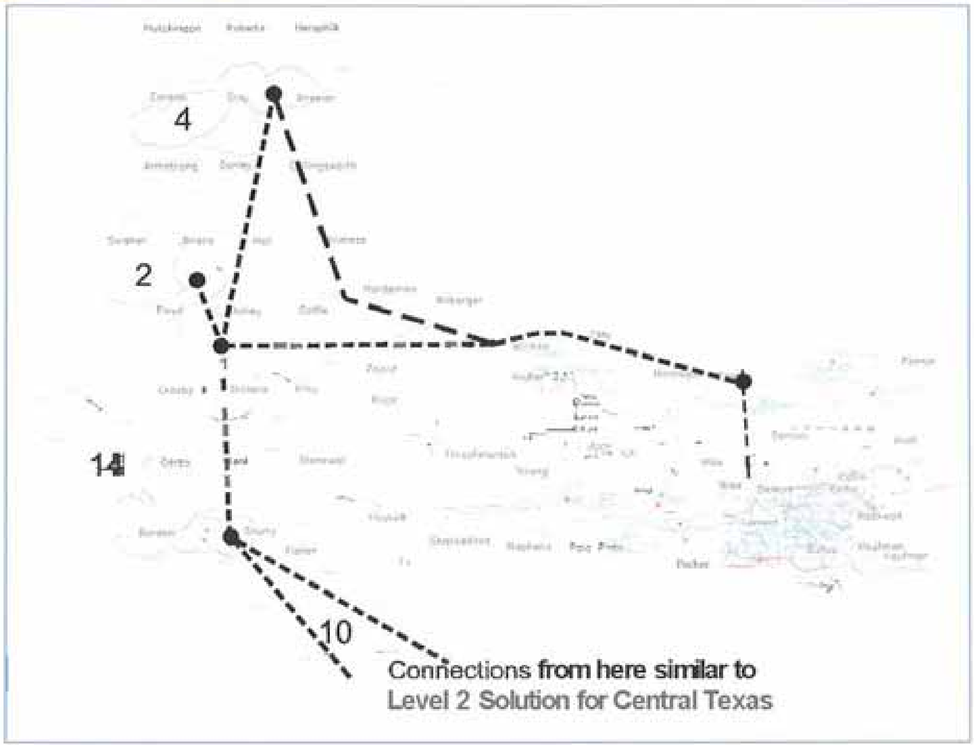


Figure 19: Third Level of Transmission Solution for Panhandle Wind Resources

The fourth level of transmission solution developed for Panhandle wind resources incorporates the improvements described in Levels 2 and 3 above (see Figure 18) along with the improvements included in both the Bluff Creek to Bosque option and the Red Creek to Hill Country option. This fourth Panhandle solution also includes the construction of a loop from the Oklaunion substation northwest up to Zone 4, and then southwest to Zone 2. This option is depicted in Figure 20. Its estimated cost includes the combined costs of the Red Creek and Bluff Creek options ($700 million), the cost of Level 2 described above ($645 million) as well as 170 miles of new 345 circuit (from zone 4 to zone 2, and from zone 2 to zone 10) for a total of $1,515 million.



Connections from here similar to Level 2 Solution for Central Texas

Figure 20: Fourth Level of Transmission Solution for Panhandle Region

5. Combination Scenarios

It is possible that the PUCT, after taking into account some type of commitment of interest by wind generation developers, will choose to designate some level of CREZ in more than one of the four discrete areas. It was not feasible to anticipate and evaluate all potential combinations of possible wind development interest in each zone within the available time. Therefore,

VI. DISCUSSION

A. Comparison of Alternatives

The analysis described in this report has indicated a need for additional pathways between areas with significant wind resources, most notably areas west of Abilene, and significant load centers, generally along and east of the Interstate 35 corridor. The existing ERCOT 345-kV system generally resembles V rotated towards the left, with one side of the V extending from Odessa to the Dallas/Fort Worth area, and the other side made up of the relatively integrated system covering a triangular area with Dallas, San Antonio and Houston at the vertices.

Results from the base case of this study, which includes 4,850 MW of wind capacity in West Texas, indicate that in the vicinity of the vertex of this inverted V, near Fort Worth, the 345-kV system is supporting about as much wind generation as it can. The transmission system generally from the Oklaunion substation south through the Graham substation and to the Parker substation cannot support any significant new additions of wind generation beyond what the 4,850 MW in the base case (although it should be noted that this amount includes approximately 1,500 MW of proxy wind generation for which there is not signed interconnection agreements). This leads to the main result of this study: that there is a need for more corridors that cross the divide of this inverted V, i.e., corridors that run generally from West Texas to the east and southeast, rather than northeast towards Fort Worth.

It is also noteworthy that although the 345-kV system in East Texas is well-developed, there are several areas of significant load growth on the western side of this area that are not served by any 345-kV circuits. This is the case in the Hill Country, from northwest San Antonio to Killeen, where significant load growth is currently projected to be served only by the existing 138-kV system. Areas such as this can be good locations for end points for lines originating in the wind generation zones because they have sufficient load to absorb the output of new wind generation. However, because there is no existing 345-kV infrastructure in these areas, additional circuits must be planned so that the injection of wind energy does not exceed the capacity of the existing 138-kV system.

This study also shows that the existing congestion in the area from Oklaunion to the Parker substation significantly limits additional power-flows in this area, even with the addition of new circuits. Even with significant upgrades on the lines from Oklaunion to Parker, the system in that area can only support 800 MW of new wind generation capacity. With an additional new circuit from Oklaunion to north Dallas (terminating at the proposed West Krum substation), only an additional 1,000 MW of wind capacity can be supported (for a total of 1,800 MW). Because the existing system is being utilized near its limitations, incremental additions in this area do not provide significant amounts of additional transfer capability.

The exact opposite situation exists near the Gulf Coast, where there is no existing wind generation, so very few system improvements must be made in order to support the first incremental amounts of wind. However, there are currently over 4,000 MW of wind generation in the ERCOT interconnection queue in South Texas. If all of these projects are developed, the total capacity would exceed the three levels of system upgrades that have been identified during this study.

B. Economic Considerations

It is a common simplification of open markets to assume that the consumer will eventually pay for all resources required to supply a product. In the case of electricity, the consumer will eventually pay for all of the resources required to produce and to transport the electricity. In other words, the consumer will pay for the capital to build the generator, the fuel to run the generator and the transmission system designed to serve loads securely.

It is important to consider that the consumer will have to pay for the capital costs of wind generation, in addition to the transmission costs that have been estimated as part of this analysis. The same can be said for all generation technologies. The comparison of the total costs of wind energy to the total costs of other technologies is beyond the scope of this study. Quantifying the other benefits from renewable technologies, such as human health impacts from reduced fossil-fuel emissions, increased fuel diversity, reduced reliance on natural gas generation, impacts of reduced demand on related markets (such as natural gas and coal), benefits from economic development, to name a few, are also beyond the scope of this study.

This study examines one aspect of designating Competitive Renewable Energy Zones, specifically what are the most cost-effective solutions to improve the transmission system and allow transportation of additional wind energy from high wind zones to customer load while maintaining system security. The results provided in this document should not be viewed as documenting all costs or all benefits to consumers associated with CREZ designations.

C. Impact of Wind Curtailment

Defining the amount of new wind generation that can be added to the system, given a specific transmission solution, is contingent on the answer to the question of how much wind curtailment is acceptable. Unfortunately, wind curtailment is a complicated issue.

First and foremost, curtailment of energy to relieve transmission congestion can represent a significant economic impact to a wind project, since the owner of a wind project relies on

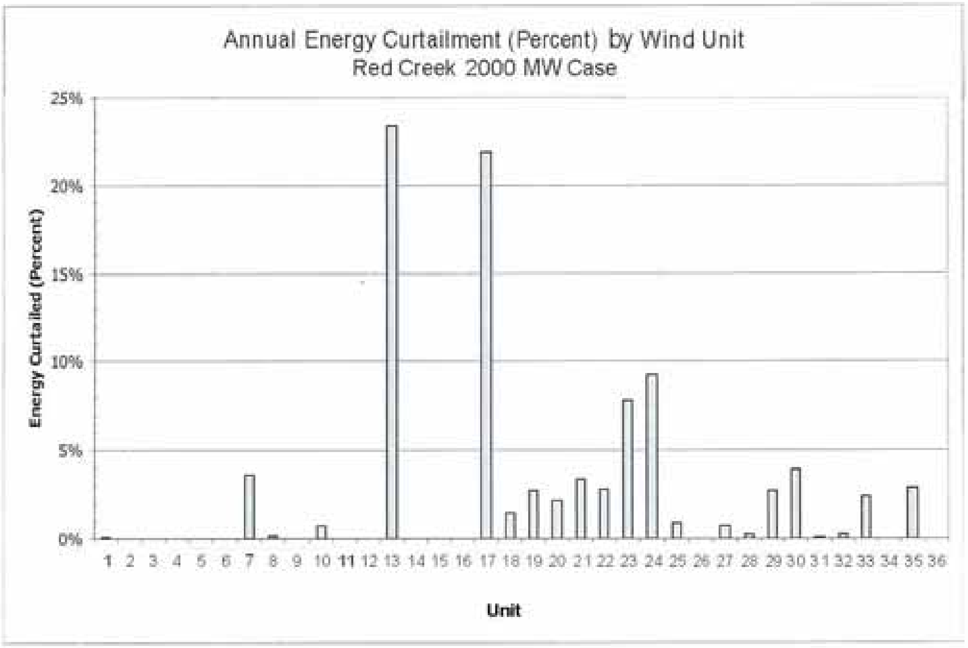
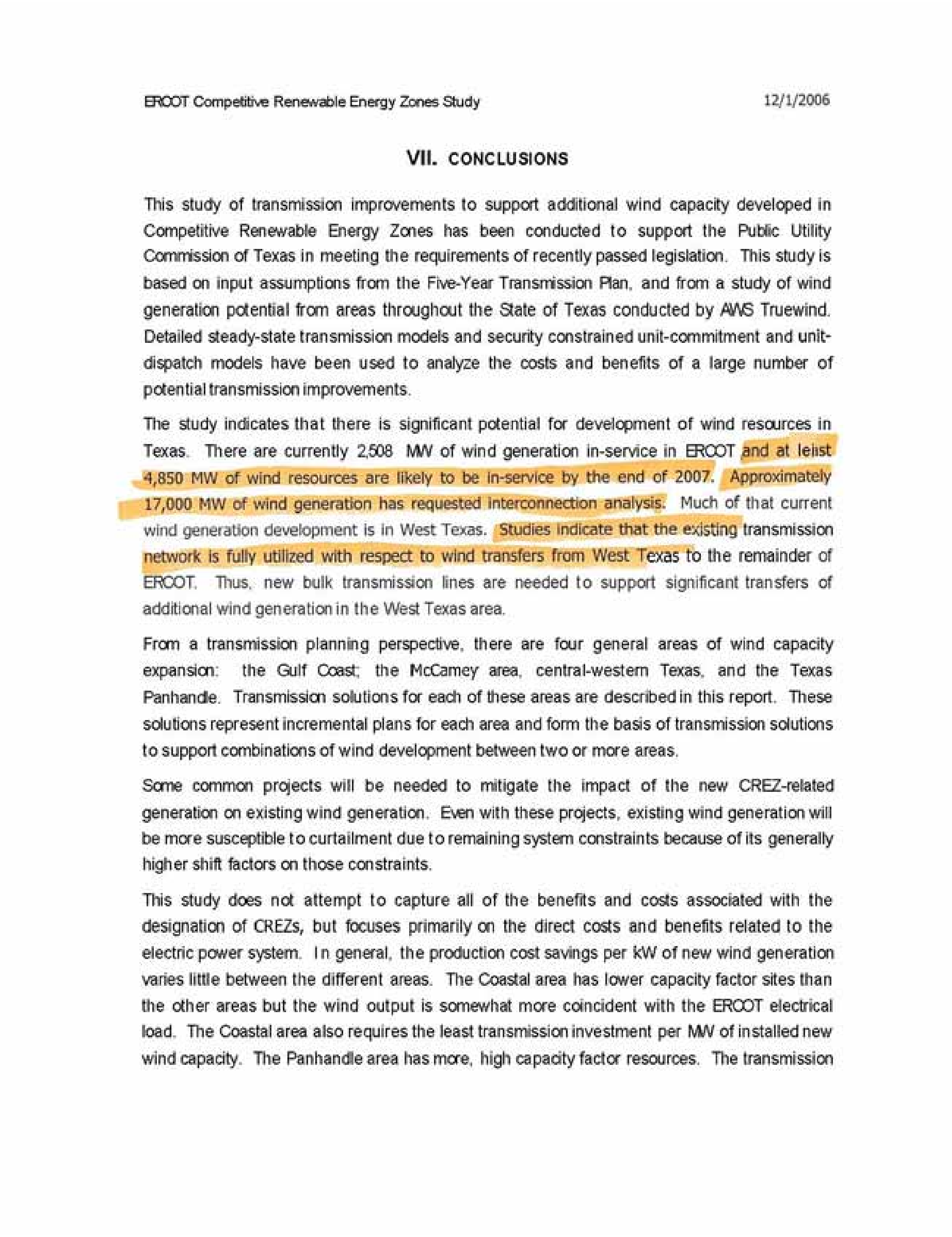


Figure 19: Wind Energy Curtailment by Unit

The established transmission planning process conducted by ERCOT System Planning through the development of the Five-Year Plan will include an evaluation of all constraints on existing wind generators. Economically feasible projects will be proposed to stakeholders and evaluated through the Regional Planning process. Remaining constraints that cannot be resolved through the economic planning process may need to be reevaluated by the PUCT as part of future iterations of the CREZ designation process.

D. Additional Wind Added to the System

One of the most important assumptions used in this study is the amount and location of wind in the base case. These 4,850 MW of "base-case wind units" are comprised of wind units that are currently in operation, wind projects that are under development and for which there is a signed interconnection agreement, and a set of proxy units, representing a small fraction of the wind generation projects that are currently in the ERCOT interconnection queue. Of these



VII. CONCLUSIONS

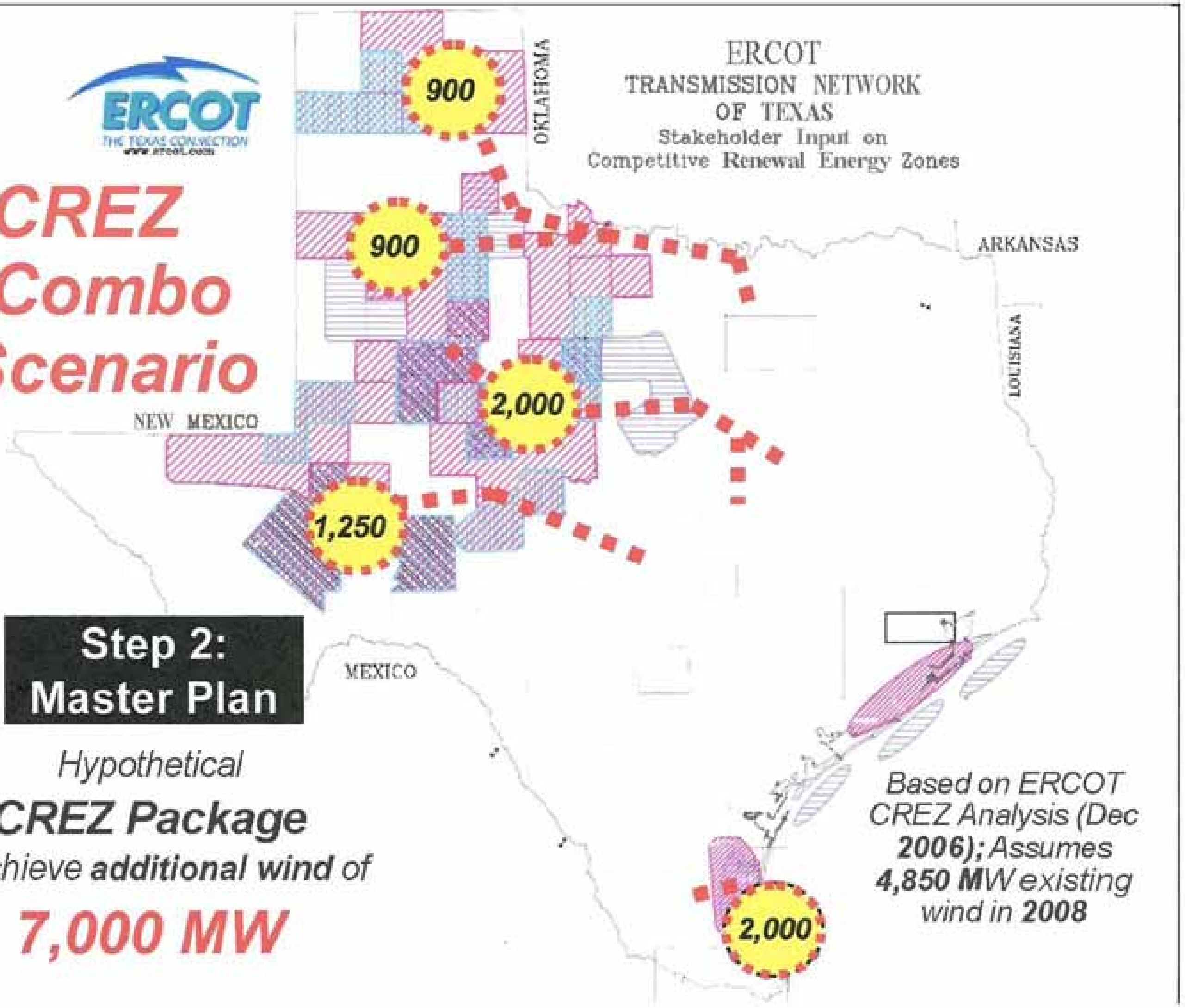
This study of transmission improvements to support additional wind capacity developed in Competitive Renewable Energy Zones has been conducted to support the Public Utility Commission of Texas in meeting the requirements of recently passed legislation. This study is based on input assumptions from the Five-Year Transmission Plan, and from a study of wind generation potential from areas throughout the State of Texas conducted by AWS Truewind. Detailed steady-state transmission models and security constrained unit-commitment and unit-dispatch models have been used to analyze the costs and benefits of a large number of potential transmission improvements.

The study indicates that there is significant potential for development of wind resources in Texas. There are currently 2,508 MW of wind generation in-service in ERCOT and at least 4,850 MW of wind resources are likely to be in-service by the end of 2007. Approximately 17,000 MW of wind generation has requested interconnection analysis. Much of that current wind generation development is in West Texas. Studies indicate that the existing transmission network is fully utilized with respect to wind transfers from West Texas to the remainder of ERCOT. Thus, new bulk transmission lines are needed to support significant transfers of additional wind generation in the West Texas area.

From a transmission planning perspective, there are four general areas of wind capacity expansion: the Gulf Coast; the McCamey area, central-western Texas, and the Texas Panhandle. Transmission solutions for each of these areas are described in this report. These solutions represent incremental plans for each area and form the basis of transmission solutions to support combinations of wind development between two or more areas.

Some common projects will be needed to mitigate the impact of the new CREZ-related generation on existing wind generation. Even with these projects, existing wind generation will be more susceptible to curtailment due to remaining system constraints because of its generally higher shift factors on those constraints.

This study does not attempt to capture all of the benefits and costs associated with the designation of CREZs, but focuses primarily on the direct costs and benefits related to the electric power system. In general, the production cost savings per kW of new wind generation varies little between the different areas. The Coastal area has lower capacity factor sites than the other areas but the wind output is somewhat more coincident with the ERCOT electrical load. The Coastal area also requires the least transmission investment per MW of installed new wind capacity. The Panhandle area has more, high capacity factor resources. The transmission



CREZ Combo Scenario

Step 2: Master Plan

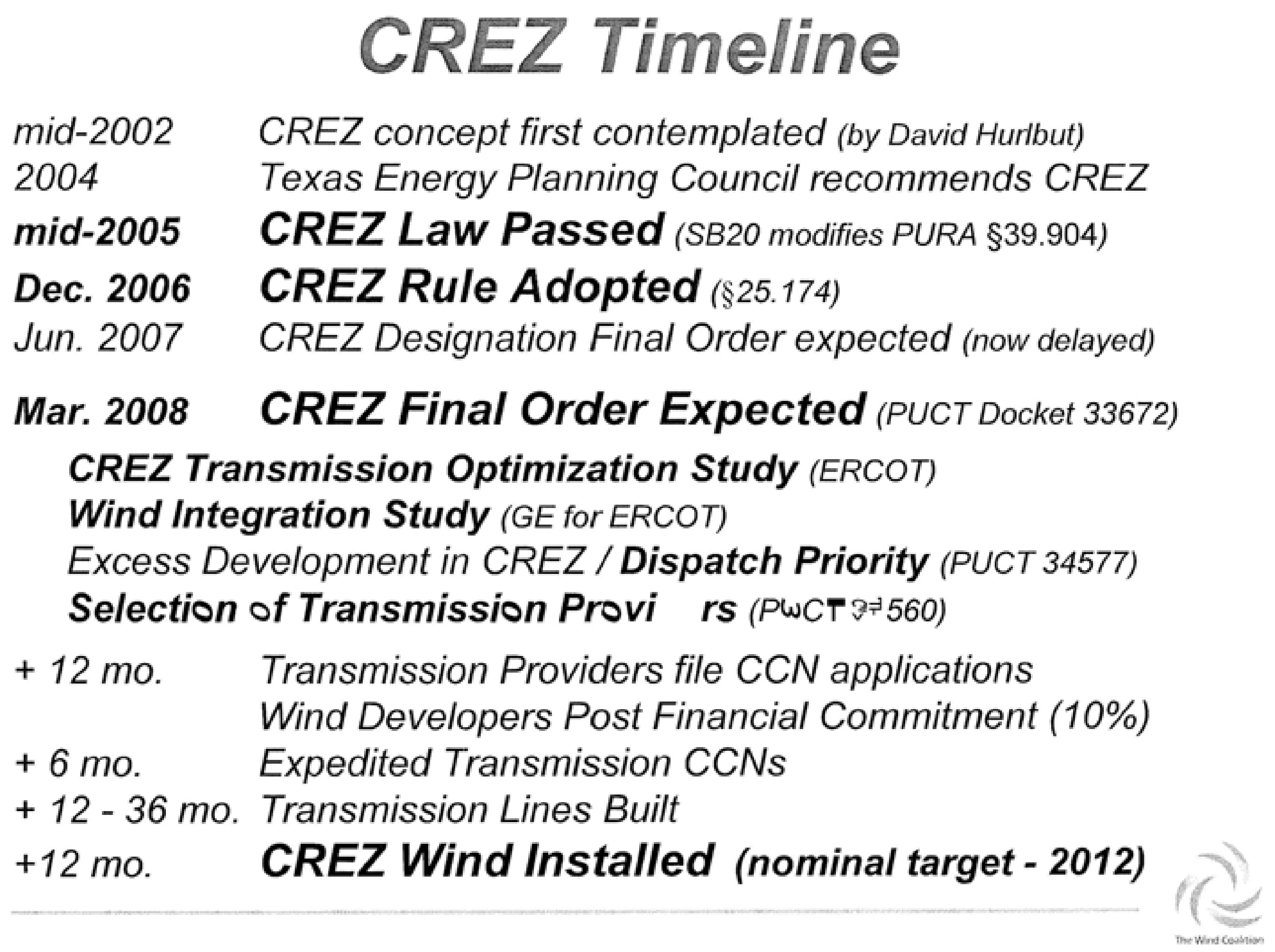
Hypothetical

CREZ Package

*to achieve **additional wind** of*

7,000 MW

*Based on ERCOT CREZ Analysis (Dec **2006)**; Assumes **4,850 MW** existing wind in **2008***



CREZ Timeline

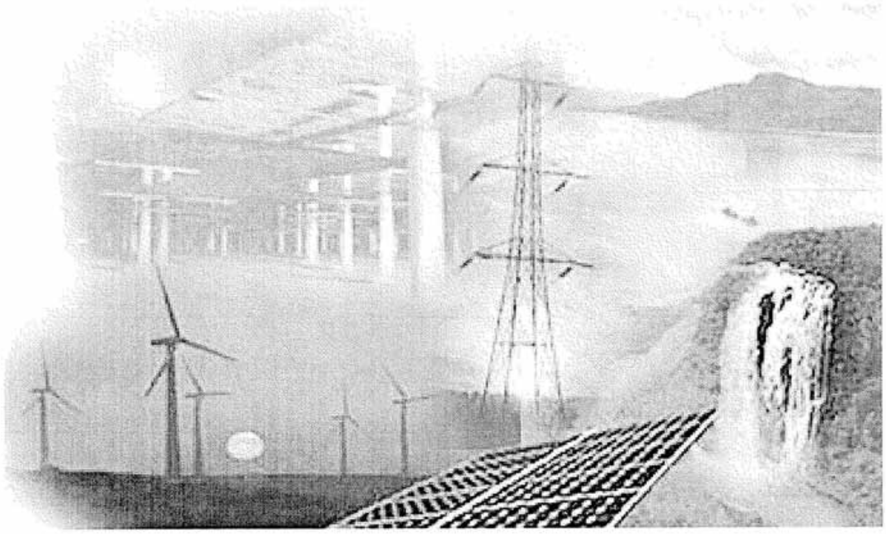
mid-2002	CREZ concept first contemplated (by David Hurlbut)
2004	Texas Energy Planning Council recommends CREZ
mid-2005	**CREZ Law Passed** (SB20 modifies PURA §39.904)
Dec. 2006	**CREZ Rule Adopted** (§25.174)
Jun. 2007	CREZ Designation Final Order expected (now delayed)
Mar. 2008	**CREZ Final Order Expected** (PUCT Docket 33672)
	CREZ Transmission Optimization Study (ERCOT)
	Wind Integration Study (GE for ERCOT)
	Excess Development in CREZ / **Dispatch Priority** (PUCT 34577)
	Selection of Transmission Providers (PUCT 35560)
+ 12 mo.	Transmission Providers file CCN applications
	Wind Developers Post Financial Commitment (10%)
+ 6 mo.	Expedited Transmission CCNs
+ 12 - 36 mo.	Transmission Lines Built
+12 mo.	**CREZ Wind Installed (nominal target - 2012)**

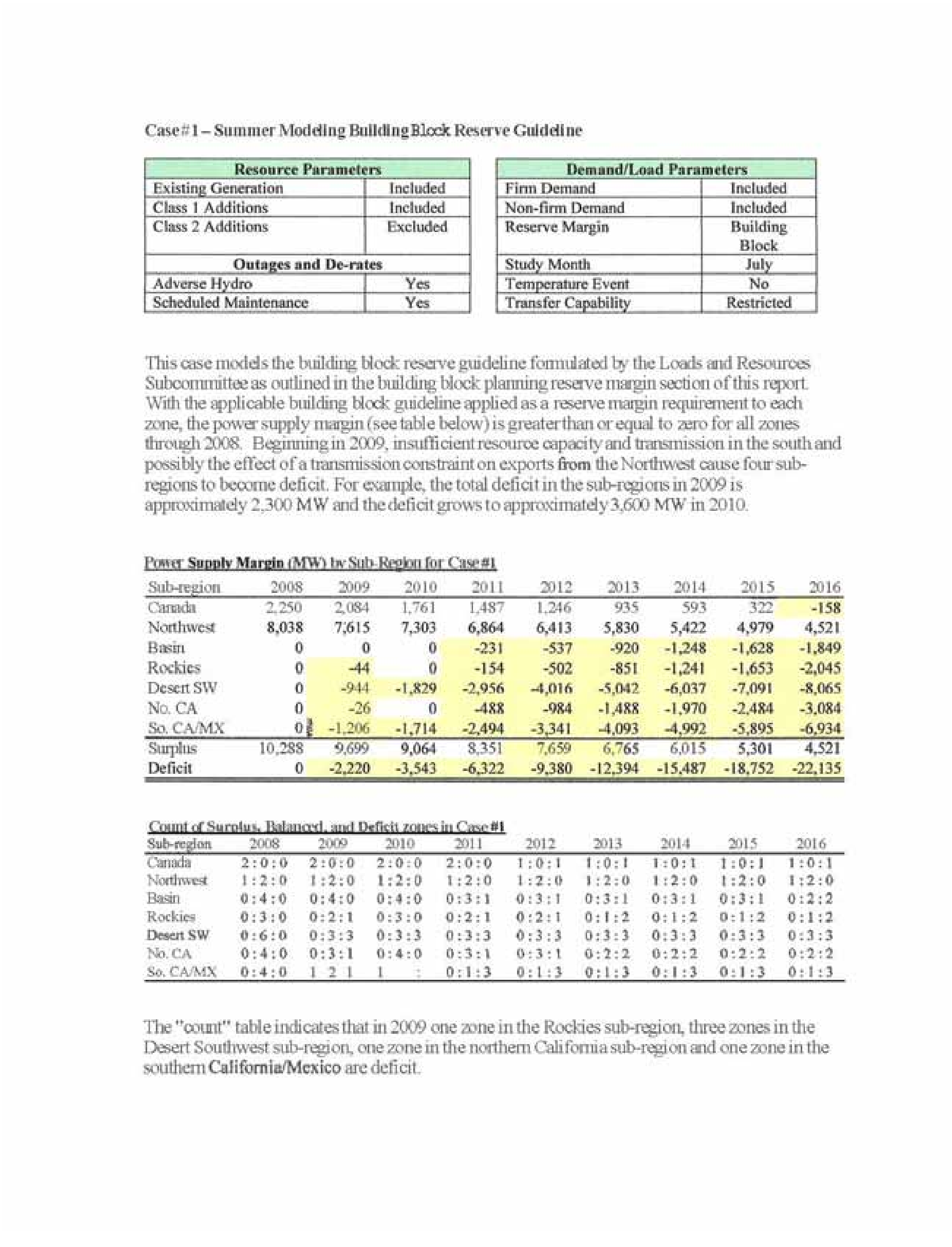
The Wind Coalition

Western Electricity Coordinating Council

2007 Power Supply Assessment

December 2007





Case #1 – Summer Modeling Building Block Reserve Guideline

Resource Parameters	
Existing Generation	Included
Class 1 Additions	Included
Class 2 Additions	Excluded
Outages and De-rates	
Adverse Hydro	Yes
Scheduled Maintenance	Yes

Demand/Load Parameters	
Firm Demand	Included
Non-firm Demand	Included
Reserve Margin	Building Block
Study Month	July
Temperature Event	No
Transfer Capability	Restricted

This case models the building block reserve guideline formulated by the Loads and Resources Subcommittee as outlined in the building block planning reserve margin section of this report. With the applicable building block guideline applied as a reserve margin requirement to each zone, the power supply margin (see table below) is greater than or equal to zero for all zones through 2008. Beginning in 2009, insufficient resource capacity and transmission in the south and possibly the effect of a transmission constraint on exports **from** the Northwest cause four sub-regions to become deficit. For example, the total deficit in the sub-regions in 2009 is approximately 2,300 MW and the deficit grows to approximately 3,600 MW in 2010.

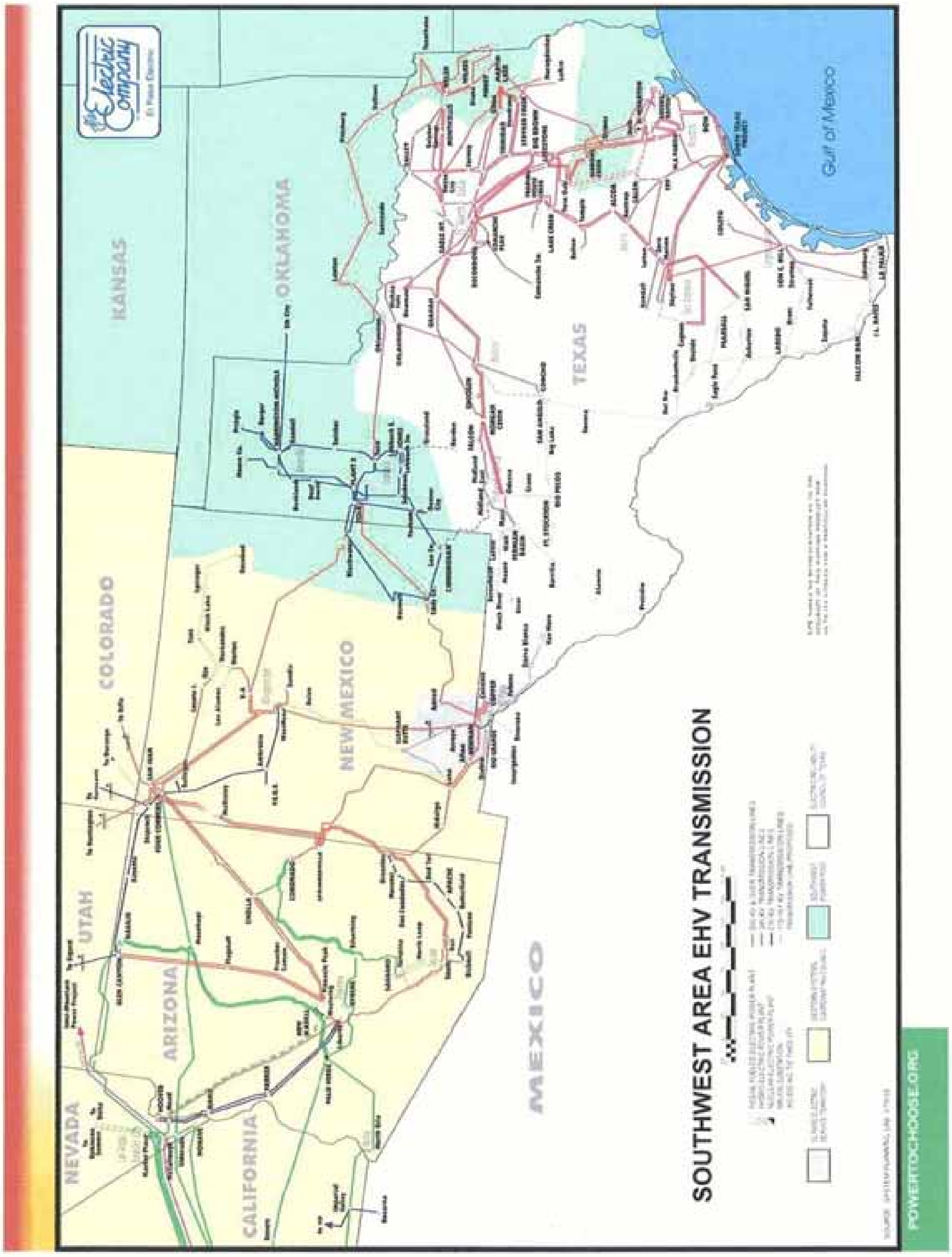
Power **Supply Margin** (MW) by Sub-Region for Case #1

Sub-region	2008	2009	2010	2011	2012	2013	2014	2015	2016
Canada	2,250	2,084	1,761	1,487	1,246	935	593	322	-158
Northwest	8,038	7,615	7,303	6,864	6,413	5,830	5,422	4,979	4,521
Basin	0	0	0	-231	-537	-920	-1,248	-1,628	-1,849
Rockies	0	-44	0	-154	-502	-851	-1,241	-1,653	-2,045
Desert SW	0	-944	-1,829	-2,956	-4,016	-5,042	-6,037	-7,091	-8,065
No. CA	0	-26	0	-488	-984	-1,488	-1,970	-2,484	-3,084
So. CA/MX	0	-1,206	-1,714	-2,494	-3,341	-4,093	-4,992	-5,895	-6,934
Surplus	10,288	9,699	9,064	8,351	7,659	6,765	6,015	5,301	4,521
Deficit	0	-2,220	-3,543	-6,322	-9,380	-12,394	-15,487	-18,752	-22,135

Count of Surplus, Balanced, and Deficit zones in Case #1

Sub-region	2008	2009	2010	2011	2012	2013	2014	2015	2016
Canada	2:0:0	2:0:0	2:0:0	2:0:0	1:0:1	1:0:1	1:0:1	1:0:1	1:0:1
Northwest	1:2:0	1:2:0	1:2:0	1:2:0	1:2:0	1:2:0	1:2:0	1:2:0	1:2:0
Basin	0:4:0	0:4:0	0:4:0	0:3:1	0:3:1	0:3:1	0:3:1	0:3:1	0:2:2
Rockies	0:3:0	0:2:1	0:3:0	0:2:1	0:2:1	0:1:2	0:1:2	0:1:2	0:1:2
Desert SW	0:6:0	0:3:3	0:3:3	0:3:3	0:3:3	0:3:3	0:3:3	0:3:3	0:3:3
No. CA	0:4:0	0:3:1	0:4:0	0:3:1	0:3:1	0:2:2	0:2:2	0:2:2	0:2:2
So. CA/MX	0:4:0	1 2 1	1 :	0:1:3	0:1:3	0:1:3	0:1:3	0:1:3	0:1:3

The "count" table indicates that in 2009 one zone in the Rockies sub-region, three zones in the Desert Southwest sub-region, one zone in the northern California sub-region and one zone in the southern **California/Mexico** are deficit.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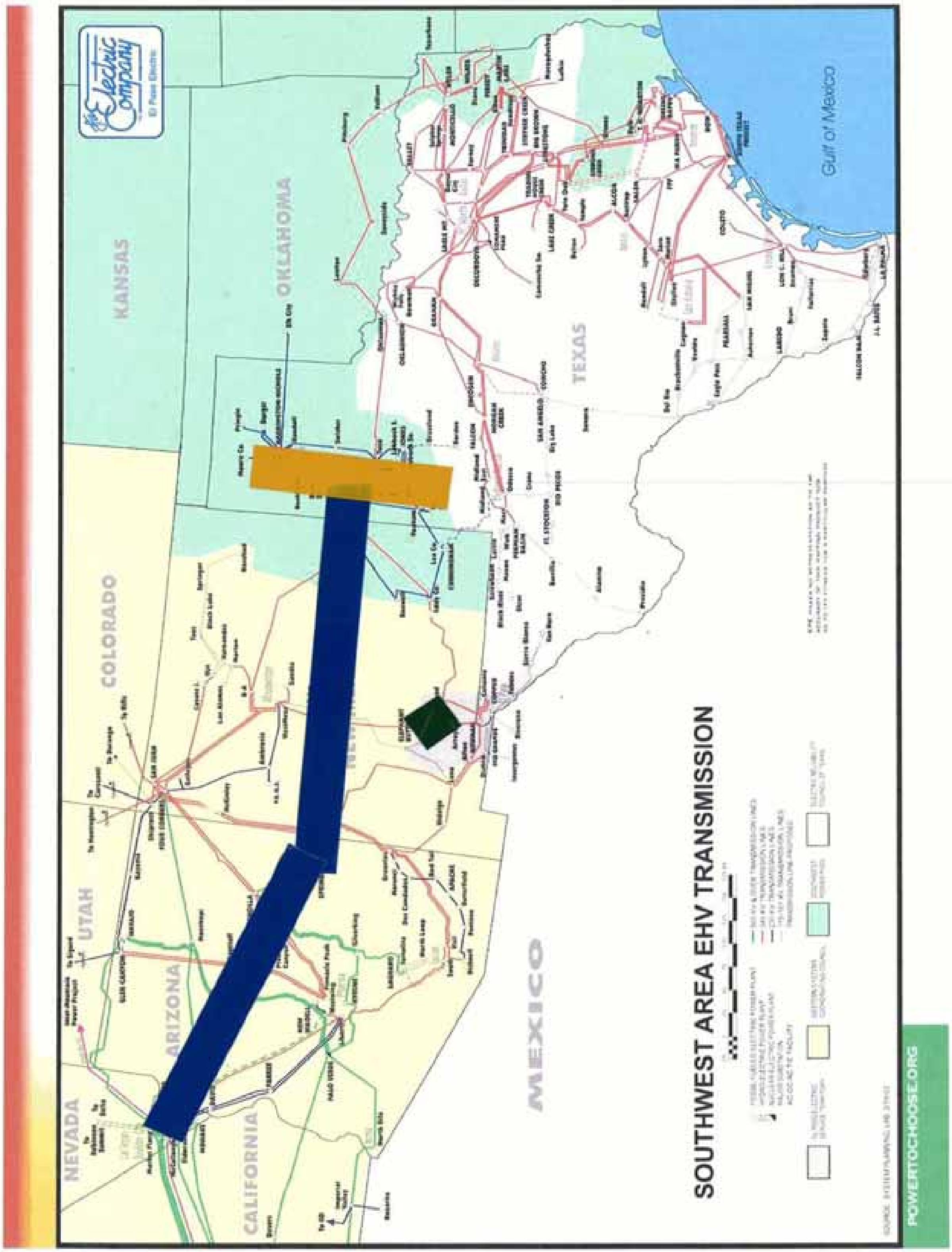
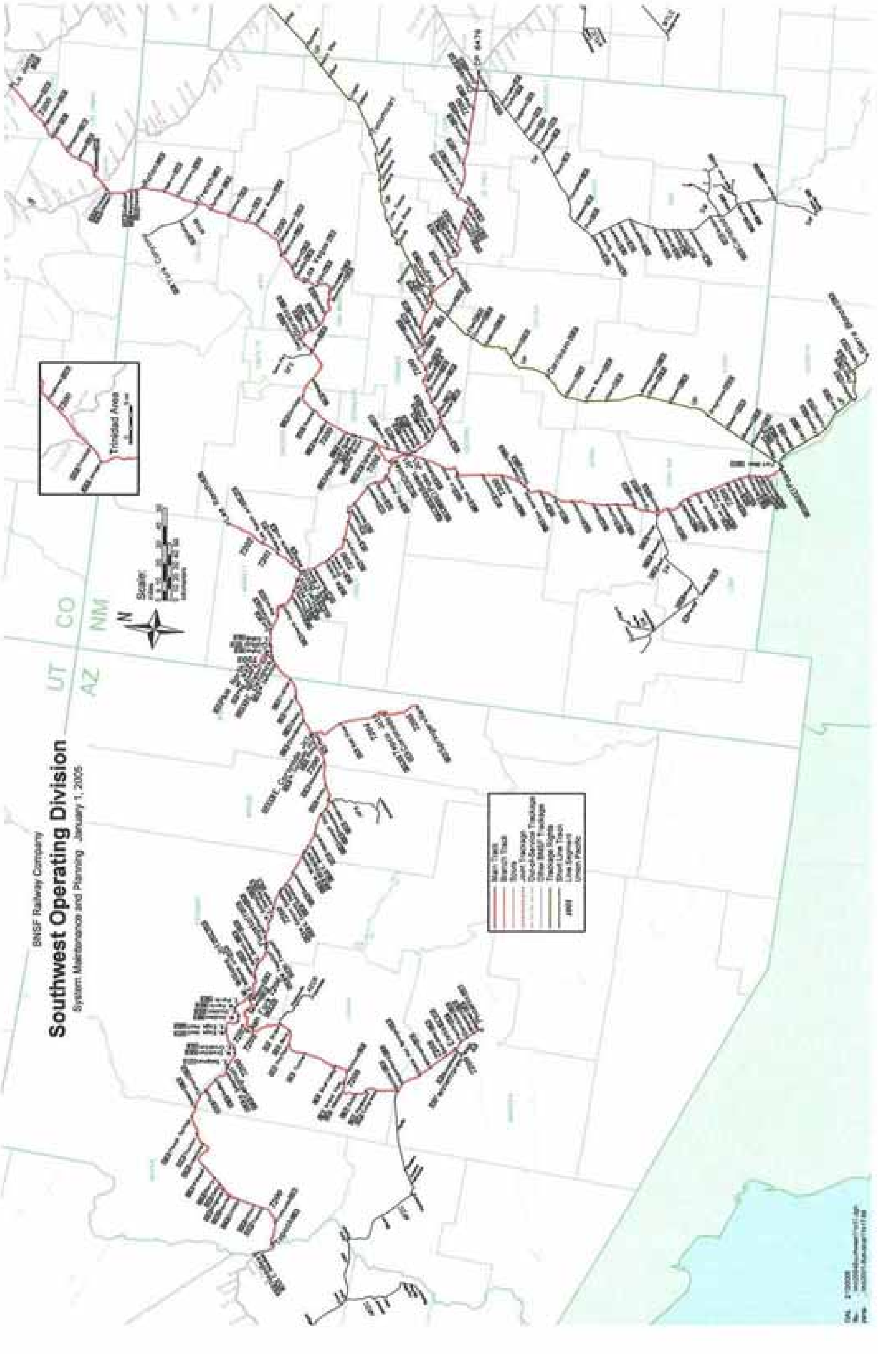
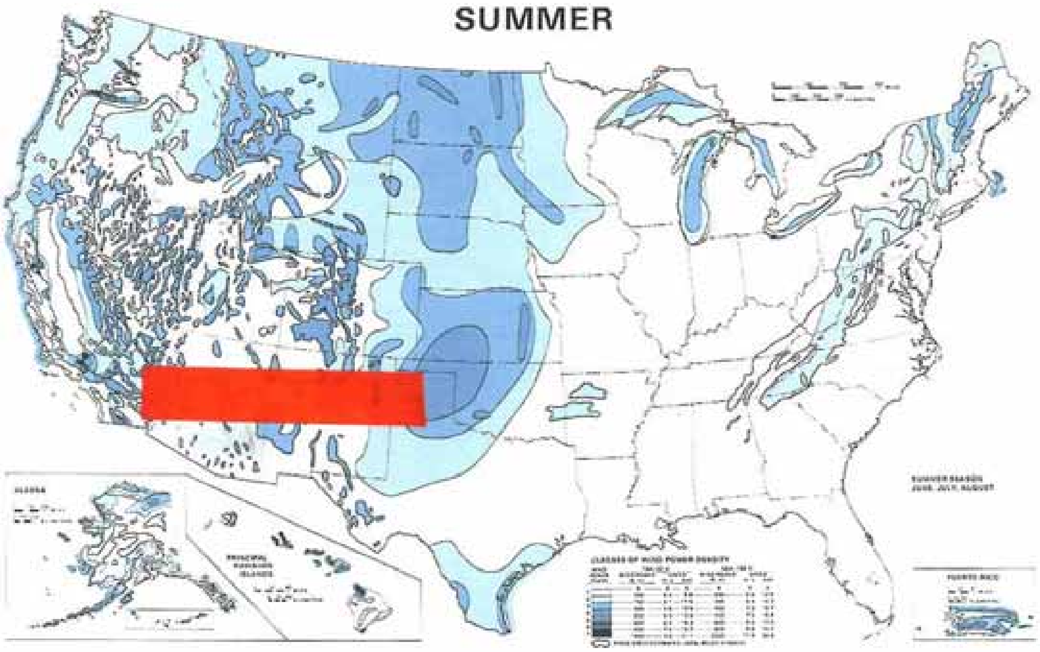
The Electric Company
El Paso Electric
NEVADA
UTAH
COLORADO
KANSAS
OKLAHOMA
CALIFORNIA
ARIZONA
NEW MEXICO
TEXAS
MEXICO
Gulf of Mexico
POWERTOCHOOSE.ORG


SOUTHWEST AREA EHV TRANSMISSION
The Electric Company
El Paso Electric
NEVADA
UTAH
COLORADO
KANSAS
OKLAHOMA
TEXAS
ARIZONA
CALIFORNIA
MEXICO
Gulf of Mexico
POWERTOCHOOSE.ORG

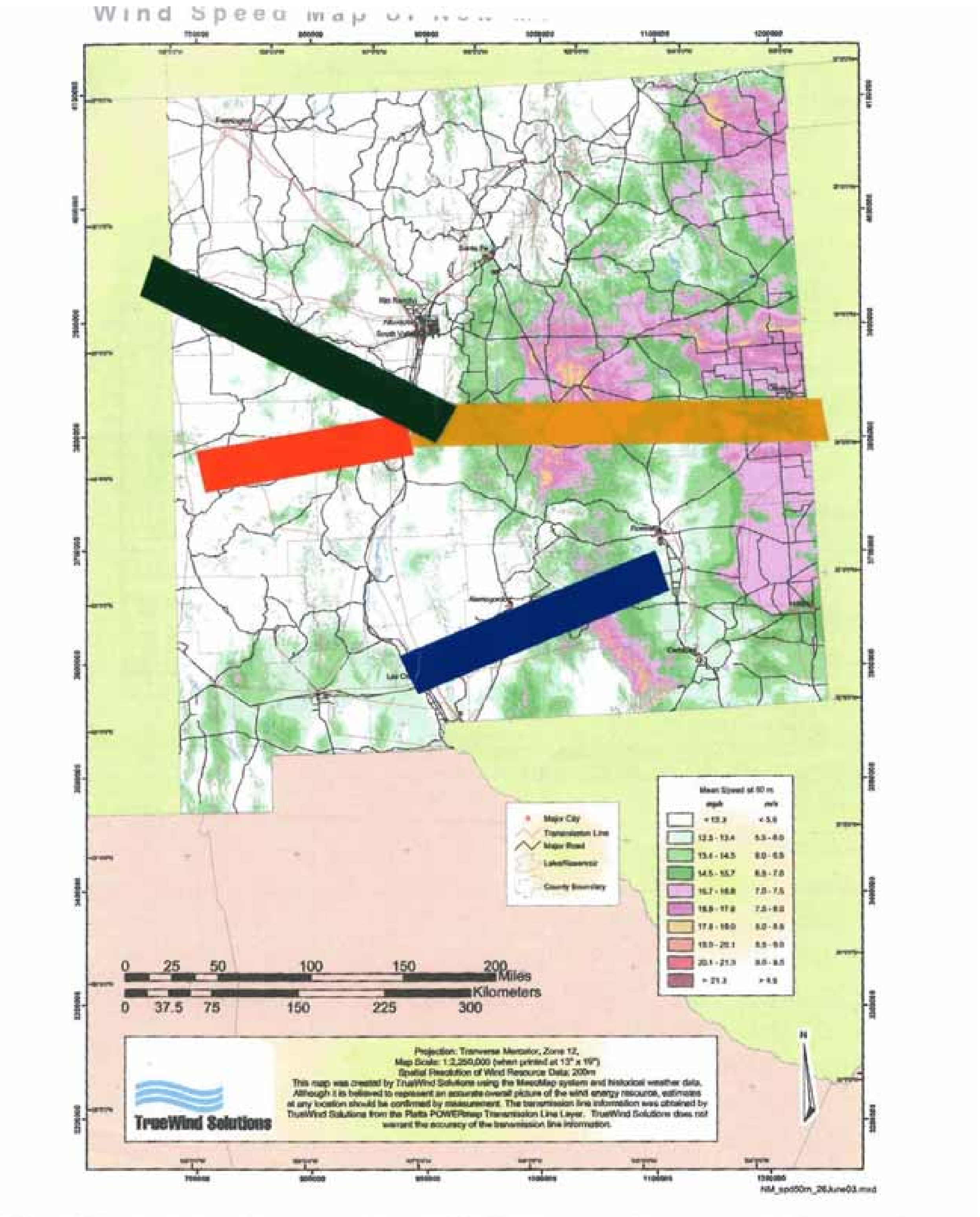

BNSF Railway Company
Southwest Operating Division
System Maintenance and Planning January 1, 2005
Trinidad Area
Scale
N
UT
CO
AZ
NM
Main Track
Branch Track
Spurs
Joint Trackage



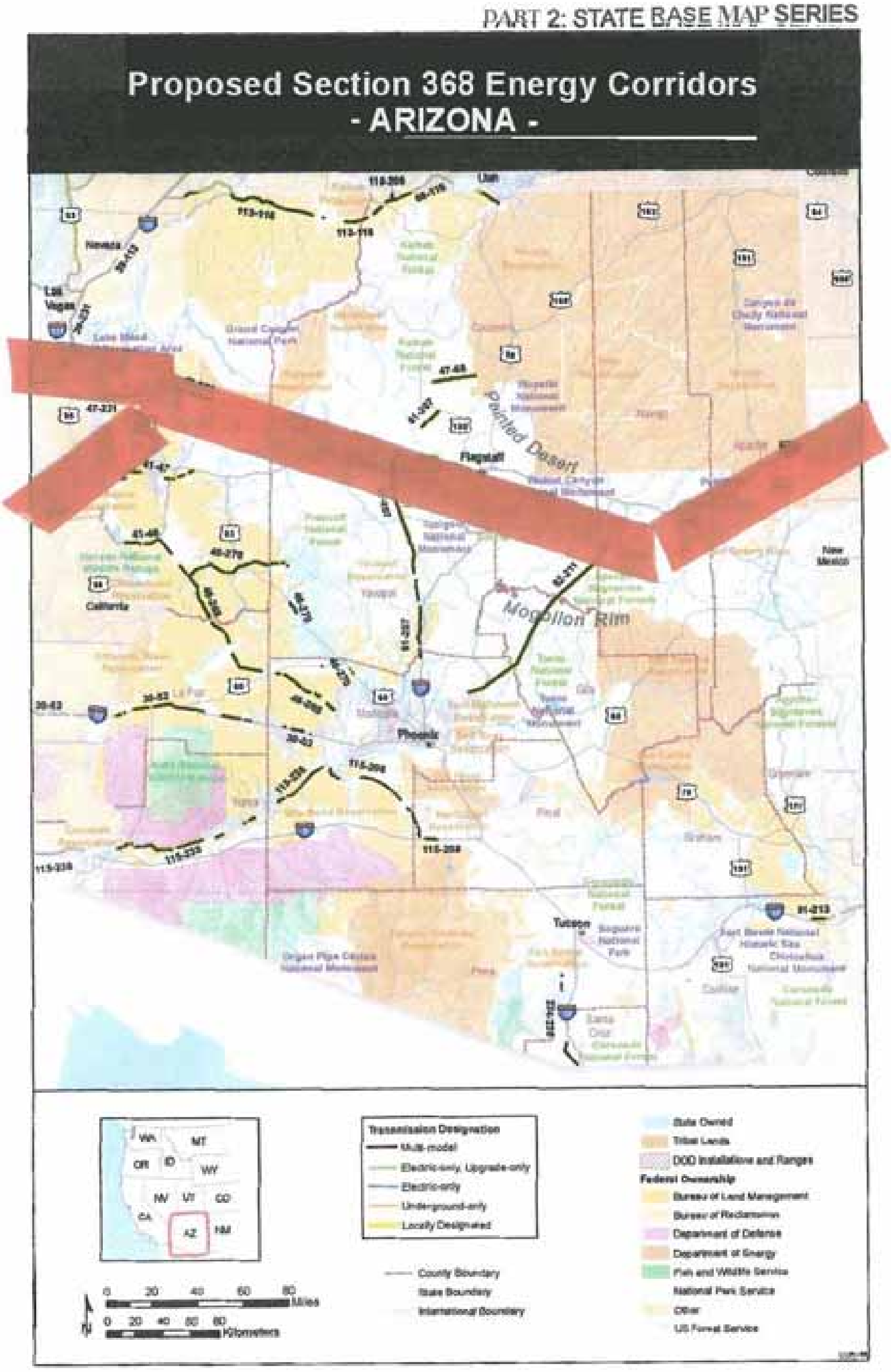
Map 2-4 Summer season-June, July, August

For more information see Map Description.

http://rredc.nrel.gov

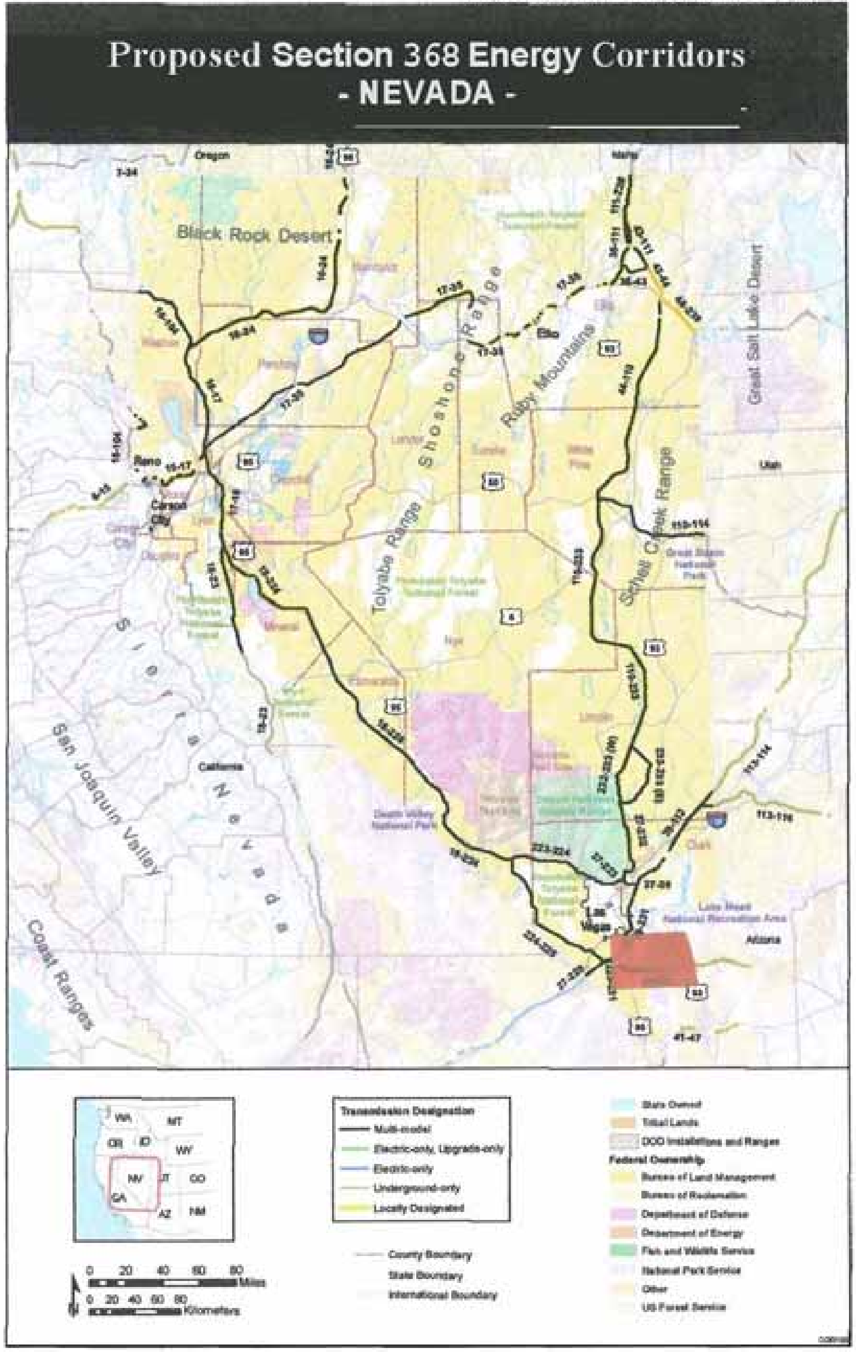


Projection: Transverse Mercator, Zone 12,
Map Scale: 1:2,250,000 (when printed at 13" x 19")
Spatial Resolution of Wind Resource Data: 200m
This map was created by TrueWind Solutions using the MesoMap system and historical weather data. Although it is believed to represent an accurate overall picture of the wind energy resource, estimates at any location should be confirmed by measurement. The transmission line information was obtained by TrueWind Solutions from the Platts POWERmap Transmission Line Layer. TrueWind Solutions does not warrant the accuracy of the transmission line information.


PART 2: STATE BASE MAP SERIES
Proposed Section 368 Energy Corridors
- ARIZONA -
Utah
Nevada
Las Vegas
113-116
66-116
47-68
47-231
41-46
46-269
30-52
115-208
115-238
81-213
Kaibab National Forest
Grand Canyon National Park
Painted Desert
Flagstaff
Prescott National Forest
Mogollon Rim
Tonto National Forest
New Mexico
California
Phoenix
Tucson
Saguaro National Park
Organ Pipe Cactus National Monument
Pima
Pinal
Graham
Cochise
Santa Cruz
Coronado National Forest
Canyon de Chelly National Monument
Havasu National Wildlife Refuge
Fort Bowie National Historic Site
Chiricahua National Monument
WA
MT
OR
ID
WY
NV
UT
CO
CA
AZ
NM
Transmission Designation
Multi-modal
Electric-only, Upgrade-only
Electric-only
Underground-only
Locally Designated
County Boundary
State Boundary
International Boundary
State Owned
Tribal Lands
DOD Installations and Ranges
Federal Ownership
Bureau of Land Management
Bureau of Reclamation
Department of Defense
Department of Energy
Fish and Wildlife Service
National Park Service
Other
US Forest Service
0 20 40 60 80 Miles
0 20 40 60 80 Kilometers
N

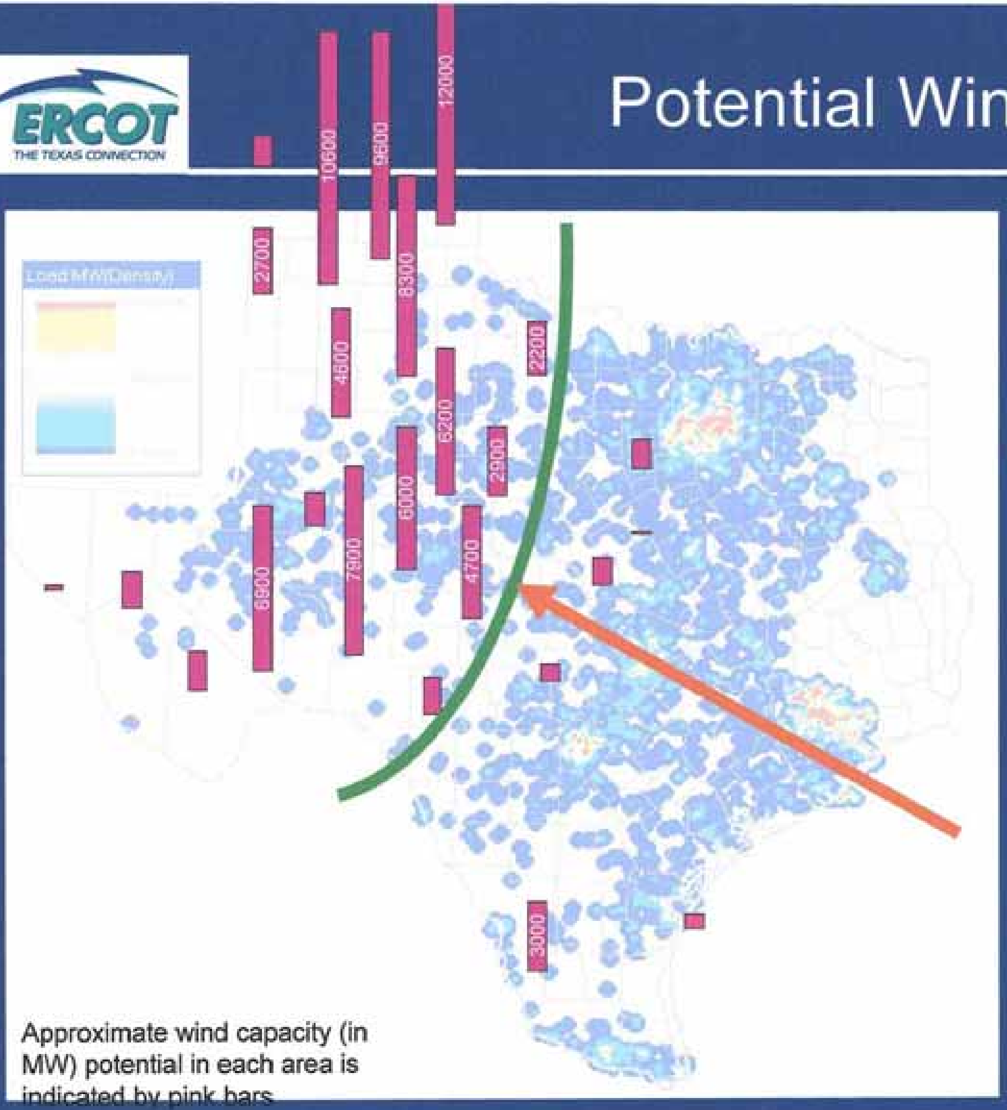
PART 2: STATE BASE MAP SERIES

Proposed Section 368 Energy Corridors - NEVADA -



ERCOT THE TEXAS CONNECTION

Potential Wind Resource



Approximate wind capacity (in MW) potential in each area is indicated by pink bars

- Nearly 100,000 MW above 35% capacity factor (CF)
- Concentrated in western half of state

Approximate west to east transfer capacity – 3200MW

ERCOT Competitive Renewable Energy Zones Study 12/1/2006

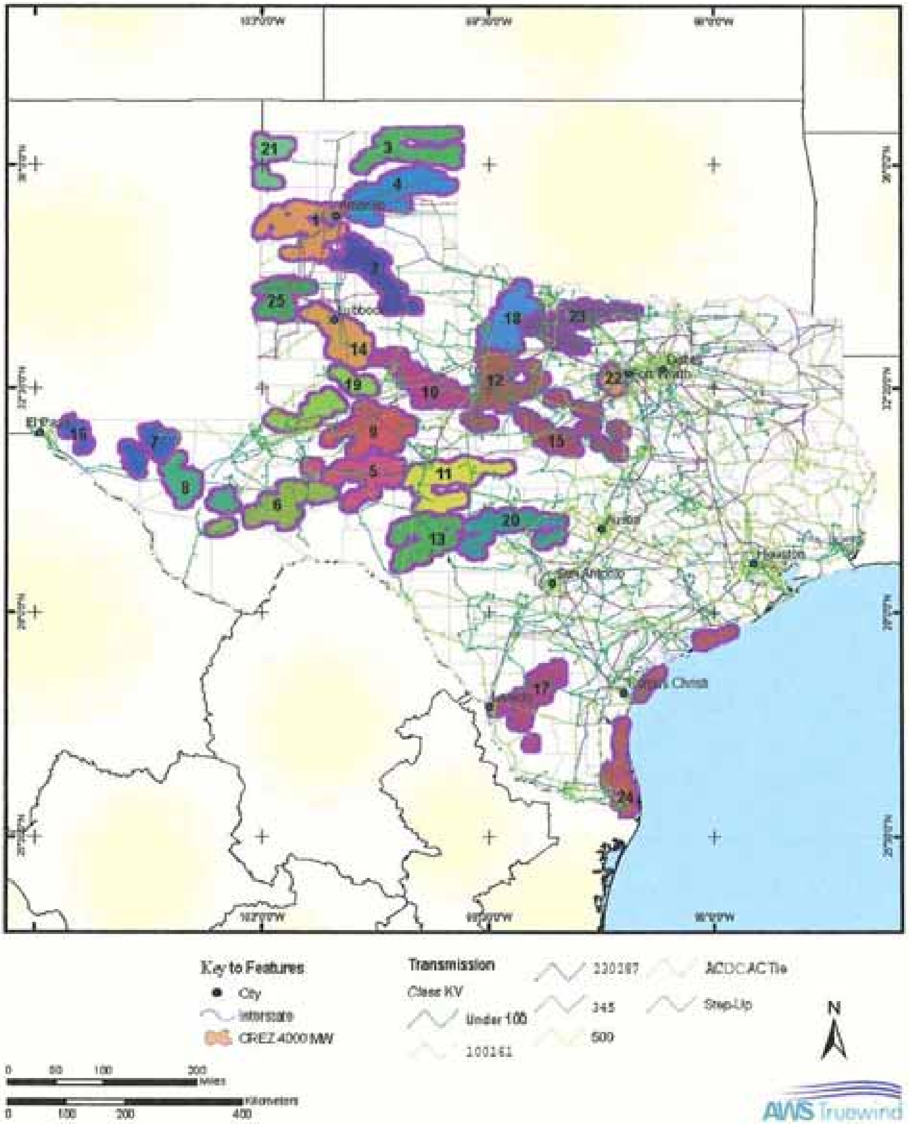
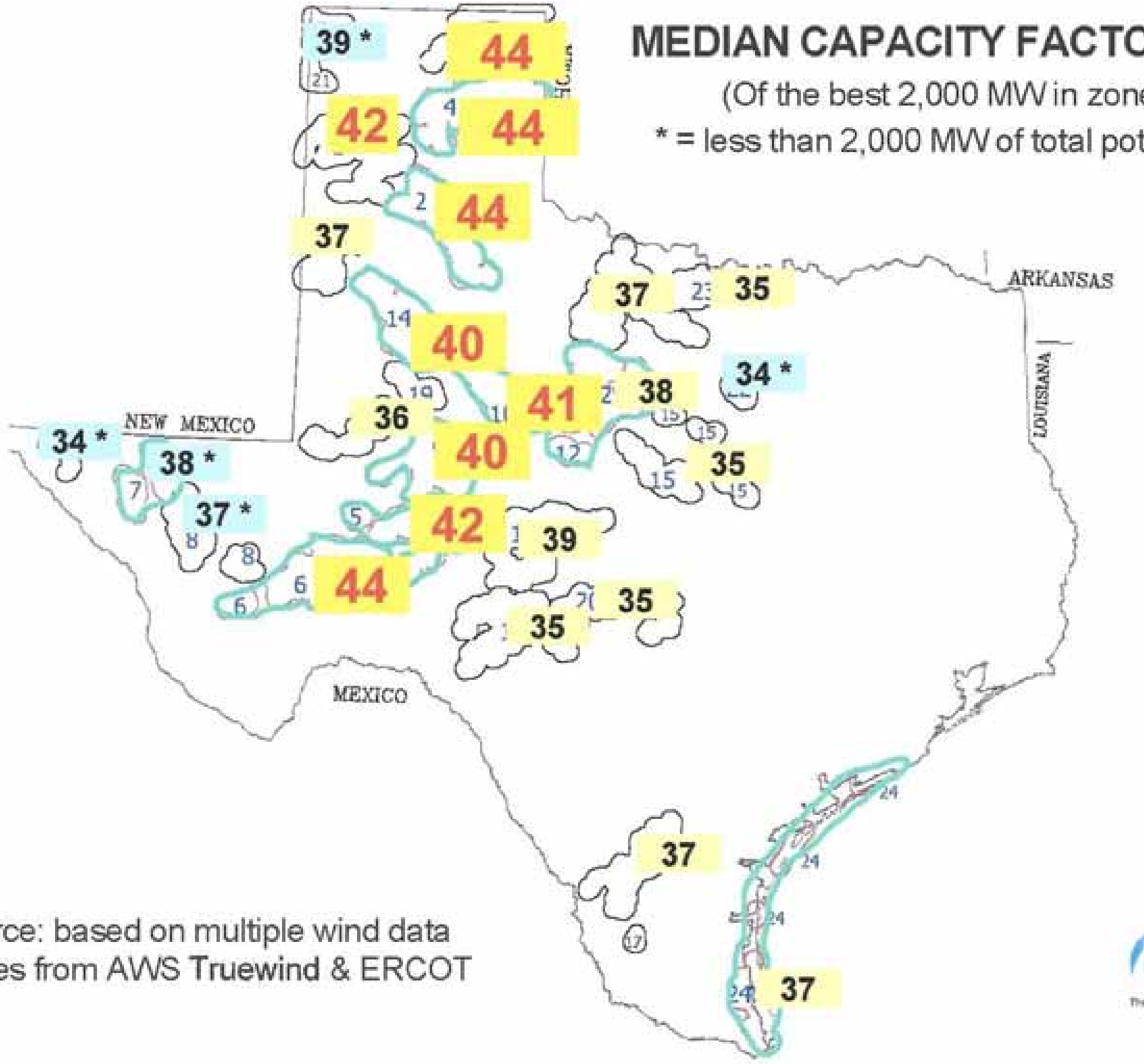
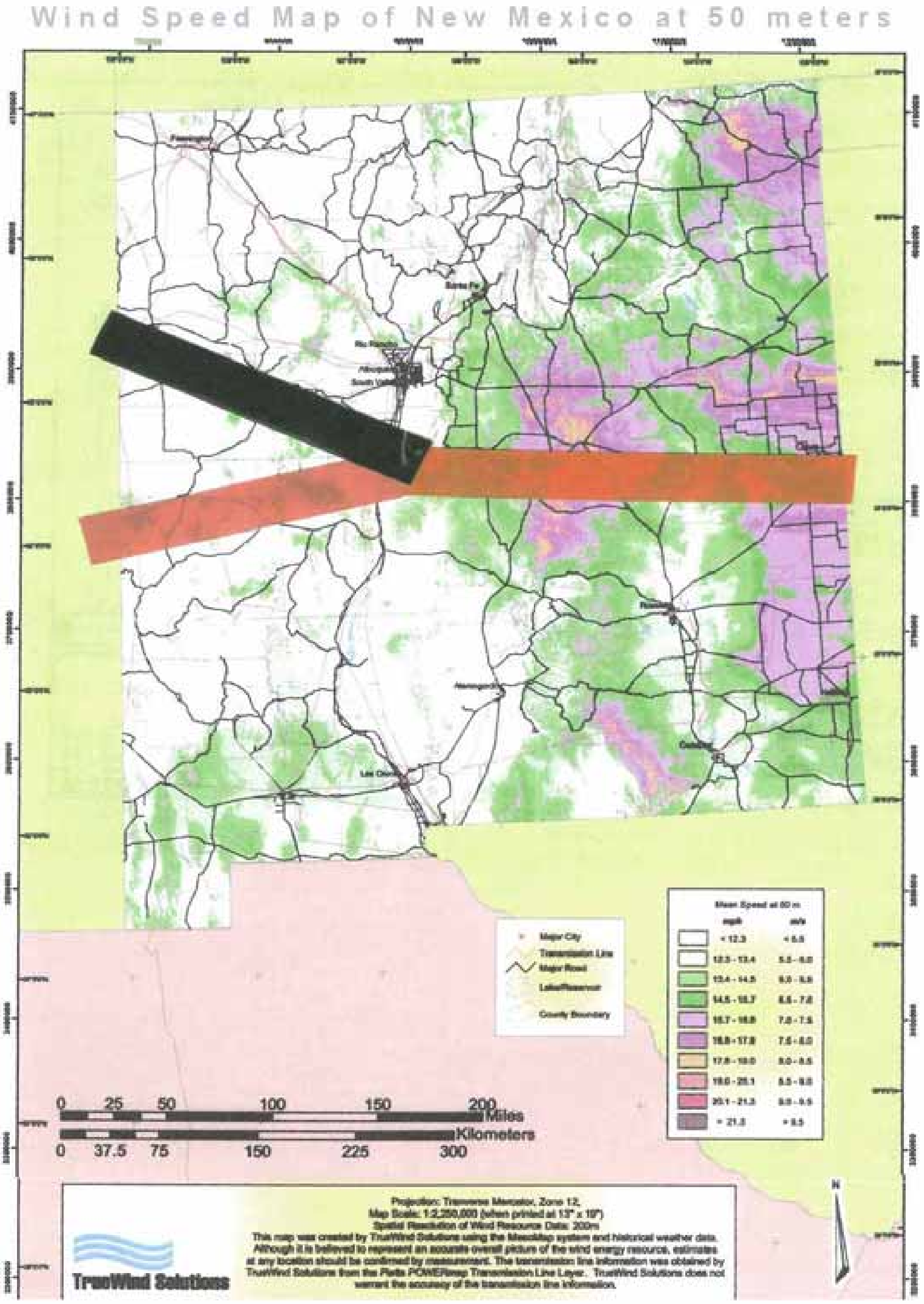


Figure 3: Areas Enclosing the Best 4,000 MW in Each of the Wind Resource Zones

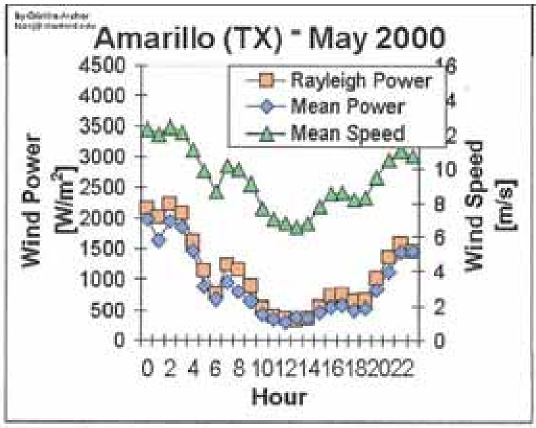


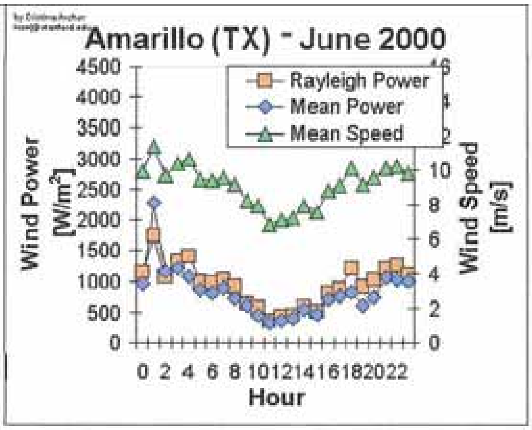
MEDIAN CAPACITY FACTOR (%)
(Of the best 2,000 MW in zone;
* = less than 2,000 MW of total potential)

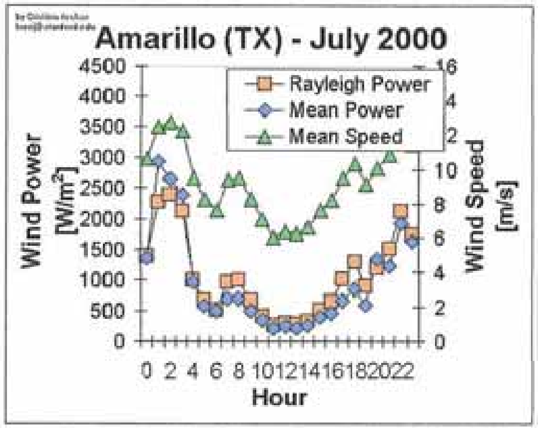
Source: based on multiple wind data
sources from AWS **Truewind** & ERCOT

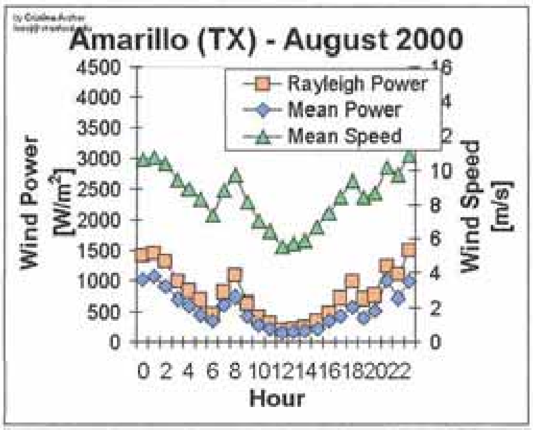


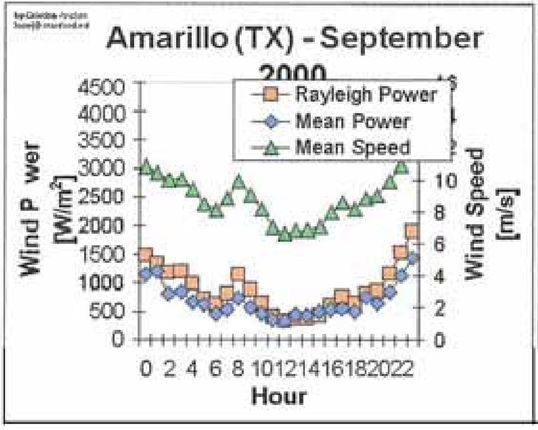
Wind Speed Map of New Mexico at 50 meters http://www.stanford.edu/group/efmh/winds/power_monthly/ama_powe...

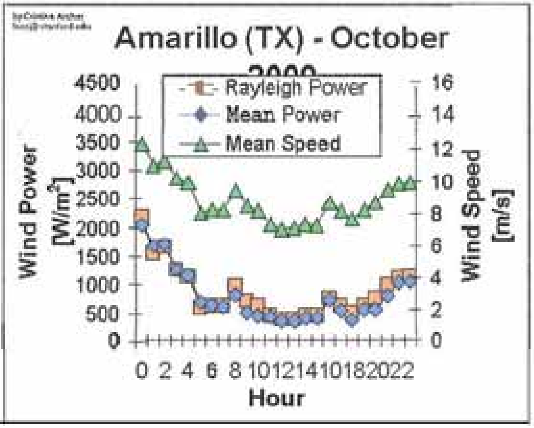




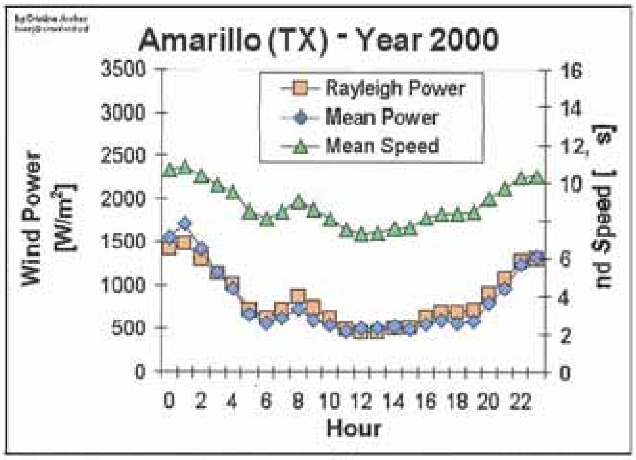


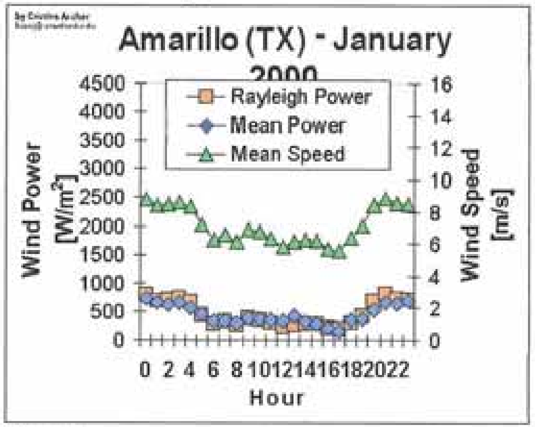


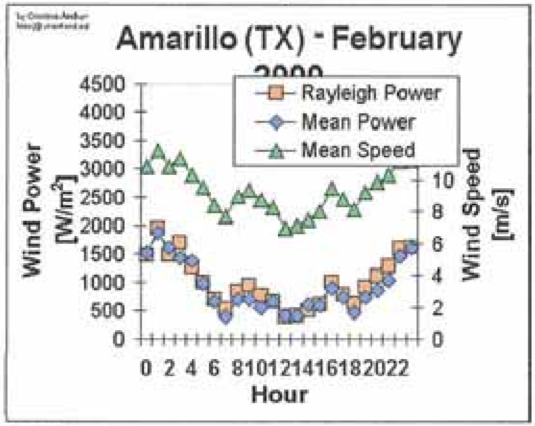


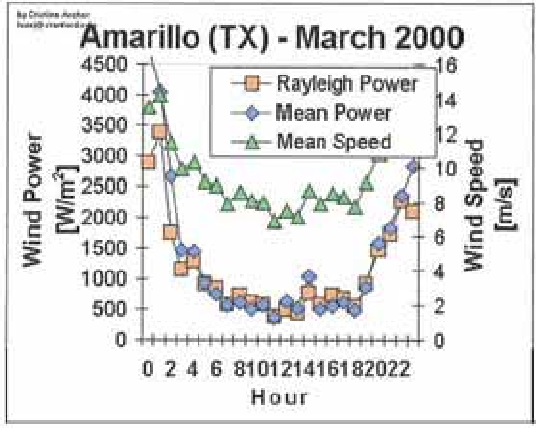


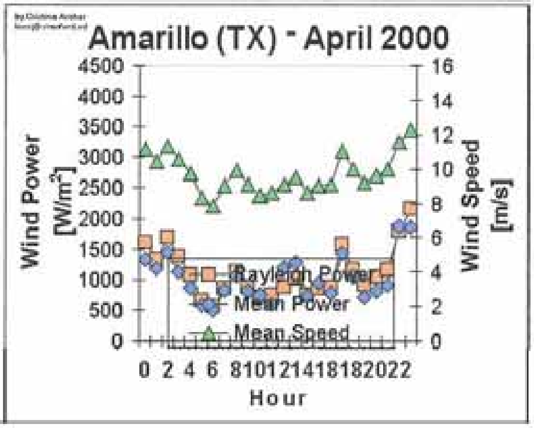
Power and mean speed trends (by month)



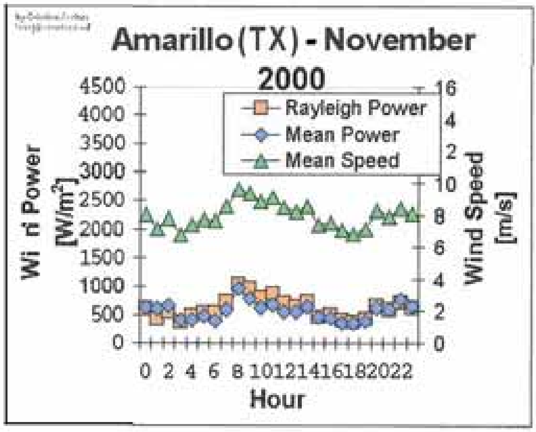


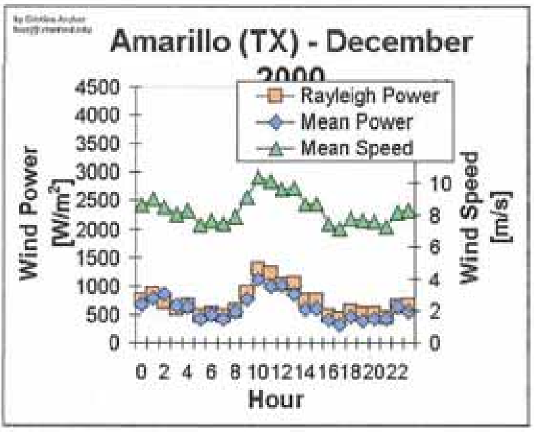






http://www.stanford.edu/group/efmh/winds/power_monthly/ama_powe.





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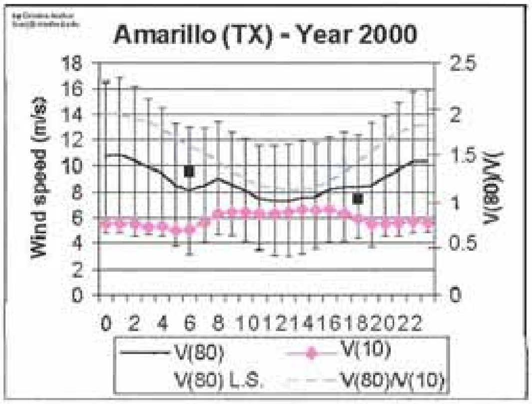
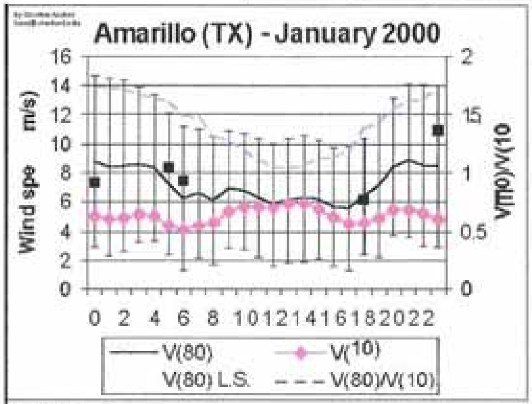
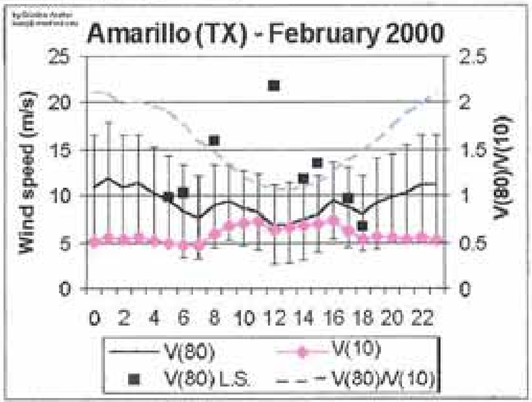
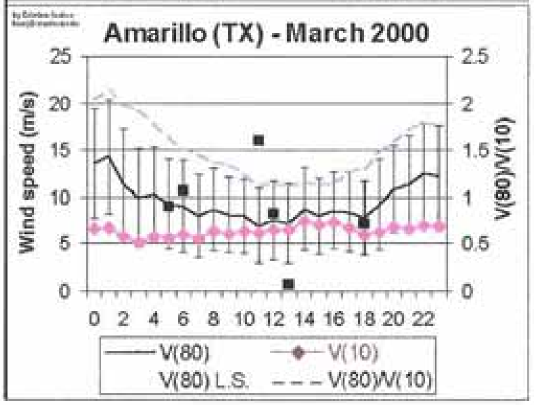
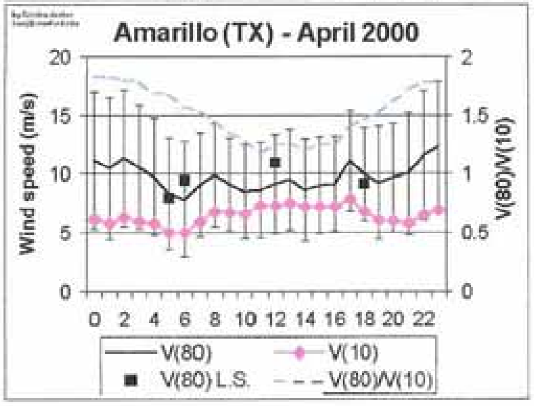
Mean wind speeds and standard deviations



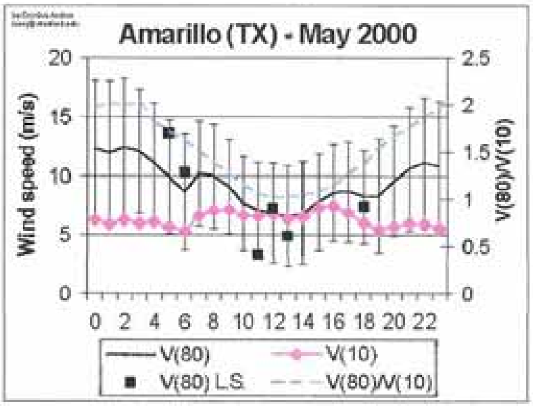


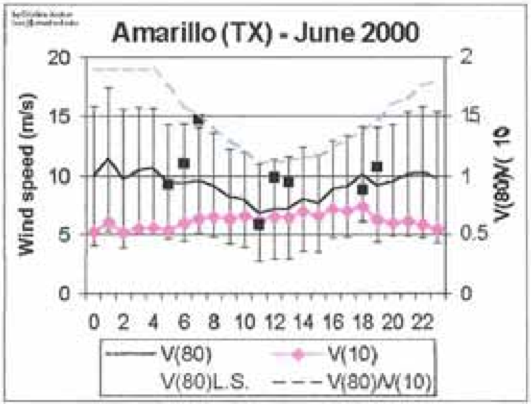


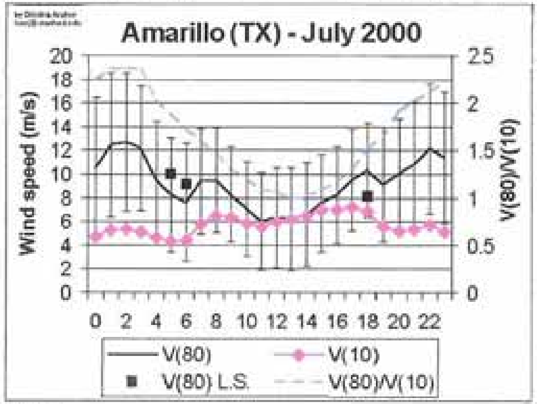


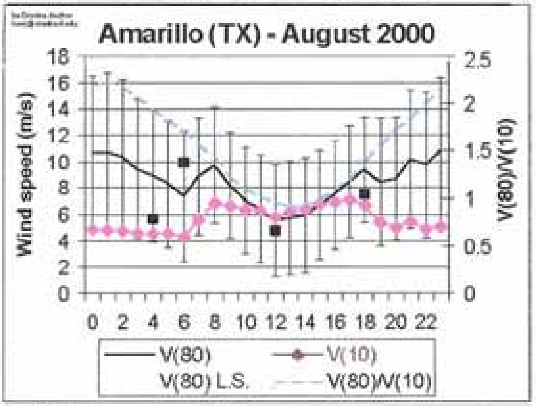


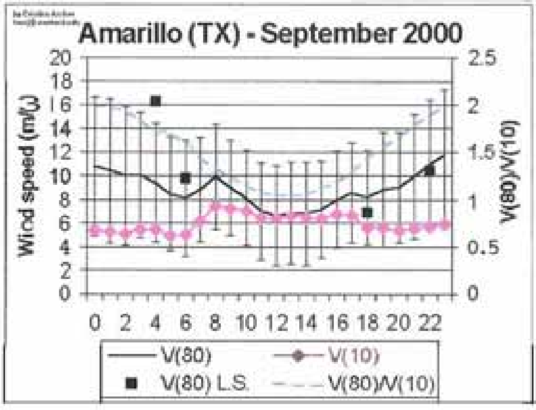
http://www.stanford.edu/group/efmh/winds/ama.htm

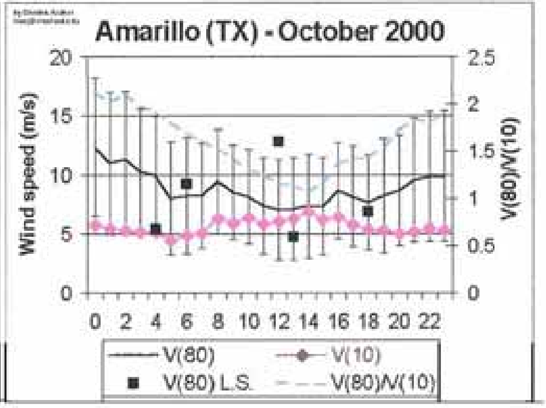












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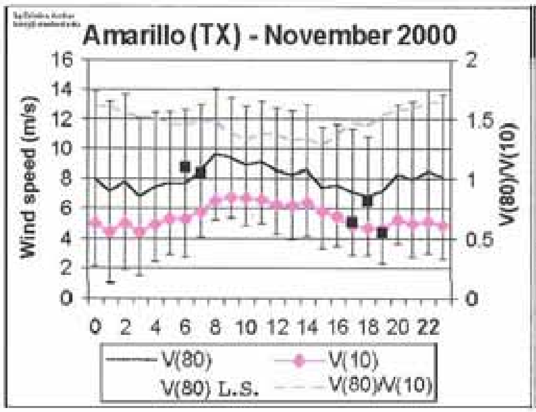
Amarillo (TX) - November 2000
Wind speed (m/s)
16
14
12
10
8
6
4
2
0
V(80)/V(10)
2
1.5
1
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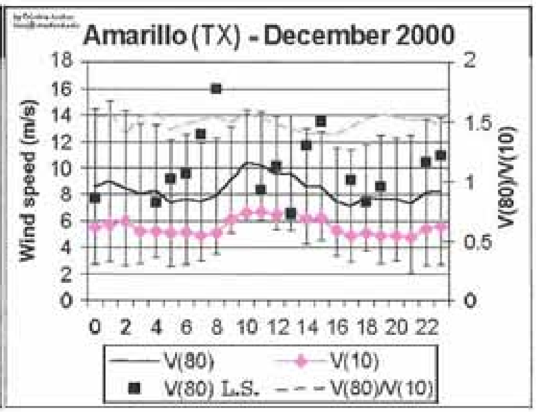
0 2 4 6 8 10 12 14 16 18 20 22
V(80)
V(10)
V(80) L.S.
V(80)/V(10)


Amarillo (TX) - December 2000
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16
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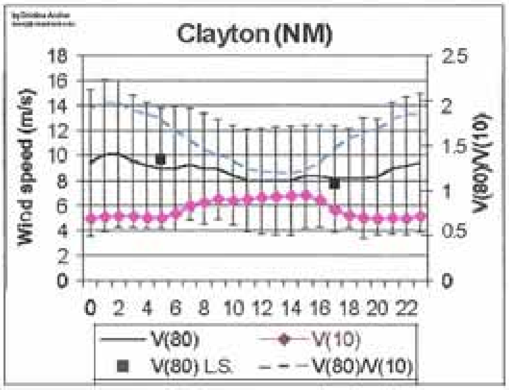
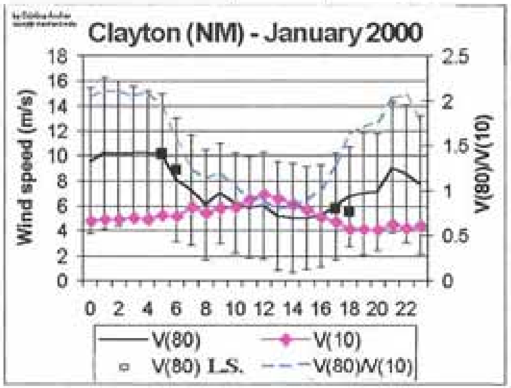
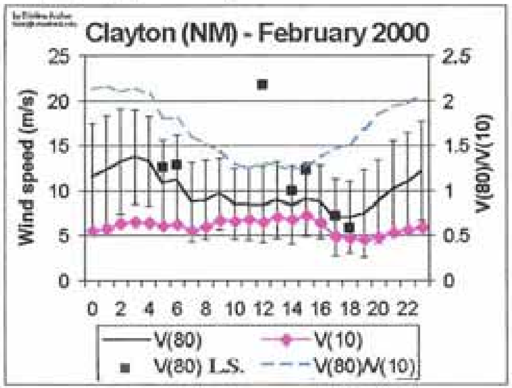
V(80)
V(10)
V(80) L.S.
V(80)/V(10)

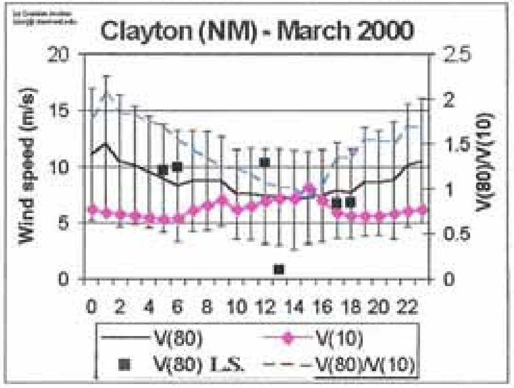
http://www.stanford.edu/group/efmh/winds/cao.html

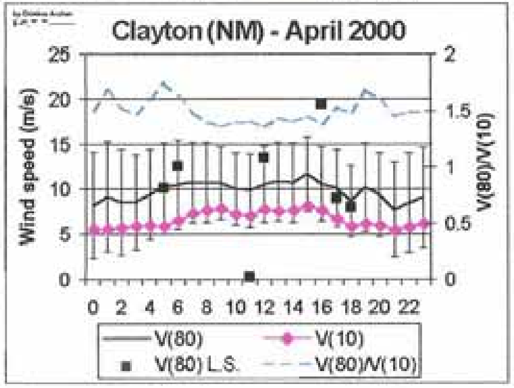
Mean wind speeds and standard deviations











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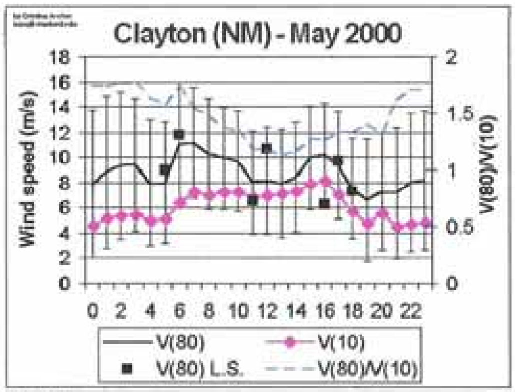
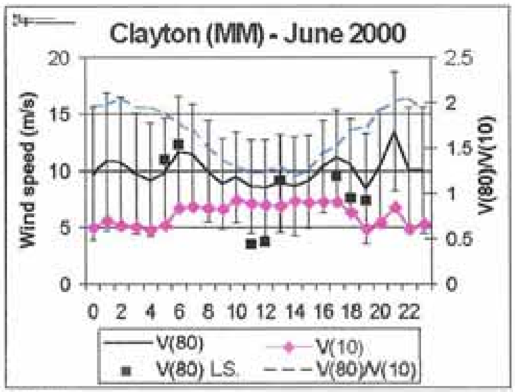
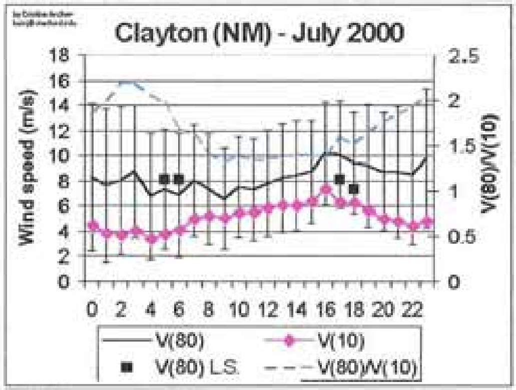
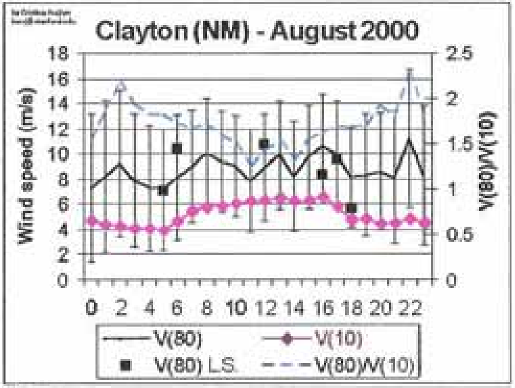
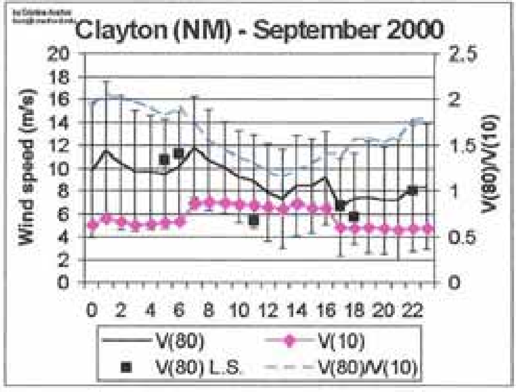
http://www.stanford.edu/group/efmh/winds/cao.html

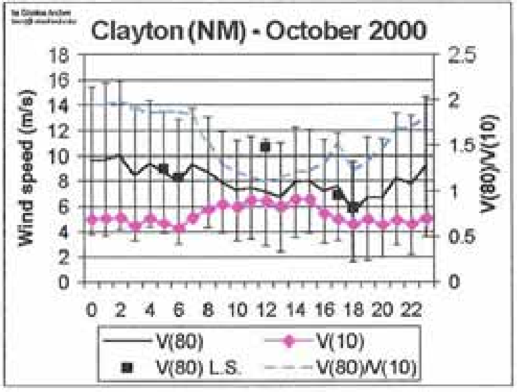


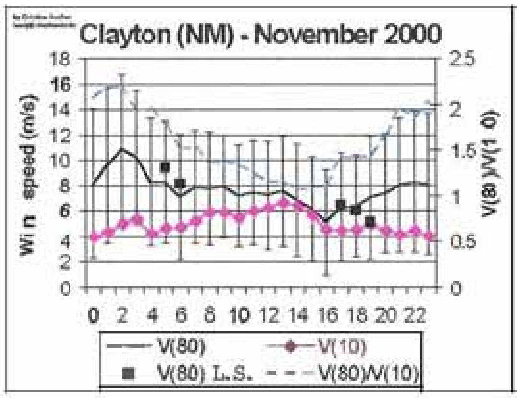











Clayton (NM) - November 2000
Wind speed (m/s)
V(80)/V(10)
18
16
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V(80)
V(10)
V(80) L.S.
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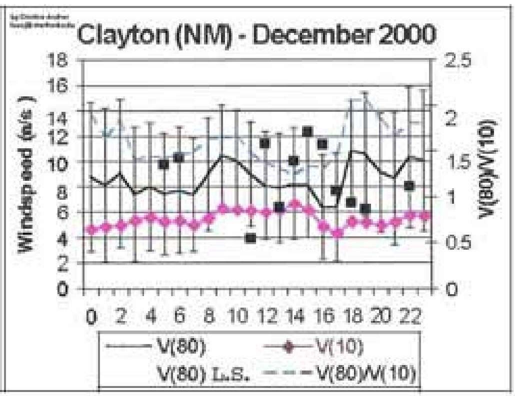
Clayton (NM) - December 2000
Windspeed (m/s)
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V(80)
V(10)
V(80) L.S.
V(80)/V(10)

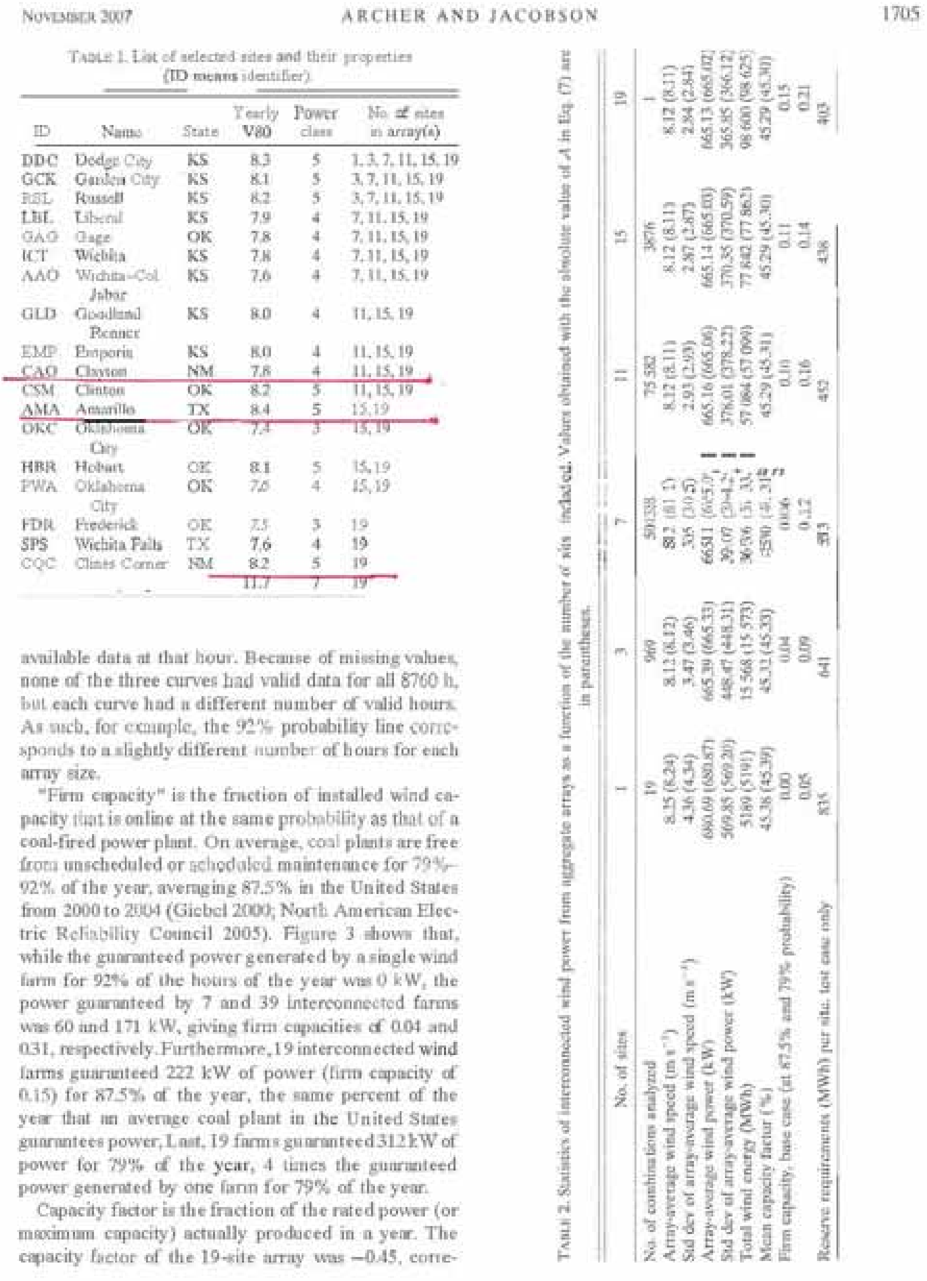


TABLE 1. List of selected sites and their properties (ID means identifier).

ID	Name	State	Yearly V80	Power class	No. of sites in array(s)
DDC	Dodge City	KS	8.3	5	1, 3, 7, 11, 15, 19
GCK	Garden City	KS	8.1	5	3, 7, 11, 15, 19
RSL	Russell	KS	8.2	5	3, 7, 11, 15, 19
LBL	Liberal	KS	7.9	4	7, 11, 15, 19
GAG	Gage	OK	7.8	4	7, 11, 15, 19
ICT	Wichita	KS	7.8	4	7, 11, 15, 19
AAO	Wichita–Col Jabar	KS	7.6	4	7, 11, 15, 19
GLD	Goodland Renner	KS	8.0	4	11, 15, 19
EMP	Emporia	KS	8.0	4	11, 15, 19
CAO	Clayton	NM	7.8	4	11, 15, 19
CSM	Clinton	OK	8.2	5	11, 15, 19
AMA	Amarillo	TX	8.4	5	15, 19
OKC	Oklahoma City	OK	7.4	3	15, 19
HBR	Hobart	OK	8.1	5	15, 19
PWA	Oklahoma City	OK	7.6	4	15, 19
FDR	Frederick	OK	7.5	3	19
SPS	Wichita Falls	TX	7.6	4	19
CQC	Clines Corner	NM	8.2	5	19
			11.7	7	19

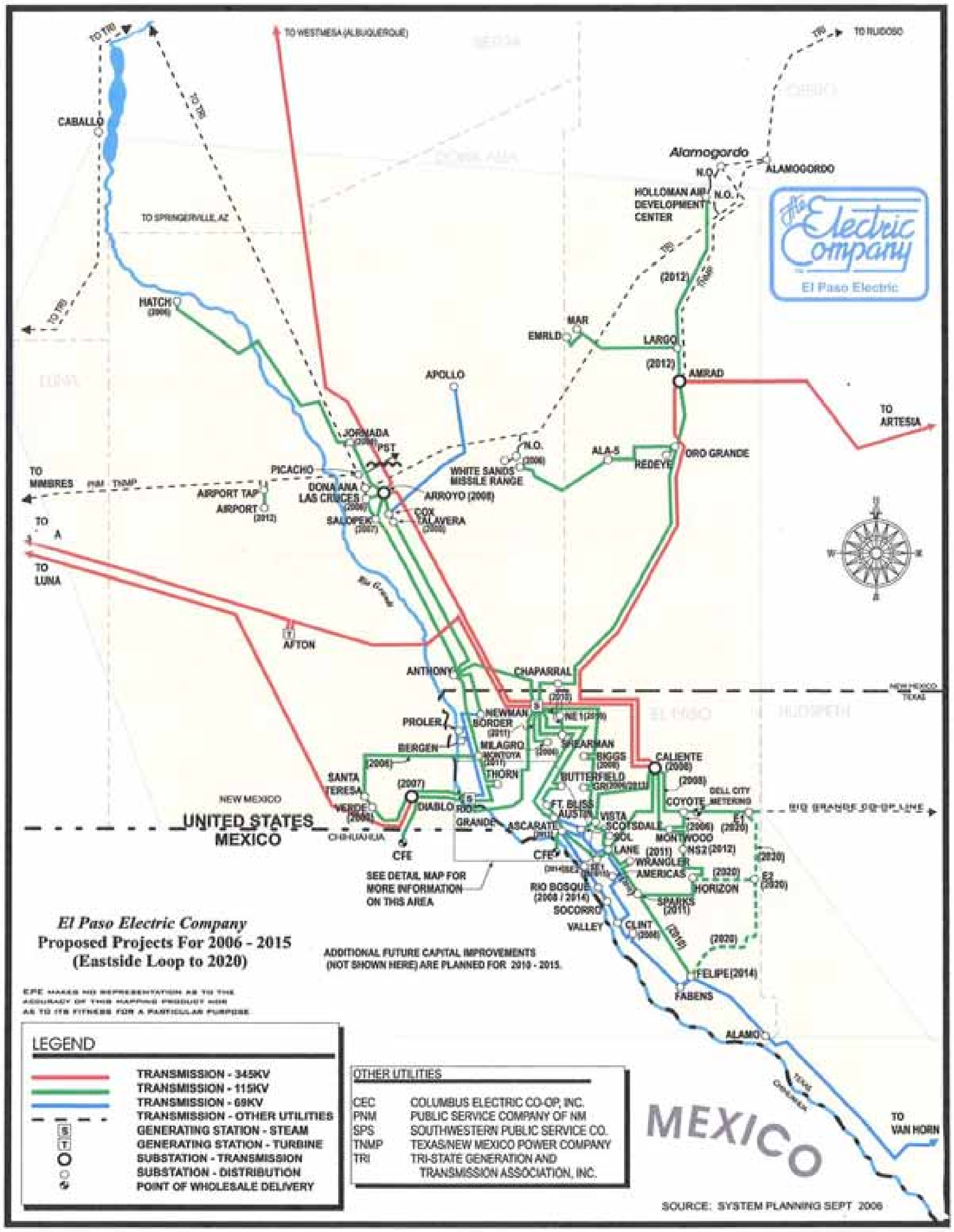
available data at that hour. Because of missing values, none of the three curves had valid data for all 8760 h, but each curve had a different number of valid hours. As such, for example, the 92% probability line corresponds to a slightly different number of hours for each array size.

"Firm capacity" is the fraction of installed wind capacity that is online at the same probability as that of a coal-fired power plant. On average, coal plants are free from unscheduled or scheduled maintenance for 79%–92% of the year, averaging 87.5% in the United States from 2000 to 2004 (Giebel 2000; North American Electric Reliability Council 2005). Figure 3 shows that, while the guaranteed power generated by a single wind farm for 92% of the hours of the year was 0 kW, the power guaranteed by 7 and 39 interconnected farms was 60 and 171 kW, giving firm capacities of 0.04 and 0.31, respectively. Furthermore, 19 interconnected wind farms guaranteed 222 kW of power (firm capacity of 0.15) for 87.5% of the year, the same percent of the year that an average coal plant in the United States guarantees power. Last, 19 farms guaranteed 312 kW of power for 79% of the year, 4 times the guaranteed power generated by one farm for 79% of the year.

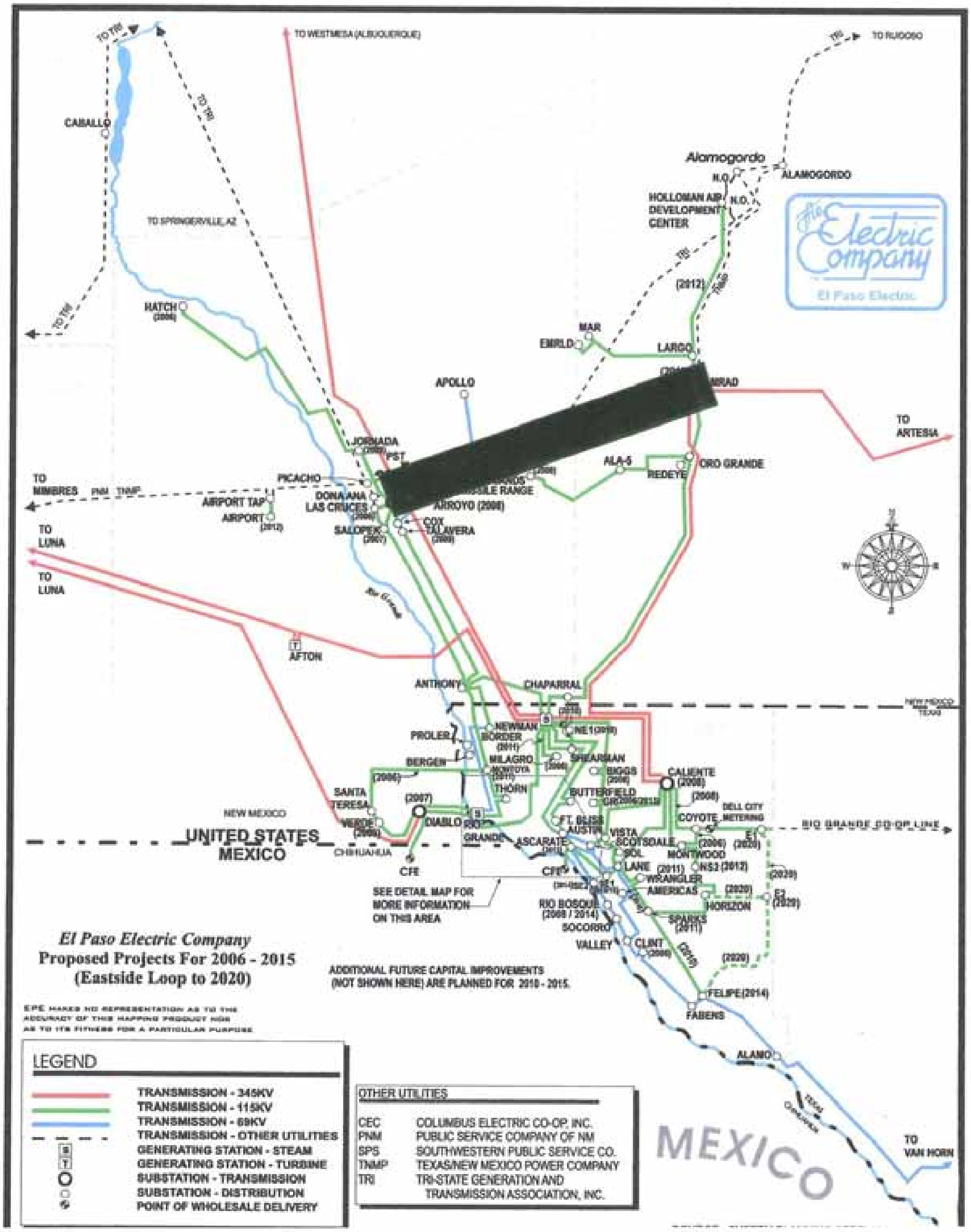
Capacity factor is the fraction of the rated power (or maximum capacity) actually produced in a year. The capacity factor of the 19-site array was ~0.45, corre-

TABLE 2. Statistics of interconnected wind power from aggregate arrays as a function of the number of sites included. Values obtained with the absolute value of A in Eq. (7) are in parentheses.

No. of sites	1	3	7	11	15	19
No. of combinations analyzed	19	969	50 388	75 582	3876	1
Array-average wind speed (m s^{-1})	8.25 (8.24)	8.12 (8.12)	8.12 (8.12)	8.12 (8.11)	8.12 (8.11)	8.12 (8.11)
Std dev of array-average wind speed (m s^{-1})	4.36 (4.34)	3.47 (3.46)	3.05 (3.05)	2.93 (2.93)	2.87 (2.87)	2.84 (2.84)
Array-average wind power (kW)	680.69 (680.87)	665.39 (665.33)	665.11 (665.0[illegible])	665.16 (665.06)	665.14 (665.03)	665.13 (665.02)
Std dev of array-average wind power (kW)	569.85 (569.20)	448.47 (448.31)	39[illegible].07 (394.2[illegible])	378.01 (378.22)	370.35 (370.59)	365.85 (366.12)
Total wind energy (MWh)	5189 (5191)	15 568 (15 573)	36 306 (3[illegible] 33[illegible])	57 084 (57 099)	77 842 (77 862)	98 600 (98 625)
Mean capacity factor (%)	45.38 (45.39)	45.32 (45.33)	45.30 (4[illegible].31)	45.29 (45.31)	45.29 (45.30)	45.29 (45.30)
Firm capacity, base case (at 87.5% and 79% probability)	0.00 0.05	0.04 0.09	0.06 0.12	0.10 0.16	0.11 0.14	0.15 0.21
Reserve requirements (MWh) per site, test case only	835	641	533	452	438	403


El Paso Electric Company
Proposed Projects For 2006 - 2015
(Eastside Loop to 2020)
EPE MAKES NO REPRESENTATION AS TO THE ACCURACY OF THIS MAPPING PRODUCT NOR AS TO ITS FITNESS FOR A PARTICULAR PURPOSE
LEGEND
TRANSMISSION - 345KV
TRANSMISSION - 115KV
TRANSMISSION - 69KV
TRANSMISSION - OTHER UTILITIES
GENERATING STATION - STEAM
GENERATING STATION - TURBINE
SUBSTATION - TRANSMISSION
SUBSTATION - DISTRIBUTION
POINT OF WHOLESALE DELIVERY
OTHER UTILITIES
CEC COLUMBUS ELECTRIC CO-OP, INC.
PNM PUBLIC SERVICE COMPANY OF NM
SPS SOUTHWESTERN PUBLIC SERVICE CO.
TNMP TEXAS/NEW MEXICO POWER COMPANY
TRI TRI-STATE GENERATION AND TRANSMISSION ASSOCIATION, INC.
SOURCE: SYSTEM PLANNING SEPT 2006
The Electric Company
El Paso Electric
TO WESTMESA (ALBUQUERQUE)
TO RUIDOSO
TO TRI
TO SPRINGERVILLE, AZ
CABALLO
HATCH (2006)
APOLLO
Alamogordo
ALAMOGORDO
N.O.
HOLLOMAN AIR DEVELOPMENT CENTER
(2012)
MAR
EMRLD
LARGO
AMRAD
TO ARTESIA
JORNADA
PST
PICACHO
TO MIMBRES
PNM TNMP
AIRPORT TAP
AIRPORT (2012)
DONA ANA
LAS CRUCES
SALOPEK (2007)
ARROYO (2008)
COX
TALAVERA
WHITE SANDS MISSILE RANGE
ALA-5
REDEYE
ORO GRANDE
TO A
TO LUNA
AFTON
Rio Grande
ANTHONY
CHAPARRAL
NEWMAN
BORDER
PROLER
BERGEN
MILAGRO
MONTOYA
THORN
NE1
SHEARMAN
BIGGS
CALIENTE (2008)
BUTTERFIELD
SANTA TERESA
VERDE
DIABLO
RIO GRANDE
CFE
ASCARATE
FT. BLISS
AUSTIN
VISTA
SCOTSDALE
COYOTE
DELL CITY METERING
E1
RIO GRANDE CO-OP LINE
SOL
MONTWOOD
NS2 (2012)
LANE
WRANGLER
AMERICAS
HORIZON
E2 (2020)
RIO BOSQUE (2008 / 2014)
SOCORRO
SPARKS (2011)
VALLEY
CLINT
FELIPE (2014)
FABENS
ALAMO
TO VAN HORN
NEW MEXICO
UNITED STATES
MEXICO
CHIHUAHUA
NEW MEXICO TEXAS
TEXAS CHIHUAHUA
SEE DETAIL MAP FOR MORE INFORMATION ON THIS AREA
ADDITIONAL FUTURE CAPITAL IMPROVEMENTS (NOT SHOWN HERE) ARE PLANNED FOR 2010 - 2015.
LUNA
DONA ANA
OTERO
EL PASO
HUDSPETH
MEXICO

Page 6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Alamogordo
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HOLLOMAN AIR DEVELOPMENT CENTER
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TO SPRINGERVILLE, AZ
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CFE
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WRANGLER
(2020)
AMERICAS
(2020)
E2 (2020)
SEE DETAIL MAP FOR MORE INFORMATION ON THIS AREA
RIO BOSQUE (2008 / 2014)
HORIZON
SOCORRO
SPARKS (2011)
VALLEY
CLINT (2008)
(2010)
(2020)
ADDITIONAL FUTURE CAPITAL IMPROVEMENTS (NOT SHOWN HERE) ARE PLANNED FOR 2010 - 2015.
FELIPE (2014)
FABENS
El Paso Electric Company
Proposed Projects For 2006 - 2015
(Eastside Loop to 2020)
EPE MAKES NO REPRESENTATION AS TO THE ACCURACY OF THIS MAPPING PRODUCT NOR AS TO ITS FITNESS FOR A PARTICULAR PURPOSE
ALAMO
TEXAS
CHIHUAHUA
LEGEND
TRANSMISSION - 345KV
TRANSMISSION - 115KV
TRANSMISSION - 69KV
TRANSMISSION - OTHER UTILITIES
S GENERATING STATION - STEAM
T GENERATING STATION - TURBINE
SUBSTATION - TRANSMISSION
SUBSTATION - DISTRIBUTION
POINT OF WHOLESALE DELIVERY
OTHER UTILITIES
CEC COLUMBUS ELECTRIC CO-OP, INC.
PNM PUBLIC SERVICE COMPANY OF NM
SPS SOUTHWESTERN PUBLIC SERVICE CO.
TNMP TEXAS/NEW MEXICO POWER COMPANY
TRI TRI-STATE GENERATION AND TRANSMISSION ASSOCIATION, INC.
MEXICO
TO VAN HORN
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S
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[redacted]

EPE Transmission Rights

Maximum Firm SNMI Rights	925 MW
El Paso Electric	645 MW
Texas-New Mexico Power	110 MW
Public Service New Mexico	75 MW
Tri-State G&T	95 MW
HVDC Interconnection Rights	
El Paso Electric	133 MW
Texas-New Mexico Power	67 MW

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Supplying Baseload Power and Reducing Transmission Requirements by Interconnecting Wind Farms

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ABSTRACT

Wind is the world's fastest growing electric energy source. Because it is intermittent, though, wind is not used to supply baseload electric power today. Interconnecting wind farms through the transmission grid is a simple and effective way of reducing deliverable wind power swings caused by wind intermittency. As more farms are interconnected in an array, wind speed correlation among sites decreases and so does the probability that all sites experience the same wind regime at the same time. The array consequently behaves more and more similarly to a single farm with steady wind speed and thus steady deliverable wind power. In this study, benefits of interconnecting wind farms were evaluated for 19 sites, located in the midwestern United States, with annual average wind speeds at 80 m above ground, the hub height of modern wind turbines, greater than 6.9 $\mathrm{m\ s^{-1}}$ (class 3 or greater). It was found that an average of 33% and a maximum of 47% of yearly averaged wind power from interconnected farms can be used as reliable, baseload electric power. Equally significant, interconnecting multiple wind farms to a common point and then connecting that point to a far-away city can allow the long-distance portion of transmission capacity to be reduced, for example, by 20% with only a 1.6% loss of energy. Although most parameters, such as intermittency, improved less than linearly as the number of interconnected sites increased, no saturation of the benefits was found. Thus, the benefits of interconnection continue to increase with more and more interconnected sites.

1. Introduction

Stabilizing global climate, reducing air pollution, and addressing energy shortages will require a change in the current energy infrastructure. One method to address these problems is to initiate a large-scale wind energy program. The world's electric power demand of 1.6–1.8 TW (International Energy Agency 2003; Energy Information Administration 2004) could, for example, theoretically be satisfied with approximately 890 000 currently manufactured 5-MW turbines with 126-m diameter blades placed in yearly averaged wind speeds at hub height of 8.5 $\mathrm{m\ s^{-1}}$ or faster, assuming a 10% loss from energy conversions and transmission (derived from Jacobson and Masters 2001; Masters 2004). This number is only 7–8 times the total number of much smaller turbines currently installed worldwide. The offshore average wind speed at 80 m is 8.6 $\mathrm{m\ s^{-1}}$, and sufficient winds >6.9 $\mathrm{m\ s^{-1}}$ at 80 m may be available over land and near shores to supply all electric power needs 35 times over and all energy needs 5 times over (Archer and Jacobson 2005).

However, a well known barrier to large-scale implementation of wind power is the intermittency of winds. Over a time frame of a few minutes, it is possible to experience sudden changes in wind speed, such as gusts or lulls. The predictability of wind in the short-term is still low, and, even with elaborate forecasting tools, it is often difficult to beat persistency (Giebel 2003; Ahlstrom et al. 2005). The intermittency of wind is directly transmitted into wind power, which dramatically reduces the marketing value of wind (Milligan and Porter 2005). On the other hand, because coal combustion can be controlled, coal energy is not considered intermittent and is often used as "baseload" energy. Nevertheless, because coal plants were shut down for scheduled maintenance 6.5% of the year and unscheduled maintenance or forced outage for another 6% of the year on average in the United States from 2000 to 2004, coal

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energy from a given plant is guaranteed only 87.5% oi the year, with 3 typical range of 79%–92% (North American Electric Reliability Council 2005; Giebel 2000).

A solution to improve wind power reliability is interconnected wind power. In other words, by linking multiple wind farms together it is possible to improve substantially the overall performance of the interconnected system (i.e., array) when compared with that of any individual wind farm. The idea is that, while wind speed could he calm at a given location, it will be noncalm somewhere else in the aggregate array.

This idea is not new. The first complete study about the effect of geographically dispersed wind power generation was done by Kahn (1979), who analyzed re& ability, availability, and effective load carrying capabilit [ELCC: see Milligan and Porter (2005) for a review of ELCC] of arrays of different sizes in California, varying from 2 to 13 connected sites. He found that most parameters (such as correlation and availability at low wind speeds) improved as the size of the array increased. Archer and Jacobson (2003, 2004) found that the frequency of zero- and low-wind events over. a network of eight sites in the central United States was less than 2% at 80-m hub height. Simonsen and Stevens (2004) compared wind power output from individual wind farms with that from an array of 28 sites in the central United States anti concluded that variability in energy production was reduced by a factor of 1.75–3.4. They also found that the combined energy output from 50-m hub height, 660-kW turbines in the 28-site array, had a smoother diurnal pattern and a relative maximum in the afternoon, during the peak time of electricity demand. Czisch and Ernst (2001) showed that a network of wind farms over parts of Europe and Northern Africa could supply about 70% of the entire European electricity demand. In Spain, one of the leading countries for wind power production (American Wind Energy Association 2004; Energy Information Administration 2004), the combined output of 81% of the nation's wind farms is remarkably smooth, and sudden wind power swings are eliminated (Red Eléctrica de España real-time data are available online at http://www.ree.es/apps/i-index_dinamico.asp?menu=/ingles/i-cap07/i-menu_sis.htm&principal=/apps_eolica/curvas2ing.asp).

The benefits of interconnected wind power are greater for larger catchment areas. Statistical correlation among stations is the key factor in understanding why. In fact, weather conditions may not vary over. small areas, especially over horizontally uniform terrain. This would be reflected in a high correlation among nearby Farin pairs. However, as distance between farms or terrain variability increases, the correlation among farms becomes smaller. Kahn (1979) found that the average correlation between site pairs decreased from 0.49 to 0.25 as the number of farms connected was increased from 2 to 13. However, the marginal benefits decreased as well. For example, by doubling the number of sites connected together, the availability at low wind speeds improved by only ~14%. Whether or not a zero correlation can eventually be reached is still an open question. Kahn (1979) suggested that statistical correlation of wind speed never disappears entirely. This effect will be hereinafter referred to as the "saturation" of the benefits, to indicate that, at some point, no incremental benefits are found in increasing the array size.

Kahn (1979) also analyzed the capacity credit for such arrays, defined as the "amount of conventional capacity which can be displaced by wind generation." He found that, for a fixed ELCC, the capacity credit of larger arrays increased less than linearly with the number of sites. This effect can be interpreted as "diminishing returns to implementing state-wide pooling of the wind resource." Note that of the 13 sites analyzed, only 4 were in class 3 or higher at 60 m. As such, it is not surprising that the addition of "slow" sites to the array did not improve its overall performance.

The issue of wind integration in the power system has been receiving more attention recently (Ackermann 2005; DeMeo et al. 2005; Piwko et al. 2005; Zavadil et al. 2005). Most studies assumed a low (10% or less) penetration of wind power (expressed as ratio of nameplate wind generation over peak load) and treated the output of farms as negative load (Piwko et al. 2005; DeMeo et al. 2005). Only a few countries in Europe have high (20% or more) wind penetrations (Eriksen et at. 2005): Denmark (49%), Germany (22%), and Spain (22%). High penetrations of wind power without reductions in system stability can only he achieved with turbines equipped with fault ride-through capability (Eriksen et al. 2005). No study to date has examined the ability of interconnected wind farms to provide guaranteed (or baseload) power. Only a few studies have looked at reducing transmission requirements by interconnecting wind farms. Romanowitz (2005) reported that an additional 100 MW of wind power could be added to the Tehachapi grid in California without increasing the transmission capacity. Matevosyan (2005) showed that, in areas with limited transmission capacity, curtailing (or "spilling") a small percent of the power produced by interconnected wind farms could be effective. This study examines both issues in detail. It does not, however, examine the ability of wind to match peaks in energy demand. It assumes that wind can provide a portion of baseload energy, and that peaking energy would be provided by other sources.

2. Interconnected wind power

a. Method

Wind speed data from the National Climatic Data Center (2004) and former Forecast Systems Laboratory (2004), now the Global Systems Division of the Earth System Research Laboratory, for 2000 were used to evaluate the effects of connecting wind farms. More details on the dataset can be found in Archer and Jacobson (2005). Hourly and daily averaged wind speed measurements were available from surface stations at a standard elevation of ~10 m above the ground (V10 hereinafter). Observed vertical profiles of wind speed were available at sounding stations, generally 2 times per day (0000 and 1200 UTC). This study utilized the least squares (LS) method to obtain relevant statistics of wind speed at 80 m (V80 hereinafter), the hub height of modern wind turbines. The reader is referred to Archer and Jacobson (2003, 2004, 2005) for details of the method, which will be further validated in the next section.

To determine wind power output from connected wind farms, the benchmark turbine selected was the GE 1.5 MW with 77-m blade diameter at 80-m hub height. Manufacturer data were provided only at one $\mathrm{m\,s^{-1}}$ intervals of hub height wind speed (General Electric 2004). It was necessary therefore to determine an appropriate curve that would provide power output P for any value of wind speed V. Several multiparameter curves were tried out, including third-order polynomial, sinusoidal, and linear. The best curve was found to be a combination of two third-order polynomials:

$$P = \begin{cases} 0 & V < V_{\mathrm{min}} \\ P_{\mathrm{lower}}(V) & V_{\mathrm{min}} \le V < V_{\mathrm{split}} \\ P_{\mathrm{upper}}(V) & V_{\mathrm{split}} \le V < V_{\mathrm{rated}} \\ P_{\mathrm{rated}} & V_{\mathrm{rated}} \le V < V_{\mathrm{max}} \\ 0 & V \ge V_{\mathrm{max}} \end{cases}, \qquad (1)$$

where P_{rated} is the rated power of the turbine (1500 kW) at the rated wind speed V_{rated} ($12\ \mathrm{m\,s^{-1}}$). V_{min} (V_{max}) is the speed below (above) which no power can be produced (3 and $25\ \mathrm{m\,s^{-1}}$, respectively), V_{split} is the speed above (below) which the P_{upper} (P_{lower}) formulation is imposed (i.e., where the concavity of the power curve changes sign), and P_{upper} and P_{lower} are the third-order polynomials that pass through the upper and lower points of the GE 1.5-MW power curve, respectively:

$$P_i = a_i V^3 + b_i V^2 + c_i V + d_i, \quad i = \text{upper, lower}. \qquad (2)$$

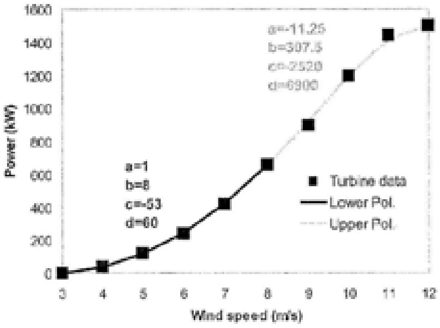

FIG. 1. Fitting curves for the GE 1.5-MW turbine.

Values of the fitting coefficients are reported in Fig. 1. Third-order polynomials were preferred over higher-order curves because of the theoretical dependence of wind power on the third power of wind speed.

Next, the selection of appropriate locations to connect is discussed. From Archer and Jacobson (2003), the central United States was identified as a favorable area for locating and connecting wind farms. Also, locations with mean annual 80-m wind speed > $6.9\ \mathrm{m\,s^{-1}}$ (i.e., in class 3 or higher) were recommended. As such, this study focused on the area shown in Fig. 2.

The LS method was first applied to daily averages of V10 at all surface stations in the area to obtain the spatial distribution of yearly average V80 (hourly data will be used next). LS parameters were calculated from the sounding stations 2 times per day, at 0000 and 1200 UTC, corresponding to 0500–1700 LST, for the entire year 2000. Figure 2 shows annual averages of V80 at sites favorable for harnessing wind power (in class 3 or higher) in the region. The stations selected for the rest of this analysis are listed in Table 1 and marked with their acronyms in Fig. 2. The selection proceeded by enlarging the area around Dodge City, Kansas, the site selected as representative of a single farm.

To determine the differences in power output for individual versus connected wind sites, hourly observed 10-m wind speeds were used to calculate the hourly evolution of V80 via the so-called shear function, described later in section 2b. Last, the hourly power output at each station was calculated with Eq. (1) and averaged over N stations, where N was either 1, 3, 7, 11, 15, or 19. Sites that had missing data at a given hour were not counted in the average for that hour. The frequency of missing data was surprisingly large, about 10%. Given a pool of 19 sites and an array size of K (where K = 1, 3, 7, 11, 15, or 19), the number of pos-

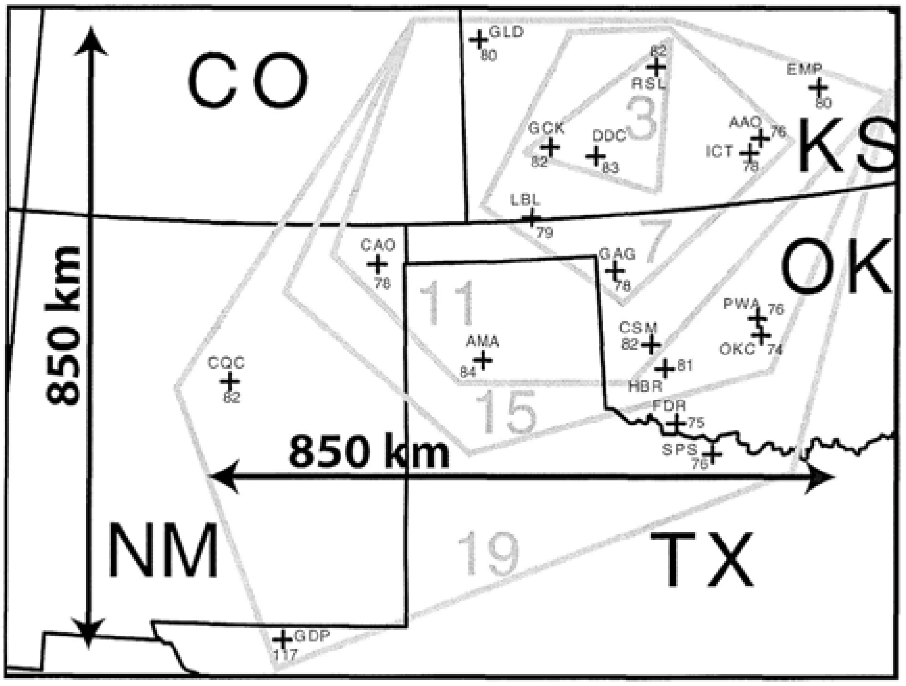

FIG. 2. Locations of the 19 sites used in arrays. Sites included in the 3-, 7-, 11-, 15-, and 19-site array configuration based on geography only are grouped within gray lines; also shown are annual average wind speeds (10^{-1} m s^{-1}) at each site.

sible combinations of sites that can be included is large (Table 2). For example, there are 50 388 possible combinations of seven sites among the 19 of interest. The "base case" for this study is based solely on geographical proximity, and it is described in Table 1. Unless otherwise stated, all possible combinations of sites for each array size are evaluated in the rest of this study.

b. Results

The analysis indicated that the reliability of interconnected wind systems increased with the number of farms. Reliability in this context is defined in terms of a "generation duration curve," also known as a "duration curve" (Nørgård et al. 2004; Holttinen and Hirvonen 2005), which is analogous to the load duration curve used for electricity demand. All hours in a year (i.e., 365 × 23 = 8760) are rearranged based on decreasing wind power magnitude, and the corresponding power is plotted as a decreasing curve. The generation curve can also be interpreted as a "reversed" cumulative probability distribution, in which each point on the y axis represents the probability (in terms of number of hours in a year) of wind power production greater or equal to the corresponding y value on the curve. The adjective reversed was used because a traditional cumulative probability distribution is monotonically increasing, and it shows the probability of the variable being lower or equal to the value on the curve.

Figure 3 shows generation duration curves for the 1-, 7-, and 19-site base-case arrays. For the figure, all hours in a year, less 2% of randomly selected hours where wind turbines were assumed to be down because of unplanned maintenance, were rearranged based on decreasing wind power magnitude per hour. For simplicity, each site is considered to have a single GE 1500-kW turbine (General Electric 2004), and each curve shows the wind power output per turbine, averaged over all sites in the array. For the seven-site array, for example, each point shows the total power produced by the array divided by the number of sites (seven at most) with

TABLE 1. List of selected sites and their properties (ID means identifier).

ID	Name	State	Yearly V80	Power class	No. of sites it arrays(s)
DDC	Dodge City	KS	3.3	5	1, 3, 7, 11, 15, 19
I	Garden i	KS	8.1	5	3, 7, 11, 15, 19
RSL	Russell	KS	8.2	5	3, 7, 11, 15, 19
LBL	Liberal	KS	7.9	4	7, 11, 15, 19
GAG	Gage	OK	7.8	4	7, 11, 15, 19
ICT	Wichita	KS	7.8	4	7, 11, 15, 19
AAO	Wichita–Col. Jabar	KS	7.6	4	7, 11, 15, 19
GLD	Goodland Rennes	KS	8.0	4	11, 15, 19
EMP	Emporia	KS	8.0	4	11, 15, 19
CAO	Clayton	NM	7.8	4	11, 15, 19
CSM	Clinton	OK	8.2	5	11, 15, 19
AMA	Amarillo	TX	8.4	5	15, 19
OKC	Oklahoma City	OK	7.4	3	15, 19
HBR	Hobart	OK	8.1	5	15, 19
,	Oklahoma City	OK	7.6	4	15, 19
FDR	Frederick	OK	7.5	.	19
SPS	Wichita Falls	TX	7.6	4	19
CQC	Clines Corner	NM	8.2	5	19
GDP	Pine Springs	TX	11.7	7	19

available data at that hour. Because of missing values, none of the three curves had valid data for all 8760 h, but each curve had a different number of valid hours. As such, for example, the 92% probability line corresponds to a slightly different number of hours for each array size.

"Firm capacity" is the fraction of installed wind capacity that is online at the same probability as that of a coal-fired power plant. On average, coal plants are free from unscheduled or scheduled maintenance for 79%–92% of the year, averaging 87.5% in the United States from 2000 to 2004 (Giebel 2000; North American Electric Reliability Council 2005). Figure 3 shows that, while the guaranteed power generated by a single wind farm for 92% of the hours of the year was 0 kW, the power guaranteed by 7 and 19 interconnected farms was 60 and 171 kW, giving firm capacities of 0.04 and 0.11, respectively. Furthermore, 19 interconnected wind farms guaranteed 222 kW of power (firm capacity of 0.15) for 87.5% of the year; the same percent of the year that an average coal plant in the United States guarantees power. Last, 19 farms guaranteed 312 kW of power for 79% of the year, 4 times the guaranteed power generated by one farm for 79% of the year.

Capacity factor is the fraction of the rated power (or maximum capacity) actually produced in a year. The capacity factor of the 19-site array was ~0.45, corre-

TABLE 2. Statistics of interconnected wind power from aggregate arrays as a function of the number of sites included. Values obtained with the absolute value of A in Eq. (7) are in parentheses.

No. of sites	1	3	7	11	15	19
No. of combinations analyzed	19	969	50 388	75 582	3876	1
Array-average wind speed (m s^{-1})	8.25 (8.24)	8.12 (8.12)	8.12 (8.11)	8.12 (8.11)	8.12 (8.11)	8.12 (8.11)
Std dev of array-average wind speed (m s^{-1})	4.36 (4.34)	3.47 (3.46)	3.05 (3.05)	2.93 (2.93)	2.87 (2.87)	2.84 (2.84)
Array-average wind power (kW)	680.69 (680.87)	665.39 (665.33)	665.11 (665.01)	665.16 (665.06)	665.14 (665.03)	665.13 (665.02)
Std dev of array-average wind power (kW)	569.85 (569.20)	448.47 (448.31)	394.07 (394.21)	378.01 (378.22)	370.35 (370.59)	365.85 (366.12)
Total wind energy (MWh)	5189 (5191)	15 568 (15 573)	36 326 (36 336)	57 084 (57 099)	77 842 (77 862)	98 600 (98 625)
Mean capacity factor (%)	45.38 (45.39)	45.32 (45.33)	45.30 (45.31)	45.29 (45.31)	45.29 (45.30)	45.29 (45.30)
Firm capacity, base case (at 87.5% and 79% probability)	0.00 0.05	0.04 0.09	0.06 0.12	0.10 0.16	0.11 0.14	0.15 0.21
Reserve requirements (MWh) per site, test case only	835	641	513	452	438	403

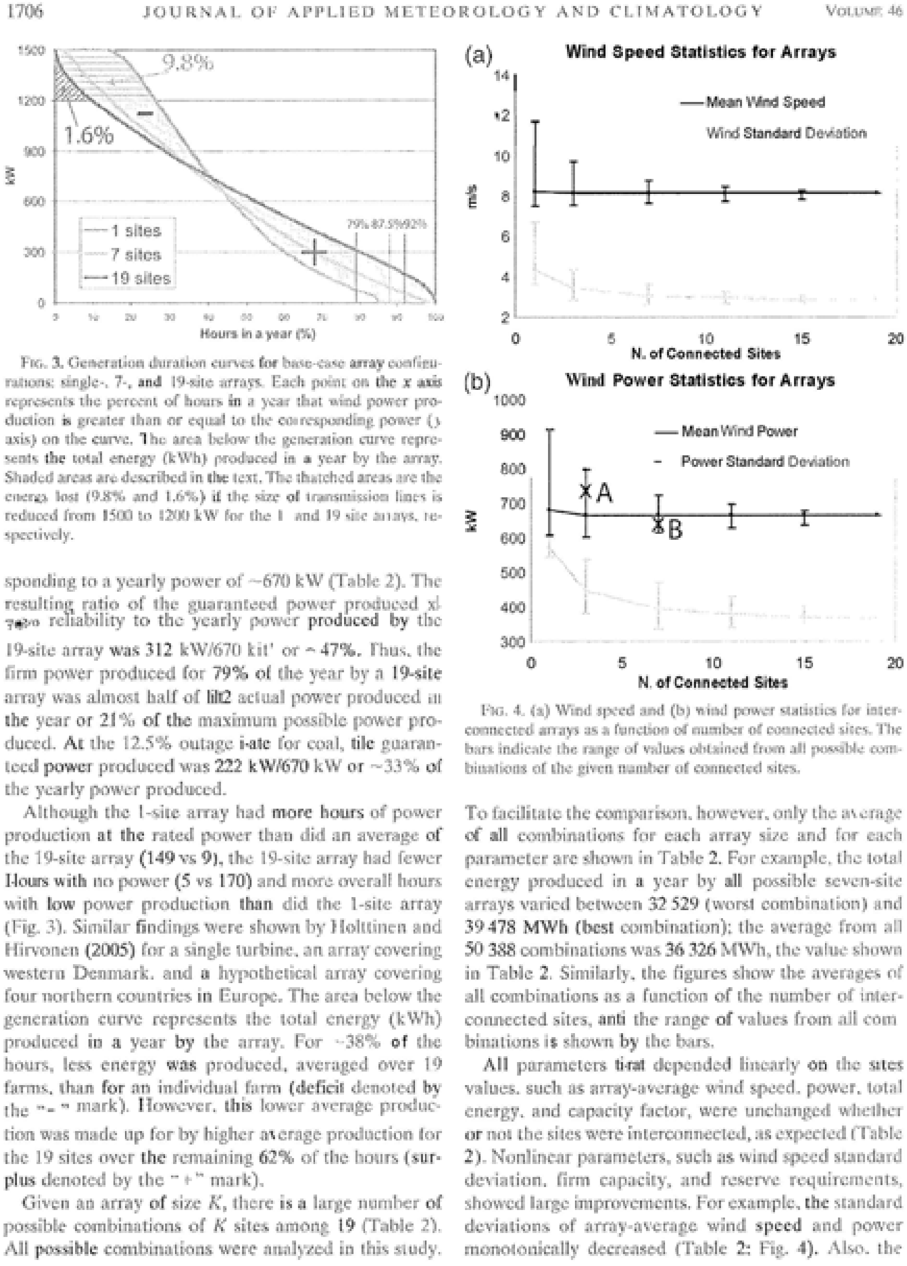

FIG. 3. Generation duration curves for base-case array configurations: single-, 7-, and 19-site arrays. Each point on the *x* axis represents the percent of hours in a year that wind power production is greater than or equal to the corresponding power (*y* axis) on the curve. The area below the generation curve represents the total energy (kWh) produced in a year by the array. Shaded areas are described in the text. The thatched areas are the energy lost (9.8% and 1.6%) if the size of transmission lines is reduced from 1500 to 1200 kW for the 1- and 19-site arrays, respectively.

sponding to a yearly power of ~670 kW (Table 2). The resulting ratio of the guaranteed power produced at 79% reliability to the yearly power produced by the 19-site array was 312 kW/670 kW or ~47%. Thus, the firm power produced for 79% of the year by a 19-site array was almost half of the actual power produced in the year or 21% of the maximum possible power produced. At the 12.5% outage rate for coal, the guaranteed power produced was 222 kW/670 kW or ~33% of the yearly power produced.

Although the 1-site array had more hours of power production at the rated power than did an average of the 19-site array (149 vs 9), the 19-site array had fewer hours with no power (5 vs 170) and more overall hours with low power production than did the 1-site array (Fig. 3). Similar findings were shown by Holttinen and Hirvonen (2005) for a single turbine, an array covering western Denmark, and a hypothetical array covering four northern countries in Europe. The area below the generation curve represents the total energy (kWh) produced in a year by the array. For ~38% of the hours, less energy was produced, averaged over 19 farms, than for an individual farm (deficit denoted by the "−" mark). However, this lower average production was made up for by higher average production for the 19 sites over the remaining 62% of the hours (surplus denoted by the "+" mark).

Given an array of size *K*, there is a large number of possible combinations of *K* sites among 19 (Table 2). All possible combinations were analyzed in this study.

FIG. 4. (a) Wind speed and (b) wind power statistics for interconnected arrays as a function of number of connected sites. The bars indicate the range of values obtained from all possible combinations of the given number of connected sites.

To facilitate the comparison, however, only the average of all combinations for each array size and for each parameter are shown in Table 2. For example, the total energy produced in a year by all possible seven-site arrays varied between 32 529 (worst combination) and 39 478 MWh (best combination); the average from all 50 388 combinations was 36 326 MWh, the value shown in Table 2. Similarly, the figures show the averages of all combinations as a function of the number of interconnected sites, and the range of values from all combinations is shown by the bars.

All parameters that depended linearly on the sites values, such as array-average wind speed, power, total energy, and capacity factor, were unchanged whether or not the sites were interconnected, as expected (Table 2). Nonlinear parameters, such as wind speed standard deviation, firm capacity, and reserve requirements, showed large improvements. For example, the standard deviations of array-average wind speed and power monotonically decreased (Table 2; Fig. 4). Also, the

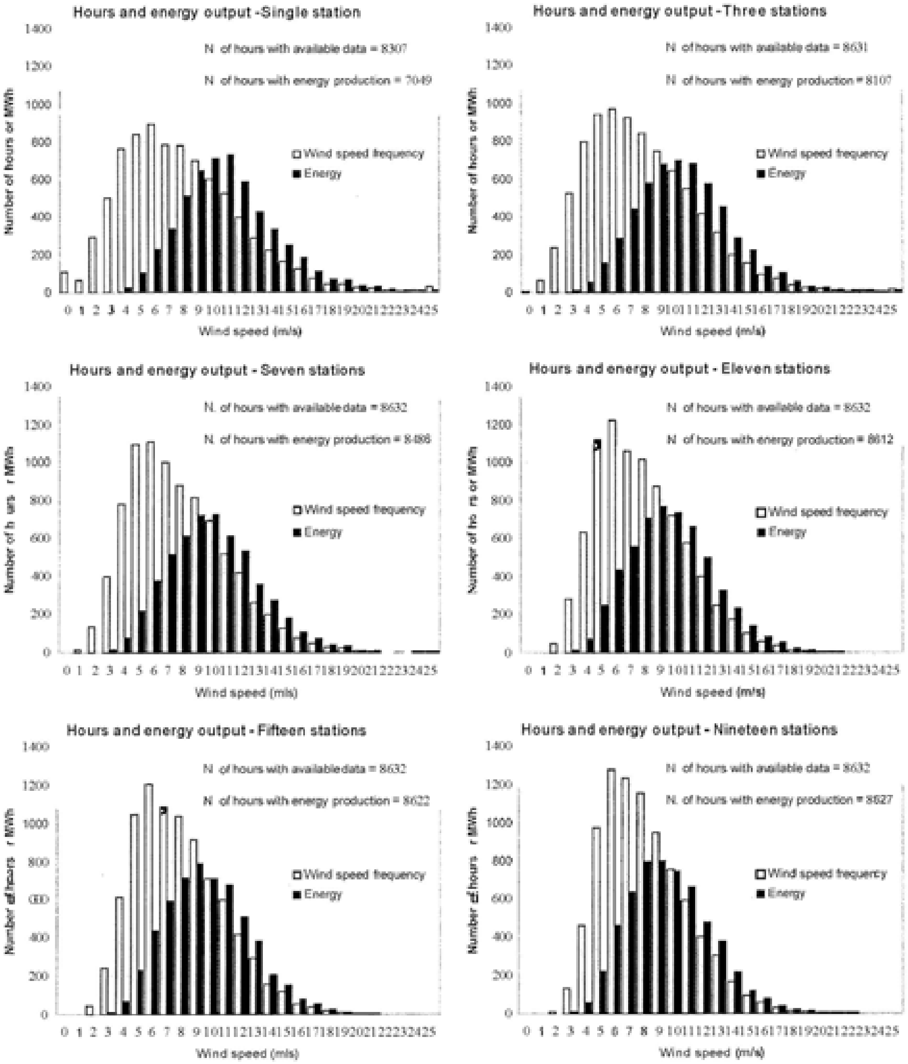

FIG. 5. Number of hours and energy output (kWh) at given wind speeds (m s^{-1}) for all hours of 2000 averaged over (a) 1, (b) 3 (c) 7, (d) 11, (e) 15, and (f) 19 stations.

frequency distribution of wind speed shifted to the right and became more symmetric as the number of stations included in the network increased (Fig. 5). This is consistent with previous findings by Archer and Jacobson (2003) and indicates that the array wind speed distribution is closer to Gaussian than it is to Rayleigh. As such, the more sites that are interconnected, the more the array resembles a single farm with steady winds.

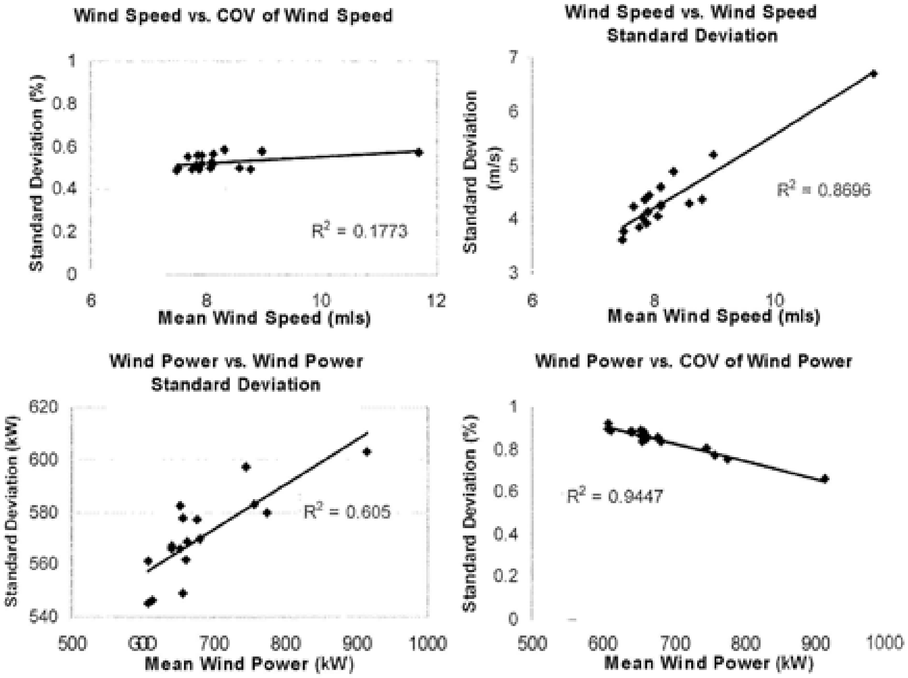

FIG. 6. Standard deviations and coefficients of variation of wind speed and wind power at the 19 sites selected

Second, it appears that marginal benefits decrease with an increase in the number of farms. In other words, even though all nonlinear parameters improved as the number of farms went up, the incremental benefit of adding new stations kept decreasing. This is consistent with both common sense and Kahn (1979). Figure 4 shows that wind speed and wind power standard deviations decreased less than linearly with an increasing number of sites. Note, however, that no saturation of the benefits was found, or, in other words, an improvement was obtained, even if small, for every addition to the array size.

Third, the optimal configuration was not necessarily the one with the highest number of sites. Figure 4b shows that some combinations of seven sites (e.g., point A in the figure) produced higher array-average wind power than some other combinations of 11 sites (e.g., point 13). The same applied to all other statistics. However, so long as more sites were added in a given array in such a way that the area covered became increasingly larger (as in the base case), statistical correlation among the sites decreased and so did standard deviations (Table 2 and Fig. 4), thus improving array reliability and performance. Note that array-average wind speed and power may become lower for increasingly larger areas if sites in lower wind power class are added to the initial pool.

Is there a trade-off between wind speed and intermittency? Simonsen and Stevens (2004) found that, as single-site wind speed increases, so does the ratio between single-site wind speed standard deviation and standard deviation of array-average wind speed (linearly). An incorrect interpretation of this finding would be that, as average wind speed increases, so does intermittency. While it is true that wind power (speed) standard deviation increases as wind power (speed) increases (Figs. 6a,b), this is not indicative of increased intermittency. One should not look at standard deviation per se, but at standard deviation and mean wind speed together to evaluate intermittency. A better parameter to look at is the ratio of standard deviation over the mean. This ratio, known as "coefficient of

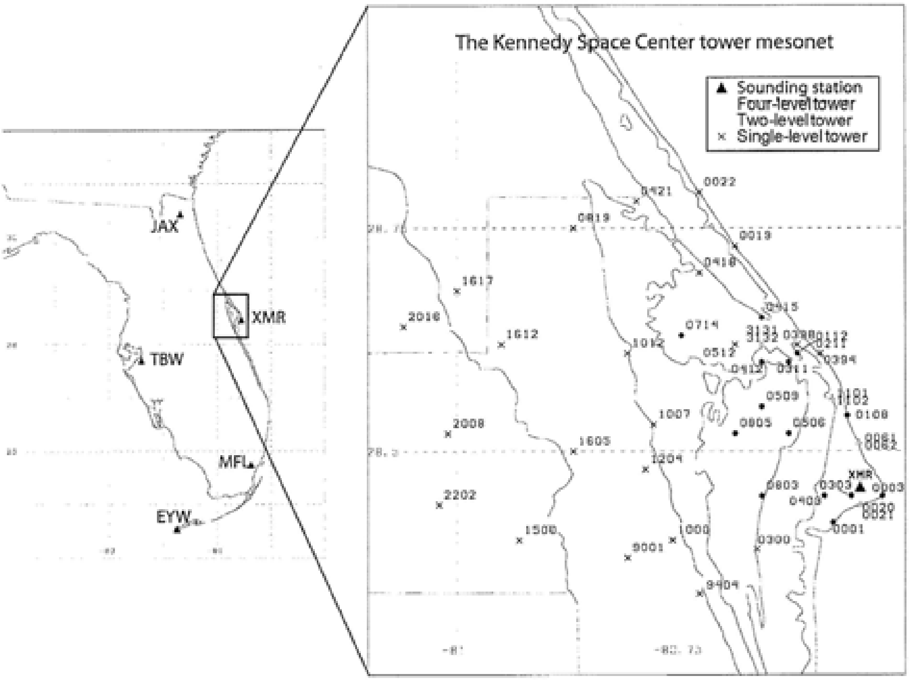

FIG. 9. Location of sounding stations and towers near the KSC

surface station. valid at the same hour as the soundings. The tinily average of V^{HUB} at the surface station should then be calculated from hourly values as follows:

$$\overline{V_H^{\mathrm{HUB}}} = \frac{1}{24} \times \left\{ \sum_{h=1}^{24} \frac{1}{\sum_{k=1}^{K} \frac{1}{R_k^2}} \times \left[\sum_{k=1}^{K} \frac{1}{R_k^2} L_{h,k}(V_h^{\mathrm{REF}}) \right] \right\}, \tag{3}$$

where $L_{h,k}$ is the LS function [as in Archer and Jacobson (2005)] at sounding station k for. hour h. V_h^{REF} is the hourly average of V^{REF} at the surface station, and $\overline{V_H^{\mathrm{HUB}}}$ is the daily average of $V^{\mathrm{IT\ B}}$ at the surface station as determined from hourly values.

However. neither sounding nor surface data are available on an hourly basis for all locations. Daily averages of wind speeds at the surface stations and 2-times-per-day sounding profiles are often the only available data. For the typical case of two sounding profiles (at 0000 and 1200 UTC), the estimate of the daily average wind speed at hub height based on daily average reference height wind speed V_D^{REF} was therefore

$$\overline{V_D^{\mathrm{HUB}}} = \frac{1}{\sum_{k=1}^{K} \frac{1}{R_k^2}} \times \left[\sum_{k=1}^{K} \frac{1}{R_k^2} \times \frac{L_{00,k}(\overline{V_D^{\mathrm{REF}}}) + L_{12,k}(\overline{V_D^{\mathrm{REF}}})}{2} \right], \tag{4}$$

where $L_{00,k}$ and $L_{12,k}$ are calculated at 0000 and 1200 UTC. respectively, from each sounding station k.

Archer and Jacobson (2005) used data from the KSC network to conclude that Eq. (4) was an acceptable (and conservative) approximation for Eq. (3). In this study, the same dataset is used to evaluate further the extent of the error introduced in Eq. (4) and the dependence of such error on the time zone of the stations of interest.

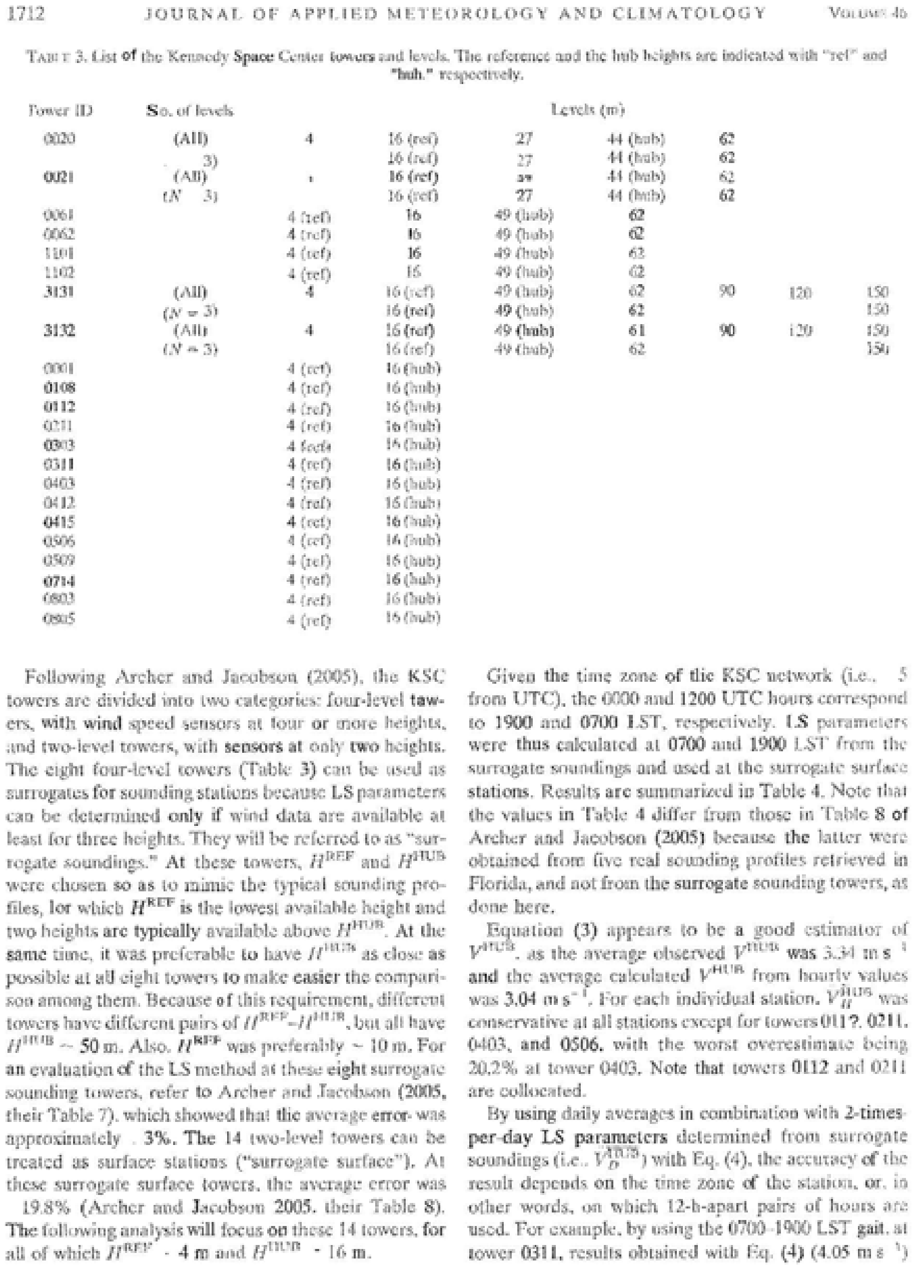

TABLE 3. List of the Kennedy Space Center towers and levels. The reference and the hub heights are indicated with "ref" and "hub," respectively.

Tower ID	No. of levels		Levels (m)					
0020	(All)	4	16 (ref)	27	44 (hub)	62		
	3)		16 (ref)	27	44 (hub)	62		
0021	(All)	4	16 (ref)	27	44 (hub)	62		
	(N 3)		16 (ref)	27	44 (hub)	62		
0061		4 (ref)	16	49 (hub)	62			
0062		4 (ref)	16	49 (hub)	62			
1101		4 (ref)	16	49 (hub)	62			
1102		4 (ref)	16	49 (hub)	62			
3131	(All)	4	16 (ref)	49 (hub)	62	90	120	150
	(N = 3)		16 (ref)	49 (hub)	62			150
3132	(All)	4	16 (ref)	49 (hub)	61	90	120	150
	(N = 3)		16 (ref)	49 (hub)	62			150
0001		4 (ref)	16 (hub)					
0108		4 (ref)	16 (hub)					
0112		4 (ref)	16 (hub)					
0211		4 (ref)	16 (hub)					
0303		4 (ref)	16 (hub)					
0311		4 (ref)	16 (hub)					
0403		4 (ref)	16 (hub)					
0412		4 (ref)	16 (hub)					
0415		4 (ref)	16 (hub)					
0506		4 (ref)	16 (hub)					
0509		4 (ref)	16 (hub)					
0714		4 (ref)	16 (hub)					
0803		4 (ref)	16 (hub)					
0805		4 (ref)	16 (hub)					

Following Archer and Jacobson (2005), the KSC towers are divided into two categories: four-level towers, with wind speed sensors at four or more heights, and two-level towers, with sensors at only two heights. The eight four-level towers (Table 3) can be used as surrogates for sounding stations because LS parameters can be determined only if wind data are available at least for three heights. They will be referred to as "surrogate soundings." At these towers, H^{REF} and H^{HUB} were chosen so as to mimic the typical sounding profiles, for which H^{REF} is the lowest available height and two heights are typically available above H^{HUB}. At the same time, it was preferable to have H^{HUB} as close as possible at all eight towers to make easier the comparison among them. Because of this requirement, different towers have different pairs of H^{REF}–H^{HUB}, but all have $H^{HUB} \sim 50$ m. Also, H^{REF} was preferably ~ 10 m. For an evaluation of the LS method at these eight surrogate sounding towers, refer to Archer and Jacobson (2005, their Table 7), which showed that the average error was approximately 3%. The 14 two-level towers can be treated as surface stations ("surrogate surface"). At these surrogate surface towers, the average error was 19.8% (Archer and Jacobson 2005, their Table 8). The following analysis will focus on these 14 towers, for all of which H^{REF} - 4 m and H^{HUB} - 16 m.

Given the time zone of the KSC network (i.e., 5 from UTC), the 0000 and 1200 UTC hours correspond to 1900 and 0700 LST, respectively. LS parameters were thus calculated at 0700 and 1900 LST from the surrogate soundings and used at the surrogate surface stations. Results are summarized in Table 4. Note that the values in Table 4 differ from those in Table 8 of Archer and Jacobson (2005) because the latter were obtained from five real sounding profiles retrieved in Florida, and not from the surrogate sounding towers, as done here.

Equation (3) appears to be a good estimator of V^{HUB}, as the average observed V^{HUB} was 3.34 m s^{-1} and the average calculated V^{HUB} from hourly values was 3.04 m s^{-1}. For each individual station, V_H^{HUB} was conservative at all stations except for towers 011?, 0211, 0403, and 0506, with the worst overestimate being 20.2% at tower 0403. Note that towers 0112 and 0211 are collocated.

By using daily averages in combination with 2-times-per-day LS parameters determined from surrogate soundings (i.e., V_D^{HUB}) with Eq. (4), the accuracy of the result depends on the time zone of the station, or, in other words, on which 12-h-apart pairs of hours are used. For example, by using the 0700–1900 LST gait, at tower 0311, results obtained with Eq. (4) (4.05 m s^{-1})

TABLE 4. Values of observed and calculated LS wind speeds at KSC two-level towers. Calculated values were obtained by either simultaneous V_{ref} and sounding parameters (hourly) or by using the daily average of V_{ref} with 12-h-apart sounding parameters. In boldface are the average observed wind speeds and those calculated from hourly profiles; also in boldface are the average wind speeds calculated from 2-times-per-day profiles for the time zones of the United States.

			Sounding times (LST)											
Tower	Obs	Hourly	0000–1200	0100–1300	0200–1400	0300–1500	0400–1600	0500–1700	0600–1800	0700–1900	0800–2000	0900–2100	1000–2200	1100–2300
0001	3.70	2.24	2.23	2.24	2.26	2.29	2.32	2.39	2.44	2.41	2.29	2.24	2.22	2.22
0108	3.51	2.60	2.50	2.49	2.52	2.54	2.56	2.61	2.67	2.64	2.57	2.54	2.51	2.51
0112	3.65	3.69	3.64	3.63	3.66	3.69	3.71	3.82	3.99	3.91	3.79	3.73	3.68	3.68
0211	4.24	4.34	4.24	4.21	4.35	4.43	4.48	4.54	4.66	4.65	4.42	4.17	4.15	4.23
0303	2.97	2.31	2.33	2.34	2.36	2.41	2.44	2.51	2.59	2.54	2.43	2.36	2.32	2.33
0311	3.96	3.86	3.79	3.80	3.80	3.84	3.88	3.97	4.12	4.05	3.92	3.87	3.79	3.82
0403	3.68	4.42	4.32	4.34	4.38	4.45	4.49	4.62	4.73	4.63	4.46	4.35	4.30	4.30
0412	3.20	2.72	2.76	2.76	2.76	2.80	2.83	2.91	3.03	2.94	2.85	2.77	2.75	2.77
0415	2.98	2.60	2.64	2.63	2.60	2.66	2.68	2.77	2.91	2.85	2.74	2.67	2.63	2.64
0506	3.34	3.72	3.62	3.62	3.64	3.64	3.67	3.70	3.72	3.75	3.72	3.70	3.62	3.64
0509	3.08	2.86	2.84	2.84	2.82	2.84	2.86	2.91	3.01	2.96	2.93	3.87	2.84	2.84
0714	3.26	2.40	2.41	2.40	2.38	2.42	2.44	2.51	2.60	2.53	2.47	2.44	2.39	2.41
0803	2.43	2.29	2.27	2.27	2.30	2.33	2.35	2.42	2.48	2.45	2.35	2.28	2.26	2.27
0805	2.72	2.51	2.51	2.50	2.52	2.53	2.55	2.59	2.66	2.60	2.54	2.54	2.50	2.51
Avg	**3.34**	**3.04**	3.01	3.01	3.03	3.06	3.09	**3.16**	**3.26**	**3.21**	3.11	3.04	3.00	3.01

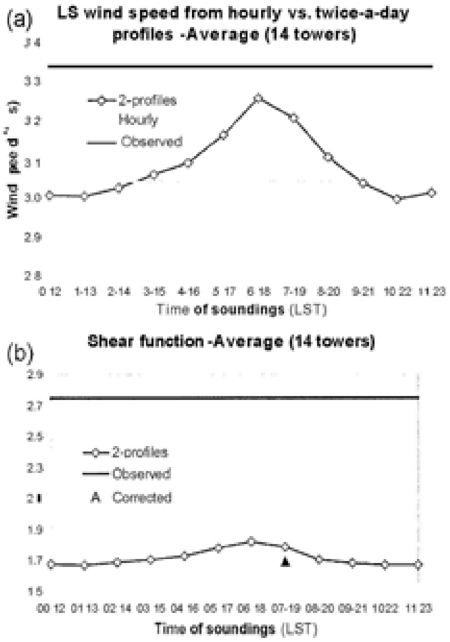

FIG. 10. (a) Observed winds, calculated from hourly V_{ref}, and calculated from daily averages of V_{ref} with 2-times-per-day soundings values of LS wind speed, averaged over all two-level towers of the KSC network. (b) Values of the shear function ρ averaged over all hours and all KSC two-level towers obtained with all 12-h-apart pairs of sounding times. The value obtained with correction factors at 0700–1900 LST (corresponding to 0000 and 1200 UTC in Florida) is shown with a rhomboidal mark. Reproduced from Archer and Jacobson (2006).

are slightly larger than those obtained with Eq. (3) (3.86 m s^{-1}). The same applies to the six 12-h-apart pairs between 0300–1500 and 0800–2000 LST. For all other pairs, a small underestimate is instead introduced by using daily averages. Figure 10a shows that, on average, pairs between 0500–1700 and 0700–1900 LST, that is, the three easternmost time zones of the United States, generate estimates of V^{HUB} that are larger than those generated with simultaneous sounding and surface hourly values. However, such estimates are lower than observations by 2.4% on average, with −35.3% (tower 0001 at 0500–1700 LST) and +28.7% (tower 0403 at 0600–1800 LST) as extremes.

In summary, the application of the LS method to simultaneous surrogate sounding and surrogate surface hourly values appears to be generally accurate and conservative. By using daily averages at surrogate surface stations in combination with 2-times-per-day LS parameters derived from surrogate soundings, results differ slightly depending on the time zone. If the LS parameters are obtained in the late afternoon and early morning (i.e., 0500–1700, 0600–1800, and 0700–1900 LST), V^{HUB} estimates are larger than those obtained from hourly values, but still smaller than observed values on average. As such, the LS method appears to be acceptable and conservative even when used with daily averages of V^{REF}

b. Error in using the ρ function (with and without correction factors)

From Archer and Jacobson (2003), the variation with time h of the ratio between V^{HUB} and V^{REF}, also known as the shear function $\rho(h)$, can be represented as a sinusoidal as follows:

$$\rho(h) = \bar{\rho} + A \sin\left[\frac{\pi}{12}(h - \delta)\right], \qquad (5)$$

where A is the curve amplitude, δ is the time shift necessary for the sine curve to have a minimum at 1300 LT (−5), and ρ is the daily mean of ρ. The hourly values of V^{HUB} can then be obtained by multiplying hourly values of V^{REF} by $\rho(h)$. If only the values of ρ at 0000 and 1200 UTC are known (i.e., ρ_{00} and ρ_{12}), then the two unknown parameters ρ and A can be estimated as

$$\bar{\rho} = \alpha\frac{\rho_{12} + \rho_{00}}{2} \quad \text{and} \qquad (6)$$

$$A = \beta\frac{\rho_{12} - \rho_{00}}{2}, \qquad (7)$$

where α and β are factors depending on the time zone. Note that amplitude A in Eq. (7) is allowed to become negative (when $\rho_{00} > \rho_{12}$), to capture the real variability of the shear function. However, Eq. (7) was originally derived for the central U.S. time zones, for which ρ has a minimum around 0000 UTC. In Florida, ρ at 0000–1200 UTC is near zero, which could cause spurious sign switches in the amplitude value. Thus, in this section only, the absolute value was used in Eq. (7). This choice was also introduced to avoid sign dependency on the time zone. The absolute-value formulation was generally conservative at most of the stations tested (as discussed later), and it is consistent with findings by Lazarus and Bewley (2005).

After combining Eq. (5) with Eqs. (6) and (7), ρ_h can be expressed as

$$\rho_h = \alpha\frac{\rho_{12} + \rho_{00}}{2} + \beta\frac{\rho_{12} - \rho_{00}}{2}\sin\left[\frac{\pi}{12}(h - \delta)\right]. \qquad (8)$$

The KSC tower data were used again to evaluate the accuracy of Eq. (8). To simplify the analysis, the correction factors α and β were both set to one at first. Results, summarized in Table 5, are once again slightly dependent on the time zone. On average, the shear function is largely underpredicted by using Eq. (8), as the mean observed value of ρ_h was 2.8 and the mean calculated one was 1.8 (using 0700-1900 LST). The same was true at each individual tower for all pairs of 12-h-apart times. Again, the early-morning–late-afternoon pairs of hours (i.e., 0500–1700 through 0700–1900 LST) gave rise to larger values of the shear function than did all other pairs. For example, at tower 0403, the average observed value of ρ_h was 2.015, the average calculated value with the 0700–1900 LST pair was 1.864, and the average calculated value with the 0100–1300 LST pair was 1.761. The average behavior of ρ at all towers as a function of the 12-h-apart pairs of hours is shown in Fig. 10b. By using the correction factors $\alpha = 0.95$ and $\beta = 1.2$ [suggested in Archer and Jacobson (2004)], valid for the continental U.S. time zones (i.e., −5, −6, and −7 from UTC), the early-morning late-afternoon effect was virtually eliminated. In fact, the average ρ obtained with correction factors at 0700–1900 LST was comparable to the average ρ obtained with other pairs of hours (Fig. 10b and Table 5).

The final question to investigate is how well the proposed formulation for the shear function actually mimics the real one. Figures 11a–c show examples of calculated and observed ρ_h at the tower closest to the average (0415), the tower with the worst performance (0001), and the tower with the best performance (0506), respectively. In general, the proposed sinusoidal pattern of ρ_h is a good approximation for the real pattern of the shear function. However, besides the general underestimation of the average value discussed above, the observed pattern shows a larger amplitude and a sharper transition from day to night (and from night to day). Also, the early-morning/late-afternoon hour pairs tend to produce a larger daily mean ρ than do other hour pairs. This supports the choice of the correction factors in Archer and Jacobson (2004), which forced a reduction of ρ ($\alpha < 1$) and an increase of A ($\beta > 1$).

4. Conclusions

In this study, the effects of interconnecting multiple wind farms through the transmission grid were investigated. The area of interest was within the midwestern United States, previously identified as one of the best locations for wind power harnessing over land. Nineteen sites with annual average wind speed at 80 m above ground, the hub height of modern wind turbines, greater than 6.9 m s^{-1} were identified and intercon-

TABLE 5. Values of observed and calculated ρ at twelve towers of the [illegible] network. The calculated values were obtained for all 12-h input pairs of sounding times. Values obtained with correction factors are also shown in the last column. In bold face are the average values of ρ observed and calculated at 0700–1900 LST, corresponding to 0000–1200 UTC in Florida, with and without correction factors.

		Sounding times (LST)												
Tower	Obs	0000–1200	0100–1300	0200–1400	0300–1500	0400–1600	0500–1700	0600–1800	0700–1900	0800–2000	0900–2100	1000–2200	1100–2300	0700–1900 LST corrected
0001	3.997	1.741	1.739	1.761	1.787	1.809	1.866	1.896	1.873	1.785	1.48	1.731	1.729	1.779
0008	3.210	1.752	1.743	1.753	1.771	1.783	1.807	1.845	1.825	1.772	1.63	1.754	1.756	1.73
0012	1.875	1.648	1.636	1.651	1.666	1.667	1.723	1.779	1.733	1.670	1.62	1.634	1.645	1.652
0211	2.215	1.581	1.577	1.604	1.621	1.640	1.753	1.741	1.790	1.679	1.70	1.638	1.649	1.697
0 13	3.546	1.758	1.772	1.782	1.815	1.848	1.898	1.906	1.869	1.771	1.56	1.747	1.741	1.772
0 1	1.872	1.618	1.614	1.628	1.642	1.662	1.752	1.780	1.751	1.669	1.35	1.617	1.626	1.663
0 3	2.085	1.744	1.761	1.767	1.797	1.832	1.857	1.899	1.864	1.790	1.762	1.739	1.747	1.767
0412	3.380	1.620	1.615	1.632	1.651	1.672	1.766	1.811	1.756	1. 51	1.629	1.608	1.618	1.671
0 5	2.564	1.608	1.616	1.625	1.644	1.684	1.756	1.848	1.759	1.656	1.616	1.606	1.604	1.676
0 6	1.83	1.693	1.695	1.689	1.711	1.694	1.719	1.742	1.724	1.734	1.673	1.665	1.661	1.641
0 9	2.435	1.677	1.642	1.641	1.684	1.679	1.734	1.774	1.733	1.661	1.652	1.631	1.633	1.641
0 4	3.318	1.630	1.614	1.642	1.6 3	1.741	1.743	1.828	1.748	1.662	1.631	1.620	1.636	1.66
0803	2.903	1.755	1.765	1.782	1.798	1.817	1.865	1.890	1.857	1.728	1.760	1.755	1.748	1.758
08 5	3.408	1.662	1 12	1.714	1.691	1.730	1.756	1.808	1.745	1.671	1.659	1.671	1.655	1.652
A	**2.748**	1.678	1 74	1.691	1.710	1.732	1.786	1.825	**1.788**	1.709	1.685	1.674	1.673	**1.697**

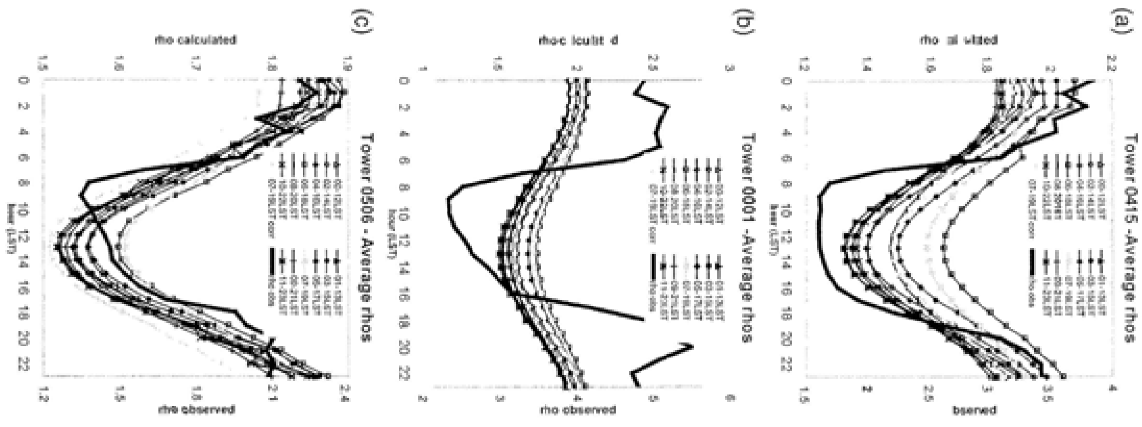

FIG. 11. Observed and calculated hourly ρ at (a) tower 0415 (closest to average), (b) tower 0001 (worst case), and (c) tower 0504 (best case). Note the different scales on axes.

nected within an increasingly larger array. Wind speeds at 80 m were calculated via the least squares method, which involved a combination of 10-m wind speed observations at the sites of interest and vertical wind profiles retrieved at nearby sounding stations. Observed data from the Kennedy Space Center in Florida were used to validate the method.

Array-average statistics were compared with those obtained from each individual site and from the same sites if they were not interconnected (linear sum). Parameters that depend linearly on the values at each individual site, such as array-average wind speed, wind power, and capacity factor, were unaffected by the interconnection, as expected. All other nonlinear parameters showed substantial improvements as the number of interconnected sites increased. These included standard deviations of array-average wind speed and wind power, which decreased as array size increased, array reliability, and reserve requirements, which decreased relative to both the linear sum and the total electricity delivered. The marginal benefit of each additional site decreased. However, no saturation of benefits was found, that is, positive marginal benefits were always found, even if small.

Contrary to common knowledge, an average of 33% and a maximum of 47% of yearly averaged wind power from interconnected farms can be used as reliable, baseload electric power. Equally significant, interconnecting multiple wind farms to a common point, and then connecting that point to a far-away city can allow the long-distance portion of transmission capacity to be reduced, for example, by 20% with only a 1.6% loss of energy.

Reliability was studied with the generation duration curve because it is relatively simple to implement and it does not require any load data. As such, the results described in this study are general and do not depend on the load. An alternative method to study reliability is the Effective Load Carrying Capability. Because of its complexity and dependency on load data, the ELCC approach is recommended for future studies.

In conclusion, this study implies that if interconnected wind is used on a large scale, a third or more of its energy can be used for reliable electric power and the remaining intermittent portion can be used for transportation (i.e., to power batteries or to produce hydrogen), allowing wind to solve energy, climate, and air pollution problems simultaneously.

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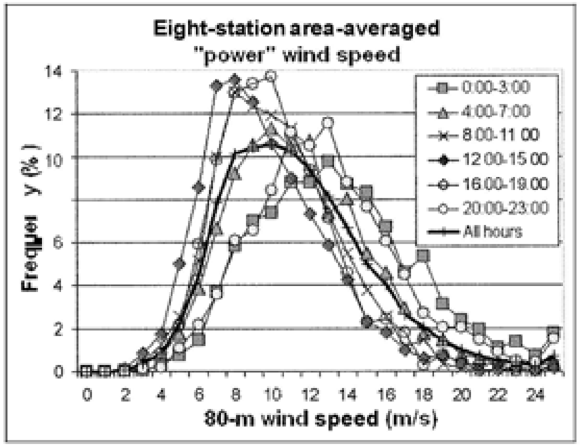

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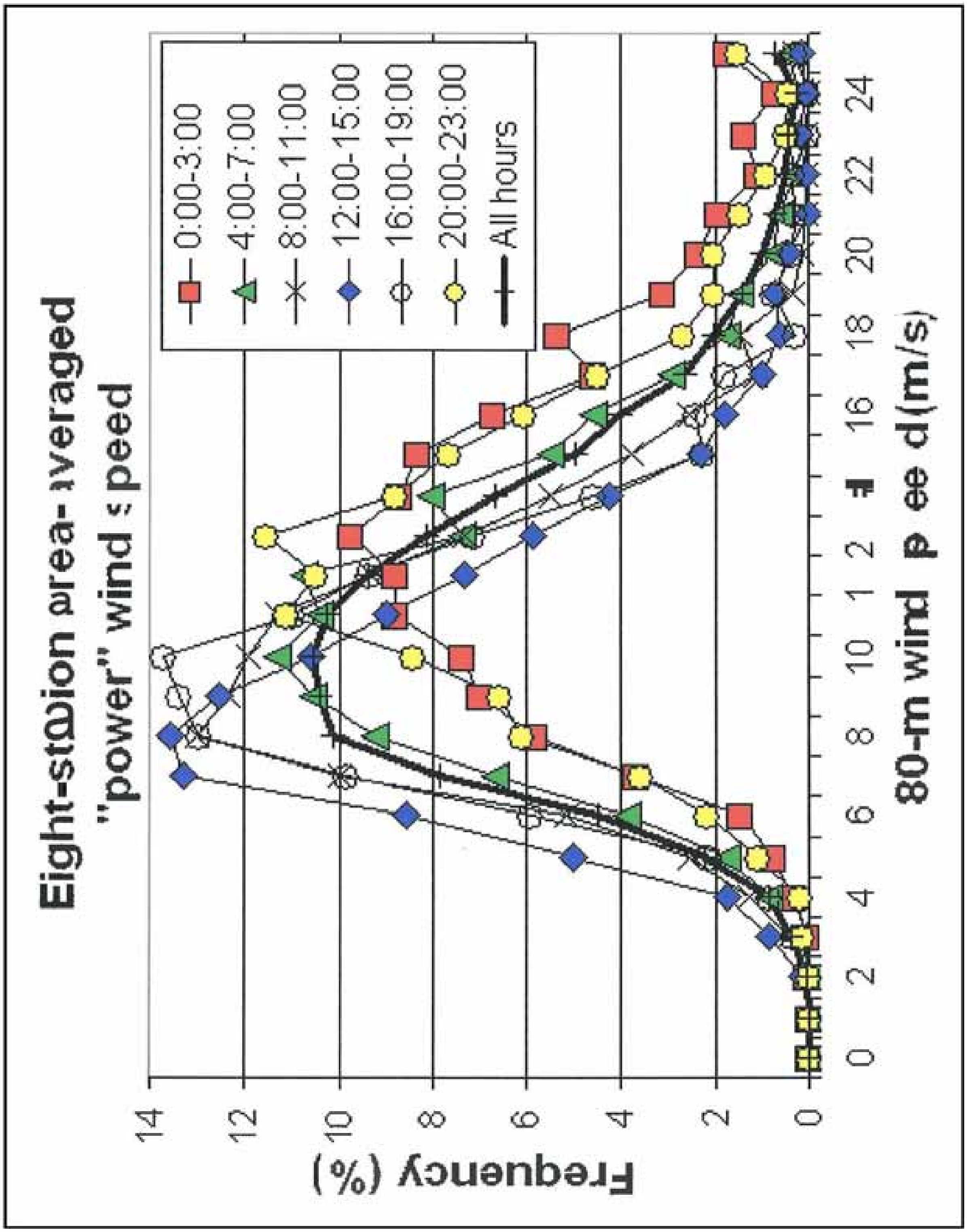
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80-m wind speed (m/s)
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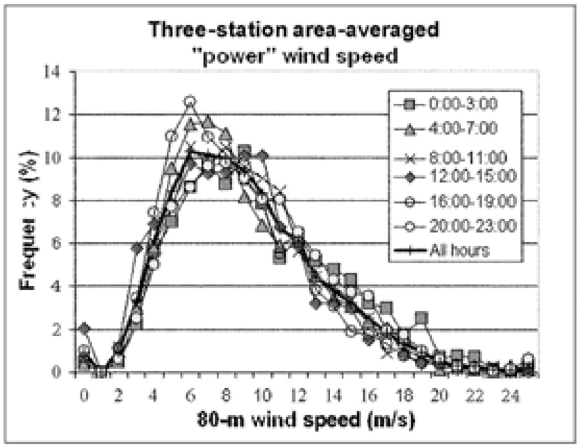

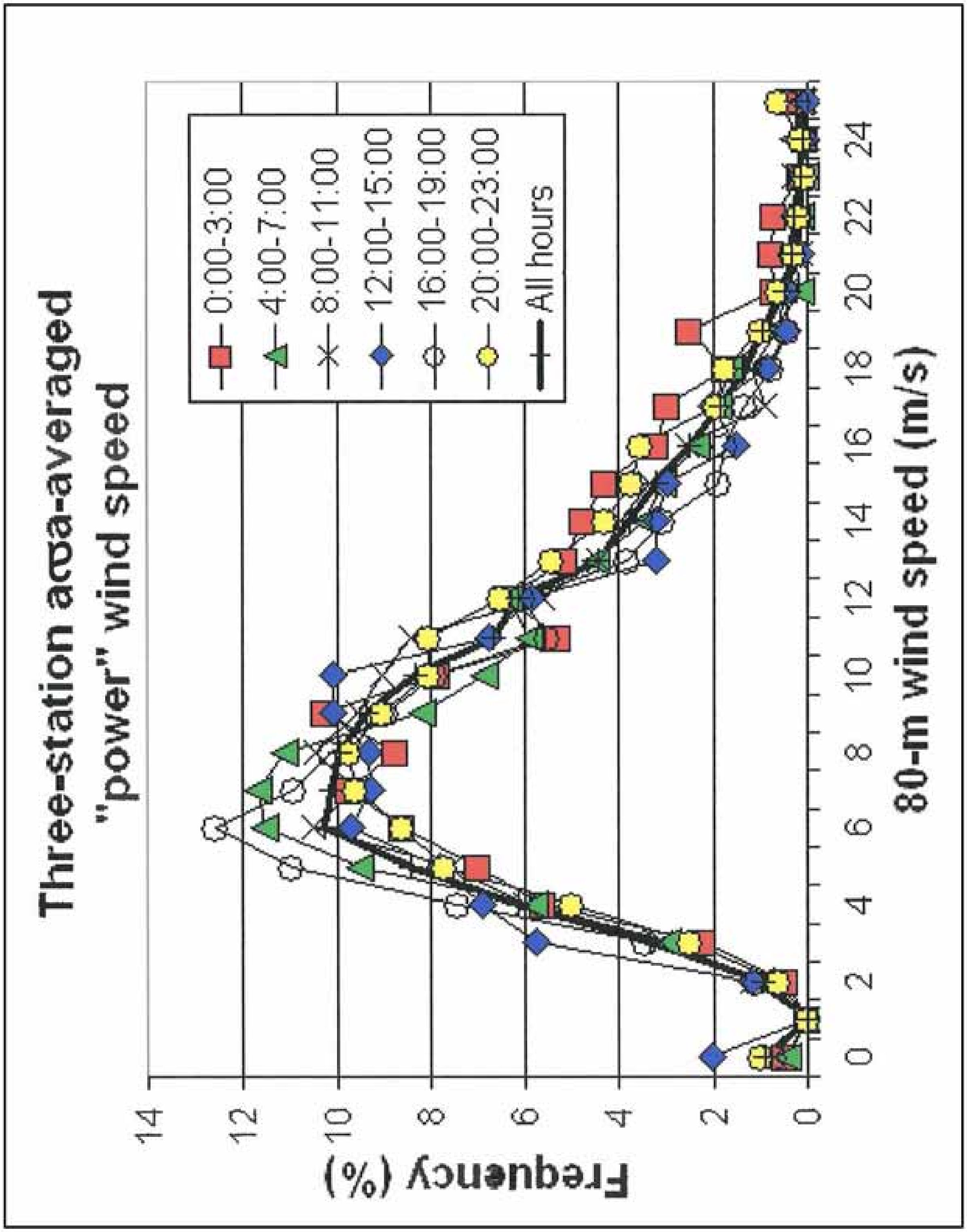
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All hours
Frequency (%)
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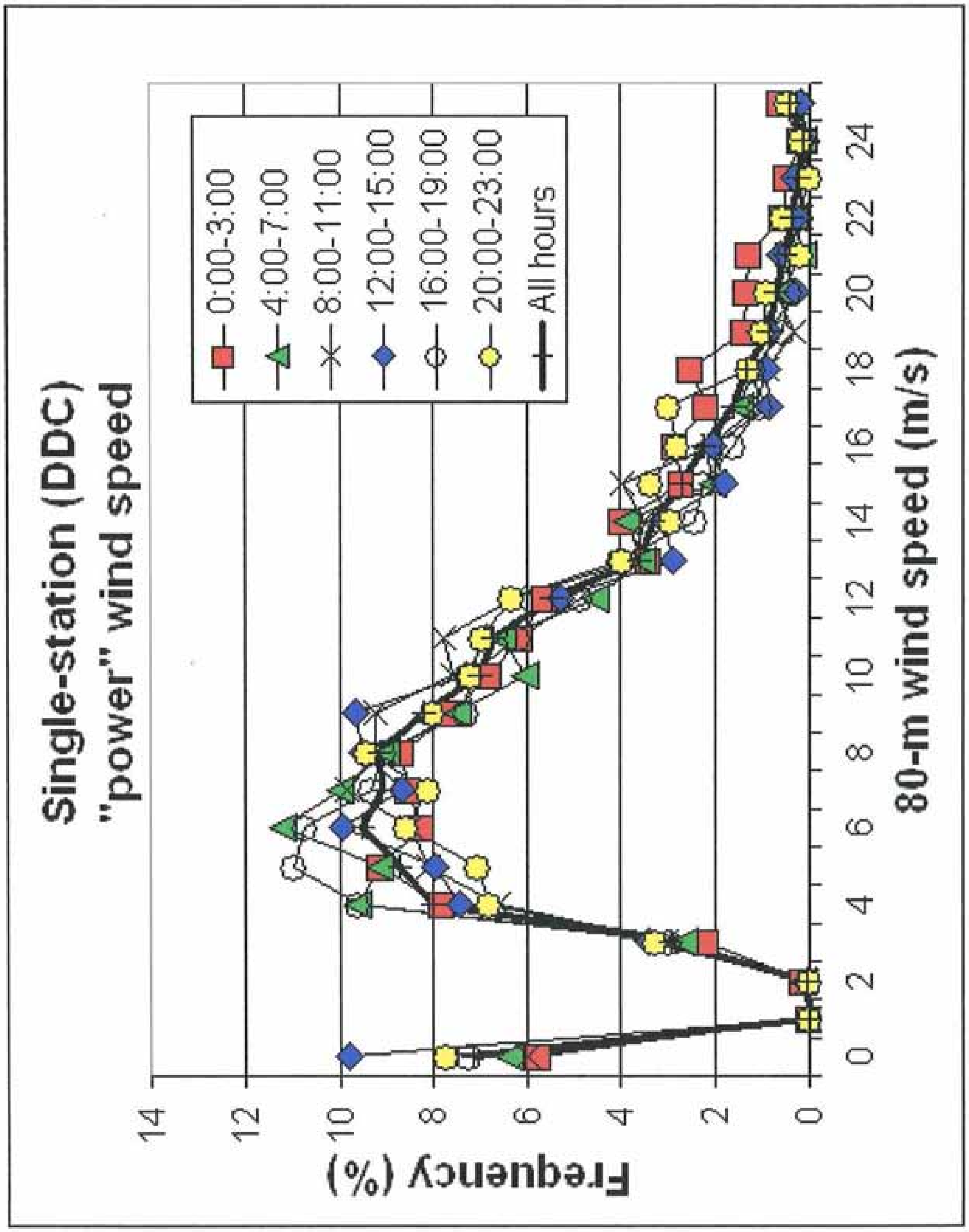
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All hours
Frequency (%)
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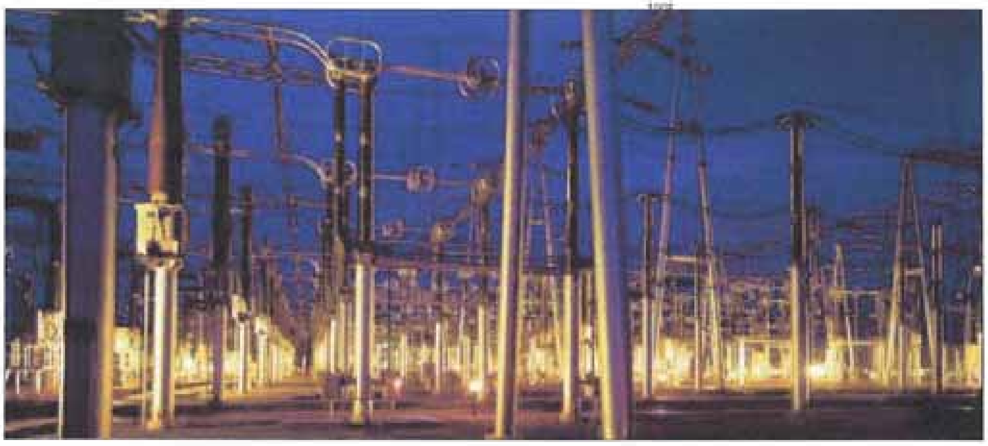


HVDC: Going the distance

Commissioning of the second of China's longest and largest power links is scheduled for completion in June 2004. Using HVDC technology, the links built by ABB will transport power from central China to the fast-developing industrialized areas around Shanghai in the east and Guangdong in the south.

As china's economy continues to grow at an extraordinary rate, so does its need for power. Currently the greatest need is bringing power to the fast-developing industrialized areas around Shanghai and Guangdong.

To address this need, a project has been undertaken by ABB to build two of the world's most powerful and longest high voltage direct current (HVDC) transmission links each with a nominal rating of 3000 MW. The links, one of which came into operation in May 2003, will transport power from the massive Three Gorges hydropower plant to the eastern coastal region and the southern region.

> *"The contract to build China's first 3000 MW link was awarded in April 1999"*

HVDC DEVELOPMENTS

The power generated by Three Gorges will be transmitted to regional grids via the Three Gorges transmission system, which will form the basis of a new national network. However, a major portion of the power will be transmitted to China's industrialized coastal areas in Shanghai and Shenzen via four HVDC links:

- Gezhouba-Shanghai 1200 MW bipole; in operation since 1991
- Three Gorges-Changzhou (3GC) 3000 MW bipole; commissioned in May 2003
- Three Gorges-Guangdong (3GG); currently being commissioned
- Three Gorges-Shanghai 3000 MW; scheduled to start up in 2007.

The contract to build China's first 3000 MW link (3GC) was awarded to ABB by the China Power Grid (CPG) in April 1999. Under this contract, ABB had the responsibility to design, build and supply the converter stations at each end of the line as well as 39 breaker-bay gas insulated switchgear (GIS) equipment at the Three Gorges dam site. This 890 km, +/-500 kV link which runs from Three Gorges to Changzhou near Shanghai in the east, formed part of the internationally financed portion of the project. The order was valued at Yuan 2.79 billion ($340 million). ABB arranged financing for the project through a group of international banks including Société Général, ANZ Banking Group, Credit Agricole Indosuez, and the Nordic Investment Bank. The loans were partially guaranteed by the Swedish Export Agency.

The contract for the second order was awarded by the State Power Corporation in October 2001. This 975 km link runs from Three Gorges to Guangdong in the south. This contract was 100 per cent funded by China and no financing was required. Under the $360 million contract ABB is providing a turnkey system including converter valves, power transformers and the smoothing reactors for both the sending and

1 HVDC PROJECT

receiving ends of the link. In total, 28 power transformers and six smoothing reactors are being supplied jointly by ABB's transformer factory in Ludvika, Sweden and the Chinese state-owned Xi'an transformer works, an ABB licensee.

HVDC has a number of advantages over HVAC. The technology is particularly suited to transmitting power over long distances because losses are low. It is also ideal for connecting separate networks since it obviates the need for network synchronization.

At the heart of the HVDC station is the converter valve for rectifying or inverting electric current. This consists of a large number of thyristors connected in series to cope with the high voltages. The thyristors are mounted in modules of six. Each valve level can house 24 thyristors. The valve is normally suspended from the ceiling of the valve hall for protection against earthquakes. The valves have to be controlled in order to transmit the required current and power. The valve must also be cooled and the cooling water cleaned. Each valve hall has a surge arrester to protect the thyristor bridges against abnormally high voltages.

An HVDC station comprises much more than a converter for rectifying or inverting electric current. In a large outdoor switching station, it must be possible to isolate the station. On the AC side, filters are needed to smooth the current from the HVDC valves and the AC line has to be compensated for the reactive power.

HVDC plants are also provided with transformers on the AC side. The most important reasons for having a transformer are:

- To optimize the level of direct voltage in HVDC transmission and to have a sufficiently low voltage in back-to-back operation
- To be able to use tap changers for rough setting of the voltage
- To obtain more even direct current and more sinusoidal alternating current (12-pulse connection)
- The transformer limits the short circuit current into the valve.

On the DC side, the current must be made smooth and the return through ground or water secured through an electrode arrangement.

The high voltages call for large distances between converter-converter, and between converter-earth. This means the HVDC station has to be spread over a large area.

THE 3GC PROJECT

ABB had the overall responsibility for the two 3GC converter stations and supplied all the equipment except the converter transformers and smoothing reactors at Zheuping (the receiving end converter station). Although most equipment was imported into China, some transformer units, capacitors, and relay protections were produced locally. CPG was responsible for building the overhead line and the ground electrode stations. It also carried out civil works and installation of the converter stations.

THE CONVERTER VALVE IS AT THE HEART OF THE HVDC STATION

The sending end HVDC converter station is located at Longquan, about 50 km from the power plant. This converter station is connected to the main network of the interconnected AC power pool which comprises the Central China Power System and Sichuan-Chonqing Power System.

The receiving end station is located 890 km to the east at Zhenping, about 80 km northwest of Shanghai. This is connected to the East China Power System which covers Shanghai, Jiangsu, Zhejiang and Anhui. Longquan is connected to the Three Gorges plant by three 500 kV AC lines. Zhengping has two 500 kV AC outgoing lines.

> *"HVDC is particularly suited to transmitting power over long distances"*

HVDC was chosen to transmit power from the Three Gorges plant for several reasons. Since the central and east China/Guangdong AC networks are not synchronized, an AC transmission scheme would have required coordination, and it would have been difficult to ensure adequate stability margins. HVDC allows controlled transmission of power between the networks, which retain their independence.

It would also have been difficult to build an AC transmission line in stages i.e. one link after another, as a very strong inter-tie would have been needed from the outset in order to keep the generators of the two grids synchronized.

DC is also more economic in terms of construction

costs and losses. Five series compensated, 500 kV AC lines would have been necessary to transmit the same amount of power and each line would require a larger right-of-way than one HVDC line of 3000 MW.

The bipolar transmission also means that half of the power can be transmitted even during an outage of one pole. The nominal DC voltage is +/- 500 kV but the operating voltage can be reduced down to +/- 350 kV to enable continued operation even when the DC withstand strength is reduced due to insulator contamination or adverse weather conditions.

The line overhead capacity of the DC transmission is about 10 per cent for two hours. A unique feature of the receiving end station is that all 500 kV DC equipment (except smoothing reactors) are located indoors. The control and protection system is ABB's Mach-2 system.

The converter station losses at rated operation is just 0.7 per cent. All critical subsystems are duplicated to ensure high availability and reliability.

The first pole (1500 MW) began commercial operation in July 2002 and the entire bipole was completed, on time, in May 2003.

THE 3GG PROJECT

While this was a short time schedule, the second project, 3GG, called for 30 per cent to be shaved off the normal lead time. This means that the first pole will be commissioned just 28 months after signing of the contract. ABB is achieving this by what it calls re-use of design engineering and the lessons learned from the first project. This was possible since both projects were similar. Indeed the tight project schedule was a major challenge.

The converter station at the sending end is located in Jingzhou, close to Yichang. At the peak time of construction there were nearly 1000 workers on site. The Jingzhou site was chosen for a number of reasons. The load distribution of the local network was a prime consideration. Jingzhou is the site of an existing substation and the AC yard is an important node in the future development of the network, together with other 500 kV substations. In addition, it has a good supply of water, good land availability and road access for heavy equipment.

When the HVDC link becomes operational, the substation will have the capacity to deliver 3000 MW to Guangdong plus 2250 MW from the existing AC substation. Testing of the system is well underway, with a list of items being tested to assure system reliability and functionality. The system will be tested under different operating scenarios. One important test will be the mode of transmission under increasing load. This is related to the power rating during transmission and will be done mutually at the sending and receiving end.

Despite the short time schedule for building the project 3GG link, construction of pole 1 was achieved by January 2004 and testing took just one month. Full load testing took place in February when the additional two units at 3G came on line. The entire system and line are due to be commissioned by June 2004, however ABB will manage to put the system into operation two months ahead of schedule. According to the CPG, this is the shortest time required for testing any project in China. All in all, the 3GG project will be completed one year faster than its sister project 3GC – a new record.

According to the project engineers at the Jingzhou substation, the biggest technical challenge was spanning the Yangtze River. But despite this, the project went smoothly and it is hoped that the experience gained at Jingzhou will be applied to future projects.

HVDC HIGHLIGHTS

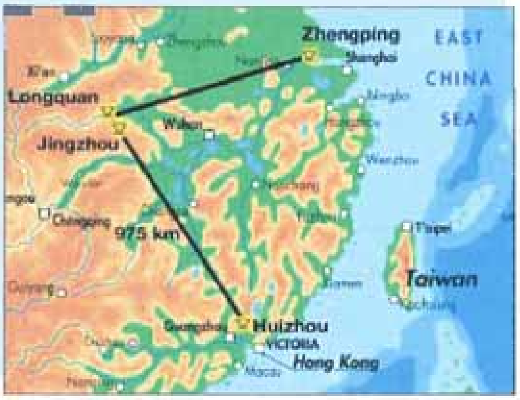
ABB's Three Gorges HVDC links set a number of records. They have the highest power flow per pole i.e. 1650 MW. The previous record was at Itaipu (1575 MW). The execution time of 32 months for the first link was shortest for its class. Itaipu took more than 60 months. At 975 km, the Three Gorges-Guangdong link is the longest DC line in its class – Itaipu is 805 km. The link uses one of the most advanced control and protection systems, ABB's state-of-the-art Mach 2 system.

Project benefits

The project has both economic and technical benefits. Economic benefits include: lower investment cost; lower power losses, less impact on the environment; and high reliability and availability.

Technical benefits include: precise and fast controllability of power flow; prevention and cure of blackouts; asynchronous interconnection; limitation of short-circuit currents; no limit on the length of cable (due to absence of charging current).

From a social aspect one link provides power supply to about 6 million households; lower on-grid tariff of renewable hydro resources; avoids emissions from 3000 MW of fossil-fuel power plants in a densely populated area; saves about 16 720 hectares of farmland and forestation; saves about 78 MW through avoidance of losses – equivalent to supply for 156 000 households.



Building a grid for a nation

The Three Gorges project is at the heart of China's power sector restructuring plans. Once complete, the project will add 18.2 GW to China's generation capacity but perhaps more importantly, it will form the backbone of China's plan for a strong national grid.

On April 3, 1992, the Fifth Session of the Seventh National People's Congress passed the Resolution on Construction of the Three Gorges Project on the Yangtze River. The project is a key project for the treatment and development of water resources on the Yangtze River. The dam will facilitate the diversion of water from the south to the north and provide flood control. But perhaps more importantly, the power project will also be at the heart of the country's national power interconnection programme.

Supported by new trunk power transmission systems, the Three Gorges power transmission project will be central to China's plans to build an integrated national grid. Power generated from the plant will be transmitted to grids in central China, east China, Sichuan and Guangdong province. With more than 10 000 km of HVAC and HVDC lines, this system will form the basis for a new national grid which will combine the seven regional networks and five independent provincial networks to create two new interconnected regional networks.

HUGE HYDRO

The Three Gorges project will be the largest hydropower plant in the world. Construction began in 1993 and upon completion in 2009 it will have a generating capacity of 18.2 GW. Power will be generated from a total of 26 generators – 14 on the left bank and 12 on the right bank – each with a capacity of 700 MW. In addition, sufficient space has been set aside on the right bank for a future underground powerhouse for six turbine generators with a total capacity of 4200 MW. The intakes of these units are being constructed simultaneously with the project.

The dam is of a concrete gravity type, with a length of 2309 m. It has a crest elevation at 185 m and a maximum height of 181 m.

Construction of the project is scheduled to last 17 years. This includes the five-year (1993-97) first phase of preparations and construction ending with the damming of the Yangtze River, the six-year (1998-2003) second phase ending when the water level of the reservoir reached 135 m and the six-year (2004-09) third phase which ends with completion of the whole project.

The main financial challenge was funding the project during the first 11 years of construction. But with the project beginning to generate income in 2003, money from electricity sales can now be used to fund the project during the latter part of the construction period.

Indeed, the year 2003 was a historic year in the construction of the project. The pivotal works began to store water on June 1, the storage went up to the elevation of 135 m on June 10 and the permanent ship locks opened on June 16. The first six units began to consecutively generate electricity in August (two went

TWO CONDUCTORS CARRY 3000 MW TO EASTERN AND SOUTHERN CHINA

into operation in August, two in October, and two before the year-end). The pivotal works entered the third phase at the beginning of 2004. An additional four units will begin commercial operation this year and a further four in 2005.

When all units are fully operational, Three Gorges will have an annual output of 84.7 TWh. A large portion of its electricity will be supplied to east China, central China and a small portion to the Chongqing municipality.

SECTOR REFORM

In the past it has been said that what has most hindered the marketing of electricity has been the country's poor power management and limited power transmission capacity. However, information from the China National Power Corporation showed that by treating Three Gorges as an opportunity, China could restructure its power industry, reform the existing power management and operation mechanisms, and speed up the construction of transmission facilities in rural and urban areas.

China has experienced an annual growth rate in installed generating capacity of more than 8 per cent for the last 52 years. At the end of 2002, installed capacity stood at 357 GW. About 50 per cent of this capacity was controlled by the State Power Corporation (SPC). The remaining 50 per cent was owned by independent power producers, large generators like Three Gorges and Guangdong Nuclear, as well as provincial or local governments.

In October 2002 the government passed the Electricity Sector Reform Act to promote competition, increase efficiency and generally streamline the industry. A regulatory body was created to supervise the electricity market. The SPC was split into five competing generating companies and two non-competing regional network companies.

The five generating companies are Huaneng Group (37 970 MW); Datang Electric Power (32 250 MW); China Huadian Group (31 090 MW); SP Electric Power (30 430 MW) and China Electric Power Investment (29 890 MW). Transmission and distribution is to remain a monopoly, under the control of the State Grid Corporation and China Southern Power Grid Co. Ltd.

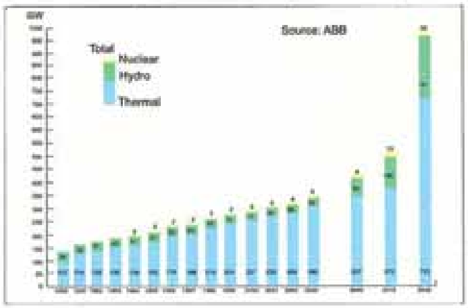
> *"China plans to create a modern power market in which plants sell power to the grid at market prices"*

China's intention is to eventually create a unified grid, and have a modern power market in which plants sell power to the grid at market-determined prices. Initially it planned to introduce competitive pricing in six areas – Zhejiang, Shanghai, Shandong, Liaoning, Jilin and Heilongjiang – on a trial basis, with each free to employ its own method of competitive pricing. These six trial regional markets were expected to be merged or expanded for a more integrated competitive market but the expansion has been temporarily stalled because of severe power shortages experienced in 2003.

TRANSMISSION ISSUES

A key issue in the development of this integrated competitive market is the development of an integrated network.

Altogether, there are seven provincial or regional



CHINA'S TOTAL INSTALLED GENERATING CAPACITY

2 GRID DEVELOPMENT

grids and five independent grids which are not connected. The regional networks – North China, Northeast, East China, **Central** China, Northwest, Sichuan **and** Chongqing and the Southern Network – operate at 500 kV, with the exception of the Northwest Network which has a 300 kV backbone. The five independent grids are Shandong, Fujian, Hainan, Xinjiang and Tibet.

The southern provinces plus Hainan are viewed as the south grid and is operated by the Southern Network Corporation. The remainder is known as the north grid and is operated by the State Network Corporation (North Company). **These** network companies still also have their own generating plants, primarily pumped storage.

While network accessibility has reached 96.4 per cent, according to ABB there are still transmission opportunities. Already, Three Gorges is providing a significant portion of these transmission opportunities. Power from the plant will be distributed via 15 transmission lines, with 500 kV AC lines to central China and Chongqing City and +/- 500 kV DC lines to east Chiia and south China. Overall, the project will require the construction of 6519 km of AC lines, with a converting capacity of 22.75 **million** kVA; and some 2965 km of DC lines with the capacity of the DC converter stations reaching 18 000 MW.

While Three Gorges will go some way to meeting the power demands in the east, there will be a continuing need for transmitting power from west to east. This is expected to be achieved via three routes:

- South lines: 10 000 MW from Guizhou/Yunnan/Guangxi to Guangdong
- North lines: 5000 MW from Shaanxi/Shanxi/Inner Mongolia to JinJingTang area
- Central lines: 9000 MW from Sichuan/Hubei to east China (including the second bipole HVDC link from Three Gorges to Shanghai).

There is also a need to interconnect the regional and independent grids using both AC and DC systems.

There are plans to step up the voltage level in the **330** kV northwest network to 750 kV. The plan is to build a 146 km 750 kV AC line from Manping to Lanzhou. This will be one of only a few 750 kV transmission lines operational in the world. Construction of this line has begun **and** ABB is bidding on the transformers and reactors for the project.

HVDC IS THE BACKBONE OF CHINA'S POWER GRID

There are also substantii requirements on the distribution side. According to ABB in the 11th Five Year Plan (2005-2010) the country plans to invest $24 billion in transmission and distribution. In addition to higher voltage HVDC systems, China will need large transformers – larger **than** today's 1000 MVA transformers which are available for single-phase. China predicts that in the next 15 years, transforming capacity will be about 20 GVA.

Technology such as FACTS (Flexible AC Transmission) will be needed to provide voltage regulation and compensation.

FUTURE HVDC

Last year was an important year in the Chinese power sector. Some 21 provinces/regions encountered power shortages. To counter **this**, some $24 **million** was invested in generation, with 37 GW being put into operation. At the same time, 8500 km of transmission lines were also put into operation.

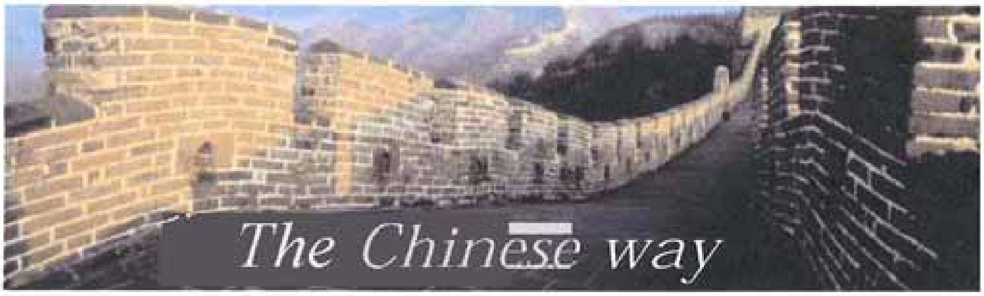
> *"In the 11th Five Year Plan (2005-2010) the country plans to invest $24 billion in transmission and distribution"*

By the end of this year some 144 plants will have been constructed and a further 10 000 km of both AC and DC lines will have come into operation.

Looking ahead, ABB sees more opportunities for the **use** of HVDC technology. China has scheduled several HVDC projects for both the near term and the longer term (e.g. up to 2015). There are plans for 16 sets of DC transmission fines between 2006 and 2020.

Interestingly,some of these projects may stretch over greater distances and operate at higher voltages than links built to date. Most 'long' transmission distances in China are currently around 1000 km but the country is looking at ways of sending power over distances of around 1800-2000 km.

Commenting on the future of HVDC in China, Peter Leupp, Chairman and President of ABB in China noted: "When you look at the amount of power and distances, you may see a need to step up voltages from 500 kV DC to 600 kV DC. China is now studying our experiences at Itaipu where we built a 600 kV DC link, which is still the highest DC voltage level after 20 years in operation. They are seeing how they **can** apply this technology to transmit power to locations which are further away."



The Chinese way

ABB's involvement in the power transmission from the Three Gorges area to the load centres at the pacific coast demonstrates the company's strong local presence in the Chinese market and its strategy of working in direct partnership with local businesses.

The impact of the Three Gorges project is huge on both a local and national scale. The project is located in Hubei Province. The main industries in the surrounding area are agriculture and fishing and one of the key goals of the project is to provide flood control in the middle and lower reaches of the Yangtze River. After completion of the project, the flood control standards in the J i g reach of the Yangtze River will be raised from the present less than 10-year frequency flood to 100-year frequency flood.

The project called for the undertaking of a huge relocation programme. But although resettlement has been a difficult task, the project is being seen as a good opportunity to develop the local economy. The reservoir region of the project is in an under-developed region of China where people living in the area have a per capita income far below the national average. Since the project's implementation, thousands of hectares of farmland have been developed as well as thousands of square metres of new housing.

The project site is located 30 km from Yichang city, which is the home of the project owners – China Yangtze Three Gorges Project Development Corporation. Yichang has a population of 400 000 and construction of the project and its surrounding infrastructure is providing jobs for some 30 000 workers from the city.

At the national level, the project will supply China with cheap, reliable and clean energy. When it is complete in 2009 the plant will account for about four per cent of China's installed generating capacity and replace some 40-50 million tonnes of raw coal each year.

TECHNOLOGY TRANSFER

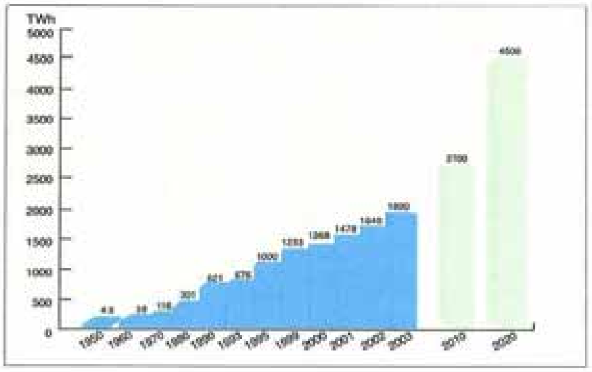
China has a policy of exchanging market share for technology, a policy which was adopted for the Three Gorges left bank power plant and its transmission links where HVDC technology was used for the transmission of power to Changzhou in east China and to Guangdong.

International manufacturers had to transfer technology to designated state-owned companies and use these companies as local sub-contractors – but take responsibility for the quality of performance and delivery of these local companies. International manufacturers were also asked to take full responsibility for the performance of the project including the performance their local partners.

THE CHINESE WAY

ABB is no stranger to doing business in China. It began selling into China almost a century ago but the turning point came about 10 years ago. Peter Leupp, Chairman and President of ABB in China, explained: 'We decided to relocate our China headquarters from Hong Kong to Beijing. At this time we began to: set up more businesses in [mainland] China; manufacture locally; and develop our people. This has made us more of a fully fledged company within the country as opposed to just a sales

ANNUAL POWER CONSUMPTION GROWTH RATE OF MORE THAN 7 PER CENT IN THE PAST 50 YEARS



company here." Today ABB has 6500 people in more than 20 companies spread across 23 major cities.

Understanding China's current approach to building projects is key to being successful. China has many design institutions which carry out detailed engineering for power technology projects. It also has installation companies, testing companies, for commissioning, and construction companies to build plant

bupp commented: "The only thing they lack is products. Even for large power plants. China has very few turnkey power plants. In the past China has been a 'product market'. They would buy the turbines, the generators, boilers, auxiliaries and then build the plant themselves."

ABB has established a strong manufacturing base in China. For example, it has three companies established for building power transformers and owns some 20 per cent of the market for large-sized power transformers. Leupp noted: "These companies are at maximum capacity and we would have to consider setting up a fourth company if we want a bigger share of the market."

These companies were set up to overcome barriers to import. "We had a lot of customers wanting to buy our products but didn't have US dollars. At that time import was also more difficult. The customer would have to go through an evaluation and debate as to why a local product could not meet his needs."

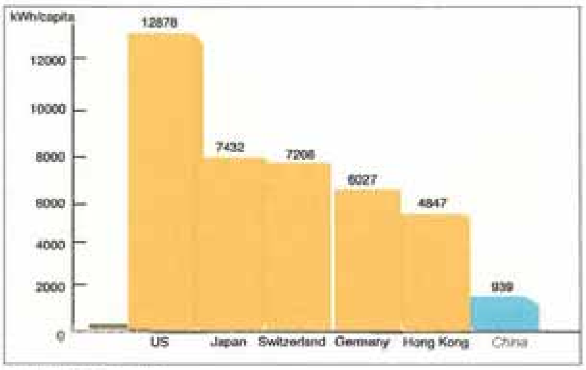
CHANGING TIMES

Certainly doing business in China has not been straightforward in the past. But with a fast growing economy and its entry to the World Trade Organization (WTO), the government is being forced to make changes.

China has one of the world's fastest growing economies and is now the world's fourth largest economy. At the 16th Party Congress in November 2002 the government set the objective to quadruple its GDP per capita (in the year 2000) by 2020. This will require a yearly growth rate of around eight per cent. This is a high growth to maintain but is necessary in order to keep down unemployment and maintain social stability.

The huge economic growth is accompanied by an increased power demand. Power consumption is expected to increase from 1890 TWh in 2003 to 4500 TWh in the year 2020. In the past 50 years already, there has been an average annual growth rate of seven per cent.

Unemployment is one of the main political challenges. There are an estimated 20-25 million job seekers each year. The state can, however, only provide some 10 million jobs each year through capital investments in infrastructure developments. China therefore has to rely on the service sector to provide the remaining jobs. This, however, requires the opening up of the service sector – a process which is being facilitated by the country's entry into the WTO in 2002.



CHINA: ELECTRIC POWER CONSUMPTION PER CAPITA

The country has a five-year grace period to become WTO compliant. The National People's Congress appointed a new government in March 2003 which will oversee a series of changes related to China's accession to the WTO. This government will serve for a five-year term.

The last two years have seen changes in legislation to make China more WTO compliant and this will be an ongoing process.

China is also opening its doors to foreign direct investment (FDI) and international events such as the 2008 Olympics and the World Expo in 2010 will promote further FDI and help lift the international image of the country.

China's economy is showing no signs of a near term recession. FDI is still strong – the actual utilization was about $50 billion in 2002 and is forecast at $60 billion in 2003. With the economy continuing to grow with no sign of a slowdown, there has been pressure to appreciate the Yuan.

WELL PLACED

China is well placed for continued growth and continuing changes in legislation will continue to encourage an influx of foreign capital and expertise. According to ABB, foreign investment accounts for more than 50 per cent of China's exports. "Foreign investment is the key behind the country's exports and its continuing growth," said bupp.

The private sector will be China's engine for job creation. It accounts for more than 30 per cent of GDP. Today, the country has more than 1.7 million private enterprises with an investment of RMB1.1 trillion. In 2000, 75 per cent of industrial output came from non-state sectors.

Basing a company in China certainly provides competitive advantages. The country has a huge, educated labour force at low cost. With these fundamentals in place and a rapidly growing electricity market, ABB believes it is well positioned to increase business as China goes through its changes.

Comments of Hinders Dairy Inc on the proposed Sec 368 Corridors Before the United States Department of Energy

Hinders Dairy Inc (HDI) is a land owner holding approximately 2100 acres of land in Randal County Texas and is party to a lease option agreement with Higher Power LLC for the development of a wind farm(Palo Duro Wind Farm aka PDWF) consisting of approximately 25 sections and to have a projected output of 400mw. This project is located within the Southwest Power Pool (SPP) and approximately 90 miles from the Blackwater DC Bus Tie between Public Service of New Mexico (PNM)and Southwestern Public Service (SPS).

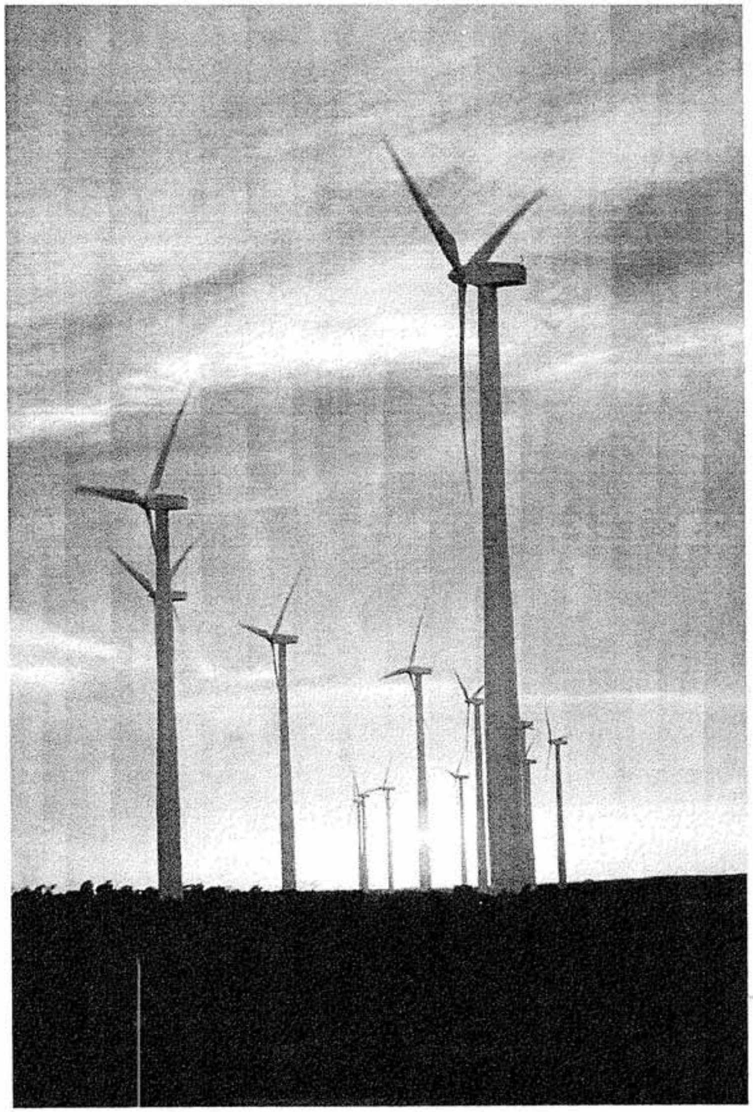
The current SPP market has no room for the the estimated 30,000+MW of wind power available for development in the Texas panhandle north of US Hwy 70. There are additional amounts of wind power in eastern New Mexico that lie in the SPS service area that have no market as well.. As of December 31" 2007 the Energy Reliability Council of Texas (ERCOT) met the current transfer capacity limitation of 4850MW of wind power. Future additions of wind power will be limited until the Texas Public Utility Commission completes its review of renewable energy and then all appeals are exhausted and construction begins on Phase 1 projects to upgrade the ERCOT system. Current plans do not show any construction into the panhandle of Texas until phase 3 (Panhandle A) and 4 (Panhandle B) begin. The costs and the limited transfer capacity(1800 mw max/$1.5 billion) dictate that less than 5% of the available wind power in the Panhandle will ever make it to market in ERCOT. The cost of adding 800mw of wind in phase 4 will exceed $800 million due to existing transfer capacity constraints beginning at the Graham substation and reaching a choke point at the Parker substation in Fort worth. See tab 1 Texas Markets

The alternatives are to move wind power in the Texas Panhandle and eastern New Mexico to the Western Electric Coordinating Council (WECC) or to the Chicago area under a joint proposal by the SPP and American Electric Power Co. AEP. Hollywood and Vine in Los Angles and 200 E Randolph in Chicago are equidistant from Randall County. The western route has the advantage of major markets in Arizona and Nevada that will be short of energy by 2009 (see p.20 of the WECC December 2007 Power Supply Assessment tab 2) PDWF can make energy available to the WECC by on peak 2010 and possibly as early as July 2009. Further development of wind in the eastern New Mexico/Texas panhandle outside the WECC grid service area would most logically be done using a bipole DC tie similar to three 3300mw systems built by ABB in China as part of the Three Gorges Dam project. Rights of Way can follow the existing double trackage of the Burlington Northern Santa Fe Railroad (Santa Fe) that runs from Clovis New Mexico to Needles California. Using this established corridor and a second probable route from Clovis, New Mexico to Springerville Arizona would not break up any critical habitat that is not already subject to disturbance by either the busiest railroad corridor west of the Mississippi River or existing US Highway 60. These two sets of lines would make 6600mw of wind power to the WECC at points where major load growth and electrical shortages are expected to occur in the next 10 years. See Tab 3 Proposed Corridors. The corridors would run from Clovis to Belen in New Mexico to Springerville in Arizona. The other corridor would run from Belen to Gallup New Mexico to Flagstaff then to Needles in California or Marketplace in Nevada as dictated by the needs of the WECC. The use of two bipole DC circuits limits the severity of an outage to ½ of the circuit capacity in most circumstances.

The resource proposed to be included in the WECC plans is the largest single source of Summer time Class 4 winds in the United States. Christine Archer and Mark Jacobson of the Civil and Environmental Engineering Department of Stanford University have done extensive modeling and research on the available wind power and effects of interconnecting multiple wind farms. The goal is to broaden the power availability by use of non coincident peaks and lows. This paper is published in the November 2007 issue of the Jpurnal of Applied Meteorology and Climatology P 1701 et seq. (Exhibit 6) The conclusion is that the use of 7 diverse wind sites can produce firm power at 12% of name plate using a 79% availability factor which is the lower end of reliability for coal fired generation. Using 87.5% the amount of name plate available is 6%. One interesting note from analysis of the winds in Amarillo and Clayton New Mexico in July/August time periods is that the winds begin to pick up at about 1600 CDT 1500MDT and 1400PDT. They crest between about 1700CDT and 2200CDT which is 1500PDT and 2000PDT . The standard deviation graphs show that Clayton during times of peak load remains on line and generating even at -1 standard deviation. Amarillo has a mean expected wind speed between 8 and 10 m/s with Rayleigh power of 1000watts/m^2 for July and 800 watts/m^2 in August in the time frame that the Pacific time zone is hitting peak load. Amarillo has the second highest mean wind speed at 8.4 m/s with an annual capacity factor of 44%. Clines Corners, New Mexico is 4th and both are class 5 wind areas. Clayton New Mexico is 7.8 m/s second and class 4. These are all far better wind resources than what is being currently used within ERCOT. (See tab 4).

Lastly ANL should consider the impact of NERC N-1 Reliability standards in planning corridors. An excellent real world example of these problems currently exists on the El Paso Electric Co (EPE) system. The Eddy Amrad Caliente line nominally supports 925 mw. But due to NERC N-1 considerations, if the Amrad Caliente portion of the line goes out fo service than only 200mw of line capacity is available to serve Alamogordo, Holloman AFB, White Sands Missile Range, Oro Grande and areas along US Hwy 54. The obvious solution is a connection between the Amrad 345kv substation and the Arroyo 345kv substation. See planning studies done in 2004 for expansion of the Eddy DC bus tie with SPS and to engineering studies done to coinnect a 500 mw wind farm in the Otero County area. NERC N-1 standards require the construction of 55 miles of 345kv line which does not really solve the reliability issue. The sound engineering solution is to build through White Sands in a Right of Way suitable to the Department of the Army. This would enable development of the Class 7 wind resource at Guadalupe Pass/Pine Springs area . Wind speed is 11.7 m/s. (SEE TAB 5)

Respectfully submitted
Hinders Dairy Inc.
29836 I 27
Canyon Tx, 79015.
By Edward Hinders
Edward Hinders
830-438-8675



Texas Wind Capacity

1995 = 0

***Mid-2006 = 2,300 MW** (passed CA):*

In Service -- Late 2007:

4,525 MW

Additional Signed Interconnection Agreements

3,600+ MW

Additional Interest Interconnection Studies

35,000+ MW

The Wind Coalition

Source: ERCOT & SPP; Texas peak load < 72 GW of SPP have specified that their proposed long-range system upgrades will allow transfer of up to 600 MW from the Texas panhandle to the Sunnyside substation. Given the transmission upgrade shown in Figure 18, the ERCOT transmission system would **be** capable of supporting a 600 MW injection at this location.

The third level of transmission solution for Panhandle wind resources combines level 1, described above, and the Level 1 solution for Central Texas wind resources, also described above. The panhandle portion of this option is depicted in Figure 19 (the additional improvements would correspond to those depicted in Figure 12). This option includes all of the upgrades described as part of level 1 for the Panhandle Region, all of the upgrades inc[illegible]n the Level 1 alternative for Central Western Texas, as well as 70 miles of new transmission line from zone 2 to zone 10. The estimated cost of this option is $715 million.

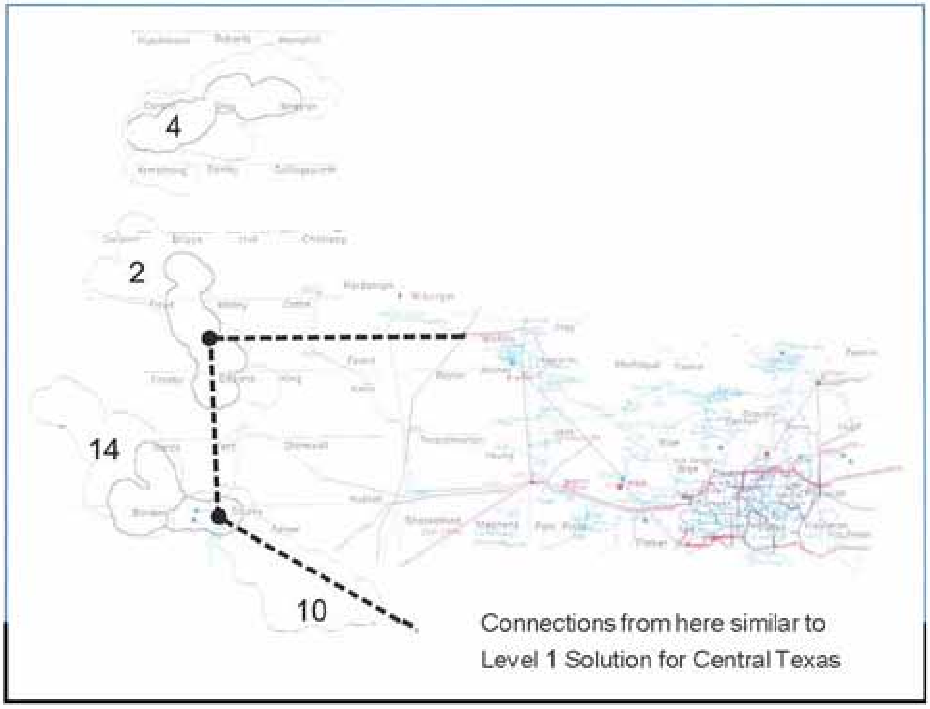
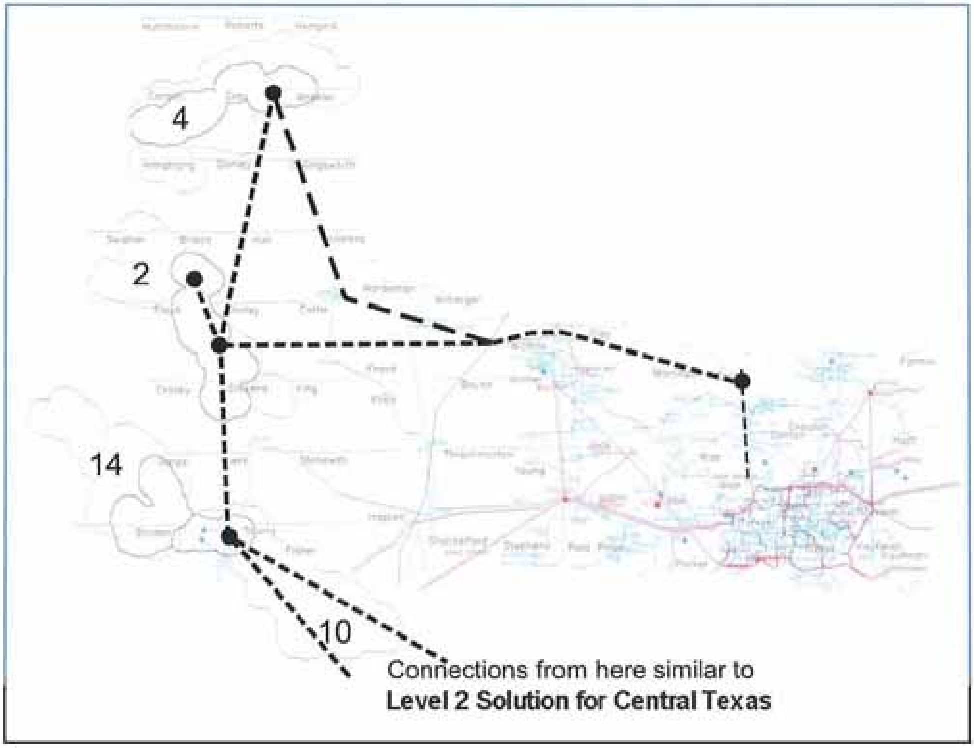


Figure 19: Third Level of Transmission Solution for Panhandle Wind Resources

The fourth level of transmission solution developed for Panhandle wind resources incorporates the improvements described in Levels 2 and 3 above (see Figure 18) along with the improvements included in both the Bluff Creek to Bosque option and the Red Creek to Hill Country option. This fourth Panhandle solution also includes the construction of a loop from the Oklaunion substation northwest up to Zone 4 and then southwest to Zone 2. **This option is depicted in Figure 20. Its estimated cost includes the combined costs** of the Red Creek and **Bluff** Creek options ($700 million), the cost of Level 2 described above ($645 million) as well as **170 miles of new 345** circuit **(from zone 4 to zone 2, and from zone 2 to zon**[redacted]**) for a total of $1,515 million.**

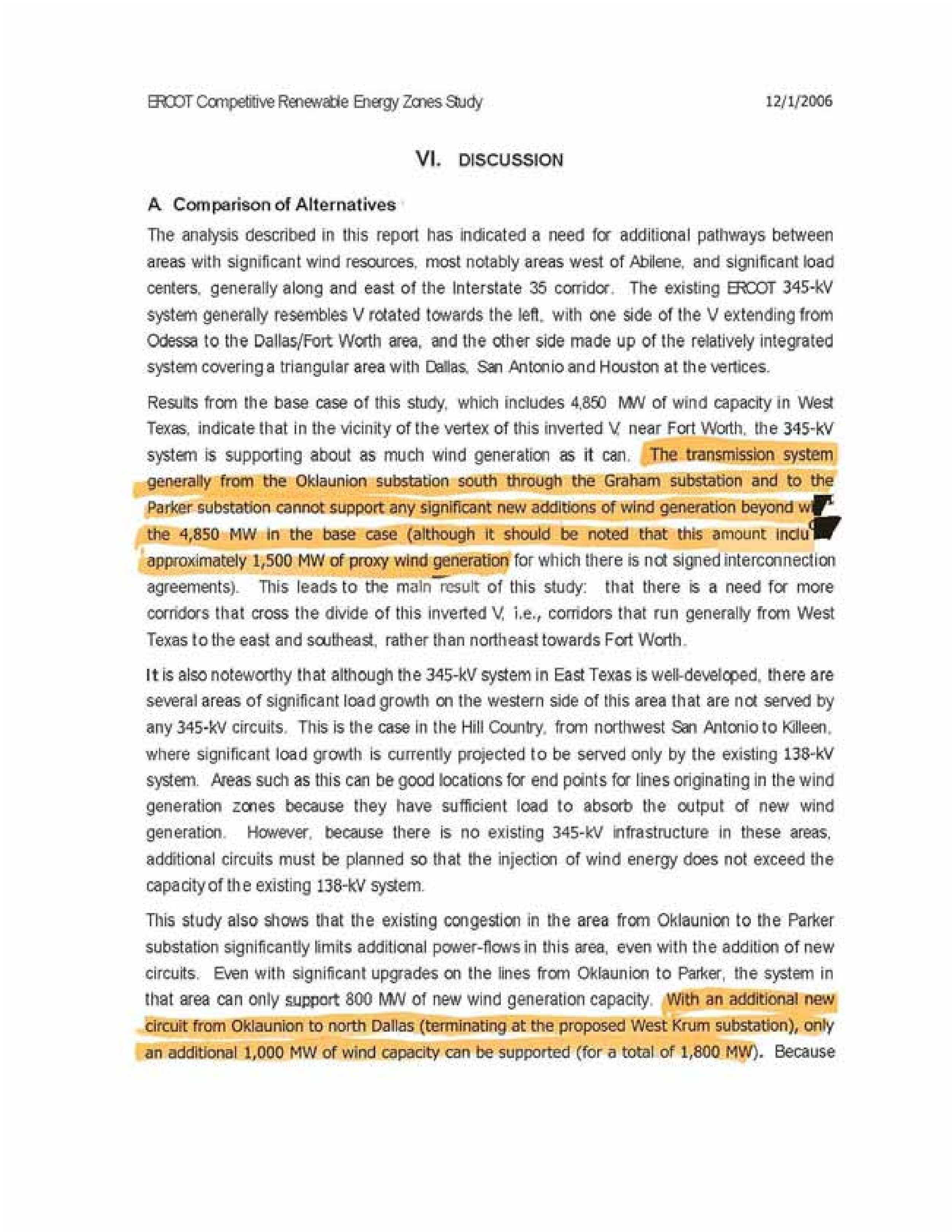


Connections from here similar to
Level 2 Solution for Central Texas

Figure 20: Fourth Level of Transmission Solution for Panhandle Region

5. Combination Scenarios

It is possible that the PUCT, after taking into account some type of commitment of interest by wind generation developers, will choose to designate some level of CREZ in more than one of the four discrete areas. It was not feasible to anticipate and evaluate all potential combinations of possible wind development interest in each zone within the available time. Therefore,



VI. DISCUSSION

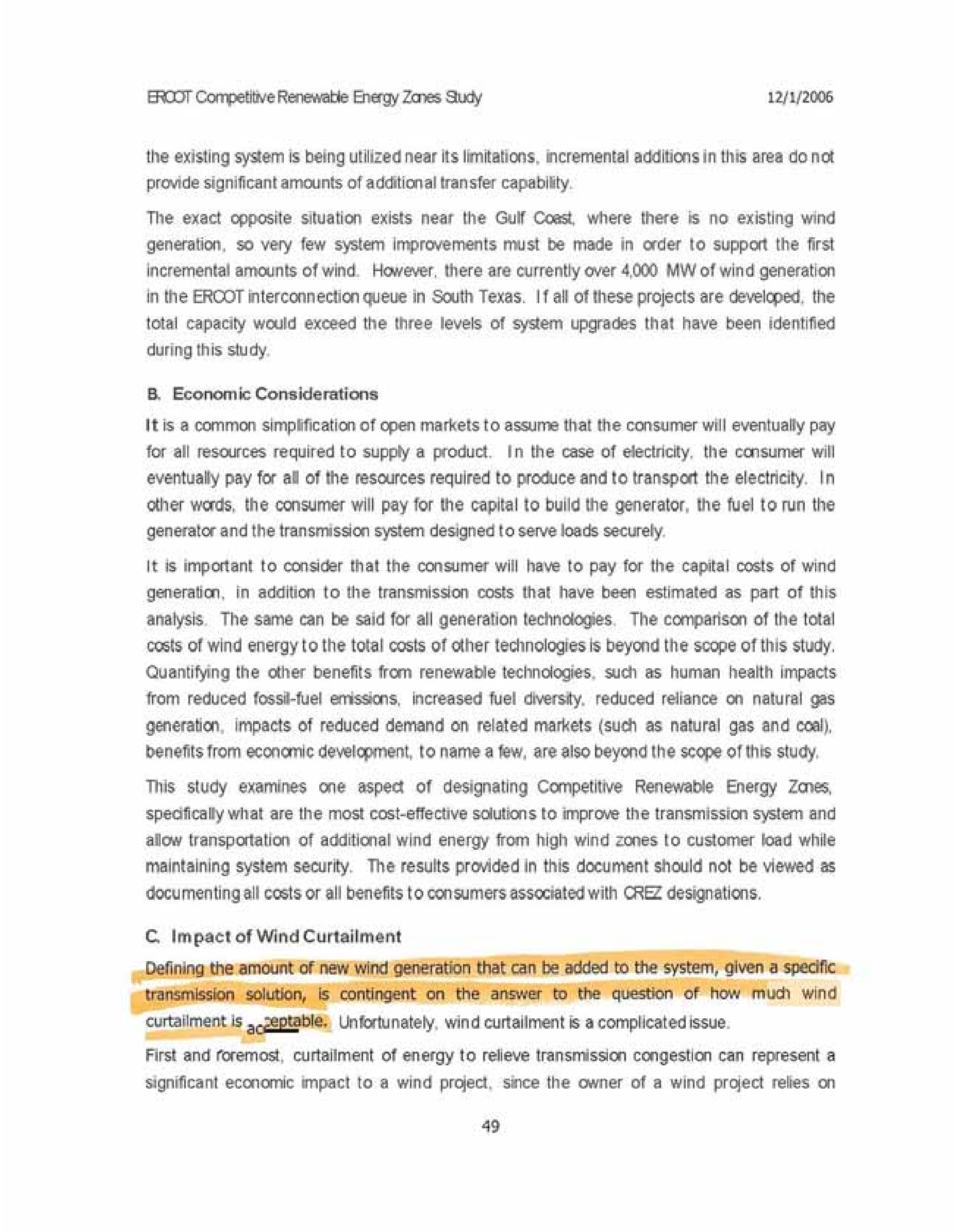
A. Comparison of Alternatives

The analysis described in this report has indicated a need for additional pathways between areas with significant wind resources, most notably areas west of Abilene, and significant load centers, generally along and east of the Interstate 35 corridor. The existing ERCOT 345-kV system generally resembles V rotated towards the left, with one side of the V extending from Odessa to the Dallas/Fort Worth area, and the other side made up of the relatively integrated system covering a triangular area with Dallas, San Antonio and Houston at the vertices.

Results from the base case of this study, which includes 4,850 MW of wind capacity in West Texas, indicate that in the vicinity of the vertex of this inverted V, near Fort Worth, the 345-kV system is supporting about as much wind generation as it can. The transmission system generally from the Oklaunion substation south through the Graham substation and to the Parker substation cannot support any significant new additions of wind generation beyond w[illegible] the 4,850 MW in the base case (although it should be noted that this amount inclu[illegible] approximately 1,500 MW of proxy wind generation for which there is not signed interconnection agreements). This leads to the main result of this study: that there is a need for more corridors that cross the divide of this inverted V, i.e., corridors that run generally from West Texas to the east and southeast, rather than northeast towards Fort Worth.

It is also noteworthy that although the 345-kV system in East Texas is well-developed, there are several areas of significant load growth on the western side of this area that are not served by any 345-kV circuits. This is the case in the Hill Country, from northwest San Antonio to Killeen, where significant load growth is currently projected to be served only by the existing 138-kV system. Areas such as this can be good locations for end points for lines originating in the wind generation zones because they have sufficient load to absorb the output of new wind generation. However, because there is no existing 345-kV infrastructure in these areas, additional circuits must be planned so that the injection of wind energy does not exceed the capacity of the existing 138-kV system.

This study also shows that the existing congestion in the area from Oklaunion to the Parker substation significantly limits additional power-flows in this area, even with the addition of new circuits. Even with significant upgrades on the lines from Oklaunion to Parker, the system in that area can only support 800 MW of new wind generation capacity. With an additional new circuit from Oklaunion to north Dallas (terminating at the proposed West Krum substation), only an additional 1,000 MW of wind capacity can be supported (for a total of 1,800 MW). Because



the existing system is being utilized near its limitations, incremental additions in this area do not provide significant amounts of additional transfer capability.

The exact opposite situation exists near the Gulf Coast, where there is no existing wind generation, so very few system improvements must be made in order to support the first incremental amounts of wind. However, there are currently over 4,000 MW of wind generation in the ERCOT interconnection queue in South Texas. If all of these projects are developed, the total capacity would exceed the three levels of system upgrades that have been identified during this study.

B. Economic Considerations

It is a common simplification of open markets to assume that the consumer will eventually pay for all resources required to supply a product. In the case of electricity, the consumer will eventually pay for all of the resources required to produce and to transport the electricity. In other words, the consumer will pay for the capital to build the generator, the fuel to run the generator and the transmission system designed to serve loads securely.

It is important to consider that the consumer will have to pay for the capital costs of wind generation, in addition to the transmission costs that have been estimated as part of this analysis. The same can be said for all generation technologies. The comparison of the total costs of wind energy to the total costs of other technologies is beyond the scope of this study. Quantifying the other benefits from renewable technologies, such as human health impacts from reduced fossil-fuel emissions, increased fuel diversity, reduced reliance on natural gas generation, impacts of reduced demand on related markets (such as natural gas and coal), benefits from economic development, to name a few, are also beyond the scope of this study.

This study examines one aspect of designating Competitive Renewable Energy Zones, specifically what are the most cost-effective solutions to improve the transmission system and allow transportation of additional wind energy from high wind zones to customer load while maintaining system security. The results provided in this document should not be viewed as documenting all costs or all benefits to consumers associated with CREZ designations.

C. Impact of Wind Curtailment

Defining the amount of new wind generation that can be added to the system, given a specific transmission solution, is contingent on the answer to the question of how much wind curtailment is acceptable. Unfortunately, wind curtailment is a complicated issue.

First and foremost, curtailment of energy to relieve transmission congestion can represent a significant economic impact to a wind project, since the owner of a wind project relies on

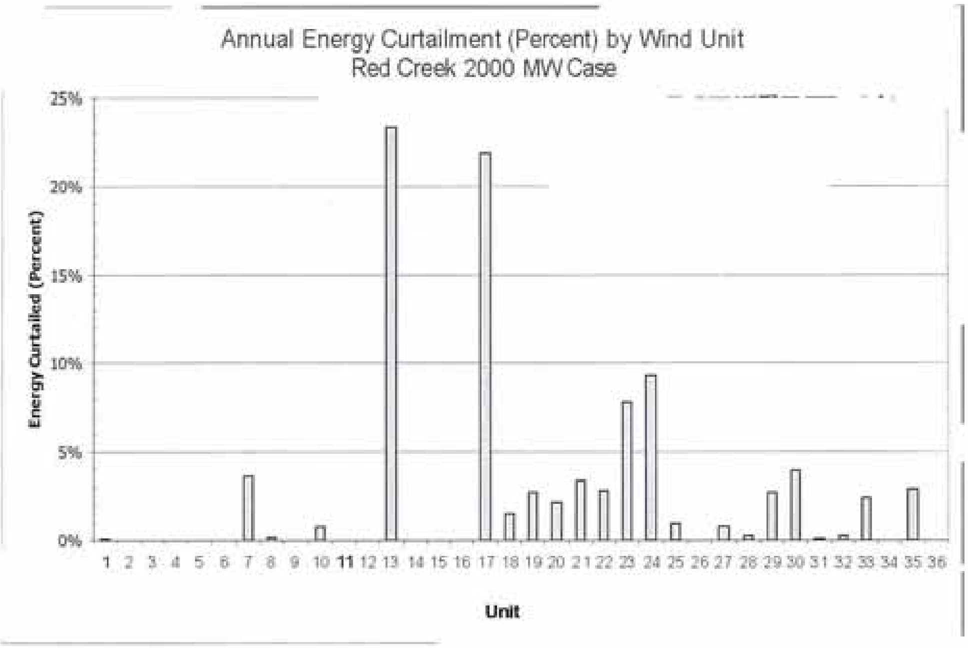
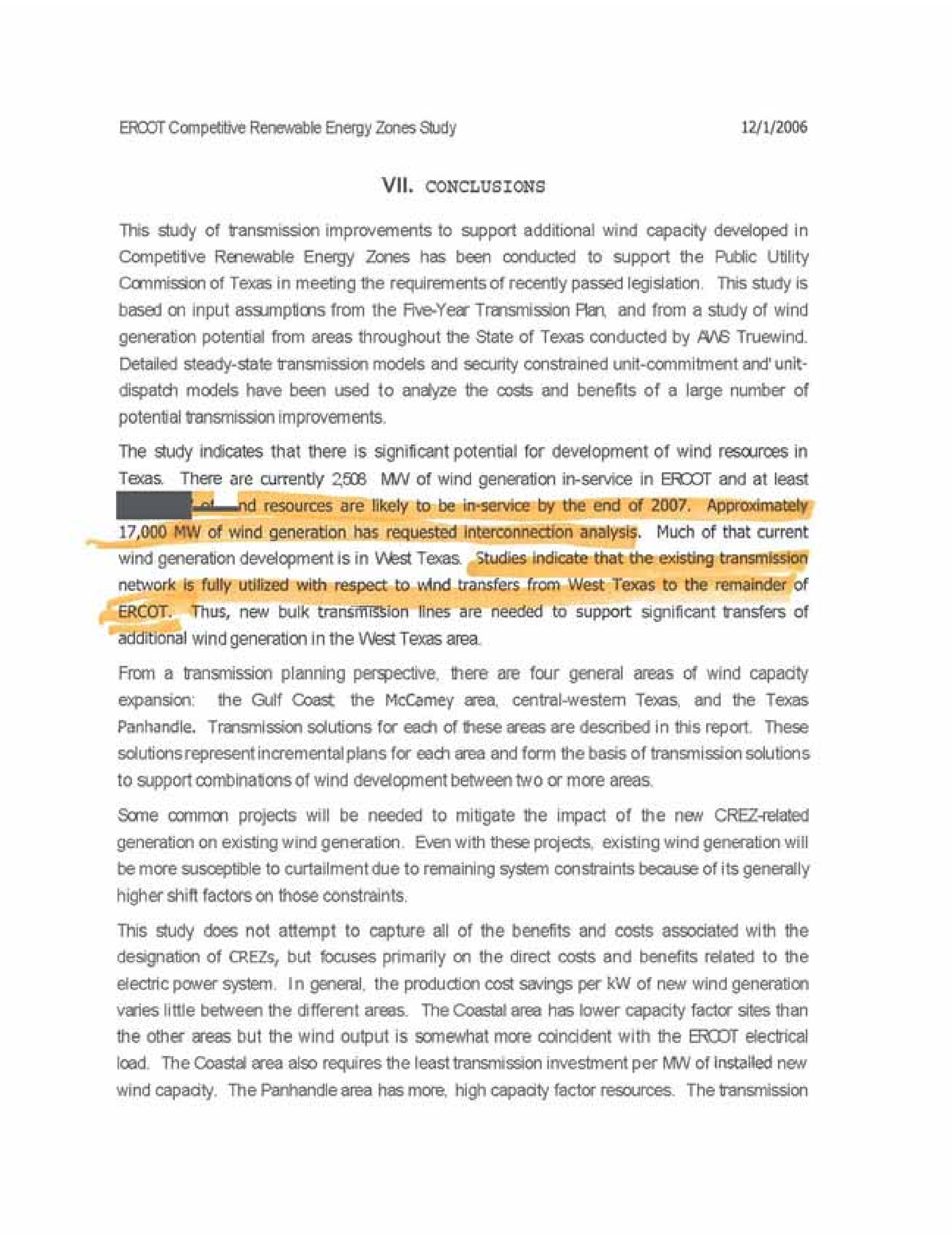


Figure 19: Wind Energy Curtailment by Unit.

The established transmission planning process conducted by ERCOT System Planning through the development of the Five-Year Plan will include an evaluation of all constraints on existing wind generators. Economically feasible projects will be proposed to stakeholders and evaluated through the Regional Planning process. Remaining constraints that cannot be resolved through the economic planning process may need to be reevaluated by the PUCT as part of future iterations of the CREZ designation process.

D. Additional Wind Added to the System

One of the most important assumptions used in this study is the amount and location of wind in the base case. These 4,850 MW of "base-case wind units" are comprised of wind units that are currently in operation, wind projects that'are under development and for which there is a signed interconnection agreement, and a set of proxy units, representing a small fraction of the wind generation projects that are currently in the ERCOT interconnection queue. Of these



VII. CONCLUSIONS

This study of transmission improvements to support additional wind capacity developed in Competitive Renewable Energy Zones has been conducted to support the Public Utility Commission of Texas in meeting the requirements of recently passed legislation. This study is based on input assumptions from the Five-Year Transmission Plan, and from a study of wind generation potential from areas throughout the State of Texas conducted by AWS Truewind. Detailed steady-state transmission models and security constrained unit-commitment and unit-dispatch models have been used to analyze the costs and benefits of a large number of potential transmission improvements.

The study indicates that there is significant potential for development of wind resources in Texas. There are currently 2,508 MW of wind generation in-service in ERCOT and at least [redacted] of wind resources are likely to be in-service by the end of 2007. Approximately 17,000 MW of wind generation has requested interconnection analysis. Much of that current wind generation development is in West Texas. Studies indicate that the existing transmission network is fully utilized with respect to wind transfers from West Texas to the remainder of ERCOT. Thus, new bulk transmission lines are needed to support significant transfers of additional wind generation in the West Texas area.

From a transmission planning perspective, there are four general areas of wind capacity expansion: the Gulf Coast, the McCamey area, central-western Texas, and the Texas Panhandle. Transmission solutions for each of these areas are described in this report. These solutions represent incremental plans for each area and form the basis of transmission solutions to support combinations of wind development between two or more areas.

Some common projects will be needed to mitigate the impact of the new CREZ-related generation on existing wind generation. Even with these projects, existing wind generation will be more susceptible to curtailment due to remaining system constraints because of its generally higher shift factors on those constraints.

This study does not attempt to capture all of the benefits and costs associated with the designation of CREZs, but focuses primarily on the direct costs and benefits related to the electric power system. In general, the production cost savings per kW of new wind generation varies little between the different areas. The Coastal area has lower capacity factor sites than the other areas but the wind output is somewhat more coincident with the ERCOT electrical load. The Coastal area also requires the least transmission investment per MW of installed new wind capacity. The Panhandle area has more, high capacity factor resources. The transmission

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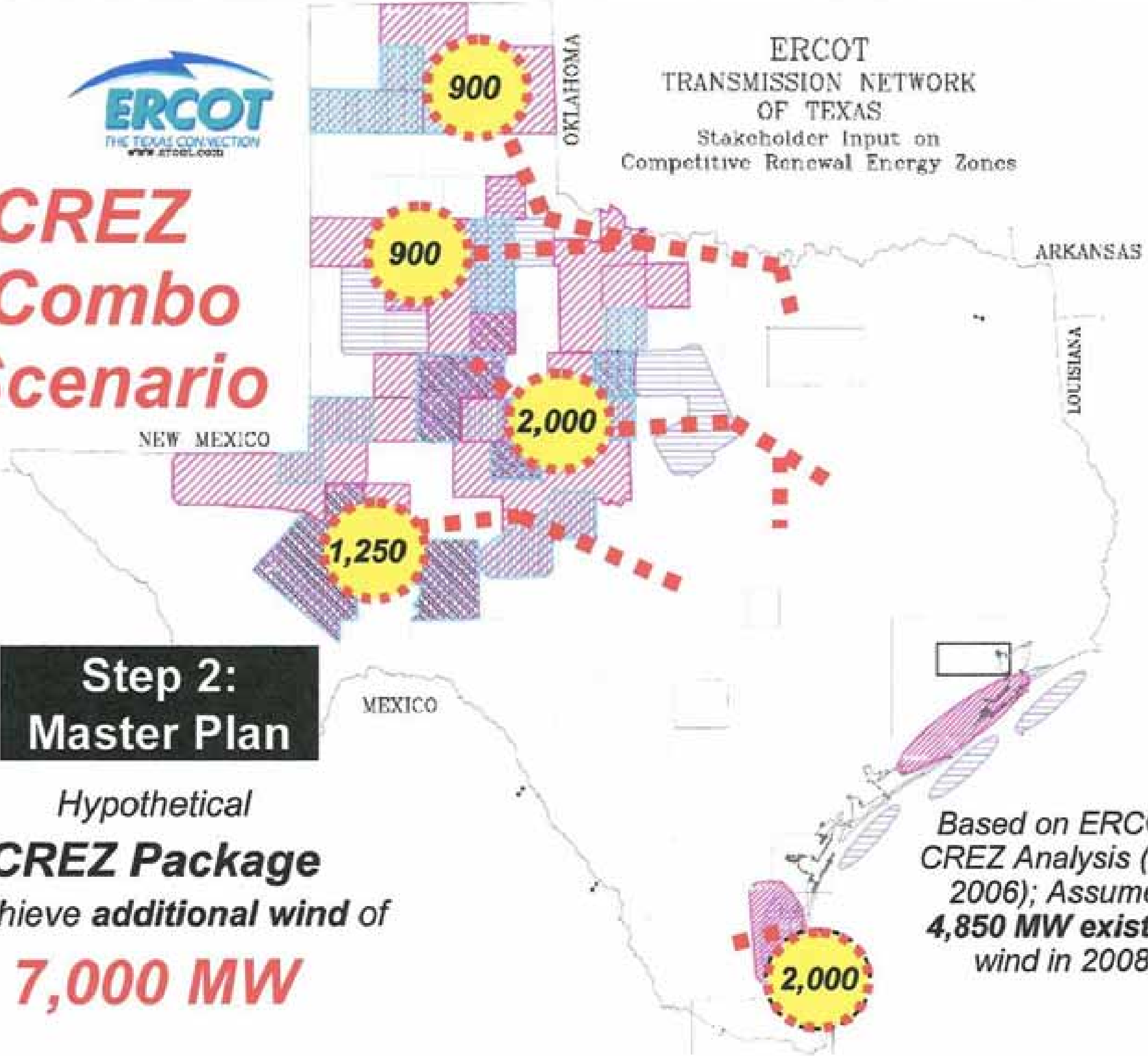
CREZ Combo Scenario



Step 2: Master Plan

Hypothetical

CREZ Package

*to achieve **additional wind** of*

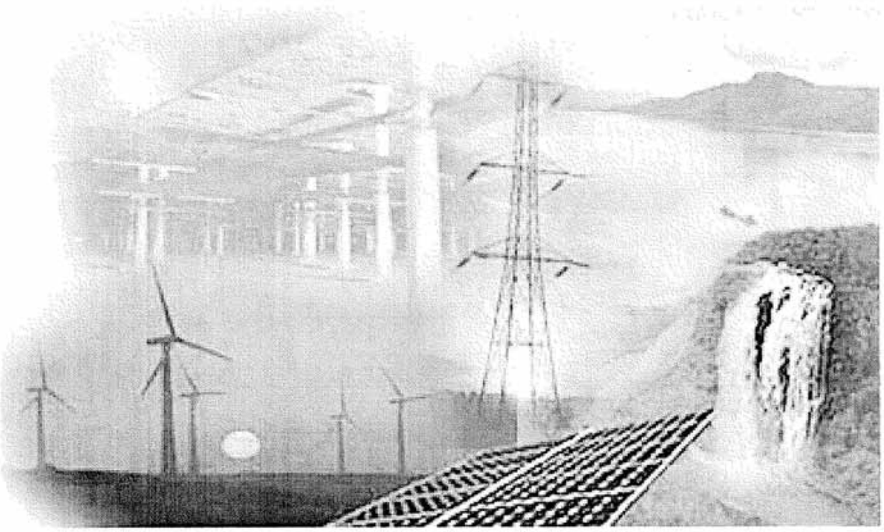
7,000 MW

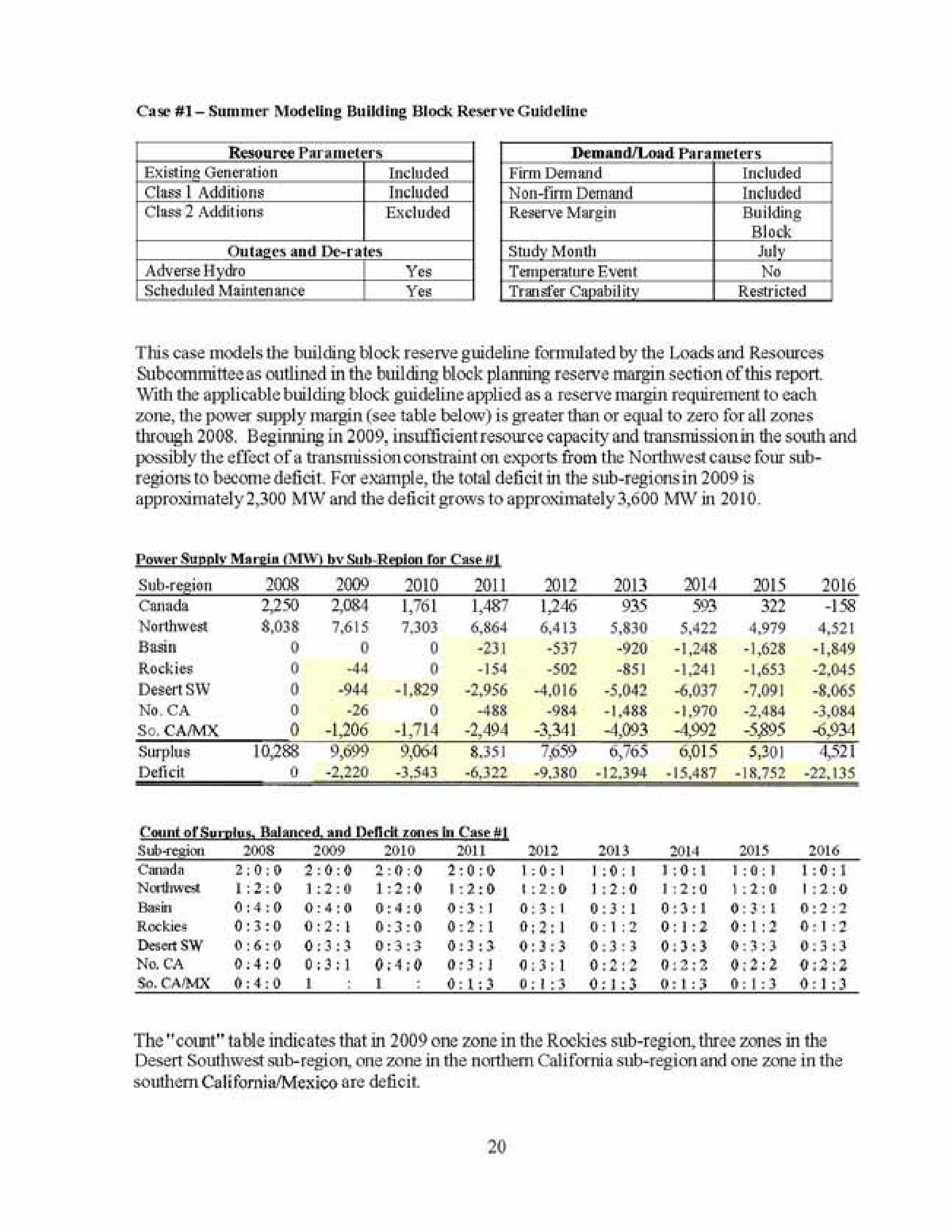
*Based on ERCOT CREZ Analysis (Dec 2006); Assumes **4,850 MW existing** wind in 2008*

Western Electricity Coordinating Council

2007 Power Supply Assessment

December 2007





Case #1 – Summer Modeling Building Block Reserve Guideline

Resource Parameters	
Existing Generation	Included
Class 1 Additions	Included
Class 2 Additions	Excluded
Outages and De-rates	
Adverse Hydro	Yes
Scheduled Maintenance	Yes

Demand/Load Parameters	
Firm Demand	Included
Non-firm Demand	Included
Reserve Margin	Building Block
Study Month	July
Temperature Event	No
Transfer Capability	Restricted

This case models the building block reserve guideline formulated by the Loads and Resources Subcommittee as outlined in the building block planning reserve margin section of this report. With the applicable building block guideline applied as a reserve margin requirement to each zone, the power supply margin (see table below) is greater than or equal to zero for all zones through 2008. Beginning in 2009, insufficient resource capacity and transmission in the south and possibly the effect of a transmission constraint on exports from the Northwest cause four sub-regions to become deficit. For example, the total deficit in the sub-regions in 2009 is approximately 2,300 MW and the deficit grows to approximately 3,600 MW in 2010.

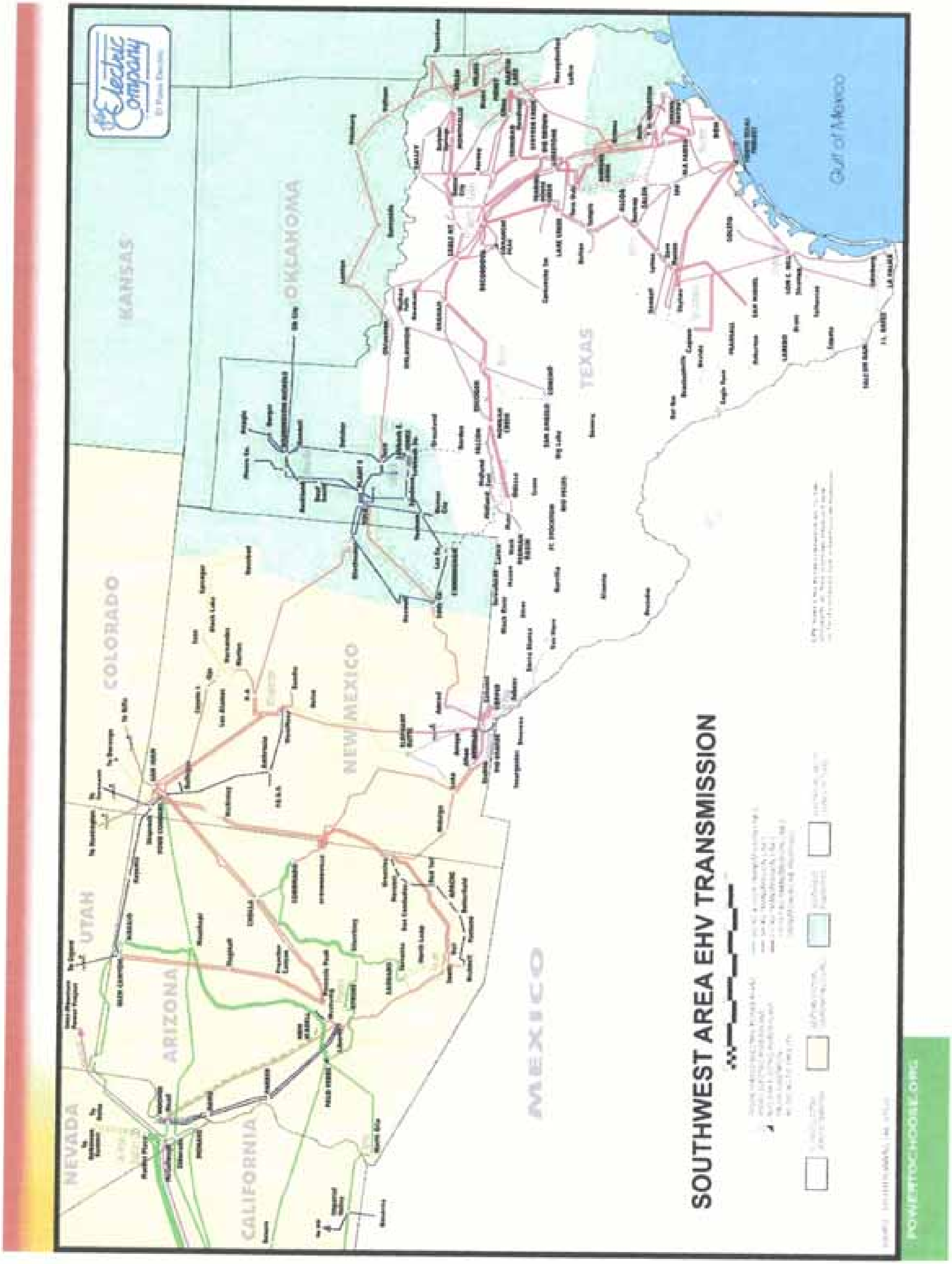
Power Supply Margin (MW) by Sub-Region for Case #1

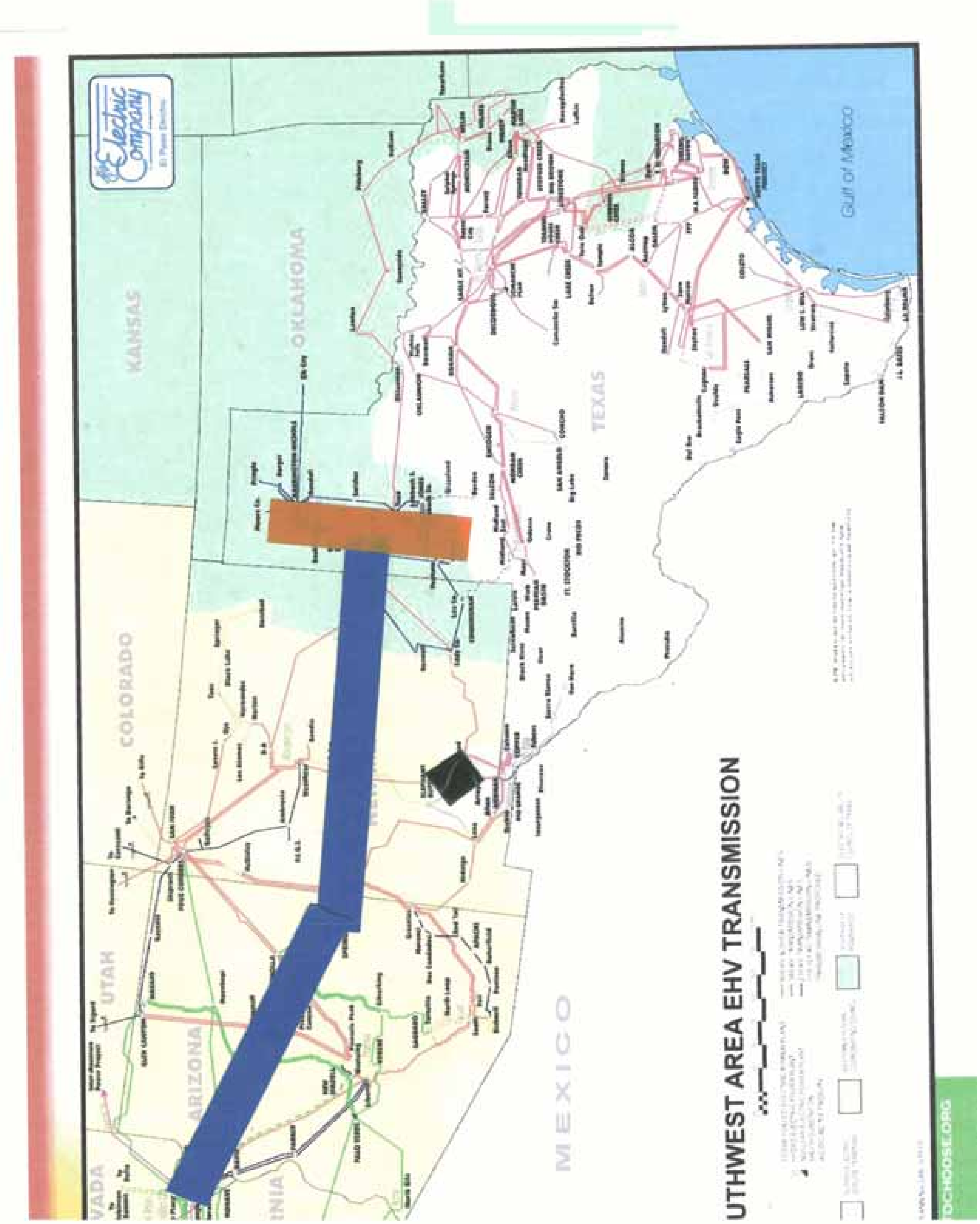
Sub-region	2008	2009	2010	2011	2012	2013	2014	2015	2016
Canada	2,250	2,084	1,761	1,487	1,246	935	593	322	-158
Northwest	8,038	7,615	7,303	6,864	6,413	5,830	5,422	4,979	4,521
Basin	0	0	0	-231	-537	-920	-1,248	-1,628	-1,849
Rockies	0	-44	0	-154	-502	-851	-1,241	-1,653	-2,045
Desert SW	0	-944	-1,829	-2,956	-4,016	-5,042	-6,037	-7,091	-8,065
No. CA	0	-26	0	-488	-984	-1,488	-1,970	-2,484	-3,084
So. CA/MX	0	-1,206	-1,714	-2,494	-3,341	-4,093	-4,992	-5,895	-6,934
Surplus	10,288	9,699	9,064	8,351	7,659	6,765	6,015	5,301	4,521
Deficit	0	-2,220	-3,543	-6,322	-9,380	-12,394	-15,487	-18,752	-22,135

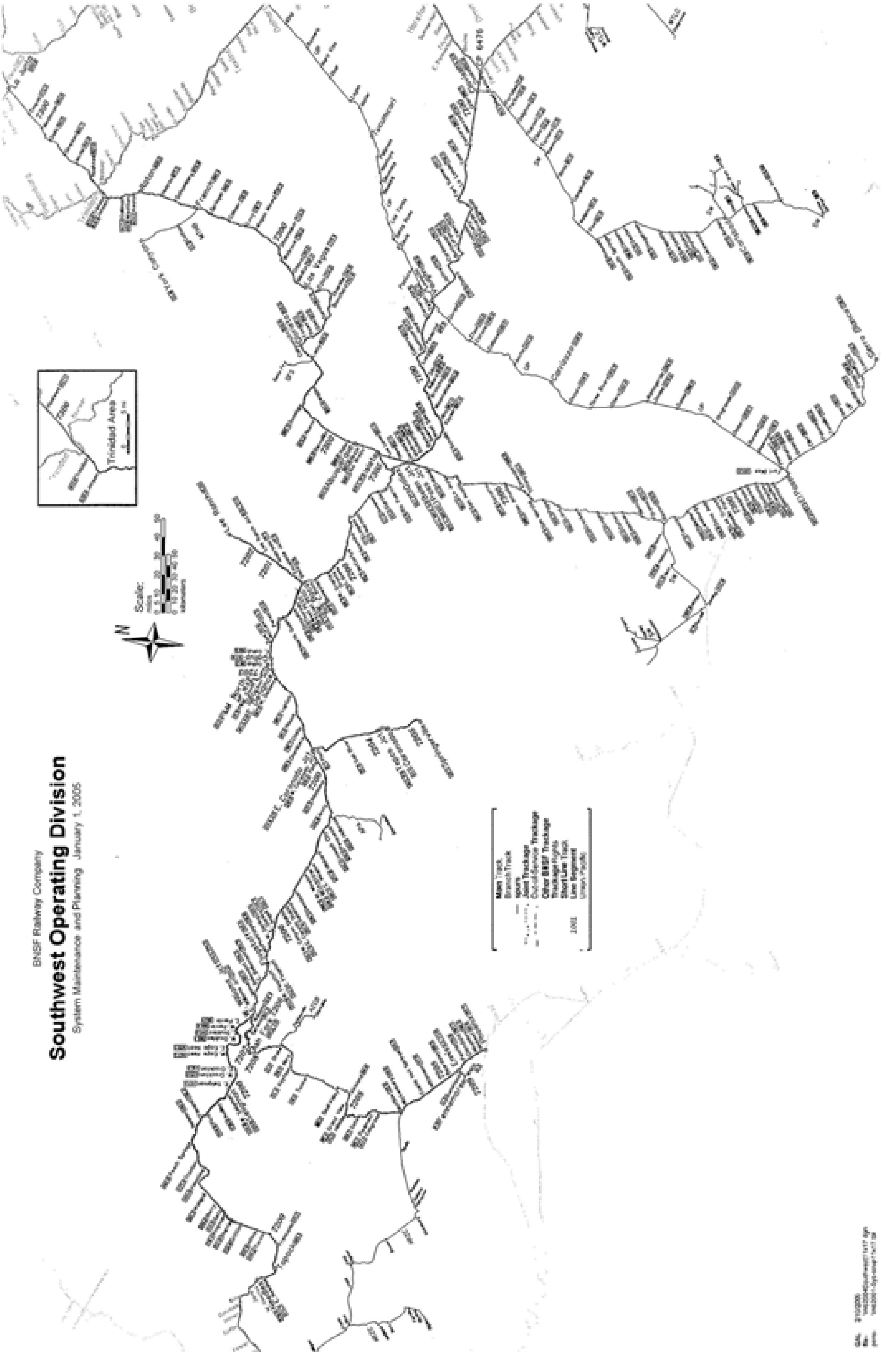
Count of Surplus, Balanced, and Deficit zones in Case #1

Sub-region	2008	2009	2010	2011	2012	2013	2014	2015	2016
Canada	2:0:0	2:0:0	2:0:0	2:0:0	1:0:1	1:0:1	1:0:1	1:0:1	1:0:1
Northwest	1:2:0	1:2:0	1:2:0	1:2:0	1:2:0	1:2:0	1:2:0	1:2:0	1:2:0
Basin	0:4:0	0:4:0	0:4:0	0:3:1	0:3:1	0:3:1	0:3:1	0:3:1	0:2:2
Rockies	0:3:0	0:2:1	0:3:0	0:2:1	0:2:1	0:1:2	0:1:2	0:1:2	0:1:2
Desert SW	0:6:0	0:3:3	0:3:3	0:3:3	0:3:3	0:3:3	0:3:3	0:3:3	0:3:3
No. CA	0:4:0	0:3:1	0:4:0	0:3:1	0:3:1	0:2:2	0:2:2	0:2:2	0:2:2
So. CA/MX	0:4:0	1 :	1 :	0:1:3	0:1:3	0:1:3	0:1:3	0:1:3	0:1:3

The "count" table indicates that in 2009 one zone in the Rockies sub-region, three zones in the Desert Southwest sub-region, one zone in the northern California sub-region and one zone in the southern California/Mexico are deficit.


The Electric Company
El Paso Electric
KANSAS
OKLAHOMA
COLORADO
UTAH
NEVADA
ARIZONA
CALIFORNIA
NEW MEXICO
TEXAS
MEXICO
Gulf of Mexico
SOUTHWEST AREA EHV TRANSMISSION
POWERTOCHOOSE.ORG


The Electric Company
El Paso Electric
KANSAS
OKLAHOMA
COLORADO
UTAH
ARIZONA
TEXAS
MEXICO
Gulf of Mexico
UTHWEST AREA EHV TRANSMISSION
TOCHOOSE.ORG


BNSF Railway Company
Southwest Operating Division
System Maintenance and Planning January 1, 2005
Scale:
Trinidad Area
N
Main Track
Branch Track
Spurs
Joint Trackage
Out-of-Service Trackage
Other BNSF Trackage
Trackage Rights
Short Line Track
Line Segment
Union Pacific
1001
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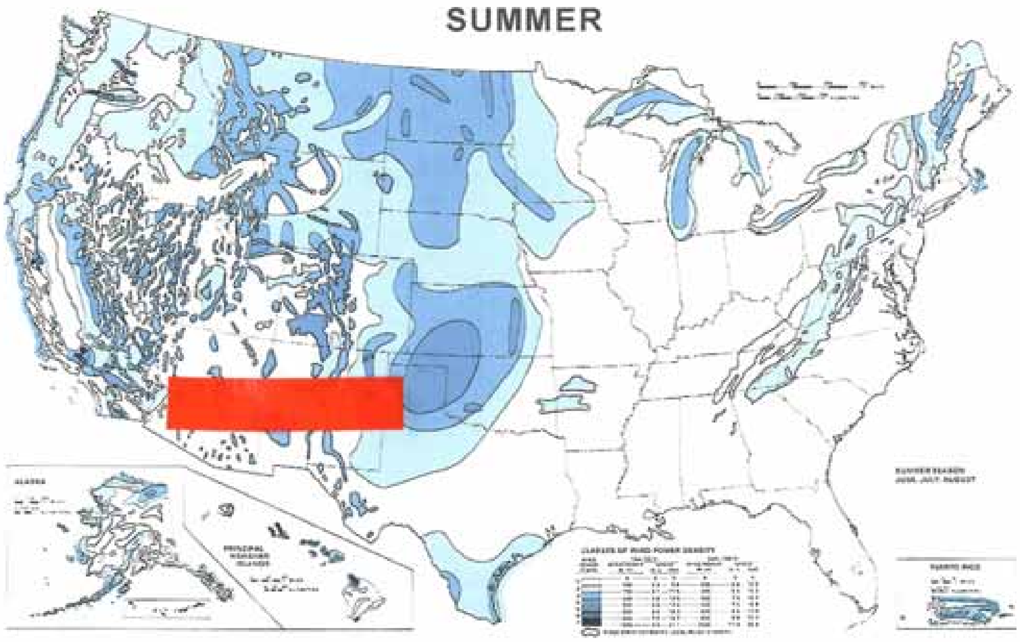
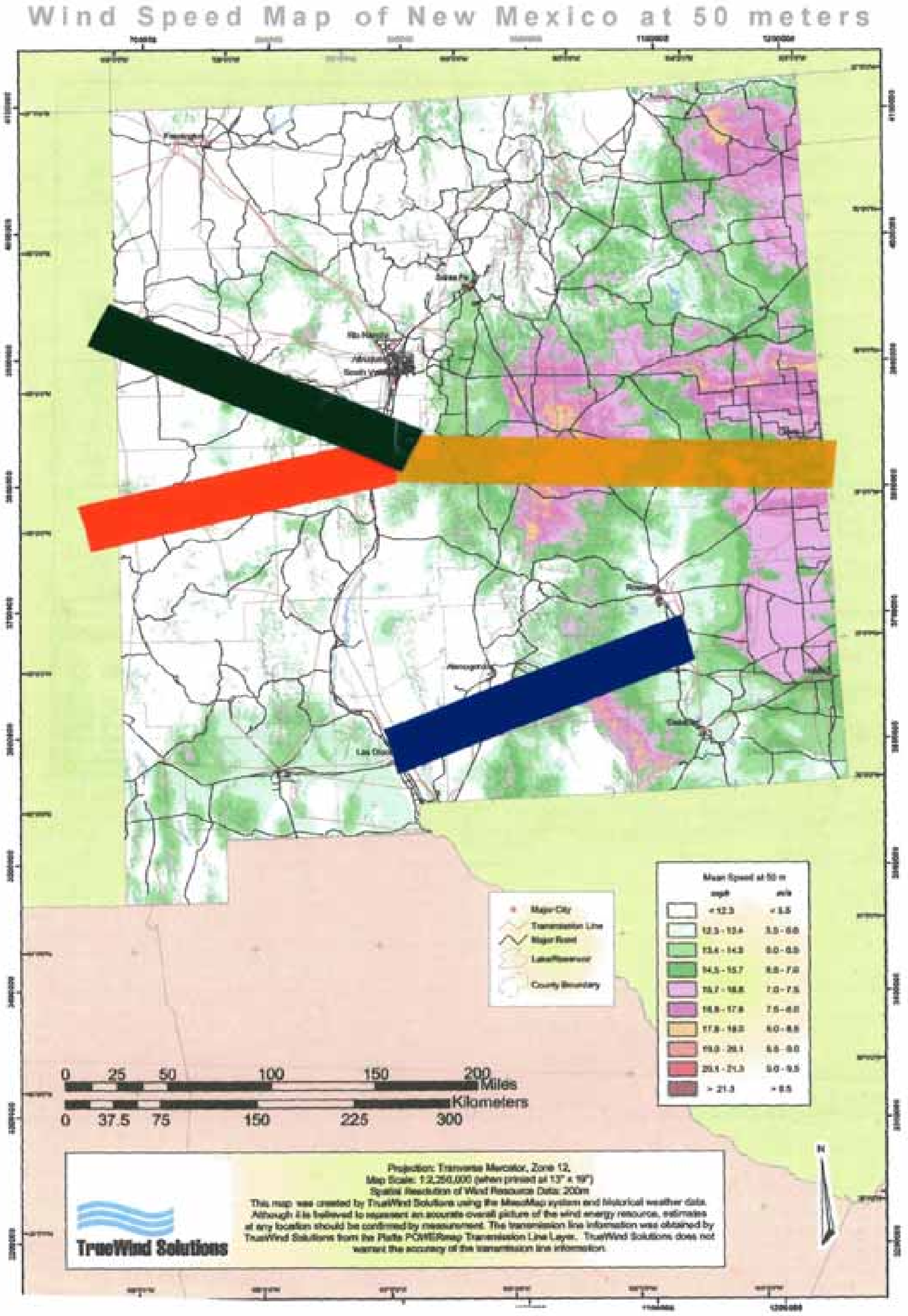
Las Vegas
Fort Worth



Map 2-4 Summer season-June, July, August

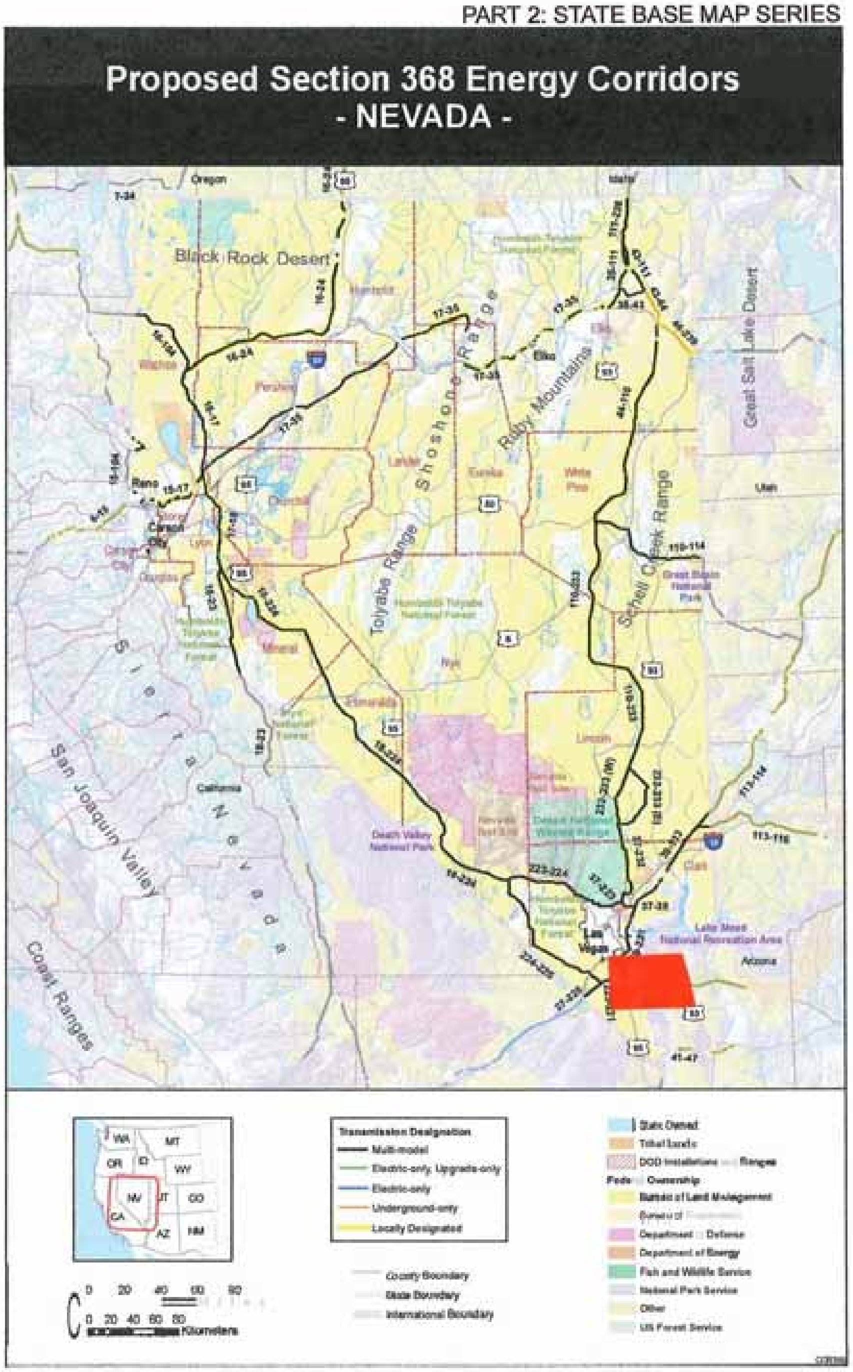
For more information see Map Description.

http://rredc.nrel.gov

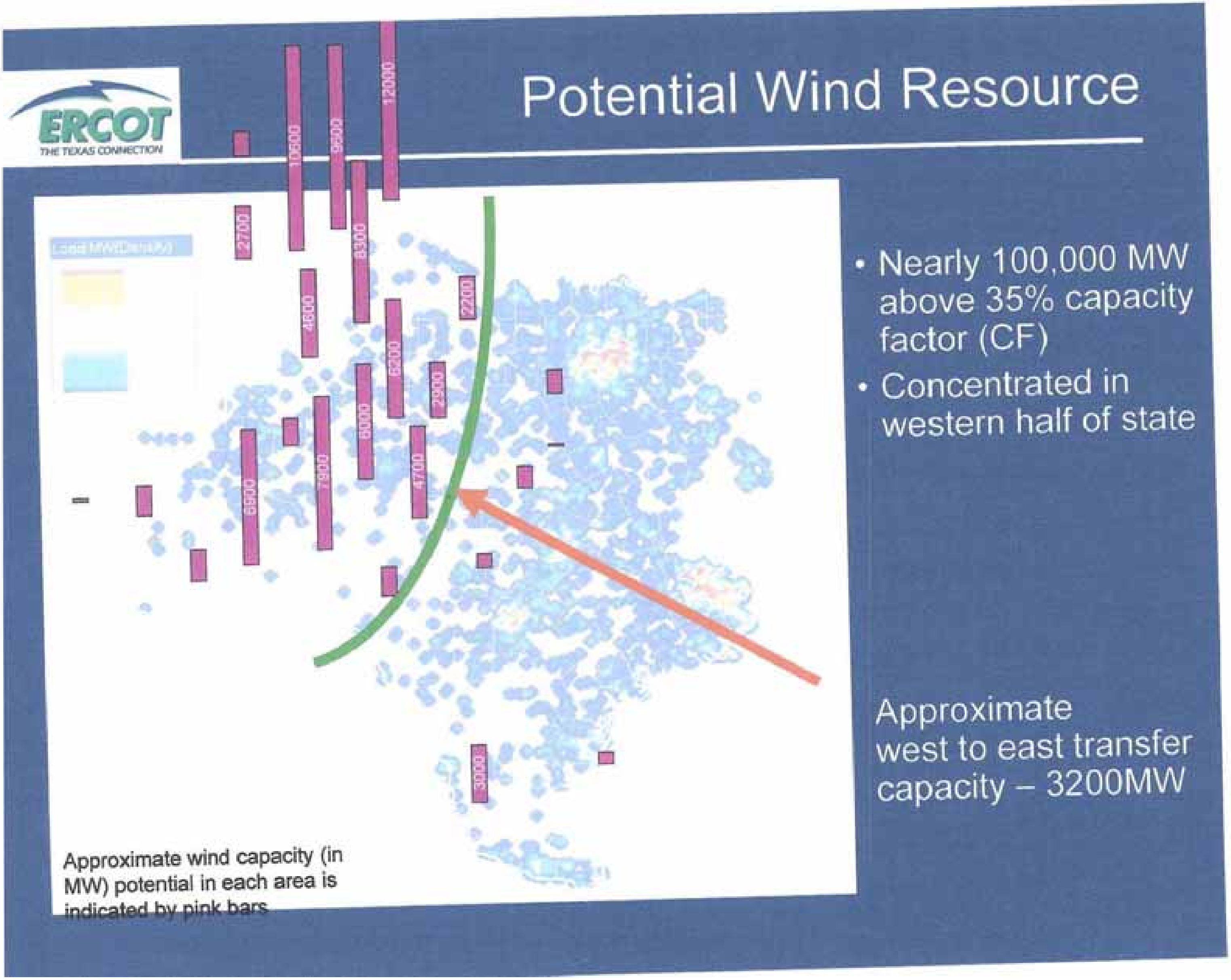


Projection: Transverse Mercator, Zone 13,
Map Scale: 1:2,250,000 (when printed at 13" x 19")
Spatial Resolution of Wind Resource Data: 200m
This map was created by TrueWind Solutions using the MesoMap system and historical weather data. Although it is believed to represent an accurate overall picture of the wind energy resource, estimates at any location should be confirmed by measurement. The transmission line information was obtained by TrueWind Solutions from the Platts POWERmap Transmission Line Layer. TrueWind Solutions does not warrant the accuracy of the transmission line information.


PART 2: STATE BASE MAP SERIES
Proposed Section 368 Energy Corridors
-ARIZONA-
Utah
Colorado
Nevada
Las Vegas
California
New Mexico
Grand Canyon National Park
Kaibab National Forest
Lake Mead National Recreation Area
Canyon de Chelly National Monument
Painted Desert
Flagstaff
Walnut Canyon National Monument
Prescott National Forest
Mogollon Rim
Tonto National Forest
Phoenix
Tucson
Saguaro National Park
Organ Pipe Cactus National Monument
Coronado National Forest
Chiricahua National Monument
Fort Bowie National Historic Site
113-116
116-206
68-116
113-114
39-113
39-231
47-68
61-207
47-231
41-47
41-46
46-269
46-270
62-211
30-52
115-208
115-238
81-213
Transmission Designation
Multi-modal
Electric-only, Upgrade-only
Electric-only
Underground-only
Locally Designated
County Boundary
State Boundary
International Boundary
State Owned
Tribal Lands
DOD Installations and Ranges
Federal Ownership
Bureau of Land Management
Bureau of Reclamation
Department of Defense
Department of Energy
Fish and Wildlife Service
National Park Service
Other
US Forest Service
WA
MT
OR
ID
WY
NV
UT
CO
CA
AZ
NM
0 20 40 60 80 Miles
0 20 40 60 80 Kilometers
N


PART 2: STATE BASE MAP SERIES

Proposed Section 368 Energy Corridors
- NEVADA -



Potential Wind Resource

- Nearly 100,000 MW above 35% capacity factor (CF)
- Concentrated in western half of state

Approximate west to east transfer capacity – 3200MW

Approximate wind capacity (in MW) potential in each area is indicated by pink bars

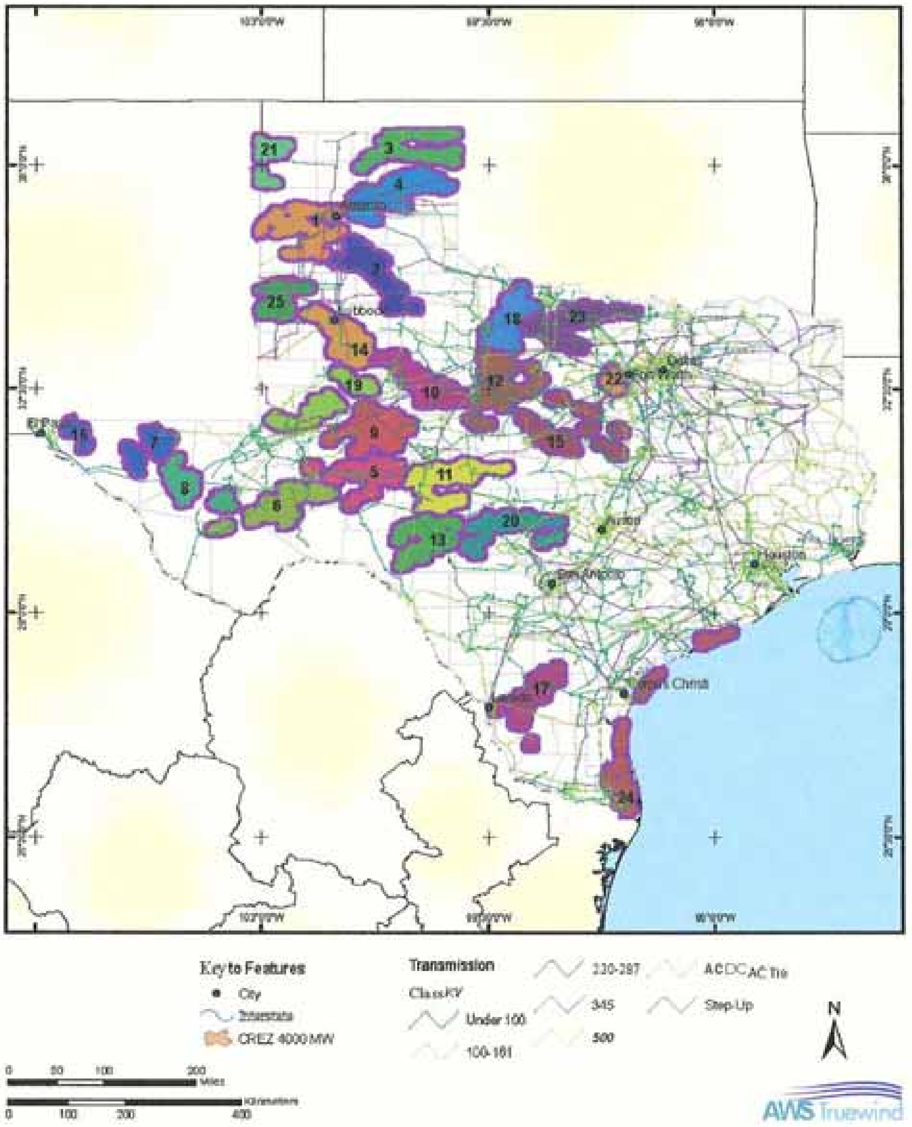
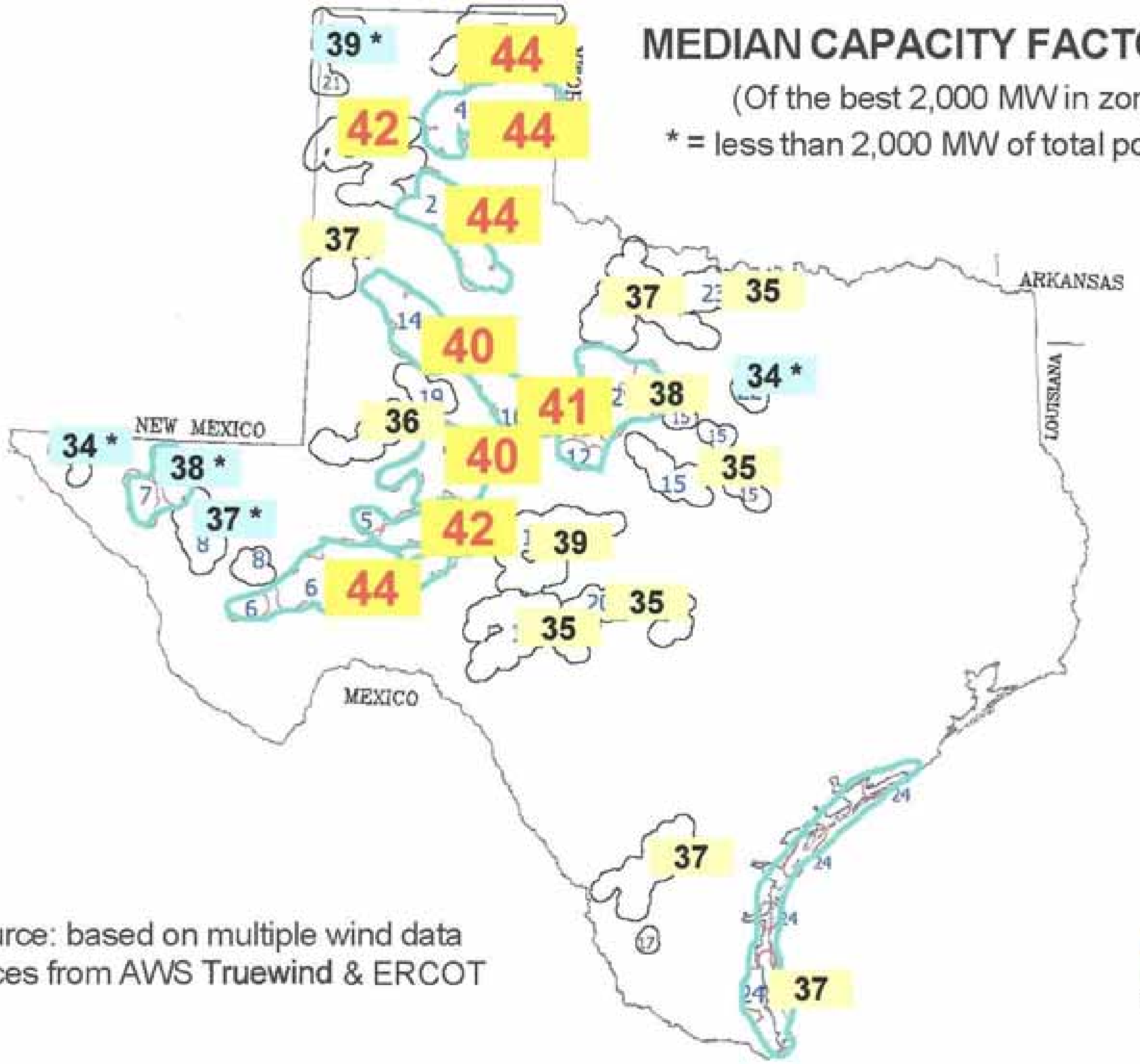


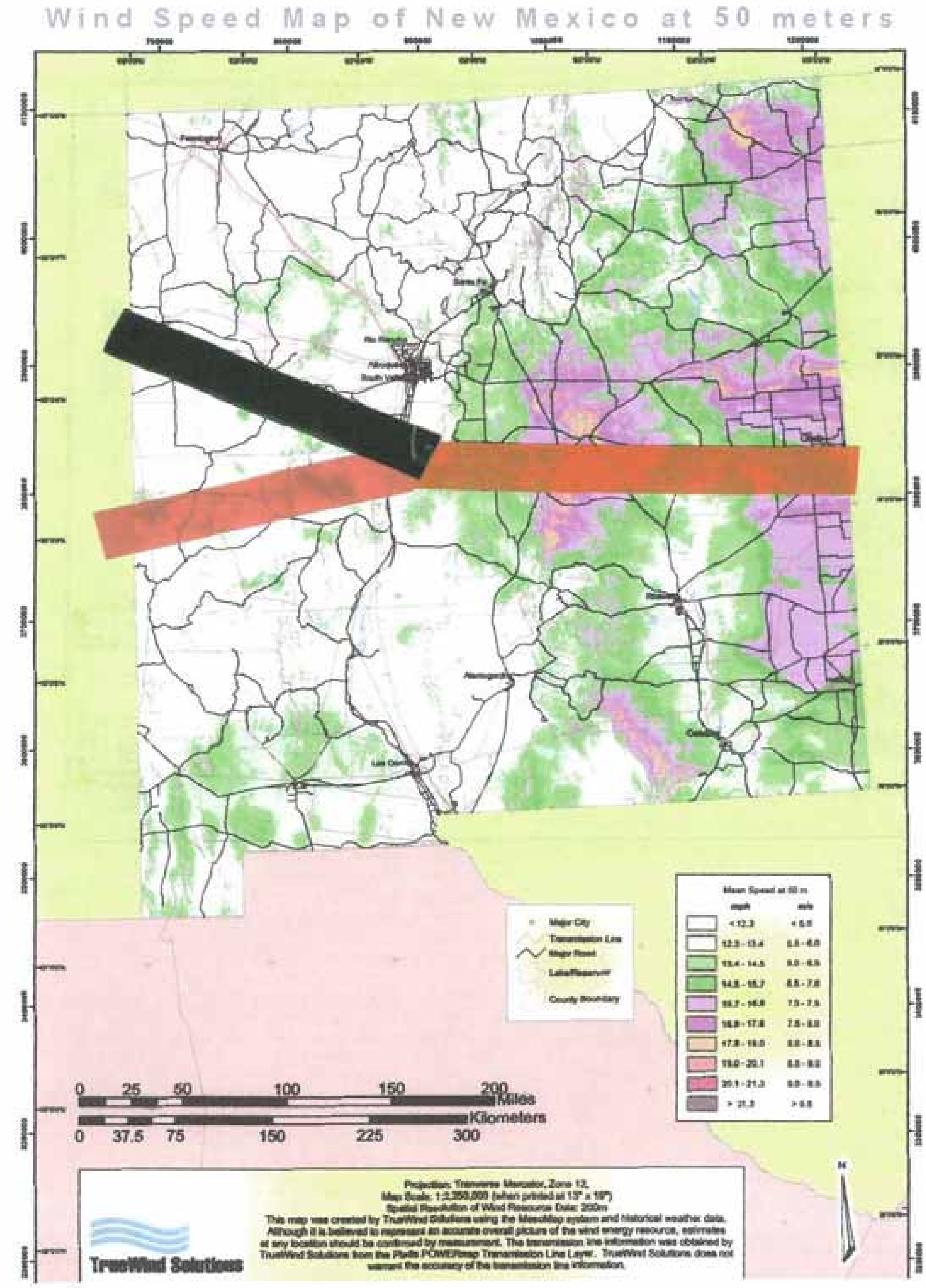
Figure 3: Areas Enclosing the Best 4,000 MW in Each of the Wind Resource Zones

MEDIAN CAPACITY FACTOR (%)

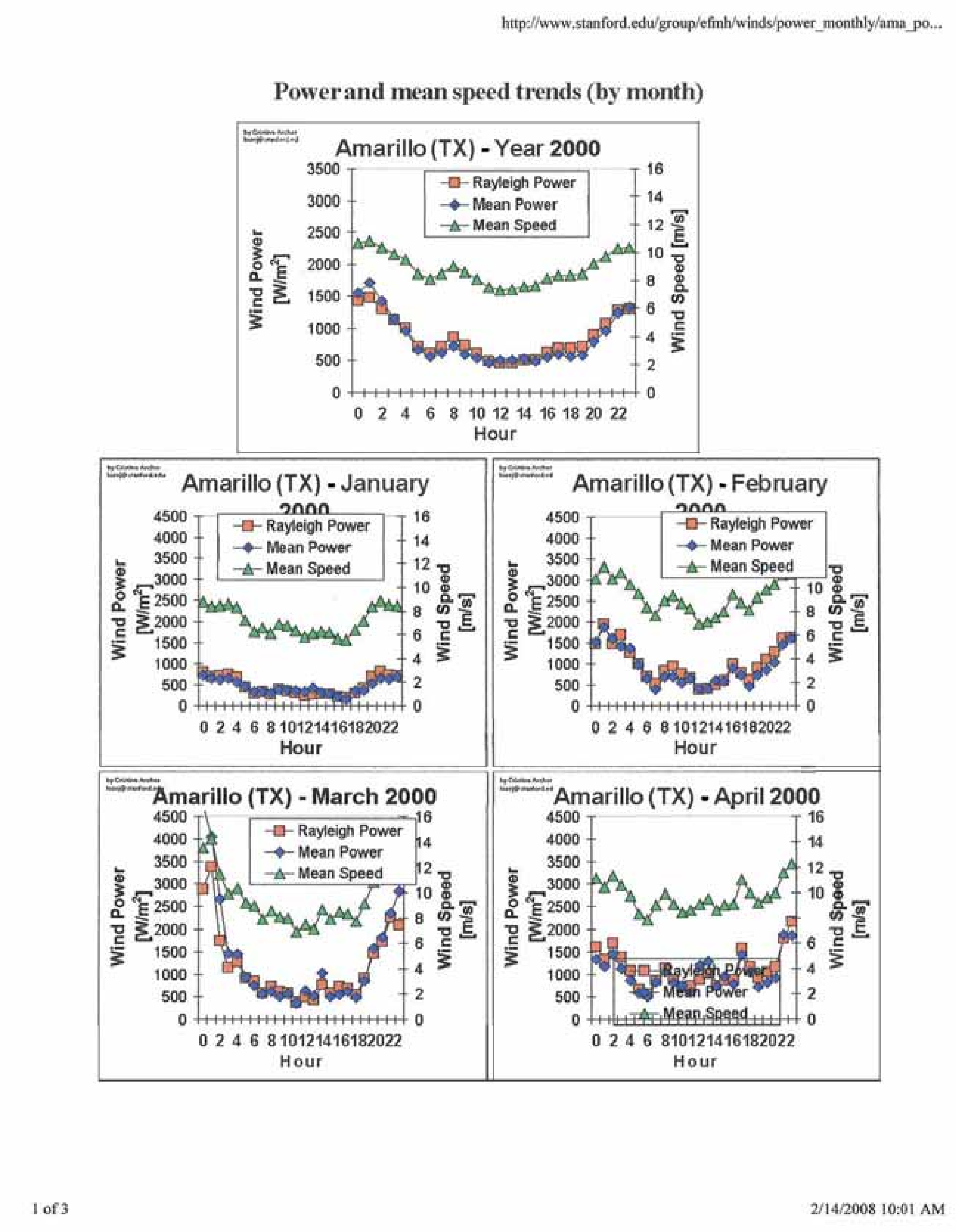
(Of the best 2,000 MW in zone;
* = less than 2,000 MW of total potential)



Source: based on multiple wind data sources from AWS Truewind & ERCOT

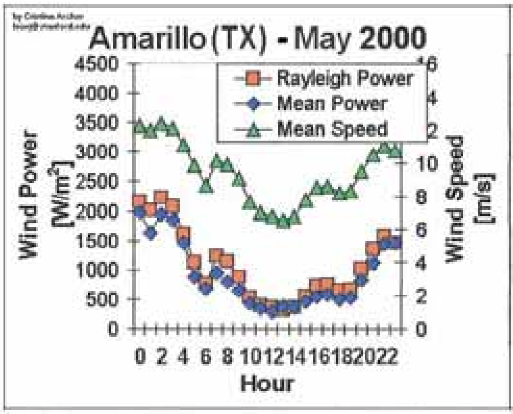


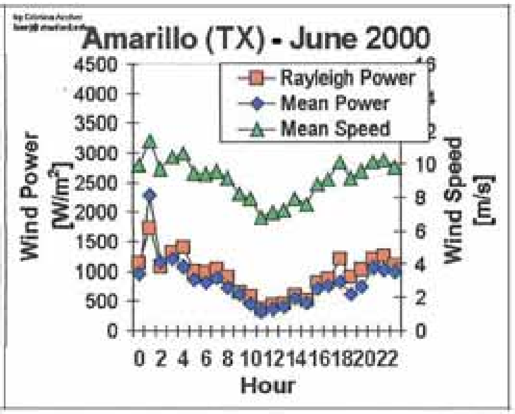
Projection: Transverse Mercator, Zone 12,
Map Scale: 1:2,350,000 (when printed at 13" x 19")
Spatial Resolution of Wind Resource Data: 200m
This map was created by TrueWind Solutions using the MesoMap system and historical weather data. Although it is believed to represent an accurate overall picture of the wind energy resource, estimates at any location should be confirmed by measurement. The transmission line information was obtained by TrueWind Solutions from the Platts POWERmap Transmission Line Layer. TrueWind Solutions does not warrant the accuracy of the transmission line information.

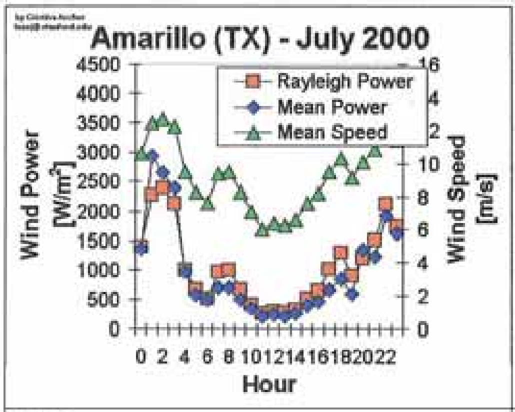


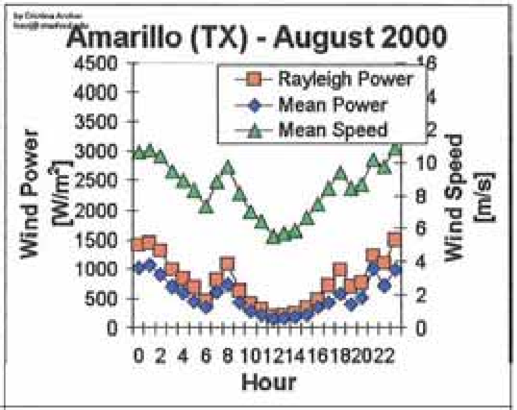
Power and mean speed trends (by month)

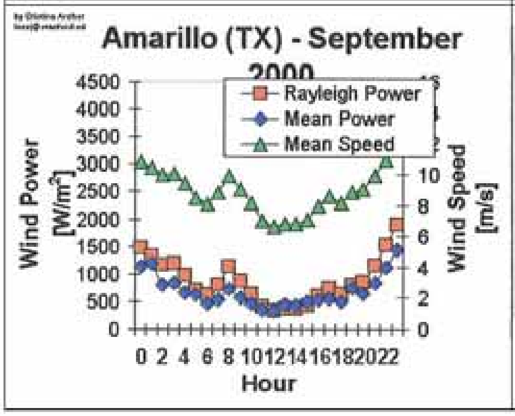
http://www.stanford.edu/group/efmh/winds/power_monthly/ama_po...

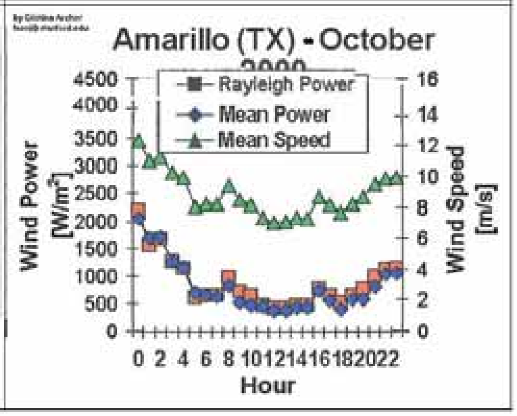












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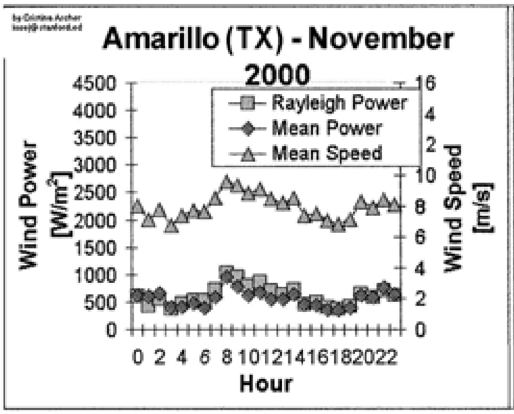
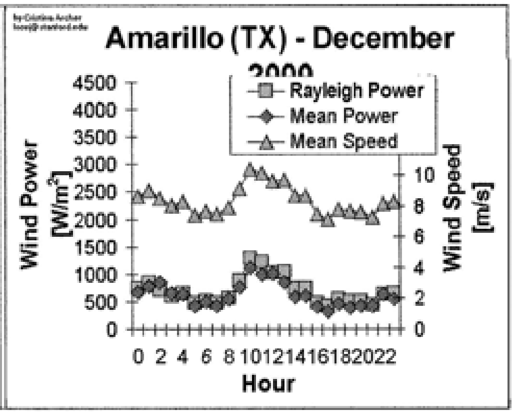
http://www.stanford.edu/group/efmh/winds/power_monthly/ama_po...



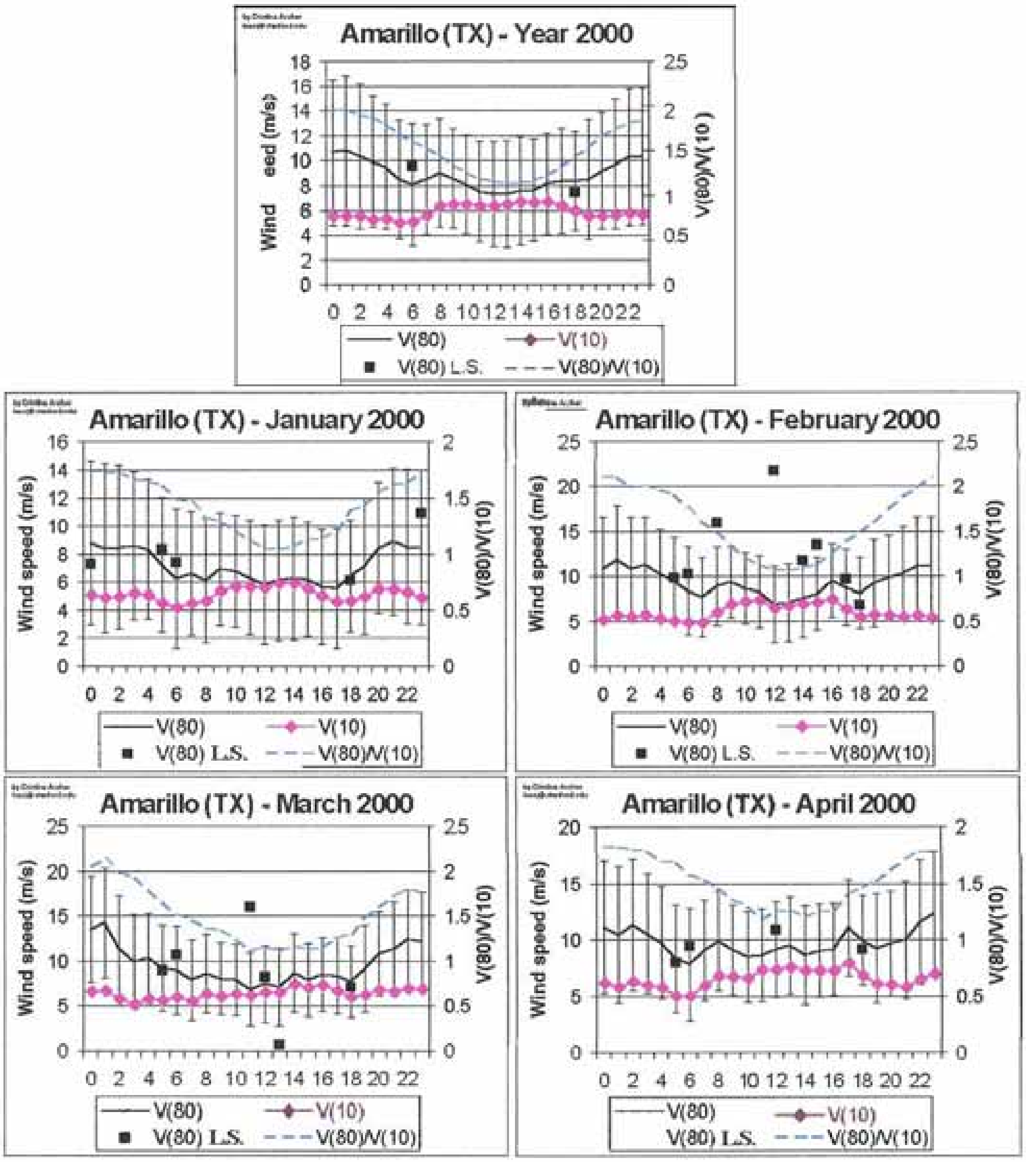
Amarillo (TX) - November 2000

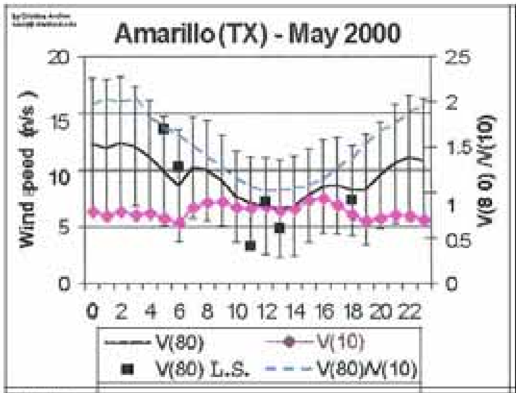


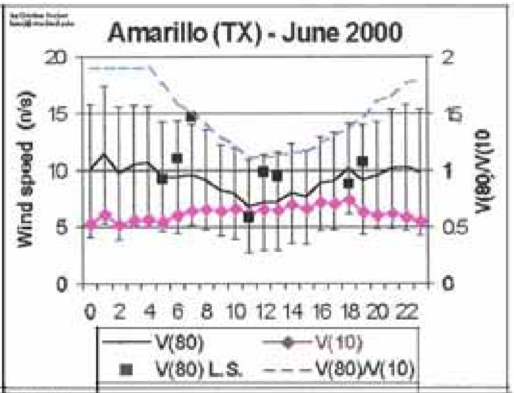
Amarillo (TX) - December 2000

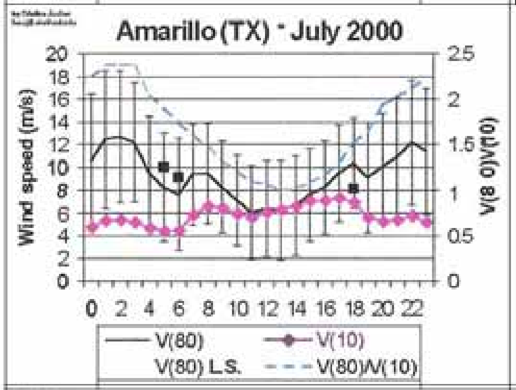
http://www.stanford.edu/group/efmh/winds/ama.html

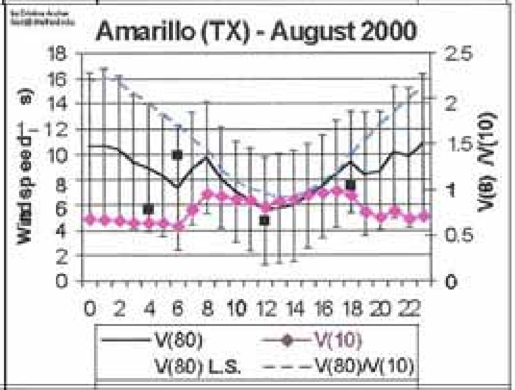
Mean wind speeds and standard deviations

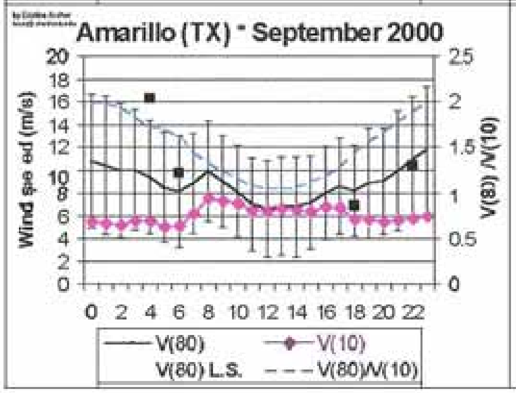


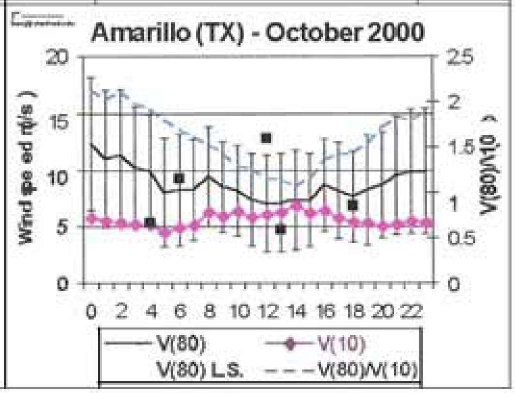

Amarillo (TX) - May 2000


Amarillo (TX) - June 2000

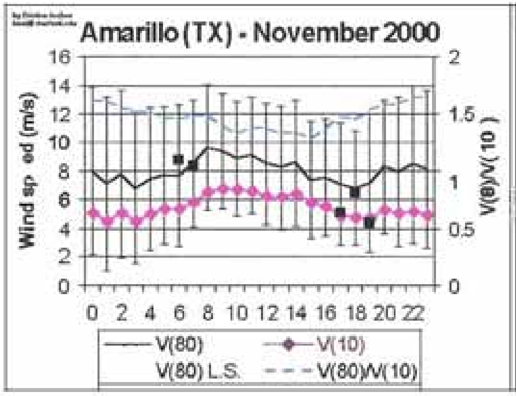

Amarillo (TX) - July 2000

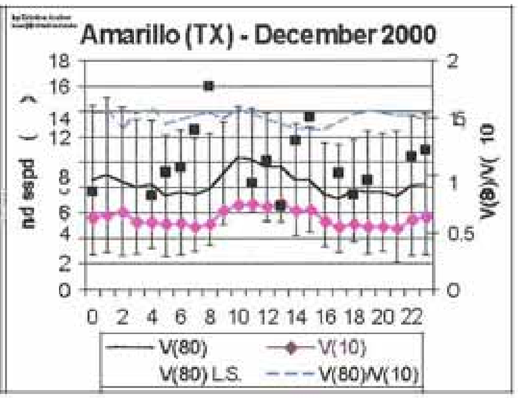

Amarillo (TX) - August 2000


Amarillo (TX) - September 2000


Amarillo (TX) - October 2000

http://www.stanford.edu/group/efmh/winds/ama.html





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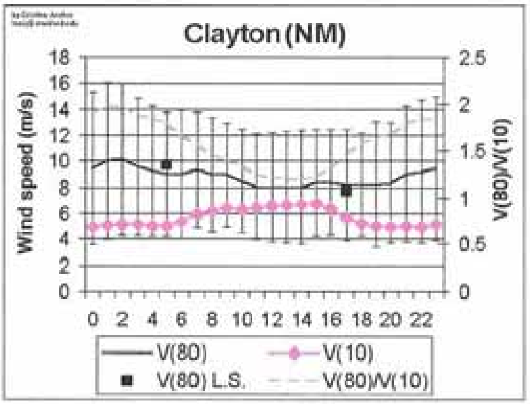
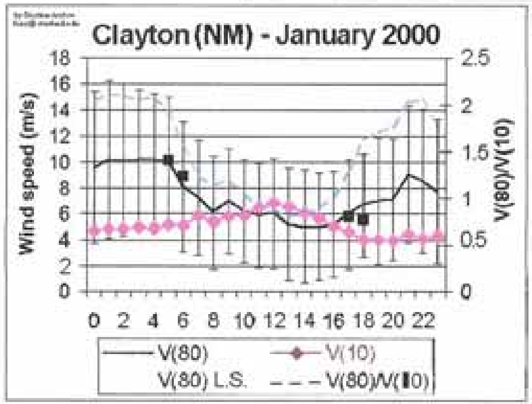
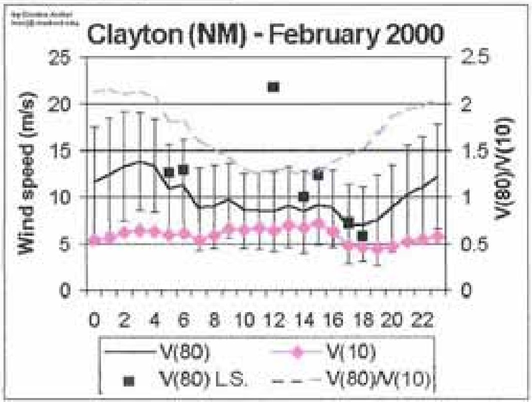
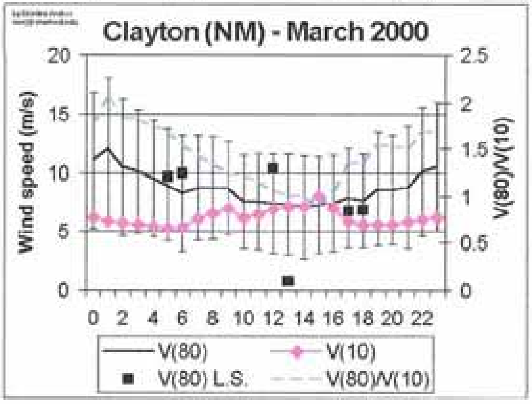
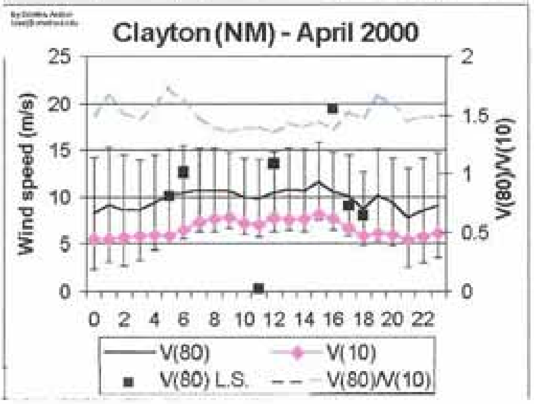
Mean wind speeds and standard deviations



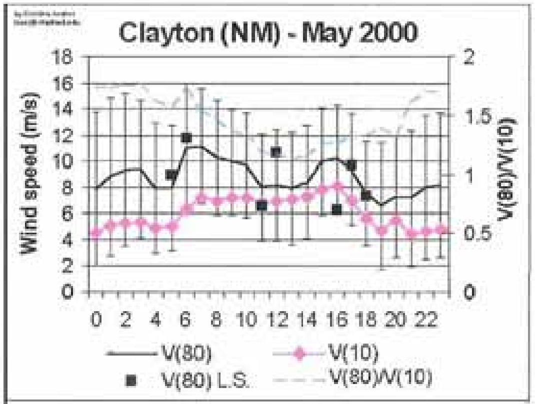


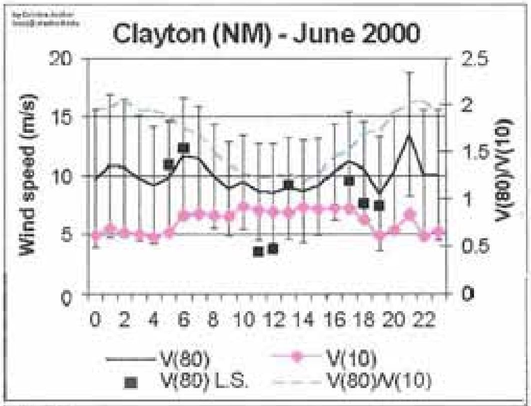


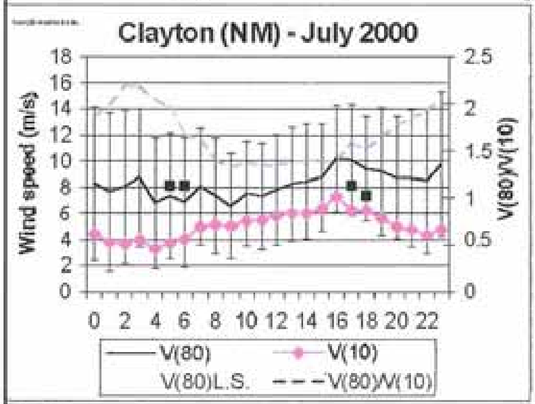


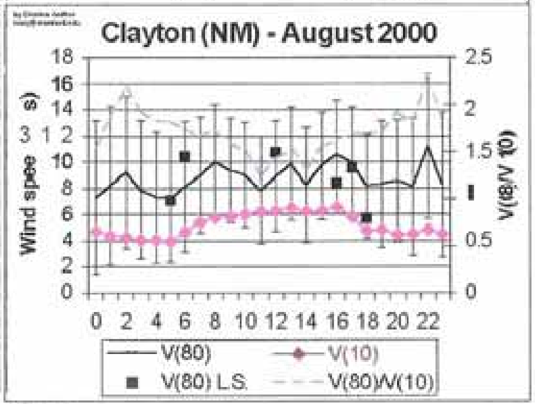


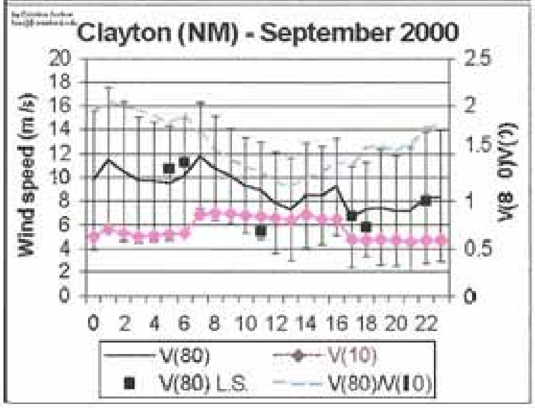
http://www.stanford.edu/group/efmh/winds/cao.htm

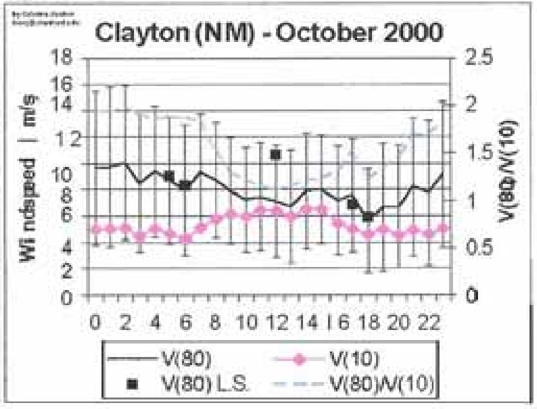












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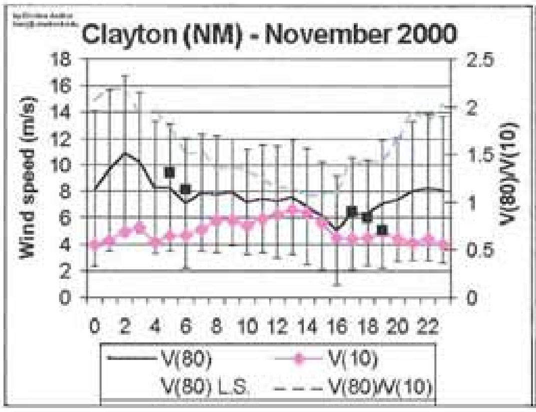
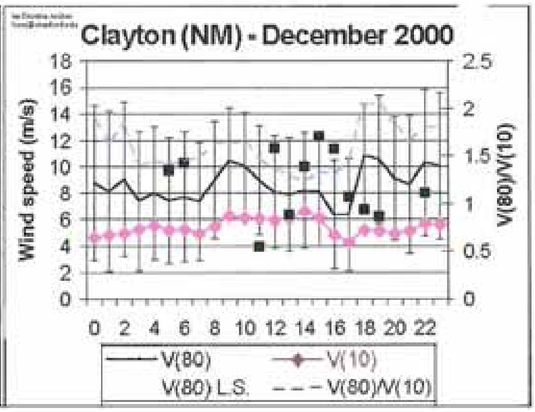

Clayton (NM) - November 2000
Wind speed (m/s)
V(80)/V(10)
0
2
4
6
8
10
12
14
16
18
0
0.5
1
1.5
2
2.5
0 2 4 6 8 10 12 14 16 18 20 22
V(80)
V(10)
V(80) L.S.
V(80)/V(10)


Clayton (NM) - December 2000
Wind speed (m/s)
V(80)/V(10)
0
2
4
6
8
10
12
14
16
18
0
0.5
1
1.5
2
2.5
0 2 4 6 8 10 12 14 16 18 20 22
V(80)
V(10)
V(80) L.S.
V(80)/V(10)

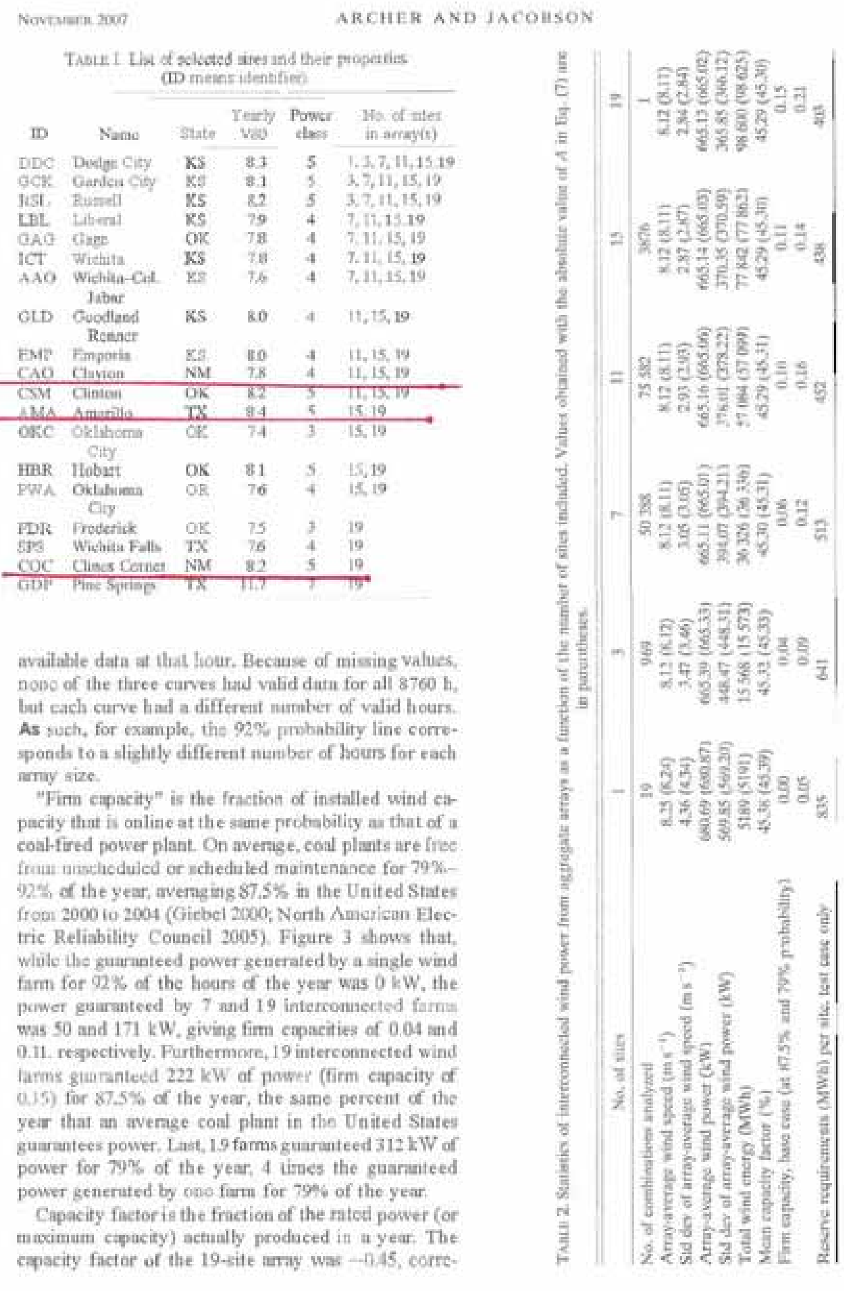


TABLE 1. List of selected sites and their properties (ID means identifier).

ID	Name	State	Yearly V80	Power class	No. of sites in array(s)
DDC	Dodge City	KS	8.3	5	1, 3, 7, 11, 15, 19
GCK	Garden City	KS	8.1	5	3, 7, 11, 15, 19
RSL	Russell	KS	8.2	5	3, 7, 11, 15, 19
LBL	Liberal	KS	7.9	4	7, 11, 15, 19
GAG	Gage	OK	7.8	4	7, 11, 15, 19
ICT	Wichita	KS	7.8	4	7, 11, 15, 19
AAO	Wichita–Col. Jabar	KS	7.6	4	7, 11, 15, 19
GLD	Goodland Renner	KS	8.0	4	11, 15, 19
EMP	Emporia	KS	8.0	4	11, 15, 19
CAO	Clayton	NM	7.8	4	11, 15, 19
CSM	Clinton	OK	8.2	5	11, 15, 19
AMA	Amarillo	TX	8.4	5	15, 19
OKC	Oklahoma City	OK	7.4	3	15, 19
HBR	Hobart	OK	8.1	5	15, 19
PWA	Oklahoma City	OK	7.6	4	15, 19
FDR	Frederick	OK	7.5	3	19
SPS	Wichita Falls	TX	7.6	4	19
COC	Clines Corner	NM	8.2	5	19
GDP	Pine Springs	TX	11.7	7	19

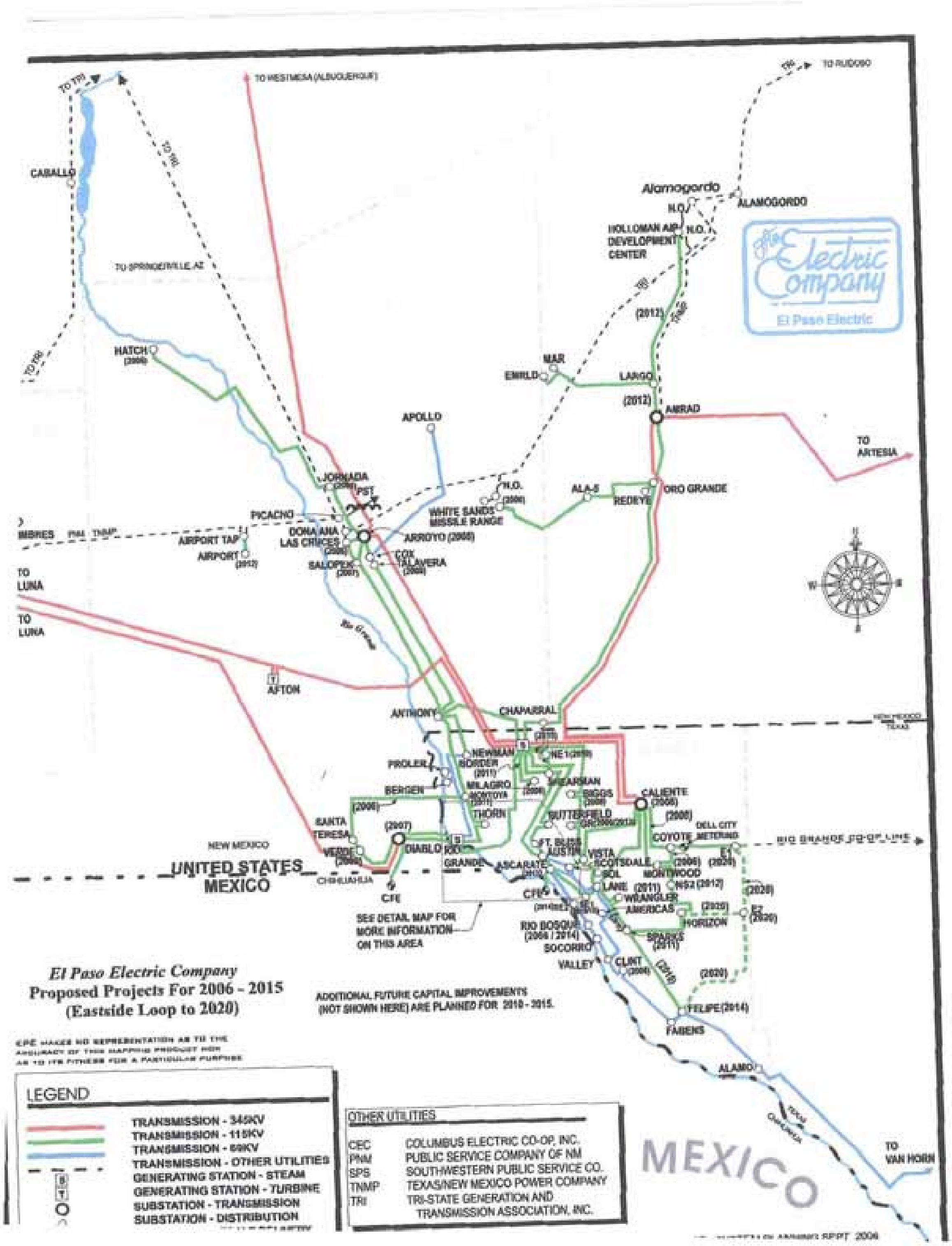
available data at that hour. Because of missing values, none of the three curves had valid data for all 8760 h, but each curve had a different number of valid hours. As such, for example, the 92% probability line corresponds to a slightly different number of hours for each array size.

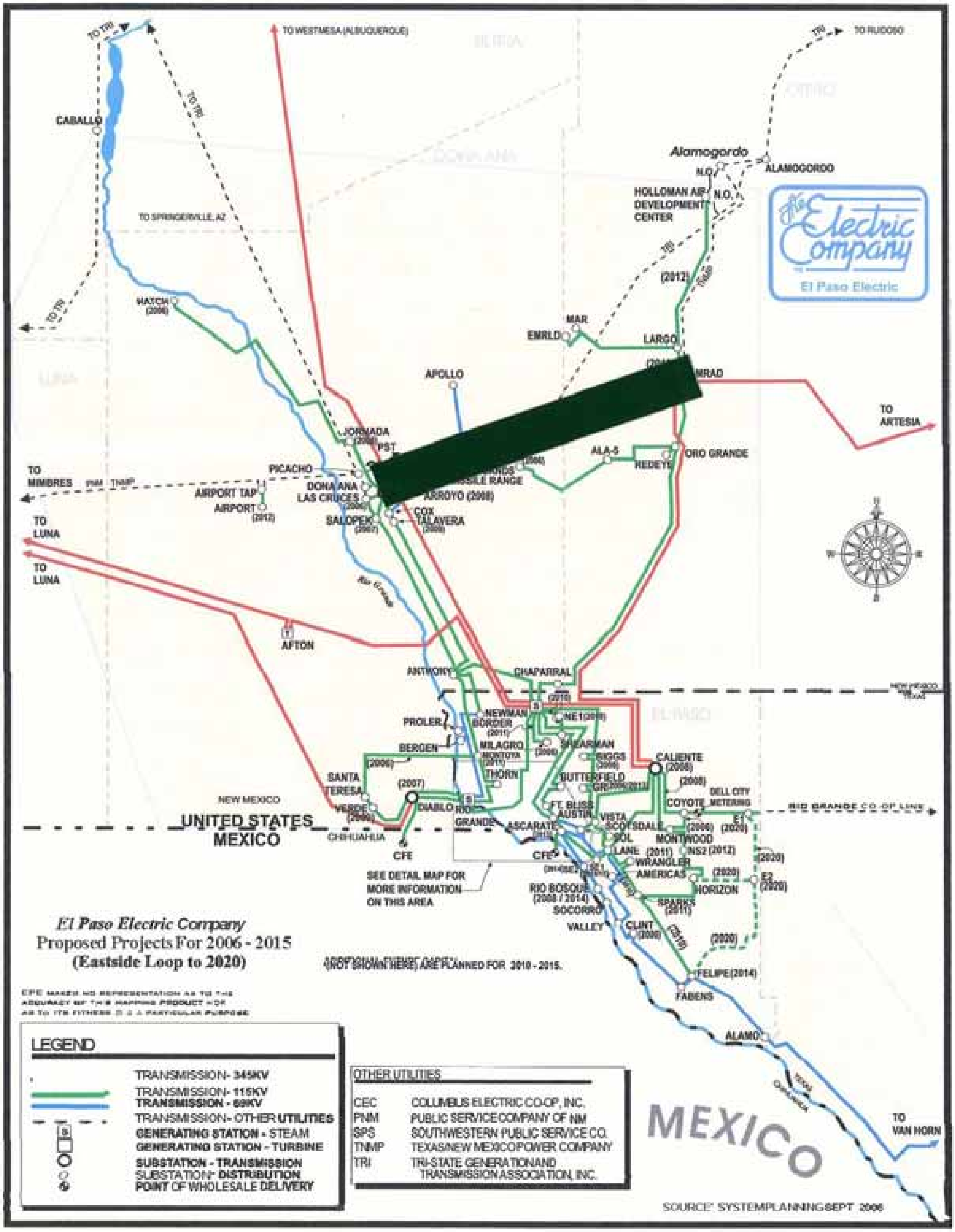
"Firm capacity" is the fraction of installed wind capacity that is online at the same probability as that of a coal-fired power plant. On average, coal plants are free from unscheduled or scheduled maintenance for 79%–92% of the year, averaging 87.5% in the United States from 2000 to 2004 (Giebel 2000; North American Electric Reliability Council 2005). Figure 3 shows that, while the guaranteed power generated by a single wind farm for 92% of the hours of the year was 0 kW, the power guaranteed by 7 and 19 interconnected farms was 50 and 171 kW, giving firm capacities of 0.04 and 0.11, respectively. Furthermore, 19 interconnected wind farms guaranteed 222 kW of power (firm capacity of 0.15) for 87.5% of the year, the same percent of the year that an average coal plant in the United States guarantees power. Last, 19 farms guaranteed 312 kW of power for 79% of the year, 4 times the guaranteed power generated by one farm for 79% of the year.

Capacity factor is the fraction of the rated power (or maximum capacity) actually produced in a year. The capacity factor of the 19-site array was ~0.45, corre-

TABLE 2. Statistics of interconnected wind power from aggregate arrays as a function of the number of sites included. Values obtained with the absolute value of A in Eq. (7) are in parentheses.

No. of sites	1	3	7	11	15	19
No. of combinations analyzed	19	969	50 388	75 582	3876	1
Array-average wind speed (m s^{-1})	8.25 (8.24)	8.12 (8.12)	8.12 (8.11)	8.12 (8.11)	8.12 (8.11)	8.12 (8.11)
Std dev of array-average wind speed (m s^{-1})	4.36 (4.34)	3.47 (3.46)	3.05 (3.05)	2.93 (2.93)	2.87 (2.87)	2.84 (2.84)
Array-average wind power (kW)	680.69 (680.87)	665.39 (665.33)	665.11 (665.01)	665.16 (665.06)	665.14 (665.03)	665.13 (665.02)
Std dev of array-average wind power (kW)	569.85 (569.20)	448.47 (448.31)	394.07 (394.21)	376.01 (378.22)	370.35 (370.59)	365.85 (366.12)
Total wind energy (MWh)	5189 (5191)	15 568 (15 573)	36 326 (36 336)	57 084 (57 099)	77 842 (77 862)	98 600 (98 625)
Mean capacity factor (%)	45.36 (45.39)	45.32 (45.33)	45.30 (45.31)	45.29 (45.31)	45.29 (45.30)	45.29 (45.30)
Firm capacity, base case (at 87.5% and 79% probability)	0.00 0.05	0.04 0.09	0.06 0.12	0.10 0.16	0.11 0.14	0.15 0.21
Reserve requirements (MWh) per site, test case only	835	641	513	452	438	403


TO TRI
TO WESTMESA (ALBUQUERQUE)
TRI
TO RUIDOSO
TO TRI
CABALLO
Alamogordo
N.O.
ALAMOGORDO
HOLLOMAN AIR DEVELOPMENT CENTER
N.O.
El Paso Electric Company
El Paso Electric
TO SPRINGERVILLE,AZ
TRI
TO TRI
(2012)
HATCH (2006)
MAR
EMRLD
LARGO
(2012)
AMRAD
APOLLO
TO ARTESIA
JORNADA (2008)
PST
N.O. (2006)
ALA-S
ORO GRANDE
REDEYE
PICACHO
WHITE SANDS MISSILE RANGE
MIMBRES
AIRPORT TAP
DONA ANA
LAS CRUCES (2006)
ARROYO (2008)
AIRPORT (2012)
COX
TALAVERA (2008)
SALOPEK (2007)
TO LUNA
TO LUNA
Rio Grande
AFTON
ANTHONY
CHAPARRAL
(2010)
NEW MEXICO
TEXAS
NEWMAN
BORDER (2011)
NE1 (2010)
PROLER
MILAGRO
MONTOYA (2011)
SHEARMAN
BERGEN
BIGGS (2008)
CALIENTE (2008)
(2006)
THORN
BUTTERFIELD
GR (2006/2014)
SANTA TERESA
(2007)
(2008)
DELL CITY METERING
COYOTE
RIO GRANDE CO-OP LINE
NEW MEXICO
VERDE (2008)
DIABLO
RIO GRANDE
FT. BLISS
AUSTIN
VISTA
SCOTSDALE
(2006)
E1 (2020)
UNITED STATES
MEXICO
CHIHUAHUA
ASCARATE
SOL
MONTWOOD
LANE (2011)
NS2 (2012)
(2020)
CFE
CFE
WRANGLER
AMERICAS
(2020)
E2 (2020)
SEE DETAIL MAP FOR MORE INFORMATION ON THIS AREA
RIO BOSQUE (2006 / 2014)
HORIZON
SPARKS (2011)
SOCORRO
VALLEY
CLINT (2008)
(2010)
(2020)
El Paso Electric Company
Proposed Projects For 2006 - 2015
(Eastside Loop to 2020)
ADDITIONAL FUTURE CAPITAL IMPROVEMENTS (NOT SHOWN HERE) ARE PLANNED FOR 2010 - 2015.
FELIPE (2014)
FABENS
EPE MAKES NO REPRESENTATION AS TO THE ACCURACY OF THIS MAPPING PRODUCT NOR AS TO ITS FITNESS FOR A PARTICULAR PURPOSE
ALAMO
TEXAS
CHIHUAHUA
LEGEND
🟥 TRANSMISSION - 345KV
🟩 TRANSMISSION - 115KV
🟦 TRANSMISSION - 69KV
- - - TRANSMISSION - OTHER UTILITIES
S GENERATING STATION - STEAM
T GENERATING STATION - TURBINE
○ SUBSTATION - TRANSMISSION
SUBSTATION - DISTRIBUTION
OTHER UTILITIES
CEC COLUMBUS ELECTRIC CO-OP, INC.
PNM PUBLIC SERVICE COMPANY OF NM
SPS SOUTHWESTERN PUBLIC SERVICE CO.
TNMP TEXAS/NEW MEXICO POWER COMPANY
TRI TRI-STATE GENERATION AND TRANSMISSION ASSOCIATION, INC.
MEXICO
TO VAN HORN
SEPT 2006



[redacted]

El Paso Electric Company
Proposed Projects For 2006 - 2015
(Eastside Loop to 2020)

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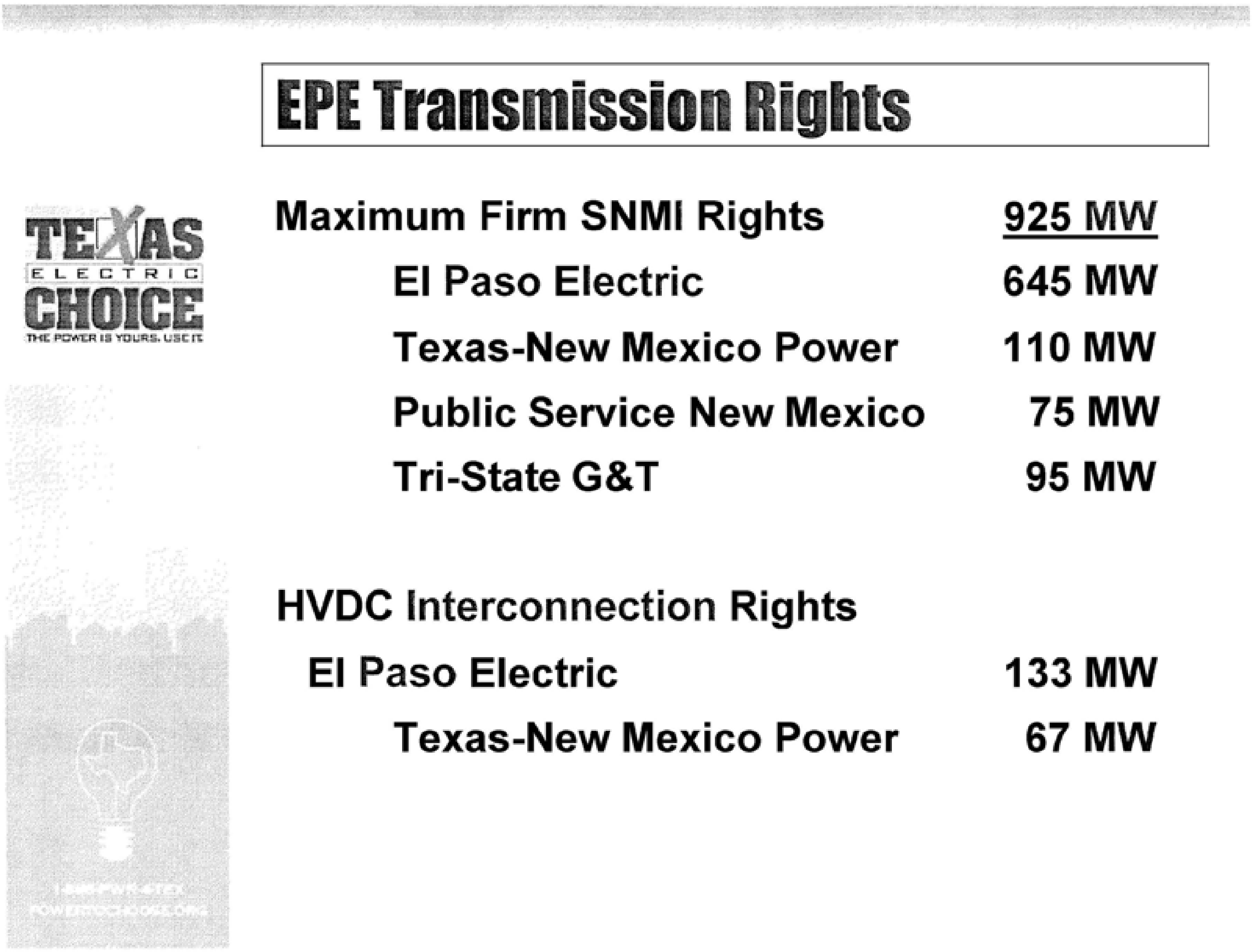

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Supplying Baseload Power and Reducing Transmission Requirements by Interconnecting Wind Farms

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ABSTRACT

Wind is the world's fastest growing electric energy source. Because it is intermittent, though, wind is not used to supply baseload electric power today. Interconnecting wind farms through the transmission grid is a simple and effective way of reducing deliverable wind power swings caused by wind intermittency. As more farms are interconnected in an array, wind speed correlation among sites decreases and so does the probability that all sites experience the same wind regime at the same time. The array consequently behaves more and more similarly to a single farm with steady wind speed and thus steady deliverable wind power. In this study, benefits of interconnecting wind farms were evaluated for 19 sites, located in the midwestern United States, with annual average wind speeds at 80 m above ground, the hub height of modern wind turbines, greater than 6.9 m s^{-1} (class 3 or greater). it was found that an average of 33% and a maximum of 47% of yearly averaged wind power from interconnected farms can be used as reliable, baseload electric power. Equally significant, interconnecting multiple wind farms to a common point and then connecting that point to a far-away city can allow the long-distance portion of transmission capacity to be reduced, for example, by 20% with only a 1.6% loss of energy. Although most parameters, such as intermittency, improved less than linearly as the number of interconnected sites increased, no saturation of the benefits was found. Thus, the benefits of interconnection continue to increase with more and more interconnected sites.

1. Introduction

Stabilizing global climate, reducing air pollution, anti addressing energy shortages will require a change in the current energy infrastructure. One method to address these problems is to initiate a large-scale wind energy program. The world's electric power demand of 1.6–1.8 TW (International Energy Agency 2003; Energy Information Administration 2004) could, for example, theoretically be satisfied with approximately 890 000 currently manufactured 5-MW turbines with 126-m diameter blades placed in yearly averaged wind speeds at hub height of 8.5 m s^{-1} or faster, assuming a 10% loss from energy conversions and transmission (derived from Jacobson and Masters 2001; Masters 2004). This number is only 7–8 times the total number of much smaller turbines currently installed worldwide. The offshore average wind speed at 80 m is 8.6 m s^{-1}, and sufficient winds >6.9 m s^{-1} at 80 m may be available over land and near shores to supply all electric power needs 35 times over and all energy needs 5 times over (Archer and Jacobson 2005).

However, a well known barrier to large-scale implementation of wind power is the intermittency of winds. Over a time frame of a few minutes, it is possible to experience sudden changes in wind speed, such as gusts or lulls. The predictability of wind in the short-term is still low, and, even with elaborate forecasting tools, it is often difficult to beat persistency (Giebel 2003; Ahlstrom et al. 2005). The intermittency of wind is directly transmitted into wind power, which dramatically reduces tire marketing value of wind (Milligan and Porter 2005). On the other hand, because coal combustion can be controlled, coal energy is trot considered intermittent and is often used as "baseload" energy. Nevertheless, because coal plants were shut down for scheduled maintenance 6.5% of the year and unscheduled maintenance or forced outage for another 6% of the year on average in the United States from 2000 to 2004, coal

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energy from a given plant is guaranteed only 87.5% of the year, with a typical range of 79%–92% (North American Electric Reliability Council 2005; Giebel 2000).

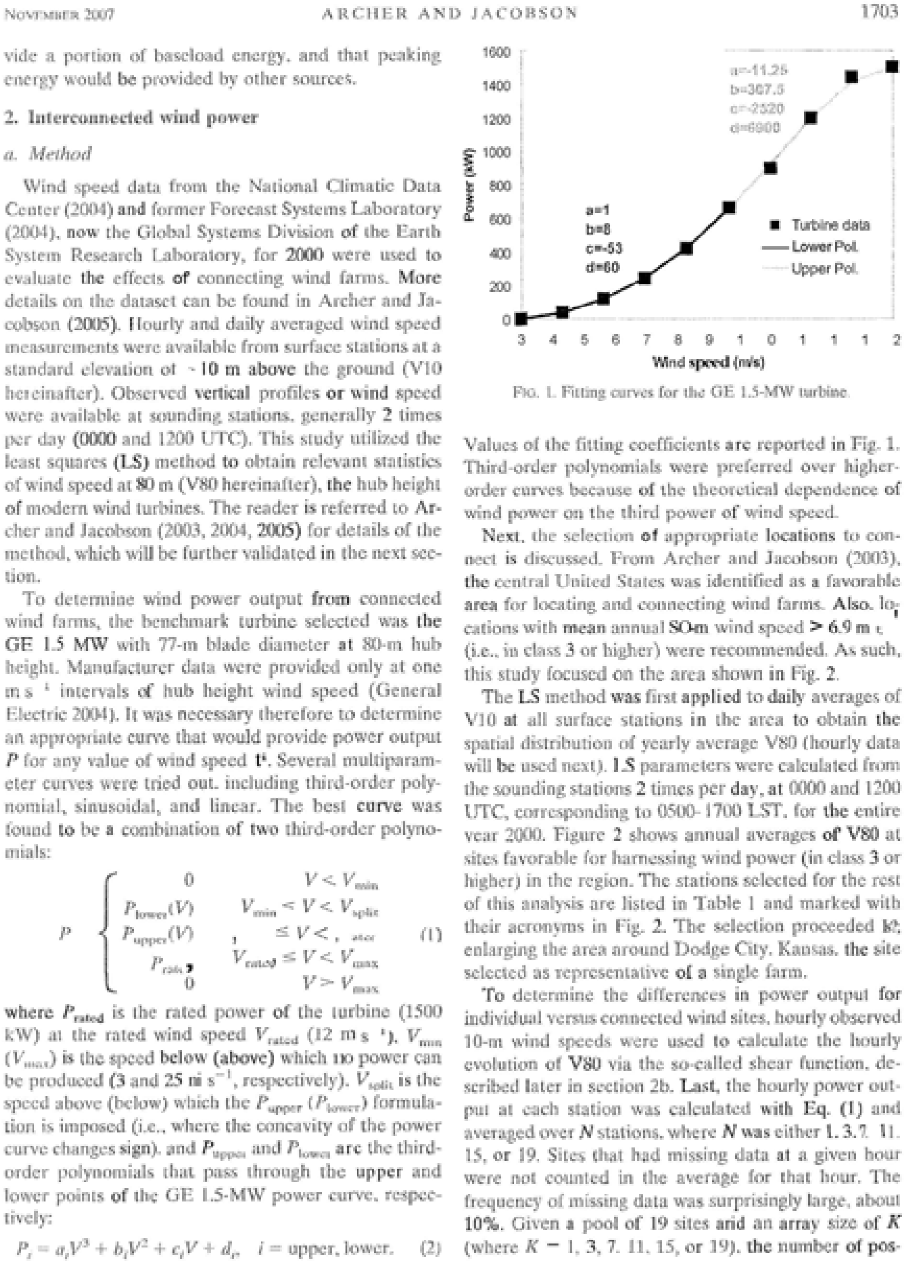
A solution to improve wind power reliability is interconnected wind power. In other words, by linking multiple wind farms together it is possible to improve substantially the overall performance of the interconnected system (i.e., array) when compared with that of any individual wind farm. The idea is that, while wind speed could be calm at a given location, it will be noncalm somewhere else in the aggregate array.

This idea is not new. The first complete study about the effect of geographically dispersed wind power generation was done by Kahn (1979), who analyzed reliability, availability, and effective load carrying capability [ELCC; see Milligan and Porter (2005) for a review of ELCC] of arrays of different sizes in California, varying from 2 to 13 connected sites. He found that most parameters (such as correlation and availability at low wind speeds) improved as the size of the array increased. Archer and Jacobson (2003, 2004) found that the frequency of zero- and low-wind events over a network of eight sites in the central United States was less than 2% at 80-m hub height. Simonsen and Stevens (2004) compared wind power output from individual wind farms with that from an array of 28 sites in the central United States and concluded that variability in energy production was reduced by a factor of 1.75–3.4. They also found that the combined energy output from 50-m hub height, 660-kW turbines in the 28-site array, had a smoother diurnal pattern and a relative maximum in the afternoon: during the peak time of electricity demand. Czisch and Ernst (2001) showed that a network of wind farms over parts of Europe and Northern Africa could supply about 70% of the entire European electricity demand. In Spain, one of the leading countries for wind power production (American Wind Energy Association 2004; Energy Information Administration 2004), the combined output of 81% of the nation's wind farms is remarkably smooth, and sudden wind power swings are eliminated (Red Eléctrica de España real-time data are available online at http://www.ree.es/apps/i-index_dinamico.asp?menu=/ingles/i-cap07/i-menu_sis.htm&principal=/apps_eolica/curvas2ing.asp).

The benefits of interconnected wind power are greater for larger catchment areas. Statistical correlation among stations is the key factor in understanding why. In fact, weather conditions may not vary over small areas, especially over horizontally uniform terrain. This would be reflected in a high correlation among nearby farm pairs. However, as distance between farms or terrain variability increases, the correlation among farms becomes smaller. Kahn (1979) found that the average correlation between site pairs decreased from 0.49 to 0.25 as the number of farms connected was increased from 2 to 13. However, the marginal benefits decreased as well. For example, by doubling the number of sites connected together, the availability at low wind speeds improved by only ~14%. Whether or not a zero correlation can eventually be reached is still an open question. Kahn (1979) suggested that statistical correlation of wind speed never disappears entirely. This effect will be hereinafter referred to as the "saturation" of the benefits, to indicate that, at some point, no incremental benefits are found in increasing the array size.

Kahn (1979) also analyzed the capacity credit for such arrays, defined as the "amount of conventional capacity which can be displaced by wind generation." He found that, for a fixed ELCC, the capacity credit of larger arrays increased less than linearly with the number of sites. This effect can be interpreted as "diminishing returns to implementing state-wide pooling of the wind resource." Note that of the 13 sites analyzed, only 4 were in class 3 or higher at 60 m. As such, it is not surprising that the addition of "slow" sites to the array did not improve its overall performance.

The issue of wind integration in the power system has been receiving more attention recently (Ackermann 2005; DeMeo et al. 2005; Piwko et al. 2005; Zavadil et al. 2005). Most studies assumed a low (10% or less) penetration of wind power (expressed as ratio of nameplate wind generation over peak load) and treated the output of farms as negative load (Piwko et al. 2005; DeMeo et al. 2005). Only a few countries in Europe have high (20% or more) wind penetrations (Eriksen et al. 2005): Denmark (49%), Germany (22%), and Spain (22%). High penetrations of wind power without reductions in system stability can only be achieved with turbines equipped with fault ride-through capability (Eriksen et al. 2005). No study to date has examined the ability of interconnected wind farms to provide guaranteed (or baseload) power. Only a few studies have looked at reducing transmission requirements by interconnecting wind farms. Romanowitz (2005) reported that an additional 100 MW of wind power could be added to the Tehachapi grid in California without increasing the transmission capacity. Matevosyan (2006) showed that, in areas with limited transmission capacity, curtailing (or "spilling") a small percent of the power produced by interconnected wind farms could be effective. This study examines both issues in detail. It does not, however, examine the ability of wind to match peaks in energy demand. It assumes that wind can pro-



vide a portion of baseload energy, and that peaking energy would be provided by other sources.

2. Interconnected wind power

a. Method

Wind speed data from the National Climatic Data Center (2004) and former Forecast Systems Laboratory (2004), now the Global Systems Division of the Earth System Research Laboratory, for 2000 were used to evaluate the effects of connecting wind farms. More details on the dataset can be found in Archer and Jacobson (2005). Hourly and daily averaged wind speed measurements were available from surface stations at a standard elevation of ~10 m above the ground (V10 hereinafter). Observed vertical profiles of wind speed were available at sounding stations, generally 2 times per day (0000 and 1200 UTC). This study utilized the least squares (LS) method to obtain relevant statistics of wind speed at 80 m (V80 hereinafter), the hub height of modern wind turbines. The reader is referred to Archer and Jacobson (2003, 2004, 2005) for details of the method, which will be further validated in the next section.

To determine wind power output from connected wind farms, the benchmark turbine selected was the GE 1.5 MW with 77-m blade diameter at 80-m hub height. Manufacturer data were provided only at one m s^{-1} intervals of hub height wind speed (General Electric 2004). It was necessary therefore to determine an appropriate curve that would provide power output P for any value of wind speed V. Several multiparameter curves were tried out, including third-order polynomial, sinusoidal, and linear. The best curve was found to be a combination of two third-order polynomials:

$$P \begin{cases} 0 & V < V_{\min} \\ P_{\text{lower}}(V) & V_{\min} \le V < V_{\text{split}} \\ P_{\text{upper}}(V) & V_{\text{split}} \le V < V_{\text{rated}} \\ P_{\text{rated}} & V_{\text{rated}} \le V < V_{\max} \\ 0 & V > V_{\max} \end{cases} \tag{1}$$

where P_{rated} is the rated power of the turbine (1500 kW) at the rated wind speed V_{rated} (12 m s^{-1}). $V_{\min}$ ($V_{\max}$) is the speed below (above) which no power can be produced (3 and 25 m s^{-1}, respectively). V_{split} is the speed above (below) which the P_{upper} (P_{lower}) formulation is imposed (i.e., where the concavity of the power curve changes sign), and P_{upper} and P_{lower} are the third-order polynomials that pass through the upper and lower points of the GE 1.5-MW power curve, respectively:

$$P_i = a_iV^3 + b_iV^2 + c_iV + d_i, \quad i = \text{upper, lower}. \tag{2}$$

FIG. 1. Fitting curves for the GE 1.5-MW turbine.

Values of the fitting coefficients are reported in Fig. 1. Third-order polynomials were preferred over higher-order curves because of the theoretical dependence of wind power on the third power of wind speed.

Next, the selection of appropriate locations to connect is discussed. From Archer and Jacobson (2003), the central United States was identified as a favorable area for locating and connecting wind farms. Also, locations with mean annual 80-m wind speed > 6.9 m s^{-1} (i.e., in class 3 or higher) were recommended. As such, this study focused on the area shown in Fig. 2.

The LS method was first applied to daily averages of V10 at all surface stations in the area to obtain the spatial distribution of yearly average V80 (hourly data will be used next). LS parameters were calculated from the sounding stations 2 times per day, at 0000 and 1200 UTC, corresponding to 0500–1700 LST, for the entire year 2000. Figure 2 shows annual averages of V80 at sites favorable for harnessing wind power (in class 3 or higher) in the region. The stations selected for the rest of this analysis are listed in Table 1 and marked with their acronyms in Fig. 2. The selection proceeded by enlarging the area around Dodge City, Kansas, the site selected as representative of a single farm.

To determine the differences in power output for individual versus connected wind sites, hourly observed 10-m wind speeds were used to calculate the hourly evolution of V80 via the so-called shear function, described later in section 2b. Last, the hourly power output at each station was calculated with Eq. (1) and averaged over N stations, where N was either 1, 3, 7, 11, 15, or 19. Sites that had missing data at a given hour were not counted in the average for that hour. The frequency of missing data was surprisingly large, about 10%. Given a pool of 19 sites and an array size of K (where K = 1, 3, 7, 11, 15, or 19), the number of pos-

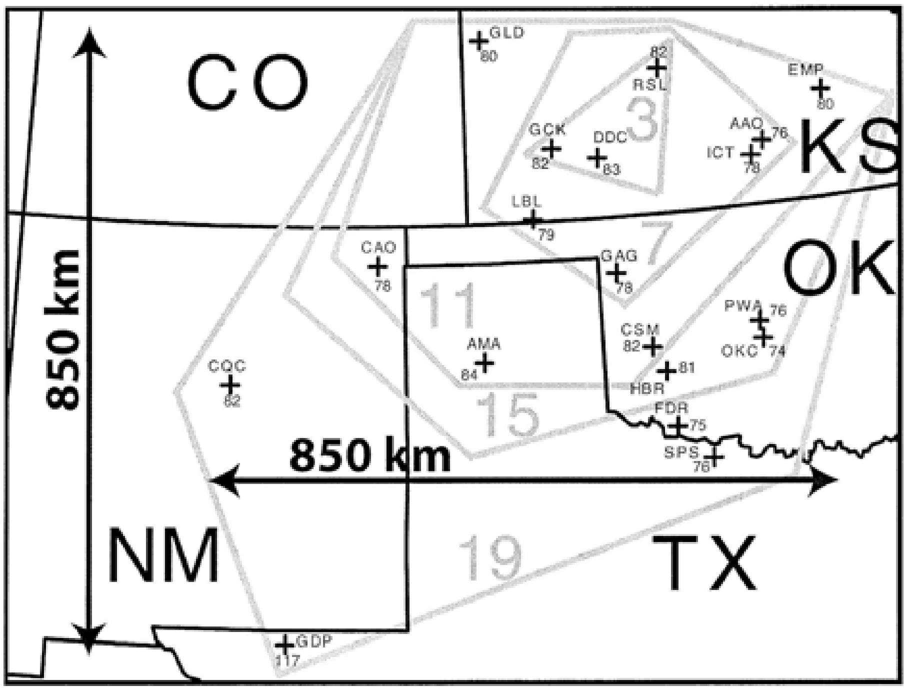


FIG. 2. Locations of the 19 sites used in arrays. Sites included in the 3-, 7-, 11-, 15-, and 19-site array configuration based on geography only are grouped within gray lines; also shown are annual average wind speeds (10^{-1} m s^{-1}) at each site.

sible combinations of sites that can be included is large (Table 2). For example, there are 50 388 possible combinations of seven sires among the 19 of interest. The "base case" for this study is based solely on geographical proximity, and it is described in Table 1. Unless otherwise stated, all possible combinations of sites for each array size are evaluated in the rest of this study.

b. Results

The analysis indicated that the reliability of interconnected wind systems increased with the number of farms. Reliability in this context is defined in terms of a "generation duration curve," also known as a "duration curve" (Nørgård et al. 2004; Holttinen and Hirvonen 2005), which is analogous to the load duration curve used for electricity demand. All hours in a year (i.e., $365 \times 24 - 8760$) are rearranged based on decreasing wind power magnitude, and the corresponding power is plotted as a decreasing curve. The generation curve can also be interpreted as a "reversed" cumulative probability distribution, in which each point on the y axis represents the probability (in terms of number of hours in a year) of wind power production greater or equal to the corresponding y value on the curve. The adjective reversed was used because a traditional cumulative probability distribution is monotonically increasing, and it shows the probability of the variable being lower or equal to the value on the curve.

Figure 3 shows generation duration curves for the i-, 7-, and 19-site base-case arrays. For the figure, all hours in a year, less 2% of randomly selected hours where wind turbines were assumed to be down because of unplanned maintenance, were rearranged based on decreasing wind power magnitude per hour. For simplicity, each site is considered to have a single GE 1500-kW turbine (General Electric 2004), and each curve shows the wind power output per turbine, averaged over all sites in the array. For the seven-site array, for example, each paint shows the total power produced by the array divided by thr number of sites (seven at most) with

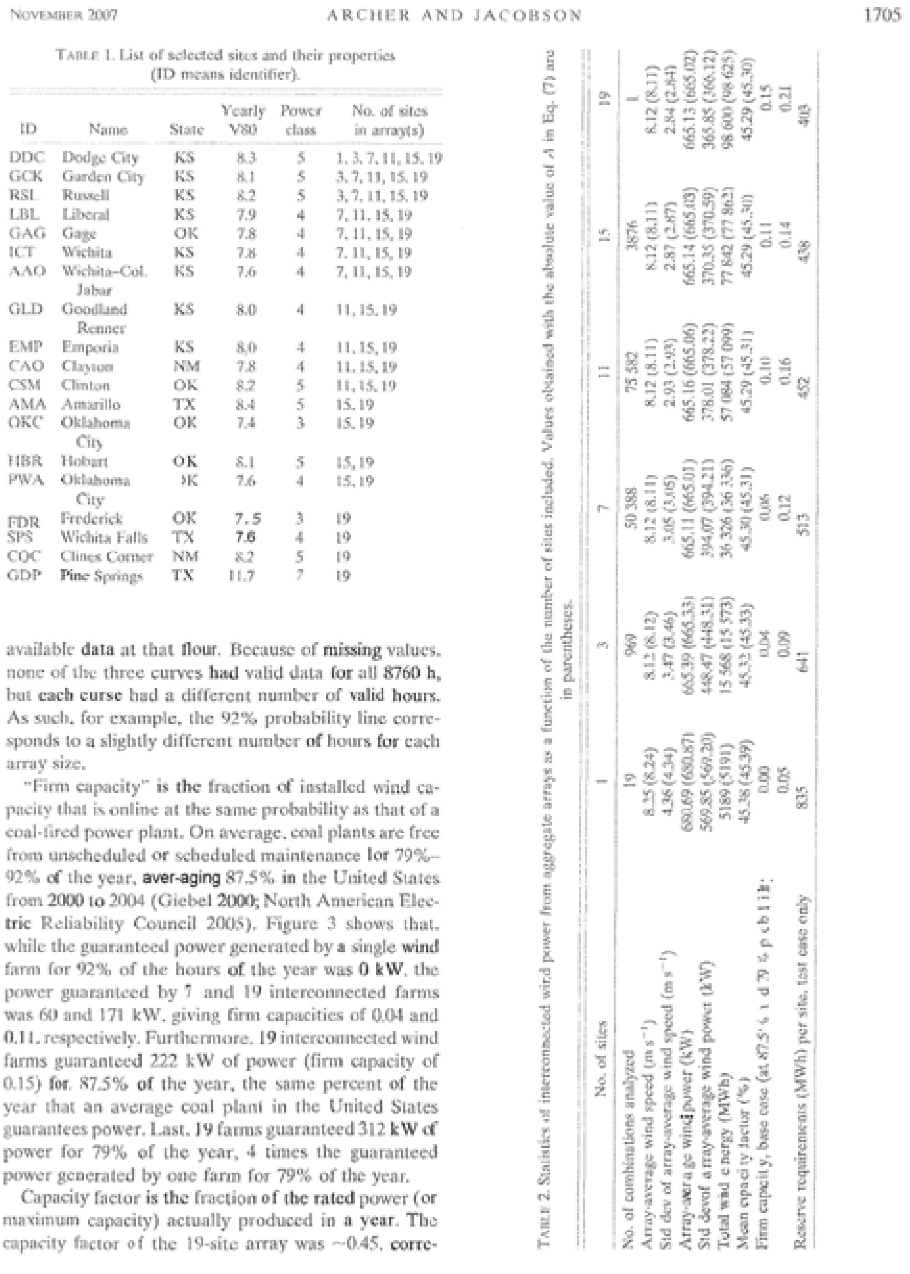


Table 1. List of selected sites and their properties (ID means identifier).

ID	Name	State	Yearly V80	Power class	No. of sites in array(s)
DDC	Dodge City	KS	8.3	5	1, 3, 7, 11, 15, 19
GCK	Garden City	KS	8.1	5	3, 7, 11, 15, 19
RSL	Russell	KS	8.2	5	3, 7, 11, 15, 19
LBL	Liberal	KS	7.9	4	7, 11, 15, 19
GAG	Gage	OK	7.8	4	7, 11, 15, 19
ICT	Wichita	KS	7.8	4	7, 11, 15, 19
AAO	Wichita–Col. Jabar	KS	7.6	4	7, 11, 15, 19
GLD	Goodland Renner	KS	8.0	4	11, 15, 19
EMP	Emporia	KS	8.0	4	11, 15, 19
CAO	Clayton	NM	7.8	4	11, 15, 19
CSM	Clinton	OK	8.2	5	11, 15, 19
AMA	Amarillo	TX	8.4	5	15, 19
OKC	Oklahoma City	OK	7.4	3	15, 19
HBR	Hobart	OK	8.1	5	15, 19
PWA	Oklahoma City	OK	7.6	4	15, 19
FDR	Frederick	OK	7.5	3	19
SPS	Wichita Falls	TX	7.6	4	19
CQC	Clines Corner	NM	8.2	5	19
GDP	Pine Springs	TX	11.7	7	19

available data at that hour. Because of missing values, none of the three curves had valid data for all 8760 h, but each curve had a different number of valid hours. As such, for example, the 92% probability line corresponds to a slightly different number of hours for each array size.

"Firm capacity" is the fraction of installed wind capacity that is online at the same probability as that of a coal-fired power plant. On average, coal plants are free from unscheduled or scheduled maintenance for 79%–92% of the year, aver-aging 87.5% in the United States from 2000 to 2004 (Giebel 2000; North American Electric Reliability Council 2005). Figure 3 shows that, while the guaranteed power generated by a single wind farm for 92% of the hours of the year was 0 kW, the power guaranteed by 7 and 19 interconnected farms was 60 and 171 kW, giving firm capacities of 0.04 and 0.11, respectively. Furthermore, 19 interconnected wind farms guaranteed 222 kW of power (firm capacity of 0.15) for 87.5% of the year, the same percent of the year that an average coal plant in the United States guarantees power. Last, 19 farms guaranteed 312 kW of power for 79% of the year, 4 times the guaranteed power generated by one farm for 79% of the year.

Capacity factor is the fraction of the rated power (or maximum capacity) actually produced in a year. The capacity factor of the 19-site array was ~0.45, corre-

Table 2. Statistics of interconnected wind power from aggregate arrays as a function of the number of sites included. Values obtained with the absolute value of A in Eq. (7) are in parentheses.

No. of sites	1	3	7	11	15	19
No. of combinations analyzed	19	969	50 388	75 582	3876	1
Array-average wind speed (m s^{-1})	8.25 (8.24)	8.12 (8.12)	8.12 (8.11)	8.12 (8.11)	8.12 (8.11)	8.12 (8.11)
Std dev of array-average wind speed (m s^{-1})	4.36 (4.34)	3.47 (3.46)	3.05 (3.05)	2.93 (2.93)	2.87 (2.87)	2.84 (2.84)
Array-average wind power (kW)	680.69 (680.87)	665.39 (665.33)	665.11 (665.01)	665.16 (665.06)	665.14 (665.03)	665.13 (665.02)
Std dev of array-average wind power (kW)	569.85 (569.20)	448.47 (448.31)	394.07 (394.21)	378.01 (378.22)	370.35 (370.59)	365.85 (366.12)
Total wind energy (MWh)	5189 (5191)	15 568 (15 573)	36 326 (36 336)	57 084 (57 099)	77 842 (77 862)	98 600 (98 625)
Mean capacity factor (%)	45.38 (45.39)	45.32 (45.33)	45.30 (45.31)	45.29 (45.31)	45.29 (45.30)	45.29 (45.30)
Firm capacity, base case (at 87.5% and 79% probability)	0.00	0.04	0.06	0.10	0.11	0.15
	0.05	0.09	0.12	0.16	0.14	0.21
Reserve requirements (MWh) per site, test case only	835	641	513	452	438	403

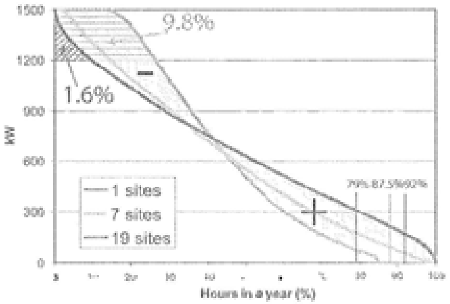


FIG. 3. Generation duration curves for base-case array configurations: single-, 7-, and 19-site arrays. Each point on the x axis represents the percent of hours in a year that wind power production is greater than or equal to the corresponding power (y axis) on the curve. The area below the generation curve represents the total energy (kWh) produced in a year by the array. Shaded areas are described in the text. The thatched areas are the energy lost (9.8% and 1.6%) if the size of transmission lines is reduced from 1500 to 1200 kW for the 1- and 19-site arrays, respectively.

sponding to a yearly power of ~670 kW (Table 2). The resulting ratio of the guaranteed power produced at 79% reliability to the yearly power produced by the 19-site array was 312 kW/670 kW or ~47%. Thus, the firm power produced for 79% of the year by a 19-site array was almost half of the actual power produced in the year or 31% of the maximum possible power produced. At the 12.5% outage rate for coal, the guaranteed power produced was 222 kW/670 kW or ~33% of the yearly power produced.

Although the 1-site array had more hours of power production at the rated power than did an average of the 19-site array (149 vs 9), the 19-site array had fewer hours with no power (5 vs 170) and more overall hours with low power production than did the 1-site array (Fig. 3). Similar findings were shown by Holttinen and Hirvonen (2005) for a single turbine, an array covering western Denmark, and a hypothetical array covering four northern countries in Europe. The area below the generation curve represents the total energy (kWh) produced in a year by the array. For ~38% of the hours, less energy was produced, averaged over 19 farms, than for an individual farm (deficit denoted by the " mark). However, this lower average production was made up for by higher average production for the 19 sites over the remaining 62% of the hours (surplus denoted by the " " mark).

Given an array of size K, there is a large number of possible combinations of K sites among 19 (Table 2). All possible combinations were analyzed in this study.

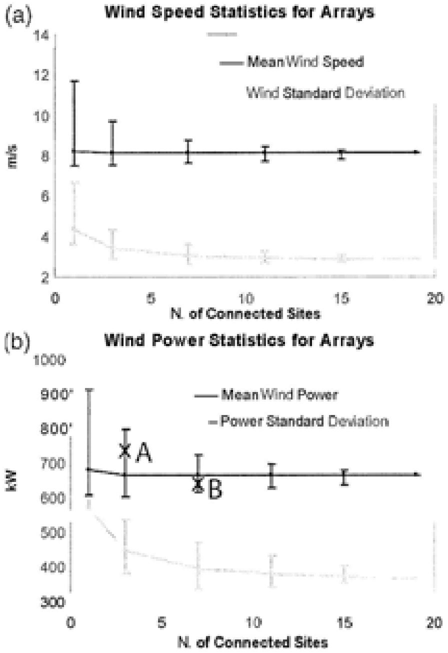


FIG. 4. (a) Wind speed and (b) wind power statistics for interconnected arrays as a function of number of connected sites. The bars indicate the range of values obtained from all possible combinations of the given number of connected sites.

To facilitate the comparison, however, only the average of all combinations for each array size and for each parameter are shown in Table 2. For example, the total energy produced in a year by all possible seven-site arrays varied between 32 529 (worst combination) and 39 478 MWh (best combination); the average from all 50 388 combinations was 36 326 MWh, the value shown in Table 2. Similarly, the figures show the averages of all combinations as a function of the number of interconnected sites, and the range of values from all combinations is shown by the bars.

All parameters that depended linearly on the sites values, such as array-average wind speed, power, total energy, and capacity factor, were unchanged whether or not the sites were interconnected, its expected (Table 2). Nonlinear parameters, such as wind speed standard deviation, firm capacity, and reserve requirements, showed large improvements. For example, the standard deviations of array-average wind speed and power monotonically decreased (Table 2: Fig. 4). Also, the

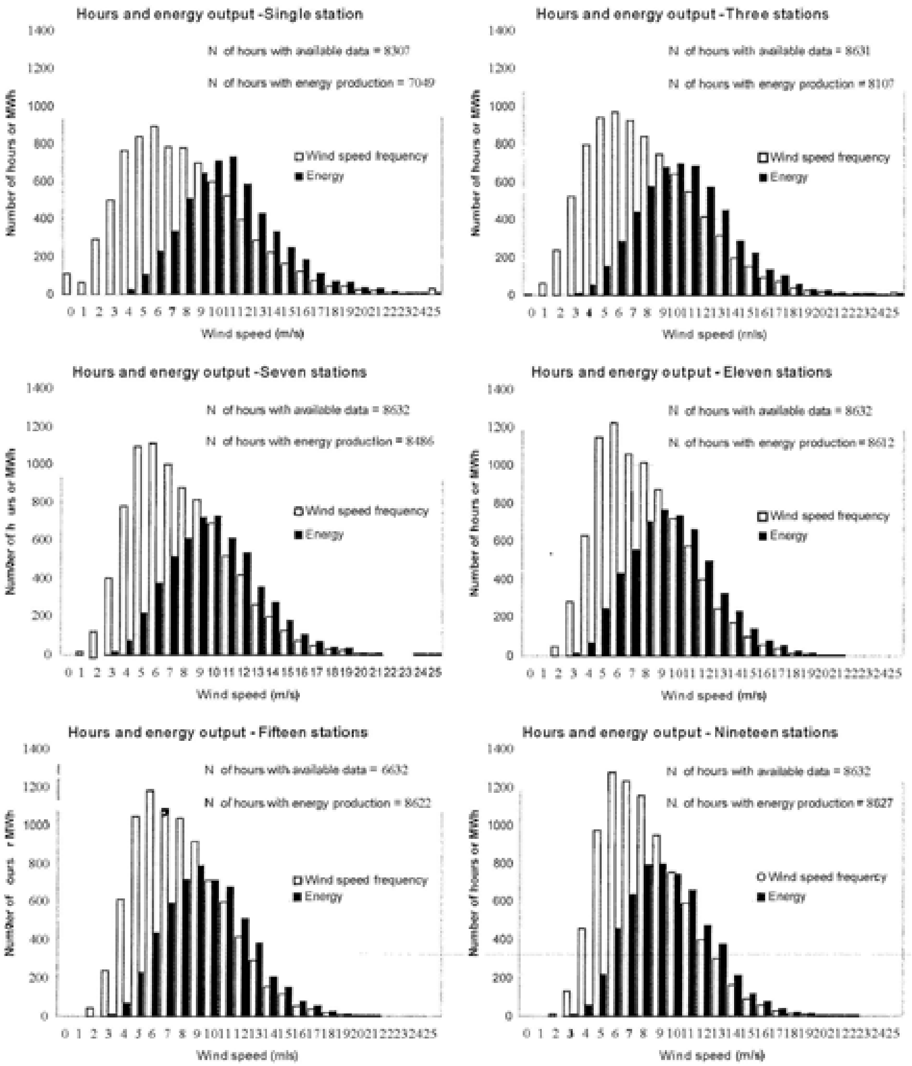


FIG. 5. Number of hours and energy output (kWh) at given wind speeds ($m\ s^{-1}$) for all hours of 2000 averaged over (a) 1, (b) 3, (c) 7, (d) 11, (e) 15, and (f) 19 stations.

frequency distribution of wind speed shifted to the right and became more symmetric as the number of stations included in the network increased (Fig. 5). This is consistent with previous findings by Archer and Jacobson (2003) and indicates that the array wind speed distribution is closer to Gaussian than it is to Rayleigh. As such, the more sites that are interconnected, the more the array resembles a single farm with steady winds.

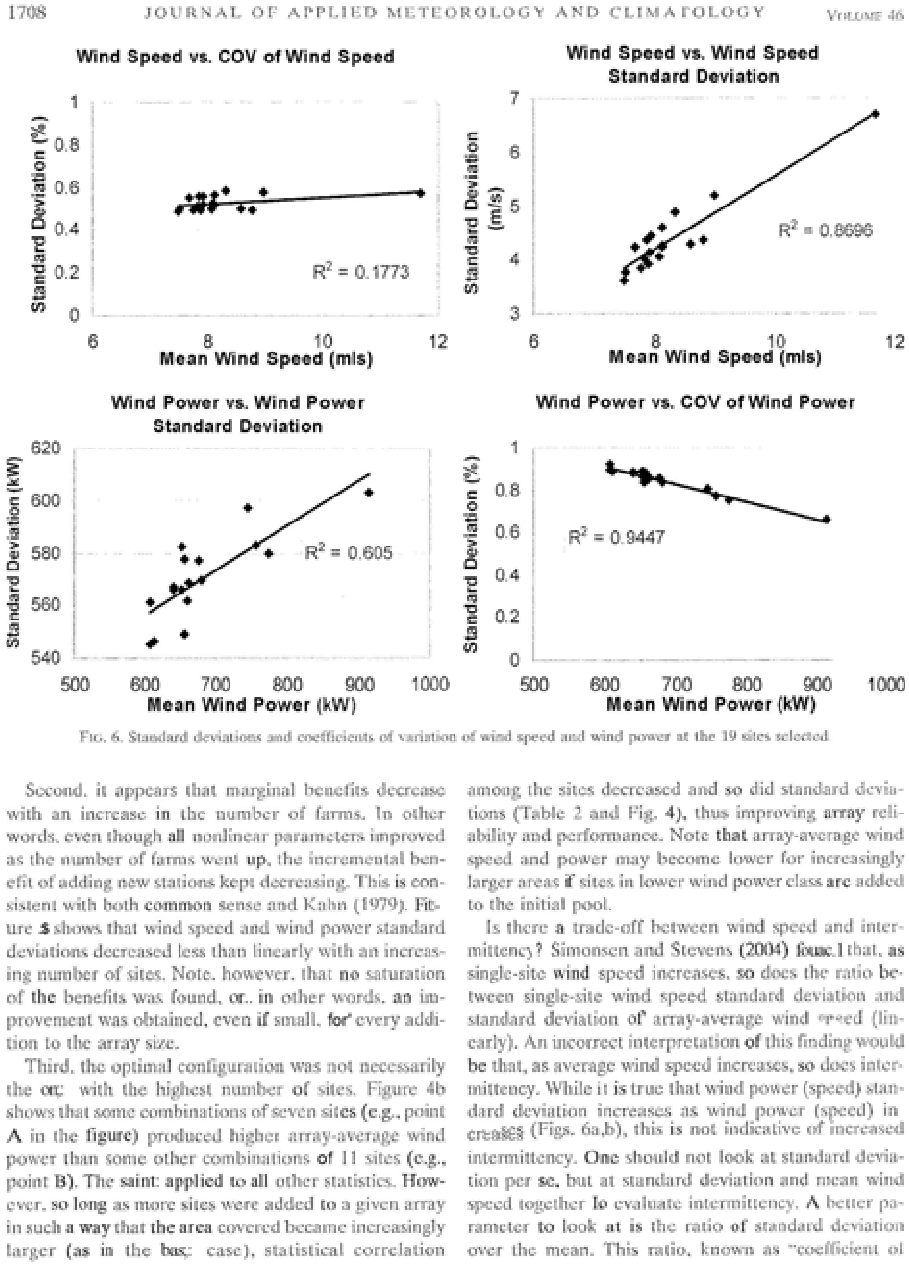
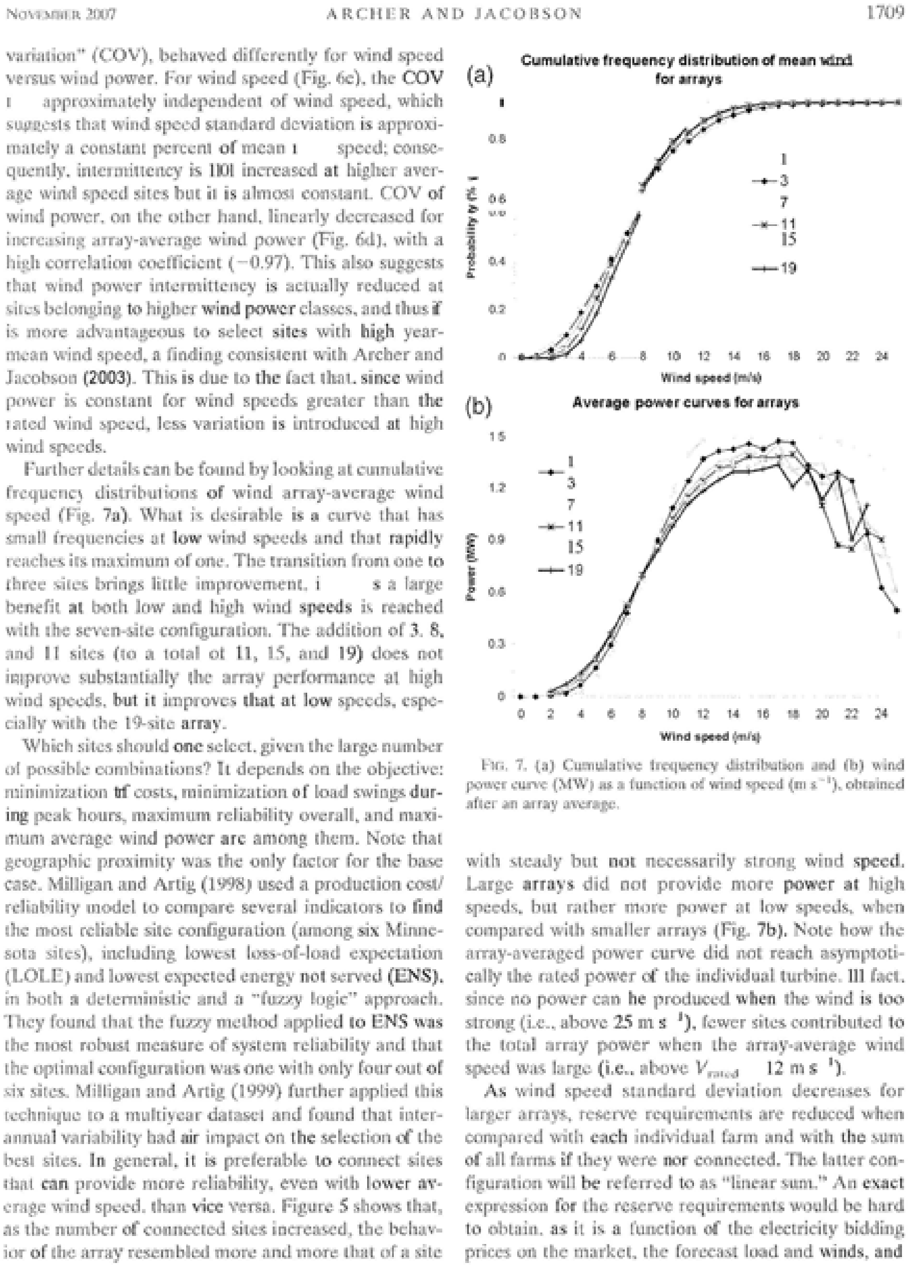


FIG. 6. Standard deviations and coefficients of variation of wind speed and wind power at the 19 sites selected.

Second, it appears that marginal benefits decrease with an increase in the number of farms. In other words, even though all nonlinear parameters improved as the number of farms went up, the incremental benefit of adding new stations kept decreasing. This is consistent with both common sense and Kahn (1979). Figure 5 shows that wind speed and wind power standard deviations decreased less than linearly with an increasing number of sites. Note, however, that no saturation of the benefits was found, or, in other words, an improvement was obtained, even if small, for every addition to the array size.

Third, the optimal configuration was not necessarily the one with the highest number of sites. Figure 4b shows that some combinations of seven sites (e.g., point A in the figure) produced higher array-average wind power than some other combinations of 11 sites (e.g., point B). The same applied to all other statistics. However, so long as more sites were added to a given array in such a way that the area covered became increasingly larger (as in the base case), statistical correlation among the sites decreased and so did standard deviations (Table 2 and Fig. 4), thus improving array reliability and performance. Note that array-average wind speed and power may become lower for increasingly larger areas if sites in lower wind power class are added to the initial pool.

Is there a trade-off between wind speed and intermittency? Simonsen and Stevens (2004) found that, as single-site wind speed increases, so does the ratio between single-site wind speed standard deviation and standard deviation of array-average wind speed (linearly). An incorrect interpretation of this finding would be that, as average wind speed increases, so does intermittency. While it is true that wind power (speed) standard deviation increases as wind power (speed) increases (Figs. 6a,b), this is not indicative of increased intermittency. One should not look at standard deviation per se, but at standard deviation and mean wind speed together to evaluate intermittency. A better parameter to look at is the ratio of standard deviation over the mean. This ratio, known as "coefficient of



variation" (COV), behaved differently for wind speed versus wind power. For wind speed (Fig. 6c), the COV ı approximately independent of wind speed, which suggests that wind speed standard deviation is approximately a constant percent of mean ı speed; consequently, intermittency is not increased at higher average wind speed sites but it is almost constant. COV of wind power, on the other hand, linearly decreased for increasing array-average wind power (Fig. 6d), with a high correlation coefficient (−0.97). This also suggests that wind power intermittency is actually reduced at sites belonging to higher wind power classes, and thus if is more advantageous to select sites with high year-mean wind speed, a finding consistent with Archer and Jacobson (2003). This is due to the fact that, since wind power is constant for wind speeds greater than the rated wind speed, less variation is introduced at high wind speeds.

Further details can be found by looking at cumulative frequency distributions of wind array-average wind speed (Fig. 7a). What is desirable is a curve that has small frequencies at low wind speeds and that rapidly reaches its maximum of one. The transition from one to three sites brings little improvement, i s a large benefit at both low and high wind speeds is reached with the seven-site configuration. The addition of 3, 8, and 11 sites (to a total of 11, 15, and 19) does not improve substantially the array performance at high wind speeds, but it improves that at low speeds, especially with the 19-site array.

Which sites should one select, given the large number of possible combinations? It depends on the objective: minimization trf costs, minimization of load swings during peak hours, maximum reliability overall, and maximum average wind power are among them. Note that geographic proximity was the only factor for the base case. Milligan and Artig (1998) used a production cost/reliability model to compare several indicators to find the most reliable site configuration (among six Minnesota sites), including lowest loss-of-load expectation (LOLE) and lowest expected energy not served (ENS), in both a deterministic and a "fuzzy logic" approach. They found that the fuzzy method applied to ENS was the most robust measure of system reliability and that the optimal configuration was one with only four out of six sites. Milligan and Artig (1999) further applied this technique to a multiyear dataset and found that interannual variability had air impact on the selection of the best sites. In general, it is preferable to connect sites that can provide more reliability, even with lower average wind speed, than vice versa. Figure 5 shows that, as the number of connected sites increased, the behavior of the array resembled more and more that of a site with steady but not necessarily strong wind speed. Large arrays did not provide more power at high speeds, but rather more power at low speeds, when compared with smaller arrays (Fig. 7b). Note how the array-averaged power curve did not reach asymptotically the rated power of the individual turbine. Ill fact, since no power can he produced when the wind is too strong (i.e., above 25 m s^{1}), fewer sites contributed to the total array power when the array-average wind speed was large (i.e., above V_{rated} 12 m s^{1}).

FIG. 7. (a) Cumulative frequency distribution and (b) wind power curve (MW) as a function of wind speed (m s^{-1}), obtained after an array average.

As wind speed standard deviation decreases for larger arrays, reserve requirements are reduced when compared with each individual farm and with the sum of all farms if they were nor connected. The latter configuration will be referred to as "linear sum." An exact expression for the reserve requirements would be hard to obtain, as it is a function of the electricity bidding prices on the market, the forecast load and winds, and

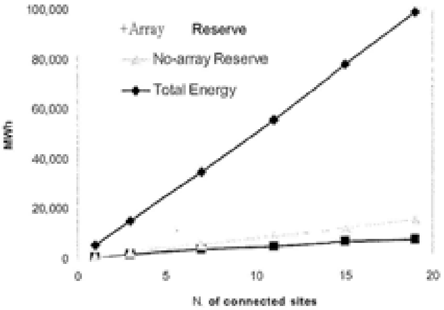


FIG. 8. Reserve requirements in a year (MWh) for the base-array and for the no-array cases (sites if they were not interconnected). Total energy (MWh) produced by the array in a year is also shown.

the exact type of backup system. A simple assumption is the persistency model, that is, at each hour h, the base array commits to producing the same power supplied the previous hour $h - 1$. Other energy sources provide peaking capacity during the year. The advantage of its relatively simple formulation is that reserve requirements of interconnected arrays can be calculated easily.

Results are summarized in Fig. 8. For the single-site configuration only, reserve requirements coincided for the array and the linear-sum cases (by definition). As more sites were interconnected, the array had substantially lower reserve requirements than the linear sum. For example, for the three-site configuration, average reserve energy per site decreased from 2103 to 1713 MWh a year (i.e., 19% reduction) when compared with the single-site case. The greatest benefit was for the largest array, with an ~60% decrease in reserve requirements when compared with the linear sum of 19 sites (Table 2) and an ~47% decrease when compared with the single-site case. As array size increased, reserve requirements represented a decreasing fraction of the total energy produced (Fig. 8). For the three-site configuration, 5138 MWh were needed as reserve in a year, corresponding to ~33% of the total energy production (15 438 MWh per year); for the 11-site configuration, this fraction was slightly lower than 25% and for the 19-site array it was ~21%.

A final benefit of interconnecting wind farms is that it can allow long-distance transmission from a common point, where several farms are connected, to a high-load area to be reduced with little loss of transmitted power. Suppose we want to bring power from N independent farms (each with a maximum capacity of, say, 1500 kW), from the Midwest to California. Each farm would need a short transmission line of 1500 kW brought to a common point in the Midwest. Between the common point and California, the size of the transmission line would normally need to be $N \times 1500$ kW. However, because geographically disperse farms cause slow winds in some locations to cancel fast winds in others, the long-distance transmission line could be reduced by 20% (to $N \times 1200$ kW) with only a small loss (2% with $N = 19$) in overall delivered power (Fig. 3). With only one farm, a 20% reduction in long-distance transmission would decrease delivered power by 9.8%. Thus, the more wind farms connected to the common point in the Midwest, the greater the reduction in long-distance transmission capacity possible with little loss in delivered power. Because of the high cost of long-distance transmission, a 20% reduction in transmission capacity with little delivered power loss would reduce the cost of wind energy.

3. Validation

The LS method was evaluated against observed data from the Kennedy Space Center (KSC) tower network (Fig. 9), described in detail in Archer and Jacobson (2005). The wind speed data used so far were retrieved at a reference height $H^{\mathrm{REF}} = 10$ m and were extrapolated to a hub height $H^{\mathrm{HUB}} = 80$ m, thus the notation V10 and V80 for the reference and the hub height wind speeds. However, the LS method can be applied to any paired reference and hub heights. Furthermore, the KSC data were retrieved at variable heights (Table 3). Therefore, the notation V^{REF} and V^{HUB} will be used in the rest of this section.

The validation will focus on two aspects of the LS method. The first one is the potential error introduced when daily averages of V^{REF} are used in combination with 2-times-per-day sounding profiles, as opposed to more frequent and simultaneous surface and sounding profiles. This step is relevant for optimal wind farm siting when only daily averages of V^{REF} are available. In this rather common case, it is important to know whether (and how much) LS results could be biased. The second aspect is the formulation of the hourly evolution of V^{HUB} given observed hourly V^{REF}. Both aspects will be examined in the next two sections.

a. Error in using daily averages

As discussed in Archer and Jacobson (2005), the LS method should be applied with simultaneous sounding and surface data. In other words, for each given hour, the LS parameters should be determined from the soundings and then applied to the value of V^{REF} at the

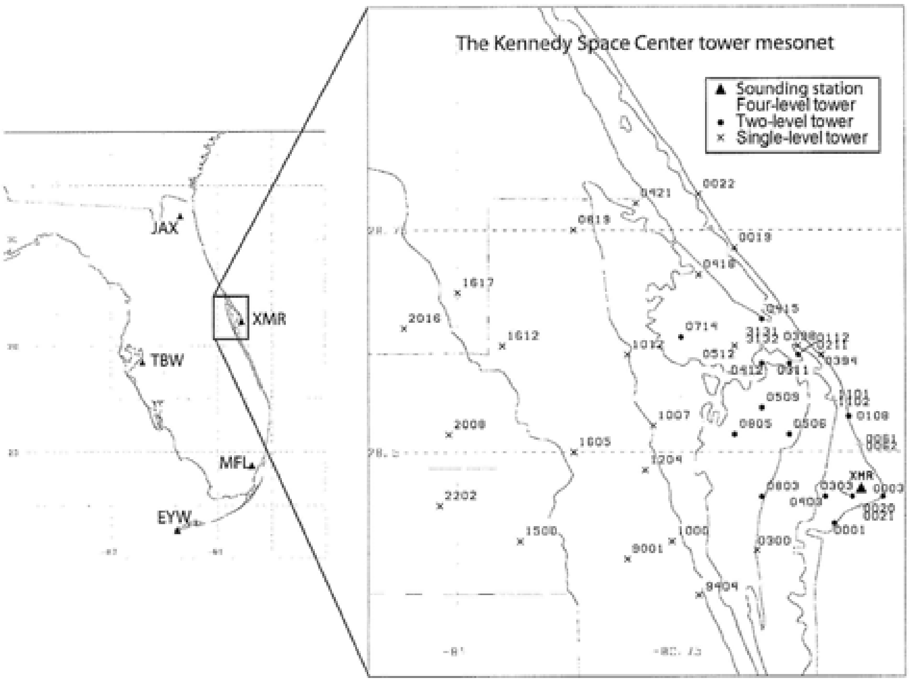


FIG. 9. Location of sounding stations and towers near the KSC.

surface station, valid at the same hour as the soundings. The daily average of V^{HUB} at the surface station should then be calculated from hourly values as follows:

$$\overline{V_H^{\mathrm{HUB}}} = \frac{1}{24} \times \left\{ \sum_{h=1}^{24} \frac{1}{\sum_{k=1}^{K} \frac{1}{R_k^2}} \times \left[\sum_{k=1}^{K} \frac{1}{R_k^2} L_{h,k}(V_h^{\mathrm{REF}}) \right] \right\}, \tag{3}$$

where $L_{h,k}$ is the LS function [as in Archer and Jacobson (2005)] at sounding station k for hour h, V_h^{REF} is the hourly average of V^{REF} at the surface station, and V_H^{HUB} is the daily average of V^{HUB} at the surface station as determined from hourly values.

However, neither sounding nor surface data are available on an hourly basis for all locations. Daily averages of wind speeds at the surface stations and 2-times-per-day sounding profiles are often the only available data. For the typical case of two sounding profiles (at 0000 and 1200 UTC), the estimate of the daily average wind speed at hub height based on daily average reference height wind speed $\overline{V_D^{\mathrm{REF}}}$ was therefore

$$\overline{V_D^{\mathrm{HUB}}} = \frac{1}{\sum_{k=1}^{K} \frac{1}{R_k^2}} \times \left[\sum_{k=1}^{K} \frac{1}{R_k^2} \times \frac{L_{00,k}(\overline{V_D^{\mathrm{REF}}}) + L_{12,k}(\overline{V_D^{\mathrm{REF}}})}{2} \right], \tag{4}$$

where $L_{00,k}$ and $L_{12,k}$ are calculated at 0000 and 1200 UTC, respectively, from each sounding station k.

Archer and Jacobson (2005) used data from the KSC network to conclude that Eq. (4) was an acceptable (and conservative) approximation for Eq. (3). In this study, the same dataset is used to evaluate further the extent of the error introduced in Eq. (4) and the dependence of such error on the time zone of the stations of interest.

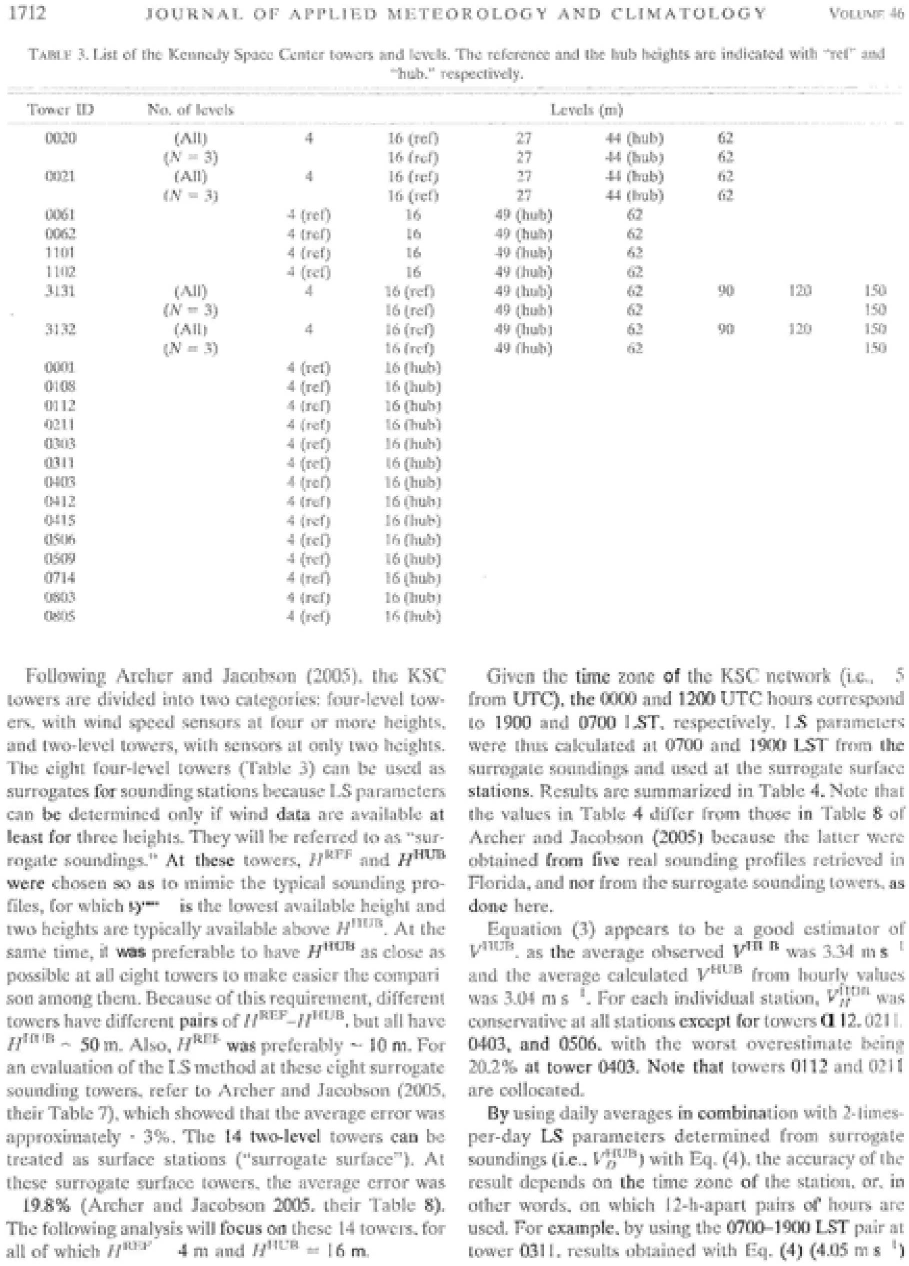


TABLE 3. List of the Kennedy Space Center towers and levels. The reference and the hub heights are indicated with "ref" and "hub," respectively.

Tower ID	No. of levels	Levels (m)						
0020	(All)	4	16 (ref)	27	44 (hub)	62		
	($N = 3$)		16 (ref)	27	44 (hub)	62		
0021	(All)	4	16 (ref)	27	44 (hub)	62		
	($N = 3$)		16 (ref)	27	44 (hub)	62		
0061		4 (ref)	16	49 (hub)	62			
0062		4 (ref)	16	49 (hub)	62			
1101		4 (ref)	16	49 (hub)	62			
1102		4 (ref)	16	49 (hub)	62			
3131	(All)	4	16 (ref)	49 (hub)	62	90	120	150
	($N = 3$)		16 (ref)	49 (hub)	62			150
3132	(All)	4	16 (ref)	49 (hub)	62	90	120	150
	($N = 3$)		16 (ref)	49 (hub)	62			150
0001		4 (ref)	16 (hub)					
0108		4 (ref)	16 (hub)					
0112		4 (ref)	16 (hub)					
0211		4 (ref)	16 (hub)					
0303		4 (ref)	16 (hub)					
0311		4 (ref)	16 (hub)					
0403		4 (ref)	16 (hub)					
0412		4 (ref)	16 (hub)					
0415		4 (ref)	16 (hub)					
0506		4 (ref)	16 (hub)					
0509		4 (ref)	16 (hub)					
0714		4 (ref)	16 (hub)					
0803		4 (ref)	16 (hub)					
0805		4 (ref)	16 (hub)					

Following Archer and Jacobson (2005), the KSC towers are divided into two categories: four-level towers, with wind speed sensors at four or more heights, and two-level towers, with sensors at only two heights. The eight four-level towers (Table 3) can be used as surrogates for sounding stations because LS parameters can be determined only if wind data are available at least for three heights. They will be referred to as "surrogate soundings." At these towers, H^{REF} and H^{HUB} were chosen so as to mimic the typical sounding profiles, for which H^{REF} is the lowest available height and two heights are typically available above H^{HUB}. At the same time, it was preferable to have H^{HUB} as close as possible at all eight towers to make easier the comparison among them. Because of this requirement, different towers have different pairs of H^{REF}–H^{HUB}, but all have $H^{\mathrm{HUB}} \sim 50$ m. Also, H^{REF} was preferably ~ 10 m. For an evaluation of the LS method at these eight surrogate sounding towers, refer to Archer and Jacobson (2005, their Table 7), which showed that the average error was approximately ~3%. The 14 two-level towers can be treated as surface stations ("surrogate surface"). At these surrogate surface towers, the average error was 19.8% (Archer and Jacobson 2005, their Table 8). The following analysis will focus on these 14 towers, for all of which $H^{\mathrm{REF}} = 4$ m and $H^{\mathrm{HUB}} = 16$ m.

Given the time zone of the KSC network (i.e., −5 from UTC), the 0000 and 1200 UTC hours correspond to 1900 and 0700 LST, respectively. LS parameters were thus calculated at 0700 and 1900 LST from the surrogate soundings and used at the surrogate surface stations. Results are summarized in Table 4. Note that the values in Table 4 differ from those in Table 8 of Archer and Jacobson (2005) because the latter were obtained from five real sounding profiles retrieved in Florida, and not from the surrogate sounding towers, as done here.

Equation (3) appears to be a good estimator of V^{HUB}, as the average observed V^{HUB} was 3.34 m s^{-1} and the average calculated V^{HUB} from hourly values was 3.04 m s^{-1}. For each individual station, V_H^{HUB} was conservative at all stations except for towers 0112, 0211, 0403, and 0506, with the worst overestimate being 20.2% at tower 0403. Note that towers 0112 and 0211 are collocated.

By using daily averages in combination with 2-times-per-day LS parameters determined from surrogate soundings (i.e., V_D^{HUB}) with Eq. (4), the accuracy of the result depends on the time zone of the station, or, in other words, on which 12-h-apart pairs of hours are used. For example, by using the 0700–1900 LST pair at tower 0311, results obtained with Eq. (4) (4.05 m s^{-1})

TABLE 4. Values of observed and calculated LS wind speeds at KSC two-level towers. Calculated values were obtained by either simultaneous V_{ref} and sounding parameters (hourly) or by using the daily average of V_{ref} with 12-h-apart sounding parameters. In boldface are the average observed wind speeds and those calculated from hourly profiles; also in boldface are the average wind speeds calculated from 2-times-per-day profiles for the time zones of the United States.

			Sounding times (LST)											
Tower	Obs	Hourly	0000–1200	0100–1300	0200–1400	0300–1500	0400–1600	0500–1700	0600–1800	0700–1900	0800–2000	0900–2100	1000–2200	1100–2300
0001	3.70	2.24	2.23	2.24	2.26	2.29	2.32	2.39	2.44	2.40	2.29	2.24	2.22	2.22
0108	3.51	2.60	2.50	2.49	2.52	2.54	2.56	2.61	2.67	2.64	2.57	2.54	2.51	2.51
0112	3.65	3.69	3.64	3.63	3.66	3.69	3.71	3.82	3.99	3.91	3.79	3.73	3.66	3.68
0211	4.24	4.34	4.24	4.23	4.35	4.43	4.48	4.54	4.66	4.65	4.42	4.17	4.15	4.23
0303	2.97	2.31	2.33	2.34	2.36	2.41	2.44	2.51	2.59	2.54	2.43	2.36	2.32	2.33
0311	3.96	3.86	3.79	3.80	3.80	3.84	3.88	3.97	4.12	4.05	3.92	3.87	3.79	3.82
0403	3.68	4.42	4.32	4.34	4.38	4.45	4.49	4.62	4.73	4.63	4.46	4.35	4.30	4.30
0412	3.20	2.72	2.76	2.76	2.76	2.80	2.83	2.91	3.03	2.94	2.85	2.77	2.75	2.77
0415	2.98	2.60	2.64	2.63	2.63	2.66	2.68	2.77	2.91	2.85	2.74	2.67	2.63	2.64
0506	3.34	3.72	3.62	3.62	3.64	3.54	3.67	3.70	3.72	3.75	3.72	3.70	3.62	3.64
0509	3.08	2.86	2.84	2.84	2.82	2.84	2.86	2.91	3.01	2.96	2.93	2.87	2.84	2.84
0714	3.26	2.40	2.41	2.40	2.38	2.42	2.44	2.51	2.60	2.53	2.47	2.44	2.39	2.41
0803	2.43	2.29	2.27	2.27	2.30	2.33	2.35	2.42	2.48	2.45	2.35	2.38	2.26	2.27
0805	2.72	2.51	51	2.50	2.52	2.53	2.55	2.59	2.66	2.60	2.54	2.54	2.50	2.51
Avg	**3.34**	**.04**	3.01	3.01	3.08	3.16	3.09	**3.16**	**3.26**	**3.21**	3.11	3.04	3.00	3.01

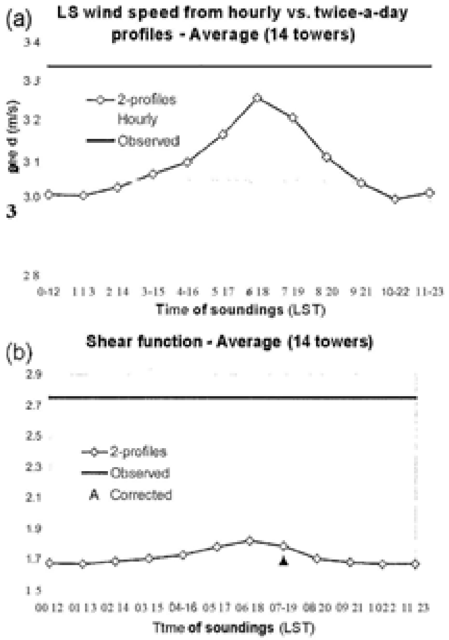
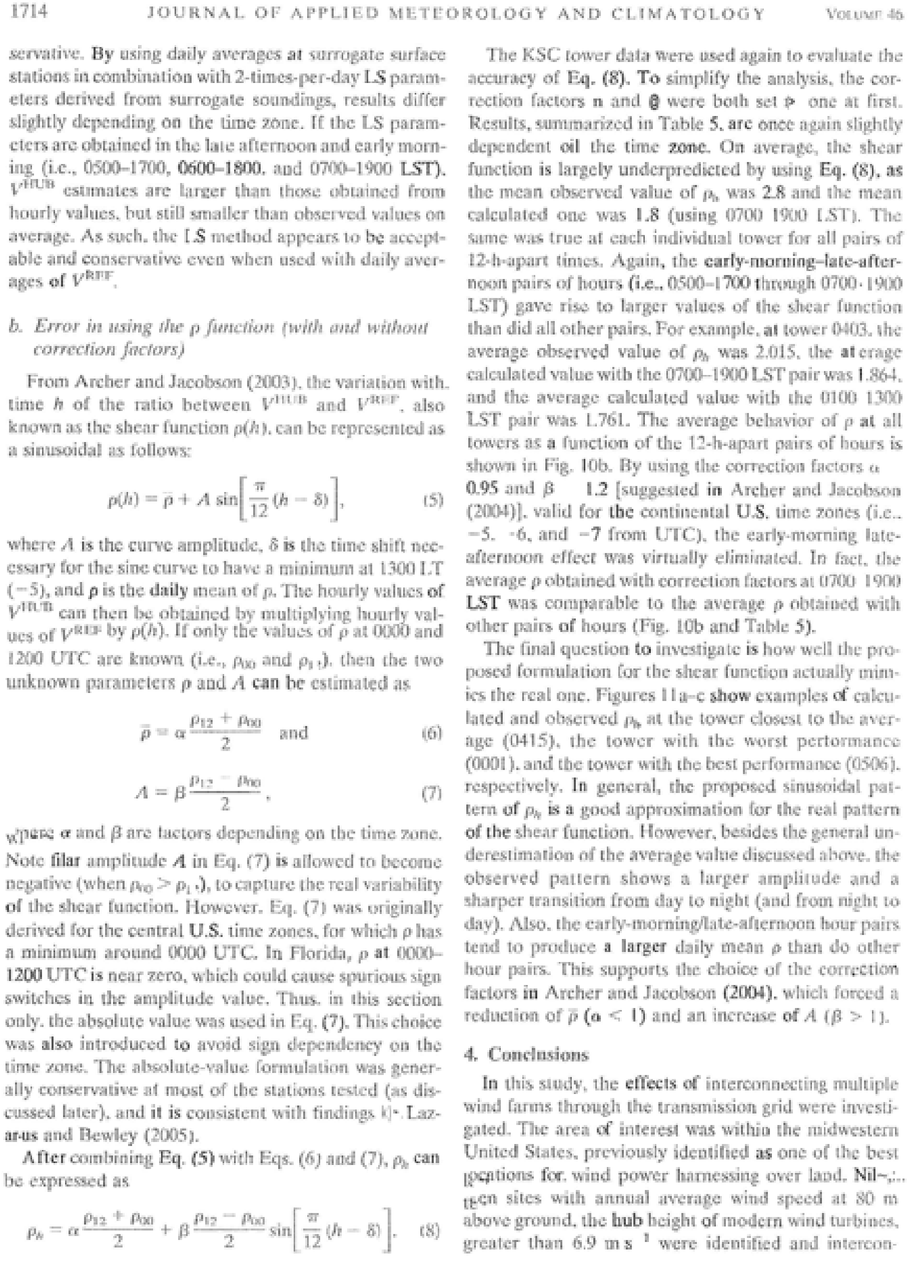


FIG. 10. (a) Observed winds, calculated from hourly V_{ref}, and calculated from daily averages of V_{ref} with 2-times-per-day soundings values of LS wind speed, averaged over all two-level towers of the KSC network. (b) Values of the shear function ρ averaged over all hours and all KSC two-level towers obtained with all 12-h-apart pairs of sounding times. The value obtained with correction factors at 0700–1900 LST (corresponding to 0000 and 1200 UTC in Florida) is shown with a rhomboidal mark. Reproduced from Archer and Jacobson (2006).

are slightly larger than those obtained with Eq. (3) (3.86 m s^{-1}). The same applies to the six 12-h-apart pairs between 0300–1500 and 0800–2000 LST. For all other pairs, a small underestimate is instead introduced by using daily averages. Figure 10a shows that, on average, pairs between 0500–1700 and 0700–1900 LST, that is, the three easternmost time zones of the United States, generate estimates of V^{HUB} that are larger than those generated with simultaneous sounding and surface hourly values. However, such estimates are lower than observations by 2.4% on average, with 35.3% (tower 0001 at 0500–1700 LST) and +28.7% (tower 0403 at 0600–1800 LST) as extremes.

In summary, the application of the LS method to simultaneous surrogate sounding and surrogate surface hourly values appears to be generally accurate and con-



servative. By using daily averages at surrogate surface stations in combination with 2-times-per-day *LS* parameters derived from surrogate soundings, results differ slightly depending on the time zone. If the *LS* parameters are obtained in the late afternoon and early morning (i.e., 0500–1700, 0600–1800, and 0700–1900 LST), V^{HUB} estimates are larger than those obtained from hourly values, but still smaller than observed values on average. As such, the *LS* method appears to be acceptable and conservative even when used with daily averages of V^{REF}.

b. Error in using the ρ function (with and without correction factors)

From Archer and Jacobson (2003), the variation with time *h* of the ratio between V^{HUB} and V^{REF}, also known as the shear function $\rho(h)$, can be represented as a sinusoidal as follows:

$$\rho(h) = \bar{\rho} + A \sin\left[\frac{\pi}{12}(h - \delta)\right], \qquad (5)$$

where A is the curve amplitude, δ is the time shift necessary for the sine curve to have a minimum at 1300 LT (−5), and $\bar{\rho}$ is the daily mean of ρ. The hourly values of V^{HUB} can then be obtained by multiplying hourly values of V^{REF} by $\rho(h)$. If only the values of ρ at 0000 and 1200 UTC are known (i.e., ρ_{00} and ρ_{12}), then the two unknown parameters $\bar{\rho}$ and A can be estimated as

$$\bar{\rho} = \alpha \frac{\rho_{12} + \rho_{00}}{2} \quad \text{and} \qquad (6)$$

$$A = \beta \frac{\rho_{12} - \rho_{00}}{2}, \qquad (7)$$

where α and β are factors depending on the time zone. Note that amplitude A in Eq. (7) is allowed to become negative (when $\rho_{00} > \rho_{12}$), to capture the real variability of the shear function. However, Eq. (7) was originally derived for the central U.S. time zones, for which ρ has a minimum around 0000 UTC. In Florida, ρ at 0000–1200 UTC is near zero, which could cause spurious sign switches in the amplitude value. Thus, in this section only, the absolute value was used in Eq. (7). This choice was also introduced to avoid sign dependency on the time zone. The absolute-value formulation was generally conservative at most of the stations tested (as discussed later), and it is consistent with findings by Lazarus and Bewley (2005).

After combining Eq. (5) with Eqs. (6) and (7), ρ_h can be expressed as

$$\rho_h = \alpha \frac{\rho_{12} + \rho_{00}}{2} + \beta \frac{\rho_{12} - \rho_{00}}{2} \sin\left[\frac{\pi}{12}(h - \delta)\right]. \qquad (8)$$

The KSC tower data were used again to evaluate the accuracy of Eq. (8). To simplify the analysis, the correction factors α and β were both set to one at first. Results, summarized in Table 5, are once again slightly dependent on the time zone. On average, the shear function is largely underpredicted by using Eq. (8), as the mean observed value of ρ_h was 2.8 and the mean calculated one was 1.8 (using 0700–1900 LST). The same was true at each individual tower for all pairs of 12-h-apart times. Again, the early-morning–late-afternoon pairs of hours (i.e., 0500–1700 through 0700–1900 LST) gave rise to larger values of the shear function than did all other pairs. For example, at tower 0403, the average observed value of ρ_h was 2.015, the average calculated value with the 0700–1900 LST pair was 1.864, and the average calculated value with the 0100–1300 LST pair was 1.761. The average behavior of ρ at all towers as a function of the 12-h-apart pairs of hours is shown in Fig. 10b. By using the correction factors α = 0.95 and β = 1.2 [suggested in Archer and Jacobson (2004)], valid for the continental U.S. time zones (i.e., −5, −6, and −7 from UTC), the early-morning late-afternoon effect was virtually eliminated. In fact, the average ρ obtained with correction factors at 0700–1900 LST was comparable to the average ρ obtained with other pairs of hours (Fig. 10b and Table 5).

The final question to investigate is how well the proposed formulation for the shear function actually mimics the real one. Figures 11a–c show examples of calculated and observed ρ_h at the tower closest to the average (0415), the tower with the worst performance (0001), and the tower with the best performance (0506), respectively. In general, the proposed sinusoidal pattern of ρ_h is a good approximation for the real pattern of the shear function. However, besides the general underestimation of the average value discussed above, the observed pattern shows a larger amplitude and a sharper transition from day to night (and from night to day). Also, the early-morning/late-afternoon hour pairs tend to produce a larger daily mean ρ than do other hour pairs. This supports the choice of the correction factors in Archer and Jacobson (2004), which forced a reduction of $\bar{\rho}$ ($\alpha < 1$) and an increase of A ($\beta > 1$).

4. Conclusions

In this study, the effects of interconnecting multiple wind farms through the transmission grid were investigated. The area of interest was within the midwestern United States, previously identified as one of the best locations for wind power harnessing over land. Nineteen sites with annual average wind speed at 80 m above ground, the hub height of modern wind turbines, greater than 6.9 m s^{-1} were identified and intercon-

TABLE 5. Values of observed and calculated ρ at two-level towers of the KSC network. The calculated values were obtained for all 12-h apart pairs of sounding times. Values obtained with correction factors are also shown in the last column. In boldface are the average values of ρ observed and calculated at 0700–1900 LST corresponding to 0000–1200 UTC in Florida, with and without correction factors.

		Sounding times (LST)											
Tower	Obs	0000–1200	0100–1300	0200–1400	0300–1500	0400–1600	0500–1700	0600–1800	0700–1900	0800–2000	0900–2100	1000–2200	1100–2300	0700–1900 LT corrected
0001	3.997	1.741	1.739	1.761	1.787	1.809	1.866	1.896	1.873	1.785	1.748	.731	1.729	1.779
0106	3.210	1.752	1.743	1.753	1.771	1.783	1.807	1.845	1.825	1.772	1.763	.754	1.756	1.735
0112	1.875	1.648	1.636	1.651	1.666	1.667	1.723	1.779	1.733	1.670	1.632	.634	1.645	1.652
0211	2.215	1.581	1.577	1.604	1.621	1.640	1.753	1.741	1.790	1.679	1.670	.638	1.609	1.697
0303	3.546	1.755	1.772	1.782	1.815	1.848	1.898	1.906	1.869	1.771	1.756	.747	1.741	1.772
0311	1.862	1.618	1.614	1.628	1.642	1.662	1.732	1.780	1.751	1.669	1.635	.617	1.626	1.663
0403	2.015	1.744	1.761	1.767	1.797	1.822	1.867	1.899	1.864	1.790	1.762	.739	1.747	1.767
0412	3.310	1.620	1.615	1.632	1.651	1.672	1.766	1.811	1.756	1.651	1.629	.608	1.618	1.671
0415	2.564	1.608	1.616	1.625	1.644	1.684	1.756	1.848	1.759	1.656	1.616	.606	1.604	1.676
0506	1.813	1.693	1.695	1.689	1.711	1.694	1.719	1.742	1.724	1.704	1.673	.685	1.681	1.641
0509	2.435	1.677	1.642	1.641	1.684	1.679	1.754	1.774	1.733	1.661	1.652	.631	1.633	1.641
0714	3.318	1.630	1.614	1.642	1.663	1.741	1.743	1.828	1.748	1.662	1.631	.620	1.636	1.661
0803	2.903	1.756	1.765	1.782	1.798	1.817	1.865	1.890	1.857	1.778	1.760	.785	1.748	1.758
0805	3.408	1.662	1.642	1.714	1.691	1.730	1.756	1.808	1.745	1.671	1.659	.67[illegible]	1.655	1.652
Avg	**2.748**	1.678	1.674	1.691	1.710	1.732	1.786	1.825	**1.788**	1.709	1.685	.674	1.673	**1.697**

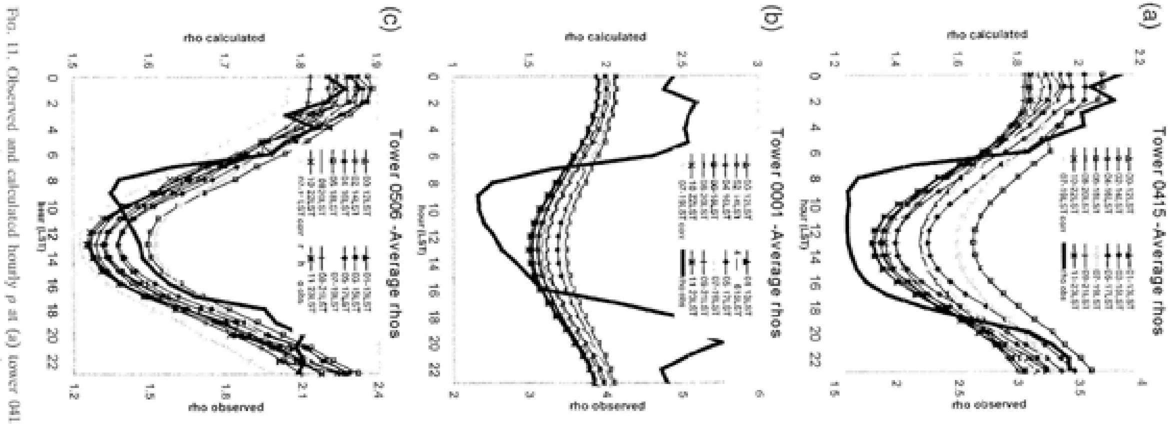


FIG. 11. Observed and calculated hourly ρ at (a) tower 0415 (closest to average), (b) tower 0001 (worst case), and (c) tower 0504 (best case). Note the different scales on axes.

nected within an increasingly larger array. Wind speeds at 80 m were calculated via the least squares method, which involved a combination of 10-m wind speed observations at the sites of interest and vertical wind profiles retrieved at nearby sounding stations. Observed data from the Kennedy Space Center in Florida were used to validate the method.

Array-average statistics were compared with those obtained from each individual site and from the same sites if they were not interconnected (linear sum). Parameters that depend linearly on the values at each individual site, such as array-average wind speed, wind power, and capacity factor, were unaffected by the interconnection, as expected. All other nonlinear parameters showed substantial improvements as the number of interconnected sites increased. These included standard deviations of array-average wind speed and wind power, which decreased as array size increased, array reliability, and reserve requirements, which decreased relative to both the linear sum and the total electricity delivered. The marginal benefit of each additional site decreased. However, no saturation of benefits was found, that is, positive marginal benefits were always found, even if small.

Contrary to common knowledge, an average of 33% and a maximum of 47% of yearly averaged wind power from interconnected farms can be used as reliable, baseload electric power. Equally significant, interconnecting multiple wind farms to a common point, and then connecting that point to a far-away city can allow the long-distance portion of transmission capacity to be reduced, for example, by 20% with only a 1.6% loss of energy.

Reliability was studied with the generation duration curve because it is relatively simple to implement and it does not require any load data. As such, the results described in this study are general and do not depend on the load. An alternative method to study reliability is the Effective Load Carrying Capability. Because of its complexity and dependency on load data, the ELCC approach is recommended for future studies.

In conclusion, this study implies that if interconnected wind is used on a large scale, a third or more of its energy can be used for reliable electric power and the remaining intermittent portion can be used for transportation (i.e., to power batteries or to produce hydrogen), allowing wind to solve energy, climate, and air pollution problems simultaneously.

Acknowledgments. We thank Prof. Willett Kempton for helpful comments and suggestions. This work was partially funded by the National Aeronautics and Space Administration.

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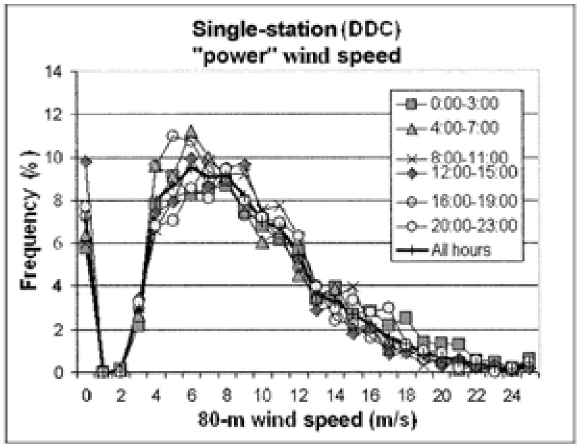
Single-station (DDC)
"power" wind speed
Frequency (%)
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80-m wind speed (m/s)
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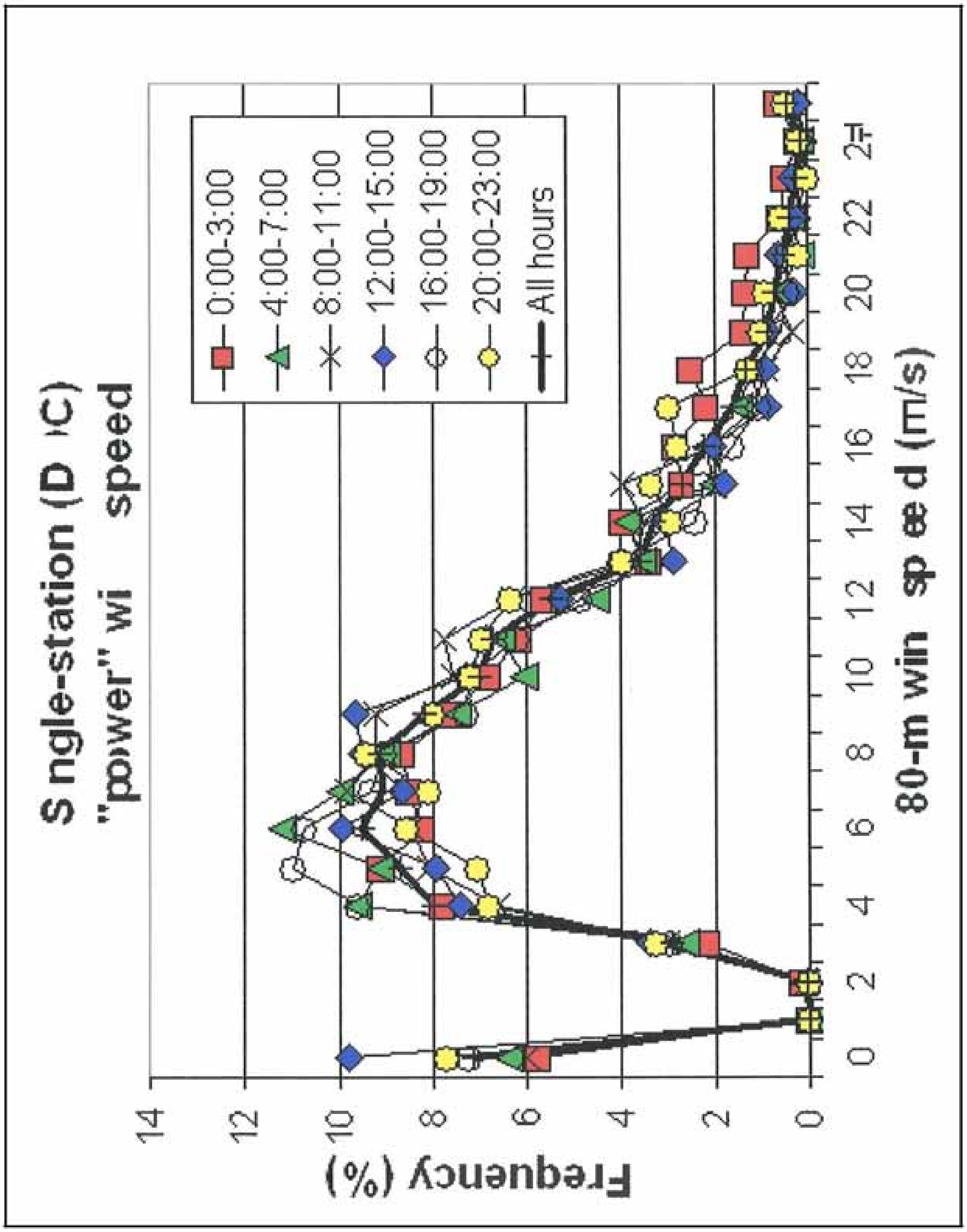
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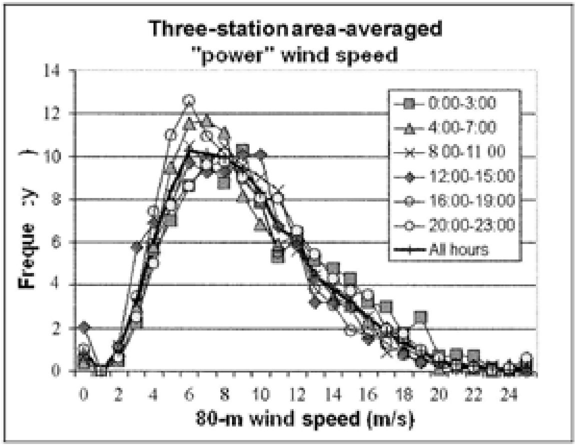
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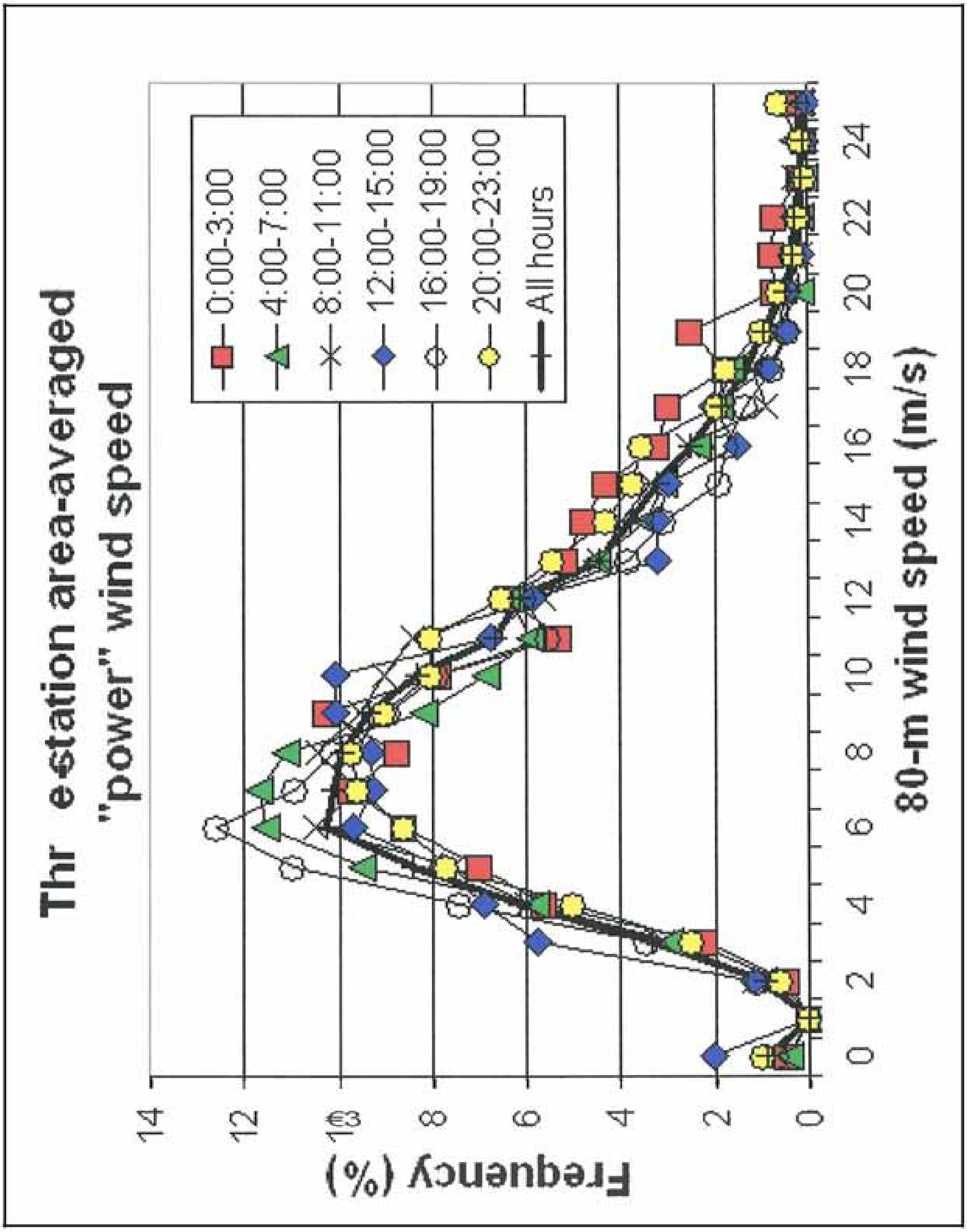
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All hours

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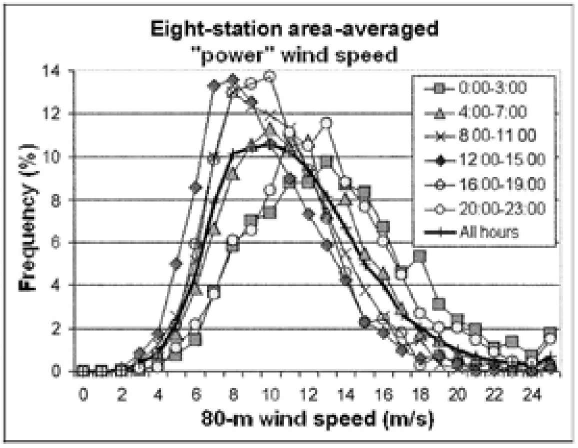

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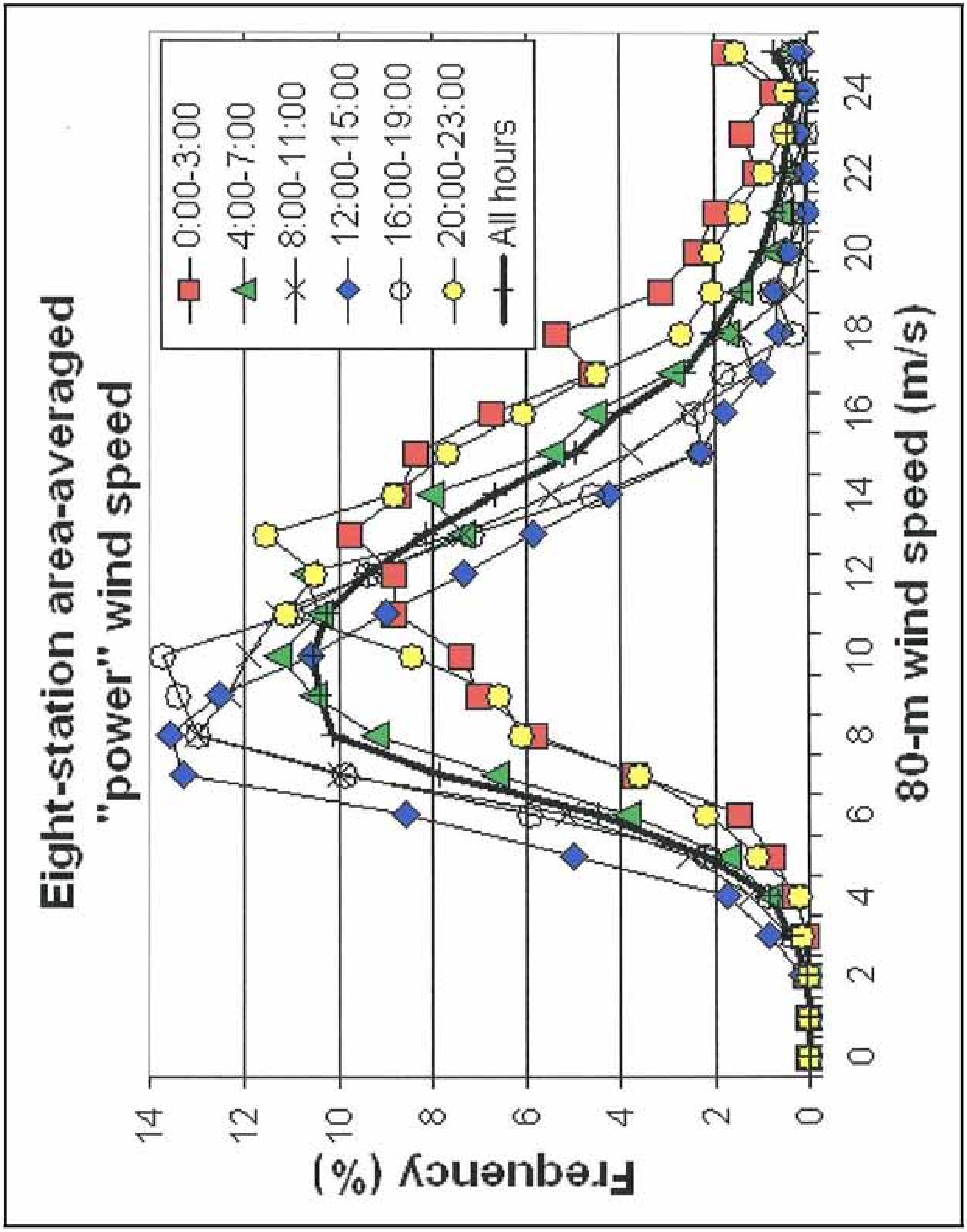
Eight-station area-averaged
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All hours
Frequency (%)
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80-m wind speed (m/s)
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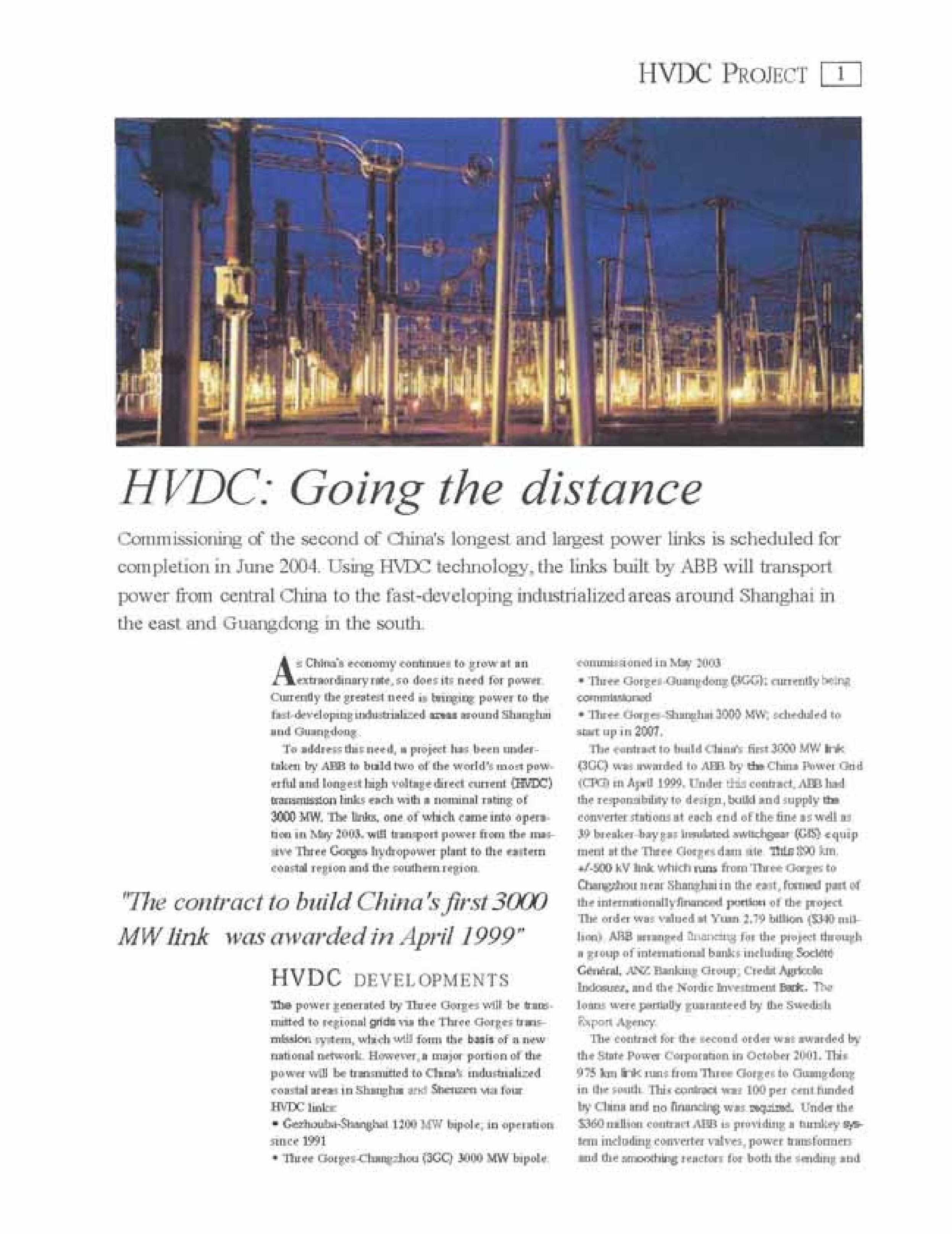


HVDC PROJECT 1

HVDC: Going the distance

Commissioning of the second of China's longest and largest power links is scheduled for completion in June 2004. Using HVDC technology, the links built by ABB will transport power from central China to the fast-developing industrialized areas around Shanghai in the east and Guangdong in the south.

As China's economy continues to grow at an extraordinary rate, so does its need for power. Currently the greatest need is bringing power to the fast-developing industrialized areas around Shanghai and Guangdong.

To address this need, a project has been undertaken by ABB to build two of the world's most powerful and longest high voltage direct current (HVDC) transmission links each with a nominal rating of 3000 MW. The links, one of which came into operation in May 2003, will transport power from the massive Three Gorges hydropower plant to the eastern coastal region and the southern region.

> *"The contract to build China's first 3000 MW link was awarded in April 1999"*

HVDC DEVELOPMENTS

The power generated by Three Gorges will be transmitted to regional grids via the Three Gorges transmission system, which will form the basis of a new national network. However, a major portion of the power will be transmitted to China's industrialized coastal areas in Shanghai and Shenzen via four HVDC links:

- Gezhouba-Shanghai 1200 MW bipole; in operation since 1991
- Three Gorges-Changzhou (3GC) 3000 MW bipole commissioned in May 2003
- Three Gorges-Guangdong (3GG): currently being commissioned
- Three Gorges-Shanghai 3000 MW; scheduled to start up in 2007.

The contract to build China's first 3000 MW link (3GC) was awarded to ABB by the China Power Grid (CPG) in April 1999. Under this contract, ABB had the responsibility to design, build and supply the converter stations at each end of the line as well as 39 breaker-bay gas insulated switchgear (GIS) equipment at the Three Gorges dam site. This 890 km +/-500 kV link which runs from Three Gorges to Changzhou near Shanghai in the east, formed part of the internationally financed portion of the project. The order was valued at Yuan 2.79 billion ($340 million). ABB arranged financing for the project through a group of international banks including Société Général, ANZ Banking Group; Credit Agricole Indosuez, and the Nordic Investment Bank. The loans were partially guaranteed by the Swedish Export Agency.

The contract for the second order was awarded by the State Power Corporation in October 2001. This 975 km link runs from Three Gorges to Guangdong in the south. This contract was 100 per cent funded by China and no financing was required. Under the $360 million contract ABB is providing a turnkey system including converter valves, power transformers and the smoothing reactors for both the sending and receiving ends of the link. In total. 28 power transformers and six smoothing reactors are being supplied jointly by ABB's transformer factory in Ludvika, Sweden and the Chinese state-owned Xi'an transformer works, an ABB licensee.

HVDC has a number of advantages over HVAC. The technology is particularly suited to transmitting power over long distances because losses are low. It is also ideal for connecting separate networks since it obviates the need for network synchronization.

At the heart of the HVDC station is the converter valve for rectifying or inverting electric current. This consists of a large number of thyristors connected in series to cope with the high voltages. The thyristors are mounted in modules of six. Each valve level can house 24 thyristors. The valve is normally suspended from the ceiling of the valve hall for protection against earthquakes. The valves have to be controlled in order to transmit the required current and power. The valve must also be cooled and the cooling water cleaned. Each valve hall has a surge arrester to protect the thyristor bridges against abnormally high voltages.

An HVDC station comprises much more than a converter for rectifying or inverting electric current. In a Large outdoor switching station it must be possible to isolate the station. On the AC side, filters are needed to smooth the current from the HVDC valves and the AC line has to be compensated for the reactive power.

HVDC plants are also provided with transformers on the AC side. The most important reasons for having a transformer are:

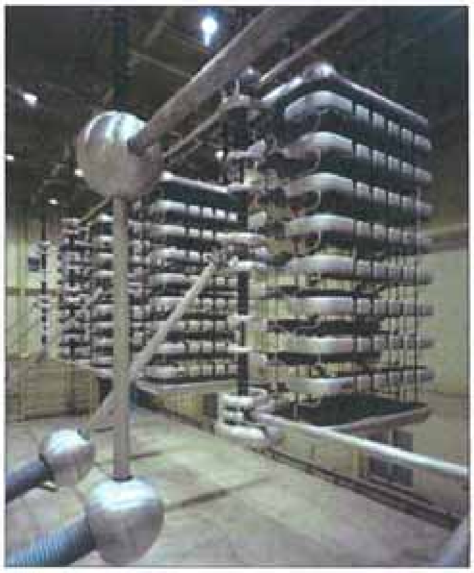
- To optimize the level of direct voltage in HVDC transmission and to have a sufficiently low voltage in back-to-back operation
- To be able to use tap changers for rough setting of the voltage
- To obtain more even direct current and more sinusoidal alternating current (12-pulse connection)
- The transformer limits the short circuit current into the valve.

On the DC side, the current must be made smooth and the return through ground or water secured through an electrode arrangement.

The high voltages call for large distances between converter-converter, and between converter-earth. This means the HVDC station has to be spread over a large area.

THE 3GC PROJECT

ABB had the overall responsibility for the two 3GC converter stations and supplied all the equipment except the converter transformers and smoothing reactors at Zhenping (the receiving end converter station). Although most equipment was imported into China, some transformer units, capacitors, and relay protections were produced locally. CPG was responsible for building the overhead line and the ground electrode stations. It also carried out civil works and installation of the converter stations.



THE CONVERTER VALVE IS AT THE HEART OF THE HVDC STATION

The sending end HVDC converter station is located at Longquan, about 50 km from the power plant. This converter station is connected to the main network of the interconnected AC power pool which comprises the Central China Power System and Sichuan-Chongqing Power System.

The receiving end station is located 890 km to the east at Zhenping, about 80 km northwest of Shanghai. This is connected to the East China Power System which covers Shanghai, Jiangsu, Zhejiang and Anhui. Longquan is connected to the Three Gorges plant by three 500 kV AC lines. Zhengping has two 500 kV AC outgoing lines.

> *"HVDC is particularly suited to transmitting power over long distances"*

HVDC was chosen to transmit power from the Three Gorges plant for several reasons. Since the central and east China/Guangdong AC networks are not synchronized, an AC transmission scheme would have required coordination, and it would have been difficult to ensure adequate stability margins. HVDC allows controlled transmission of power between the networks, which retain their independence.

It would also have been difficult to build an AC transmission line in stages i.e. one link after another, as a very strong inter-tie would have been needed from the outset in order to keep the generators of the two grids synchronized.

DC is also more economic in terms of construction

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costs and losses. Five series compensated, 500 kV AC lines would have been necessary to transmit the same amount of power and each line would require a larger right-of-way than one HVDC line of 3000 MW.

The bipolar transmission also means that half of the power can be transmitted even during an outage of one pole. The nominal DC voltage is +/- 500 kV but the operating voltage can be reduced down to +/- 350 kV to enable continued operation even when the DC withstand strength is reduced due to insulator contamination or adverse weather conditions.

The line overhead capacity of the DC transmission is about 10 per cent for two hours. A unique feature of the receiving end station is that all 500 kV DC equipment (except smoothing reactors) are located indoors. The control and protection system is ABB's Mach-2 system.

The converter station losses at rated operation is just 0.7 per cent. All critical subsystems are duplicated to ensure high availability and reliability.

The first pole (1500 MW) began commercial operation in July 2002 and the entire bipole was completed, on time, in May 2003.

THE 3GG PROJECT

While this was a short time schedule, the second project, 3GG, called for 30 per cent to be shaved off the normal lead time. This means that the first pole will be commissioned just 28 months after signing of the contract. ABB is achieving this by what it calls re-use of design engineering and the lessons learned from the first project. This was possible since both projects were similar. Indeed the tight project schedule was a major challenge.

The converter station at the sending end is located in Jingzhou, close to Yichang. At the peak time of construction there were nearly 1000 workers on site. The Jingzhou site was chosen for a number of reasons. The load distribution of the local network was a prime consideration. Jingzhou is the site of an existing substation and the AC yard is an important node in the future development of the network together with other 500 kV substations. In addition, it has a good supply of water, good land availability and road access for heavy equipment.

When the HVDC link becomes operational, the substation will have the capacity to deliver 3000 MW to Guangdong plus 2250 MW from the existing AC substation. Testing of the system is well underway, with a list of items being tested to assure system reliability and functionality. The system will be tested under different operating scenarios. One important test will be the mode of transmission under increasing load. This is related to the power rating during transmission and will be done mutually at the sending and receiving end.

Despite the short time schedule for building the project 3GG link, construction of pole 1 was achieved by January 2004 and testing took just one month. Full load testing took place in February when the additional two units at 3G came on line. The entire system and line are due to be commissioned by June 2004, however ABB will manage to put the system into operation two months ahead of schedule. According to the CPG, this is the shortest time required for testing any project in China. All in all, the 3GG project will be completed one year faster than its sister project 3GC – a new record.

According to the project engineers at the Jingzhou substation, the biggest technical challenge was spanning the Yangtze River. But despite this, the project went smoothly and it is hoped that the experience gained at Jingzhou will be applied to future projects.

HVDC HIGHLIGHTS

ABB's Three Gorges HVDC links set a number of records. They have the highest power flow per pole i.e. 1650 MW. The previous record was at Itaipu (1575 MW). The execution time of 32 months for the first link was shortest for its class. Itaipu took more than 60 months. At 975 km, the Three Gorges-Guangdong link is the longest DC line in its class – Itaipu is 805 km. The link uses one of the most advanced control and protection systems, ABB's state-of-the-art Mach 2 system

Project benefits

The project has both economic and technical benefits. Economic benefits include: lower investment cost; lower power losses, less impact on the environment; and high reliability and availability.

Technical benefits include: precise and fast controllability of power flow; prevention and cure of blackouts; asynchronous interconnection; limitation of short-circuit currents; no limit on the length of cable (due to absence of charging current).

From a social aspect one link provides power supply to about 6 million households; lower on-grid tariff of renewable hydro resources; avoids emissions from 3000 MW of fossil-fuel power plants in a densely populated area; saves about 16 720 hectares of farmland and forestation; saves about 78 MW through avoidance of losses – equivalent to supply for 156 000 households.

Building a grid for a nation

The Three Gorges project is at the heart of China's power sector restructuring plans. Once complete, the project will add 18.2 GW to China's generation capacity but perhaps more importantly, it will form the backbone of China's plan for a strong national grid.

On April 3, 1992, the fifth Session of the Seventh National People's Congress passed the Resolution on Construction of the Three Gorges Project on the Yangtze River. The project is a key project for the treatment and development of water resources on the Yangtze River. The dam will facilitate the diversion of water from the south to the north and provide flood control. But perhaps more importantly, the power project will also be at the heart of the country's national power interconnection programme.

Supported by new trunk power transmission systems, the Three Gorges power transmission project will be central to China's plans to build an integrated national grid. Power generated from the plant will be transmitted to grids in central China, east China, Sichuan and Guangdong province. With more than 10 000 km of HVAC and HVDC lines, this system will form the basis for a new national grid which will combine the seven regional networks and five independent provincial networks to create two new interconnected regional networks.

HUGE HYDRO

The Three Gorges project will be the largest hydropower plant in the world. Construction began in 1993 and upon completion in 2009 it will have a generating capacity of 18.2 GW. Power will be generated from a total of 26 generators – 14 on the left bank and 12 on the right bank – each with a capacity of 700 MW. In addition, sufficient space has been set aside on the right bank for a future underground powerhouse for six turbine generators with a total capacity of 4200 MW. The intakes of these units are being constructed simultaneously with the project.

The dam is of a concrete gravity type, with a length of 2309 m. It has a crest elevation at 185 m and a maximum height of 181 m.

Construction of the project is scheduled to last 17 years. This includes the five-year (1993-97) first phase of preparations and construction ending with the damming of the Yangtze River; the six-year (1998-2003) second phase ending when the water level of the reservoir reached 135 m; and the six-year (2004-09) third phase which ends with completion of the whole project.

The main financial challenge was funding the project during the first 11 years of construction. But with the project beginning to generate income in 2003, money from electricity sales can now be used to fund the project during the latter part of the construction period.

Indeed, the year 2003 was a historic year in the construction of the project. The pivotal works began to store water on June 1, the storage went up to the elevation of 135 m on June 10 and the permanent ship locks opened on June 16. The first six units began to consecutively generate electricity in August (two went

TWO CONDUCTORS CARRY 3000 MW TO EASTERN AND SOUTHERN CHINA

into operation in August, two in October, and two before the year-end). The pivotal works entered the third phase at the beginning of 2004. An additional four units will begin commercial operation this year and a further four in 2005.

When all units are fully operational, Three Gorges will have an annual output of 84.7 TWh. A large portion of its electricity will be supplied to east China, central China and a small portion to the Chongqing municipality.

SECTOR REFORM

In the past, it has been said that what has most hindered the marketing of electricity has been the country's poor power management and limited power transmission capacity. However, information from the China National Power Corporation showed that by treating Three Gorges as an opportunity, China could restructure its power industry, reform the existing power management and operation mechanisms, and speed up the construction of transmission facilities in rural and urban areas.

China has experienced an annual growth rate in installed generating capacity of more than 8 per cent for the last 52 years. At the end of 2002, installed capacity stood at 357 GW. About 50 per cent of this capacity was controlled by the State Power Corporation (SPC). The remaining 50 per cent was owned by independent power producers, large generators like Three Gorges and Guangdong Nuclear, as well as provincial or local governments.

In October 2002 the government passed the Electricity Sector Reform Act to promote competition, increase efficiency and generally streamline the industry. A regulatory body was created to supervise the electricity market. The SPC was split into five competing generating companies and two non-competing regional network companies.

The five generating companies are Huaneng Group (37 970 MW); Datang Electric Power (32 250 MW); China Huadian Group (31 090 MW); SP Electric Power (30 430 MW) and China Electric Power Investment (29 890 MW). Transmission and distribution is to remain a monopoly, under the control of the State Grid Corporation and China Southern Power Grid Co. Ltd.

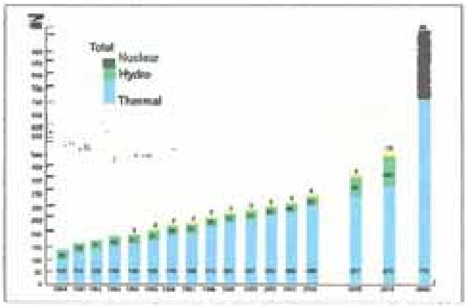
> *"China plans to create a modern power market in which plants sell power to the grid at market prices"*

Chis intention is to eventually create a unified grid, and have a modern power market in which plants sell power to the grid at marketdetermined prices. Initially it planned to introduce competitive pricing in six areas – Zhejiang, Shanghai, Shandong, Liaoning, Jilin and Heilongjiang – on a trial basis, with each free to employ its own method of competitive pricing. These six trial regional markets were expected to be merged or expanded for a more integrated competitive market but the expansion has been temporarily stalled because of severe power shortages experienced in 2003.

TRANSMISSION ISSUES

A key issue in the development of this integrated competitive market is the development of an integrated network.

Altogether, there are seven provincial or regional



CHINA'S TOTAL INSTALLED GENERATING CAPACITY

2 GRID DEVELOPMENT

HVDC IS THE BACKBONE OF CHINAS POWER GRID

grids and five independent grids which are not connected. The regional networks – North China, Northeast, East China, Central China, Northwest, Sichuan and Chongqing and the Southern Network – operate at 500 kV; with the exception of the Northwest Network which has a 300 kV backbone. The five independent grids are Shandong, Fujian, Hainan, Xinjiang and Tibet.

The southern provinces plus Hainan are viewed as the south grid and is operated by the Southern Network Corporation. The remainder is known as the north grid and is operated by the State Network Corporation (North Company). These network companies still also have their own generating plants, primarily pumped storage.

While network accessibility has reached 96.4 per cent, according to ABB there are still transmission opportunities. Already, Three Gorges is providing a significant portion of these transmission opportunities. Power from the plant will be distributed via 15 transmission lines, with 500 kV AC lines to central China and Chongqing City and +/- 500 kV DC lines to east China and south China. Overall, the project will require the construction of 6519 km of AC lines, with a converting capacity of 22.75 million kVA; and some 2965 km of DC lines with the capacity of the DC converter stations reaching 18 000 MW.

While Three Gorges will go some way to meeting the power demands in the east, there will be a continuing need for transmitting power from west to east. This is expected to be achieved via three routes:

- South lines: 10 000 MW from Guizhou/Yunnan/Guangxi to Guangdong
- North lines: 5000 MW from Shaanxi/Shanxi/Inner Mongolia to JinJingTang area
- Central lines: 9000 MW from Sichuan/Hubei to east China (including the second bipole HVDC link from Three Gorges to Shanghai).

There is also a need to interconnect the regional and independent grids using both AC and DC systems.

There are plans to step up the voltage level in the 330 kV northwest network to 750 kV. The plan is to build a 146 km, 750 kV AC line from Manping to Lanzhou. This will be one of only a few 750 kV transmission lines operational in the world. Construction of this line has begun and ABB is bidding on the transformers and reactors for the project.

There are also substantial requirements on the distribution side. According to ABB in the 11th Five Year Plan (2005-2010) the country plans to invest $24 billion in transmission and distribution. In addition to higher voltage HVDC systems, China will need large transformers – larger than today's 1000 MVA transformers which are available for single-phase. China predicts that in the next 15 years, transforming capacity will be about 20 GVA.

Technology such as FACTS (Flexible AC Transmission) will be needed to provide voltage regulation and compensation.

FUTURE HVDC

Last year was an important year in the Chinese power sector. Some 21 provinces/regions encountered power shortages. To counter this, some $24 million was invested in generation, with 37 GW being put into operation. At the same time, 8500 km of transmission lines were also put into operation.

> *"In the 11th Five Year Plan (2005-2010) the country plans to invest $24 bilion in transmission and distribution"*

By the end of this year some 144 plants will have been constructed and a further 10 000 km of both AC and DC lines will have come into operation.

Looking ahead, ABB sees more opportunities for the use of HVDC technology. China has scheduled several HVDC projects for both the near term and the longer term (e.g. up to 2015). There are plans for 16 sets of DC transmission lines between 2006 and 2020.

Interestingly, some of these projects may stretch over greater distances and operate at higher voltages than links built to date. Most 'long' transmission distances in China are currently around 1000 km but the country is looking at ways of sending power over distances of around 1800-2000 km.

Commenting on the future of HVDC in China Peter Leupp, Chairman and President of ABB in China noted: 'When you look at the amount of power and distances, you may see a need to step up voltages from 500 kV DC to 600 kV DC. China is now studying our experiences at Itaipu where we built a 600 kV DC link, which is still the highest DC voltage level after 20 years in operation. They are seeing how they can apply this technology to transmit power to locations which are further away."

The Chinese way

ABB's involvement in the power transmission from the Three Gorges area to the load centres at the pacific coast demonstrates the company's strong local presence in the Chinese market and its strategy of working in direct partnership with local businesses.

The impact of the Three Gorges project is huge on both a local and national scale. The project is located in Hubei Province. The main industries in the surrounding area are agriculture and fishing and one of the key goals of the project is to provide flood control in the middle and lower reaches of the Yangtze River. After completion of the project, the flood control standards in the Jingjiang reach of the Yangtze River will be raised from the present less than 10-year frequency flood to 100-year frequency flood.

The project called for the undertaking of a huge relocation programme. But although resettlement has been a difficult task, the project is being seen as a good opportunity to develop the local economy. The reservoir region of the project is in an under-developed region of China where people living in the area have a per capita income far below the national average. Since the project's implementation, thousands of hectares of farmland have been developed as well as thousands of square metres of new housing.

The project site is located 30 km from Yichang city, which is the home of the project owners – China Yangtze Three Gorges Project Development Corporation. Yichang has a population of 400 000 and construction of the project and its surrounding infrastructure is providing jobs for some 30 000 workers from the city.

At the national level, the project will supply China with cheap, reliable and clean energy. When it is complete in 2009 the plant will account for about four per cent of China's installed generating capacity and replace some 40-50 million tonnes of raw coal each year.

ANNUAL POWER CONSUMPTION GROWTH RATE OF MORE THAN 7 PER CENT IN THE PAST 50 YEARS

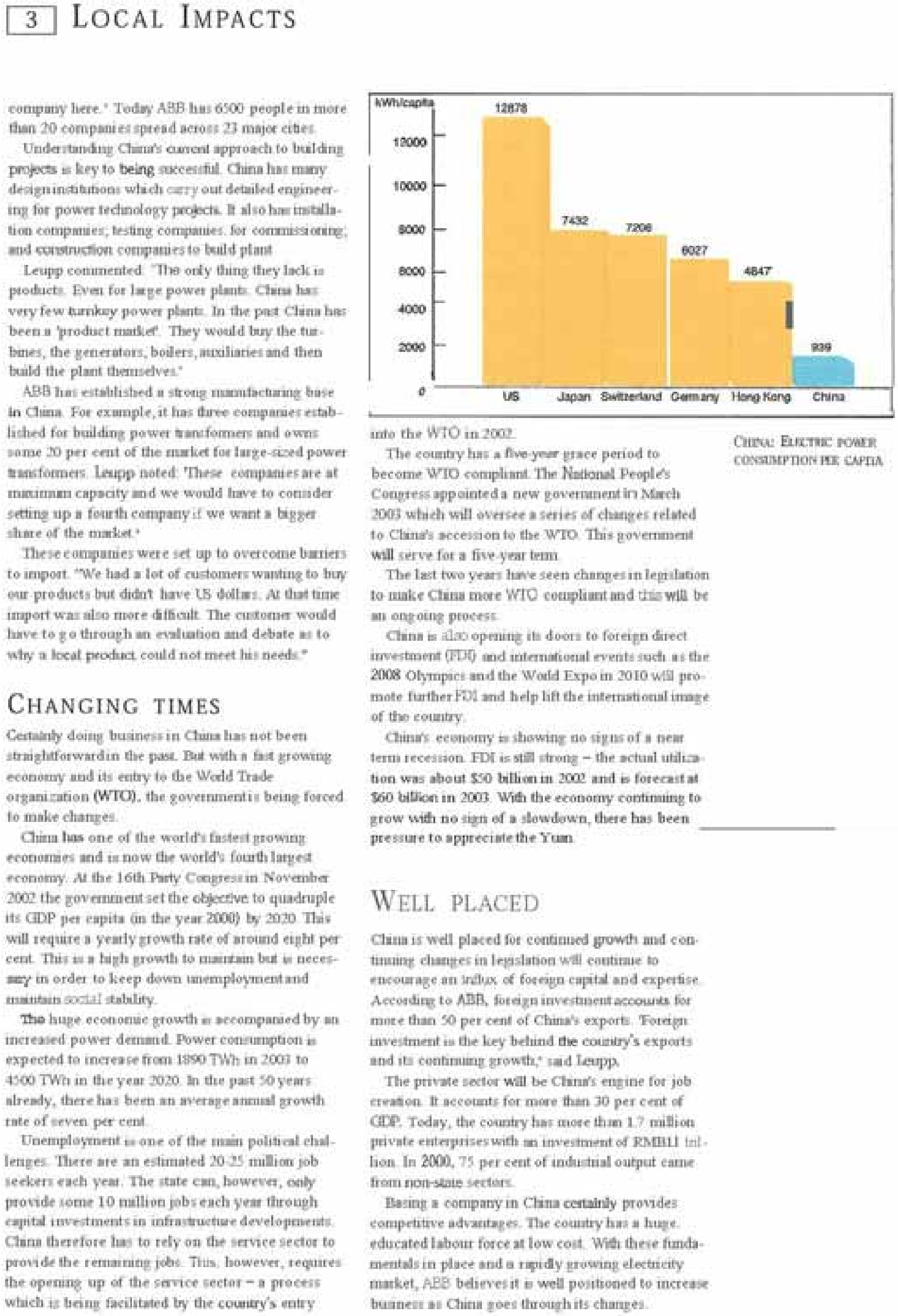
TECHNOLOGY TRANSFER

China has a policy of exchanging market share for technology; a policy which was adopted for the Three Gorges left bank power plant and its transmission links where HVDC technology was used for the transmission of power to Changzhou in east China and to Guangdong.

International manufacturers had to transfer technology to designated state-owned companies and use these companies as local sub-contractors – but take responsibility for the quality of performance and delivery of these local companies. International manufacturers were also asked to take full responsibility for the performance of the project including the performance their local partners.

THE CHINESE WAY

ABB is no stranger to doing business in China. It began selling into China almost a century ago but the turning point came about 10 years ago. Peter Leupp, Chairman and President of ABB in China, explained: "We decided to relocate our China headquarters from Hong Kong to Beijing. At this time we began to: set up more businesses in [mainland] China; manufacture locally; and develop our people. This has made us more of a fully fledged company within the country as opposed to just a sales



3 LOCAL IMPACTS

company here." Today ABB has 6500 people in more than 20 companies spread across 23 major cities.

Understanding China's current approach to building projects is key to being successful. China has many design institutions which carry out detailed engineering for power technology projects. It also has installation companies; testing companies, for commissioning; and construction companies to build plant.

Leupp commented: "The only thing they lack is products. Even for large power plants, China has very few turnkey power plants. In the past China has been a 'product market'. They would buy the turbines, the generators, boilers, auxiliaries and then build the plant themselves."

ABB has established a strong manufacturing base in China. For example, it has three companies established for building power transformers and owns some 20 per cent of the market for large-sized power transformers. Leupp noted: 'These companies are at maximum capacity and we would have to consider setting up a fourth company if we want a bigger share of the market.'

These companies were set up to overcome barriers to import. "We had a lot of customers wanting to buy our products but didn't have US dollars. At that time import was also more difficult. The customer would have to go through an evaluation and debate as to why a local product could not meet his needs."

CHANGING TIMES

Certainly doing business in China has not been straightforward in the past. But with a fast growing economy and its entry to the World Trade organization (WTO), the government is being forced to make changes.

China has one of the world's fastest growing economies and is now the world's fourth largest economy. At the 16th Party Congress in November 2002 the government set the objective to quadruple its GDP per capita (in the year 2000) by 2020. This will require a yearly growth rate of around eight per cent. This is a high growth to maintain but is necessary in order to keep down unemployment and maintain social stability.

The huge economic growth is accompanied by an increased power demand. Power consumption is expected to increase from 1890 TWh in 2003 to 4500 TWh in the year 2020. In the past 50 years already, there has been an average annual growth rate of seven per cent.

Unemployment is one of the main political challenges. There are an estimated 20-25 million job seekers each year. The state can, however, only provide some 10 million jobs each year through capital investments in infrastructure developments. China therefore has to rely on the service sector to provide the remaining jobs. This, however, requires the opening up of the service sector – a process which is being facilitated by the country's entry into the WTO in 2002.

The country has a five-year grace period to become WTO compliant. The National People's Congress appointed a new government in March 2003 which will oversee a series of changes related to China's accession to the WTO. This government will serve for a five-year term.

The last two years have seen changes in legislation to make China more WTO compliant and this will be an ongoing process.

China is also opening its doors to foreign direct investment (FDI) and international events such as the 2008 Olympics and the World Expo in 2010 will promote further FDI and help lift the international image of the country.

China's economy is showing no signs of a near term recession. FDI is still strong – the actual utilization was about $50 billion in 2002 and is forecast at $60 billion in 2003. With the economy continuing to grow with no sign of a slowdown, there has been pressure to appreciate the Yuan.

WELL PLACED

China is well placed for continued growth and continuing changes in legislation will continue to encourage an influx of foreign capital and expertise. According to ABB, foreign investment accounts for more than 50 per cent of China's exports. 'Foreign investment is the key behind the country's exports and its continuing growth,' said Leupp.

The private sector will be China's engine for job creation. It accounts for more than 30 per cent of GDP. Today, the country has more than 1.7 million private enterprises with an investment of RMB1.1 trillion. In 2000, 75 per cent of industrial output came from non-state sectors.

Basing a company in China certainly provides competitive advantages. The country has a huge, educated labour force at low cost. With these fundamentals in place and a rapidly growing electricity market, ABB believes it is well positioned to increase business as China goes through its changes.

CHINA: ELECTRIC POWER CONSUMPTION PER CAPITA