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D3. Exhibits to Letter P21, Beth Messick

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CEQA Portal

CEQA Portal Topic Paper

Mitigation Measures

What Are Mitigation Measures?

The California Environmental Quality Act (CEQA) requires public lead agencies to impose feasible mitigation measures as part of the approval of a "project" in order to substantially lessen or avoid the significant adverse effects of the project on the physical environment. California Code of Regulations, Title 14 ("CEQA Guidelines"), Section 15370 defines "mitigation" as:

- Avoiding the impact altogether,
- Minimizing the impact by limiting its degree or magnitude,
- Rectifying the impact by repairing, rehabilitating, or restoring the impacted environmental resource,
- Reducing or eliminating the impact over time, through actions that preserve or maintain the resource, and
- Compensating for the impact by replacing or providing substitute resources or environmental conditions, including through permanent protection of such resources in the form of conservation easements. P21-36

When imposing mitigation, lead agencies must ensure there is a "nexus" and "rough proportionality" between the measure and the significant impacts of the project. (CEQA Guidelines § 15126.4, subd. (a)(4)(A)–(B), citing *Nollan v. Ca. Coastal Commission* (1987) 483 U.S. 825, *Dolan v. City of Tigard* (1994) 512 U.S. 374.) All mitigation must be feasible and fully enforceable, and all feasible mitigation must be imposed by lead agencies. (CEQA Guidelines, § 15041.) But, if any suggested mitigation is found to be infeasible the lead agency must explain why and support that determination with substantial evidence, presented in their findings and a statement of overriding considerations. (CEQA Guidelines, §§ 15091 and 15093.) Mitigation measures may either be integrated into proposed projects or imposed as mitigation for identified significant environmental impacts (see "Can Mitigation Measures be Included as Part of Project Design?" below).

Note that this paper focuses on the drafting of mitigation measures and assumes that the environmental analysis has concluded that mitigation is necessary.

Why Are Mitigation Measures Important?

Mitigation measures modify a project "...to substantial lessen or avoid significant effects on the environment..."[1] thus fulfilling a basic purpose of CEQA to:

> "Prevent significant, avoidable damage to the environment by requiring changes in projects through the use of alternatives or mitigation measures when the governmental agency finds the changes to be feasible." (State CEQA Guidelines § 15002(a)(3))

As a result, the ability to mitigate significant environmental impacts is a key focus of CEQA. Conversely, the inadequacy of mitigation measures is a frequently used claim in lawsuits challenging CEQA documents.

Can I Apply a Mitigation Measure?

It is important to understand that CEQA is intended to be used in conjunction with agency's discretionary powers. CEQA does not grant an agency powers independent of the powers granted to the agency by other laws.[2] The practical implication of this is that some lead agencies do not have the authority to mitigate for some impacts because the impact will either occur outside of their powers or outside of their jurisdiction. An example might be a roadway improvement outside of a city limit or on state lands. In addition to counties and cities, there are numerous public agencies that are limited in powers (i.e. irrigation districts, fire districts, school districts, and local agency formation commissions) but may also be lead agencies. Be sure to understand the power(s) of the lead agency when preparing mitigation measures.

P21-36 cont.

Are Mitigation Measures Required in An Initial Study/Mitigated Negative Declaration?

Mitigation measures are required to be included in an initial study (IS) when the analysis identifies potentially significant or significant environmental impacts. When an IS identifies a significant environmental impact, a negative declaration (ND) or mitigated negative declaration (MND) may be prepared for the project only if the analysis in the IS:

- Shows that there is no substantial evidence, in light of the whole record before the agency, that the project may have a reasonably foreseeable significant effect on the environment (in which case a ND would be prepared), or
- Identifies potentially significant effects, but includes revisions or mitigation measures, prior to public review, that would clearly avoid or reduce the effects of the project to a less-than-significant level (in which case an MND would be prepared) (CEQA Guidelines, § 15070).

If the IS finds that there is no substantial evidence in the record to conclude that a significant

[1] CEQA Guidelines Section 15041(a).

[2] CEQA Guidelines Section 15040

environmental impact would result, the lead agency is not required to adopt any mitigation measures[3]. If mitigation is required and will reduce all impacts to a less-than-significant level, an MND can be adopted by the lead agency if "revisions in the project plans or proposals made by, or agreed to by the applicant before a proposed mitigated negative declaration and initial study are released for public review would avoid the effects or mitigate the effects to a point where clearly no significant effects would occur (CEQA Guidelines, § 15070). Mitigation measures must be included in an MND prior to public circulation. (CEQA Guidelines, § 15071). When the IS finds that there may be a significant impact and feasible measures are not available to reduce the impact to a less-than-significant level, the lead agency must prepare an environmental impact report (EIR) for the project.

Are Mitigation Measures Required In An Environmental Impact Report?

An EIR must include, for significant impacts, all feasible mitigation measures that could avoid or reduce those impacts (CEQA Guidelines, § 15126.4). Unlike measures in an MND, mitigation measures in an EIR need not reduce a significant impact to a less-than-significant level. But, if a project's significant impacts are not avoided or substantially lessened by feasible mitigation, then the lead agency must prepare and adopt findings and a statement of overriding considerations that justifies its decision to approve the project, despite the significant environmental impacts, supported by information in the EIR and other information in the record. (CEQA Guidelines, § 15093.)

P21-36 cont.

How Do I Create An Adequate Mitigation Measure?

When developing mitigation measures, the author should begin with a clear understanding of the specific impact to be mitigated, the goal of the mitigation measures, how the mitigation measures will be implemented, and who will be using them. Other agencies besides the lead agency (e.g., responsible agencies) may rely on the mitigation measures, and other parties, aside from lead agency staff (including, but not limited to, project planners, attorneys, engineers, and construction staff), may need to interpret and implement the mitigation measures.

Ultimately, the parties responsible for implementing the mitigation measures may be far removed from the drafters and may not have access to relevant project details. Clarity, completeness, and context are important concepts to keep in mind. Mitigation measures should be written clearly and provide all of the information necessary for successful implementation via a mitigation monitoring and/or reporting program (MMRP) (CEQA Guidelines, § 15097), even if the complete IS or EIR is not available. A complete mitigation measure will include details of what needs to be done, how it will be done, who is responsible for doing it, and when it needs to be done.

In practice the MMRP, or in some instances just the mitigation measures, are all the permitting

[3] While the adoption of mitigation measures is not required if significant impacts are not identified, it is not prohibited for the project proponent to voluntarily agree to measures such as Best Management Practices to further minimize a less-than-significant environmental effect.

agencies may have to work from in reviewing a project before approving a permit. They may not always have the time or access to the complete IS or EIR to help understand the intent of the mitigation measures.

The following are some rules and common best practices for writing mitigation measures:

Rules

- Do not defer mitigation measures until a later time, except as provided in the CEQA Guidelines. (see further discussion below in "Deferred Mitigation"). (CEQA Guidelines, § 15126.4, subd. (a)(1)(B)
- Ensure that mitigation measures are fully enforceable through legally binding instruments. (CEQA Guidelines § 15126.4(a)(2)
- Ensure that mitigation measures are consistent with all applicable constitutional requirements such as having a nexus to a legitimate governmental interest and being roughly proportional to the impact. (CEQA Guidelines § 15126.4(a)(4)
- Mitigation measures can only be imposed to address a significant environmental impact identified in the analysis.
- For historic resources CEQA Guidelines § 15126.4(b) provides specific recommendations for mitigation measures.
- Mitigation measures can only address impacts associated with the proposed project and not preexisting environmental conditions. P21-36 cont.
- Remember that mitigation measures must be within the powers of the lead and responsible agencies to impose and enforce to ensure that they are carried out during project implementation. CEQA does not give an agency new power. (CEQA Guidelines § 15040(b))

Best Practices

- Make sure that the mitigation measure is independently measurable. (i.e., set back x feet from the wetland)
- Avoid mitigation measures that are intended to solely 'educate' as in "Educating the backhoe driver on how to recognize fossils."
- Avoid repeating federal, state, or local legal requirements. If there is already a law that addresses the impact, compliance with the law should be discussed in the analysis but does not need to be a mitigation measure. (i.e., Applicant must pay development impact fees.)
- Ensure that mitigation measures are site appropriate, accurate, and sufficiently detailed to be effective at the time they are applied to the project.
- Be sure to tailor recurring mitigation measures to the project[4].

[4] Mitigation measures are frequently copied between documents and the failure to modify them to the specific project creates confusion during implementation. If the same mitigation measure occurs on multiple projects a better approach would be to adopt it as a standard and simply refer to compliance in the analysis.

- Be sure to use clear, straightforward language; assume that a layperson will be charged with implementing or explaining the mitigation measure.
- Avoiding impacts is the best mitigation. If the project design can avoid the environmental impact, start there as a discussion and explain why it cannot be avoided in the analysis.
- Avoid repeating mitigation measures in the same document. (i.e. if the dust control mitigation in the air quality analysis also addresses erosion concerns in geology and soils) A simple reference to the mitigation measure elsewhere in the document is sufficient. Repeating mitigation measures adds to confusion and increases the potential for errors if one of them gets changed and the others do not.
- Be sure to include the timing of implementation for each mitigation measure. Note that if the mitigation measure cannot be in place by the time needed per the environmental analysis you may have a significant and unavoidable impact. (see Timing of Mitigation below).
- Ensure that all steps necessary to implement the mitigation measure are laid out in sufficient detail to ensure proper implementation. The mitigation measures should include enough detail so that requirements are not misinterpreted.
- Mitigation measures should allow for some flexibility, where appropriate, or opportunities for modification if circumstances change following approval of the environmental document. Changes might include construction timing, phasing, or changes in site conditions. Flexibility may both allow for better protection of environmental resources and avoid problems with project implementation. However, flexibility should not reduce a mitigation measure's effectiveness or defer its implementation.

P21-36 cont.

Can Mitigation Measures Be Included As Part Of Project Design?

By definition, mitigation measures are not part of the original project design. Rather, mitigation measures are actions taken by the lead agency to reduce impacts to the environment resulting from the original project design. Mitigation measures are identified by the lead agency after the project has undergone environmental review and are above-and-beyond existing laws, regulations, and requirements that would reduce environmental impacts.

Some project proponents incorporate "avoidance and minimization measures" or "environmental commitments" into the project design as part of the project description, and the CEQA Guidelines also reference these features in Section 15064(f)(2) and 15126.4(a)(1)(A). Examples of project design features that may address environmental impacts include construction traffic management plans, use of energy efficient lighting, solar panels, construction lighting that will be shielded and directed away from neighboring properties, and building standards in excess of the requirements of Title 24 Building Code. These are not considered mitigation measures because they are part of the project that is undergoing environmental review. Nonetheless, in order to address an environmental impact, project design features that include impact avoidance and/or minimization measures must be described, and their effectiveness in reducing or avoiding potential impacts specifically analyzed, in the environmental document.

Failure to evaluate the effect of these measures in the impact analysis violates the legal requirement to provide a logical argument, supported by substantial evidence, for each impact conclusion in an environmental document (*Lotus v. Department of Transportation* (2014) 223 Cal.App.4th 645). Therefore, concluding that an impact is less than significant without describing how avoidance and minimization measures of the project design prevent or minimize the impact, is not legally adequate.

While not "mitigation", a good practice is to include those project design feature(s) that address environmental impacts in the mitigation monitoring and reporting program (MMRP). Often the MMRP is all that accompanies building and construction plans through the permit process. If the design features are not listed as important to addressing an environmental impact, it is easy for someone not involved in the original environmental process to approve a change to the project that could eliminate one or more of the design features without understanding the resulting environmental impact.

Substituting Mitigation Measures Following Public Review Of An Environmental Document

If a lead agency determines, following public review of an IS/MND or Draft EIR, that proposed mitigation measures are not feasible or would not reduce potential effects to a less-than-significant level, it may choose to remove those mitigation measures and substitute other measures. In an IS/MND, prior to making this substitution, however, the lead agency must: P21-36 cont.

- Hold a public hearing on the matter. If another public hearing for the environmental document is scheduled, this matter may be incorporated into that meeting. (CEQA Guidelines, § 15074.1, subd. (b)(1).)
- Adopt a written finding (supported by substantial evidence in the record) that the new measure is equally or more effective in mitigating the identified environmental impact and that the new measure will not itself create a significant environmental impact (CEQA Guidelines, § 15074.1, subd. (b)(2).).

If both of these conditions are met, recirculation of the document is not required; otherwise, recirculation may be required (CEQA Guidelines, § 15073.5).

Revisions to mitigation measures in Draft EIRs can be made in the Final EIR prior to certification by the lead agency, with an explanation for the revision, including why recirculation is not needed. Any substantive revisions to mitigation measures made after an EIR is approved and adopted by a lead agency generally requires public notice and adoption at a public hearing with an explanation as to why the revision(s) was required.

Mitigation Measures That Are the Responsibility Of Other Parties To Implement.

CEQA operates under the principle of "one project, one document." In other words, one environmental document should be prepared for a given project. When agencies other than the lead agency (such as responsible agencies) must comply with CEQA for the same project, the document prepared by the lead agency must be used by these other agencies to fulfill their CEQA obligations, with some limited exceptions.

The set of mitigation measures that are made a part of an MND or EIR must include not only the measures that are the responsibility of the lead agency, but also any measures that will be imposed by responsible agencies. Coordination with responsible agencies required by CEQA can be helpful in identifying such mitigation measures (see Lead Agency, Responsible Agencies, and Trustee Agencies Topic Paper).

Mitigation Monitoring and Reporting Plans

When approving an environmental document containing mitigation measures, the lead agency must adopt a mitigation monitoring and reporting program (MMRP) to ensure the measures falling under its responsibility are implemented. (CEQA Guidelines, § 15097.) The lead agency is responsible for ensuring that mitigation measures are implemented in accordance with the program; however, this responsibility may be delegated to another party if that party agrees to take responsibility. As each responsible agency approves the environmental document, it will likewise adopt an MMRP for the measures falling under its responsibility.

P21-36 cont.

The preparation of an MMRP is required only when a public agency has made findings related to an EIR or adopted an MND in conjunction with approving a project. (CEQA Guidelines, § 15097, subd. (a)) While there is no requirement to include the reporting/monitoring program in the draft EIR or MND, many agencies choose to do so.

Timing of Mitigation

The environmental analysis should clearly state when the mitigation is needed to address the identified significant environmental impact. Typically, mitigation measures are applied in one of the following time periods for a construction project:

- **Prior to Ground Disturbance.** This would include mitigation like preconstruction biological surveys or changes to key design elements (i.e., storm water detention or roadways). Usually these types of mitigation measures are also linked to permits like grading.
- **During Ground Disturbance/Construction.** Mitigation measures here might include noise attenuation for construction or ongoing monitoring for tribal resources.
- **Prior to Occupancy.** These measures are often offsite such as construction of sidewalks, traffic signals, or extension of utilities.

- **Operation.** Mitigation after occupancy (completion of a project) is difficult to enforce, and more appropriately belongs in a condition of approval. Examples include limitations on hours of operation, or the number of special events that can be held.

Certainly, there are modifications to the above timing, such as specific dates/times for preconstruction biological surveys, or limitations on grading due to winter weather. If there is something unique about the timing of a mitigation measure it should be discussed in the analysis and incorporated into the mitigation measure. Also, if a measure must be in place by a specific time, that too should be supported by the environmental analysis and technical studies.

In addition to ensuring that the timing is referred to in a consistent and understandable fashion, it is important that the agency or department responsible for implementing the mitigation measure be consistently referenced. (i.e., public works, planning, public health) If implementation or monitoring requires special expertise or equipment (i.e. noise monitoring, light meter) be sure that the responsible agency or department has both the equipment and the expertise. If the expertise is not within the agency, there may be a need bring in outside technical assistance which should be identified in the analysis and MMRP.

Deferred Mitigation

Deferred mitigation refers to the practice of putting off the precise determination of whether an impact is significant, or precisely defining required mitigation measures, until a future date. Over the years, the courts have addressed the issue of deferred mitigation numerous times to the point where patterns of appropriate and inappropriate CEQA behavior have emerged. Such certainty is not possible if the details of enforceable mitigation measures to avoid the impacts are deferred.

Deferral should only be considered when there is a legitimate reason why the agency cannot develop a specific mitigation measure at the time of the project environmental review. As discussed below, deferring mitigation does not mean deferring the inclusion of a mitigation measure in the environmental document or the implementation of that measure. It refers to deferring to a future time for the refinement or full definition of the adopted mitigation measure.

The essential rule for proper deferral of the specifics of mitigation was established in *Sacramento Old City Assoc. v. City Council of Sacramento* (1991) 229 Cal. App. 3d 1011. This case held that the City of Sacramento had correctly deferred the selection of specific mitigation measures to reduce the parking impacts from the expansion of its convention center. Under the reasoning established in this case and cited in many decisions since, in order to meet CEQA's requirements a mitigation measure must meet one of the following basic conditions:

- The agency must commit itself to the mitigation by identifying and adopting one or more mitigation measures for the identified significant effect. The mitigation measure must also set out clear performance standards for what the future mitigation must achieve.
- Alternatively, the agency must provide a menu of feasible mitigation options from which the applicant or agency staffs can choose in order to achieve the stated performance standards.

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The courts have opined on deferred mitigation in reported cases many times since the *Sacramento Old City* decision, and three points stand out. First, each case is fact-specific. So, keeping a clear administrative record that contains substantial evidence supporting the deferred approach is crucial. Second, performance standards must be included in the mitigation measure; specific performance standards are needed in order to show that the final mitigation measure will be effective. Third, the lead agency must ensure that the future mitigation will be implemented—oftentimes done through a condition of approval for obtaining a development permit. Inherent in the commitment to mitigation and adoption of performance standards is a responsibility to ensure that the final mitigation is effective and is actually implemented.

"'[W]hen a public agency has evaluated the potentially significant impacts of a project and has identified measures that will mitigate those impacts,' and has committed to mitigating those impacts, the agency may defer precisely how mitigation will be achieved under the identified measures pending further study." (*Oakland Heritage Alliance v. City of Oakland* (2011) 195 Cal.App.4th 884, citing *California Native Plant Society v. City of Rancho Cordova* (2010) 172 Cal.App.4th 603.)

Impacts of Mitigation Measures

Occasionally a mitigation measure will cause an impact. CEQA requires that impacts of mitigation measures be evaluated in the environmental document, but can be "...in less detail than the significant effects of the project as proposed." (CEQA Guidelines § 15126.4(a)(1)(d).) Examples of a mitigation measure causing an impact could include widening of a roadway, demolition of an existing building, extension of utilities. These impacts, and a method of addressing them, should be discussed in the analysis. P21-36 cont.

Important Cases

The following published cases involve issues related to mitigation measures:

- *Sundstrom v. County of Mendocino* (1988) 202 Cal.App.3d 296

  Mitigation measures must be feasible, and an MND cannot be adopted where there is a question that any mitigation measure is infeasible.

- *Sacramento Old City Assoc. v. City Council of Sacramento* (1991) 229 Cal. App. 3d 1011

  The details of mitigation may be deferred under certain circumstances.

- *Oakland Heritage Alliance v. City of Oakland* (2011) 195 Cal.App.4th 884

  Adopted building codes and standards can be assumed to minimize environmental impacts, and need not be included as mitigation measures, as long as the environmental benefits of the cited codes and sections are described.

Related CEQA Portal Topics

- Lead Agency, Responsible Agencies, and Trustee Agencies
- Impact Analysis [in process]

AEP CEQA Portal

- Overview of NEPA [in process]

Mitigation Measures In CEQA Guidelines

The following CEQA Guidelines sections address mitigation measures:

- **Section 15041** – *Authority to Mitigate*. This section summarizes the authority of the lead agency and responsible agency to require avoidance, minimization, and mitigation measures, and prohibits reduction of housing units in housing projects as mitigation if there is another feasible mitigation option.
- **Section 15073.5** – *Recirculation of a Negative Declaration Prior to Adoption*. This section summarizes circumstances under which a Negative Declaration or Mitigated Negative Declaration would or would not need to be recirculated, including the substitution of mitigation measures.
- **Section 15074.1** – *Substitution of Mitigation Measures in a Proposed Mitigated Negative Declaration*. This section summarizes requirements for substituting equivalent or more effective mitigation measures following public circulation and prior to adoption of a Mitigated Negative Declaration.
- **Section 15097** – *Mitigation Monitoring or Reporting*. This section summarizes monitoring and reporting requirements to ensure that the mitigation measures and project revisions identified in an Environmental Impact Report or Negative Declaration are implemented.
- **Section 15126.4** – *Consideration and Discussion of Mitigation Measures Proposed to Minimize Significant Effects.* This section discusses the specific parameters of mitigation measures included in an Environmental Impact Report, including specific requirements for measures to mitigate impacts on historical impacts and greenhouse gas emissions.
- **Section 15370** – *Mitigation*. This section provides the definition of mitigation and summarizes what is considered mitigation.

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Mitigation Reporting or Monitoring Program

The purpose of a mitigation reporting or monitoring program (MRMP) is to discuss feasible measures to avoid or substantially reduce the significant environmental impacts from a project identified in the EIR or ND. Please review the sample MRMP for additional guidance.

What is a Mitigation Reporting or Monitoring Program?

A MRMP is a document or a matrix identifying mitigation actions to be taken and out comes when significant environmental impacts have been identified. The MRMP is adopted at the time the EIR is certified or the ND is adopted. A responsible agency must also adopt a program for reporting or monitoring mitigation measures that were adopted or made conditions of project approval.

In practice, drafting a good mitigation measure involves clearly explaining its objectives – specifically how it will be implemented, who is responsible for its implementation, where it will occur and when it will occur.

Impact Identification

CEQA requires that, for each significant impact identified in the EIR or ND, the environmental document must discuss feasible mitigation measures to avoid or substantially reduce the project's significant environmental effect. In the EIR or ND, the preparer should include all measures that it considers feasible, even though the ultimate determination of feasibility is not made until the decision makers prepare findings later in the project approval process. A measure brought to the attention of the lead agency should not be left out of the EIR or ND unless it is infeasible on its face.

P21-36 cont.

Distinguishing Mitigation Measures

The EIR or ND must distinguish between the mitigation measures which are proposed by the project proponents to be included in the project from other measures proposed by the lead, responsible or trustee agencies, which are not included but could reasonably be expected to reduce the adverse impacts if required as conditions of approving the project. Where several measures are available to mitigate an impact, each should be discussed and the basis for selecting a particular measure should not be left out of the EIR or ND unless it is infeasible on its face.

CEQA Guidelines

The CEQA Guidelines provide, for the significant environmental effect of the proposed project, five categories of mitigation measures that:

- Avoid
- Minimize
- Rectify
- Reduce and Eliminate
- Compensate

To be considered adequate, mitigation measures should be specific, feasible actions that will actually improve adverse environmental conditions. Mitigation measures should be measurable to all monitoring their implementation. Mitigation measures consisting only of further studies or consultation with regulatory agencies that are not tied to a specific action plan may not be adequate and should therefore be avoided.

While a lead agency should attempt to apply mitigation measures consistently, CEQA does not mandate that the same mitigation measures be applied to similar projects.

When drafting mitigation measures, agencies should include only those that are feasible. A mitigation measure is considered feasible if it is capable of being accomplished in a successful manner within a reasonable period of time, taking into consideration economic, environmental, legal, social and technological factors.

Mitigation Measures

A good mitigation measure involves clearly explaining its objectives-specifically how it will be implemented, who is responsible for its implementation, where it will occur and when it will occur.

This list provides information on how to create a good mitigation measure and includes the questions to ask and a description of the details to provide to address each question.

- Why?
  - State the objectives of the mitigation measure and why it is recommended.
- What?
  - Explain the specifics of the mitigation measure and how it will be designated and implemented.
  - Identify measurable performance standards by which the success of the mitigation can be determined.
  - Provide for contingent mitigation if monitoring reveals that the success standards are not satisfied.
- Who?
  - Identify the agency, organization or individual responsible for implementing the measure.
- Where?
  - Identify the specific location of the mitigation measure.
- When?
  - Develop a schedule for implementation.

P21-36 cont.

Authority to Enforce

The mitigation measures to be monitored or the subject of reporting must be fully enforceable through permit conditions, agreements or other measures.

The overall thrust of these provisions is that mitigation measures should be implemented. The statute and Guidelines refer to three distinct but closely related concepts necessary to carry out this policy:

- Mitigation measures
- Means of implementing and enforcing mitigation measures
- Means of monitoring or reporting on the implementation and enforcement of mitigation measures

CEQA gives a public agency the authority to require feasible changes in any or all activities involved in a project to substantially lessen or avoid significant effects on the environment. An agency does not have an unlimited authority to impose mitigation measures.

In practice, the components of a MRMP typically include the following:

- Description of specific performance standards
- Master mitigation checklist
- Identification of project-specific monitoring activities
    - Assignment of responsibilities
    - Development of schedule
- Specific reporting requirements
    - Field visit verification reports

Sample MRMP

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Permit Toolbox: CEQA Requirements: https://www.calrecycle.ca.gov/SWFacilities/Permitting/CEQA/
Contact: CEQA Requirements PermitTraining&Assistance@calrecycle.ca.gov, (916) 341-6337

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It Looks Like Mitigation. It Sounds Like Mitigation. But Can It Be Part of the Project?

Lotus v. Department of Transportation - A Practitioner's View

by Gary D. Jakobs, AICP and Curtis E. Alling, AICP

May 2014

Preface

In January 2014, the First District Court of Appeal reversed a Humboldt County Superior Court ruling and determined that the California Department of Transportation (Caltrans) did not adequately analyze the significance of a proposed highway realignment's impacts to the root systems of old-growth redwood trees in Richardson Grove State Park. Missing from the environmental impact report (EIR) were the identification of a threshold of significance regarding root zone damage and an analysis of impact significance, even though disturbance in and around the root zone of the trees was specifically described and mapped.

Confounding the omission was the inclusion in the project description of environmental protection measures the court viewed as mitigation, rather than as part of the project, which created improper short-circuiting of California Environmental Quality Act (CEQA) analytical and disclosure and requirements. The EIR described these features as "avoidance, minimization and/or mitigation measures" that "have been incorporated into the project to avoid and minimize impacts, as well as to mitigate expected impacts." However, the EIR neither addressed the significance of impacts to the root systems nor specified that the impact-reducing features were actually mitigation commitments proposed in response to a significant effect. P21-36 cont.

A few months have passed since this decision. During this time, discussion has ensued in practitioner circles about whether the decision somehow impedes the use of impact minimization and avoidance features in a project description, which has been a long-used, venerable, and effective environmental planning practice. We explore the premise further in this paper, and express the opinion that, when properly carried out, the practice of including environmentally protective features in a project description can continue, but with important caveats.

Introduction

For many years, experienced lead agencies and project applicants have incorporated "environmental protection features," or the like, into project descriptions prior to conducting CEQA impact analysis. These measures have been typically included as part of the project description and are intended to result in fewer or less severe environmental impacts. This approach may be pursued because it is good environmental planning, an expression of an agency's environmentally sensitive mission, a means to streamline the CEQA process, or all of the above. One example would be a project with a potentially significant effect caused by filling wetland habitat. During project planning or preliminary lead agency review, the proponent may, under this principle, commit to a modified project design that avoids or minimizes the filled area or to wetland habitat restoration or replacement with a specified acreage ratio and habitat quality character to compensate for unavoidable fill. Not only can the significant environmental impact be avoided when considering environmental protection features as part of the project, the cost and time necessary to prepare an EIR or mitigated negative declaration (MND) may also be reduced or avoided. At the least, under this principle, mitigation monitoring and reporting requirements can be streamlined or eliminated if, rather than proposing mitigation measures in response to the impact analysis, identical measures are incorporated into the project description.

The Questions from *Lotus*

The 2014 decision, *Lotus v. Department of Transportation*, 223 Cal. App.4th 645, now makes us ask several questions: Is this practice permissible? If so, under what conditions? Can project descriptions be modified to avoid significant impacts, and thereby reduce CEQA documentation requirements? Can you reduce project impacts by design changes before analyzing them in a CEQA document?

There has been scant guidance on this issue up to now. Not surprisingly, then, where there is a void, the State courts are asked to fill it. In the setting of the majestic coast redwoods of Richardson Grove State Park, *Lotus v. Department of Transportation* provides some answers.

Key Facts

Caltrans proposed to realign a winding, one-mile stretch of U.S. Highway 101 to improve truck traffic safety where the highway passes through the redwood forest in the park. The park is home to old growth redwoods, some of which stand 300 feet tall and are thousands of years old. The project would not require removal of any of the old growth redwoods (although some younger trees would be removed), but would result in construction within the root zones of 74 trees ranging in diameter from 18 inches to 15 feet. According to the EIR, "About 41 redwood trees thirty inches or greater in diameter within the park would have fill placed within the structural root zone. The maximum depth of fill on these redwoods would be three and a half feet." The EIR also described the physical details of construction disturbance within the structural root zone of various sized trees in the park. The project description included design features, such as use of light-weight cement, that were intended to reduce potential environmental impacts to these majestic trees, along with non-design, impact-reducing or offsetting features. The non-design actions included use of special hand-construction techniques in the root zones, commitment to restore habitat, and implementation of invasive plant removal. P21-36 cont.

As stated in *Lotus*:

> The EIR also describes "avoidance, and minimization and/or mitigation measures" that "have been incorporated into the project to avoid and minimize impacts as well as to mitigate expected impacts." These include, "M-1: Restorative planting of 0.56 acre of former US 101 roadbed alignment...[¶] M-2: To offset the impacts to the trees where construction occurs within the structural root zone, mitigation will be provided to increase amount of invasive plant removal. A contract with the California Conservation Corps will be established to provide 300 hours a year for four years ... Crew to be directed at the direction of the California Department of Parks and Recreation"... "[1] An arborist shall be present to monitor any ground disturbing construction activities. [2] All excavation below the finished grade within the setback equal to three times the diameter of any redwood tree shall be done with shovels, pickaxes, or pneumatic excavator or other methods approved by the construction engineer to minimize disturbance to or damage to the roots..."

The EIR describes, in tabular form, the type of construction activity that could occur in the root zone of each of the affected redwood trees, but does not analyze consequences to the trees or determine impact significance. Instead, the EIR relies on the incorporation of the environmental protection features into the project description to conclude that any potential impacts of the project on the trees would be less than significant (without the need for other mitigation). Importantly, the EIR includes no standards/thresholds of significance for impacts to redwoods. This is critical; without a significance threshold, there is no means by which to conclude whether impacts would or would not be significant, and findings under CEQA Section

21081 cannot be properly made (i.e., whether significant impacts are reduced to a less-than-significant level and, if so, how). The court makes it clear that thresholds were available. The court cites, for instance, the California State Parks Natural Resources Handbook (available to Caltrans during the EIR process), which describes the probability of root damage by depth and type of activity, risk to tree health, etc. The Handbook states: "Construction activities in close proximity to trees can wound or destroy tree roots, the closer the activity to the tree trunk, the higher the probability that the tree will suffer injury. This includes soil disturbance from 0 to 3 foot depth..." No thresholds of significance were included in the EIR, notwithstanding the availability of the Handbook or other criteria.

The Decision

Omitting analysis of the significance of impacts on the root zone of the redwood trees was fatal, which was the initial reason the court decided to overturn the EIR. This was the fundamental flaw of the environmental document, as demonstrated by the title of this section of the decision: "*The EIR fails to comply with CEQA insofar as it fails to evaluate the significance of the project's impacts on the root systems of old growth redwood trees adjacent to the roadway.*"

In addition, the decision goes on to explain that a compounding error was the reliance on measures that were included in the project description, but should have been presented as mitigation measures in response to the identification of significant environmental effects. The court describes what constitutes mitigation under CEQA (i.e., avoiding, minimizing, rectifying, reducing, and compensating for a significant impact). In a key statement, the court says:

> As the trial court held, the "avoidance, minimization and/or mitigation measures," as they are characterized in the EIR, are not "part of the project." They are mitigation measures designed to reduce or eliminate the damage to the redwoods anticipated from disturbing the structural root zone of the trees by excavation and placement of impermeable materials over the root zones. By compressing the analysis of impacts and mitigation measures into a single issue, the EIR disregards the requirements of CEQA.

P21-36 cont.

According to the court, this "short-cutting of CEQA requirements...precludes both identification of potential environmental consequences arising from the project and also thoughtful analysis of the sufficiency of measures to mitigate those consequences." CEQA requires a lead agency to consider a proposed project, evaluate its environmental impacts and, if significant impacts are identified, to describe feasible mitigation measures to reduce the impacts. The court explained: "Simply stating there will be no significant impacts because the project incorporates 'special construction techniques' is not adequate or permissible."

What Does this Mean?

Does this mean the proposed project, as initially described, cannot be refined to reduce impacts prior to the required CEQA analysis and significance findings? Has the court thrown good environmental planning out the window? Not at all. In fact, the court, in an instructive footnote, acknowledged some protective features that legitimately can be part of the project description, but stated that the line between project design and mitigation is not always clear. In this case, the use of certain lighter weight pavement base materials, which were proposed as a design feature to minimize excavation depth, reduced potential impacts to the root zone of the redwoods. The court indicated it would have been "nonsensical to analyze the impact of using some other composition of paving and then to consider the use of this particular composition as a mitigation measure." In other words, pavement material proposed to reduce excavation impacts of highway construction was a legitimate element of the project description in this circumstance.

Can environmental protection features, then, still be included in the project description for purposes of good environmental planning and impact reduction or avoidance? We believe, based on a careful reading of this decision, that a project *can* include environmental protection features in a project description, but with certain qualifications.

First, including environmental protection features in a project description does not relieve the lead agency of the obligation to adequately analyze the potential significant environmental impacts of the project, even related to the issue that a protection feature is intended to address. The CEQA document—EIR, MND, or ND—should analyze the impact, identify the relevant threshold of significance, address whether the threshold would be exceeded and why, and describe how the "environmental protection feature" would, based on substantial evidence, maintain the effect at a less-than-significant level. Also, based on the court's decision in *Lotus*, it would be important to discuss whether additional or other more effective, feasible measures would be available.

Second, an environmental protection feature must be credible as a true component of the project plan or design, rather than a mitigating action that is separate from the project itself, and responsive to the project's impacts. The distinction between project design features that protect the environment and measures that should be considered mitigation is, at times, difficult to tease out. Returning to the example of a project that includes wetland impacts, if the project plan is refined before release of a CEQA document to avoid impacts by locating all facilities outside the footprint of the wetlands, would the site plan revision be a part of the project or considered to be mitigation? We believe, in this example, the project site plan layout can legitimately be considered part of the project description. This is good project site planning. If it avoids wetland fill, the environmental analysis would conclude that the proposed project, as designed, would not adversely affect the wetland. Alternatively, what if the wetland is occupied by an endangered species that relies on both the wetland and surrounding upland, but impacts to the species could be avoided by monitoring construction activities, installing a barrier, capturing and relocating individuals of the species, or restoring nearby habitat? Our view is that these are special actions that meet the definition of mitigation measures and are arguably not a part of the basic project. Unlike facility location, layout, or design, these measures involve more than adhering to a site plan or project design; they are special actions needed to limit the degree and magnitude of the project impacts or compensate for them. Further, these measures would each need to be analyzed for effectiveness in reducing the impact and a mitigation monitoring or reporting plan would need to be adopted.

P21-36 cont.

Other Circumstances Not Covered In *Lotus*

The *Lotus* decision addressed a specific set of facts, but it did not answer all the questions about the practice of employing environmental protection features in a project description. Between the ends of the conceptual spectrum of (1) a clearly legitimate component of a project plan or design and (2) an obvious mitigation measure, such as a compensatory action or special impact-reducing action in response to a significant impact, is the gray area of other concepts and fact-situations. For instance, highly standardized, environmentally protective, construction practices are often included as part of project implementation, i.e., "best management practices," or "BMPs." BMPs are often prescriptive and sufficiently standardized to be generally applicable, not requiring special tailoring to a project situation. Another common example of the use of environmental protection features in a project description is the "self-mitigating" community or resource management plan, e.g., a city or county general plan, state park general plan, or wildlife area land management plan. They can contain environmentally protective refinements in planning policies and implementing actions that are included to avoid significant effects.

These are important examples of common practices that are not specifically addressed by *Lotus*. We believe that there may be room to include standardized measures required by law or regulation in the project description and environmentally protective policies and actions in a proposed plan; however, we do not believe this eliminates the obligation to evaluate potential environmental effects and whether the project measures effectively reduce significance impacts.

Perhaps, these are lingering voids in CEQA guidance to be filled by the court another day...

Practice Pointers

In short, if an environmental protection feature modifies physical elements of a project, as expressed in its site plan or design, we believe it is permissible (and good environmental planning) to include the feature as part of the project description. Therefore, the significance determination would take into account the environmental protection afforded by that feature.

In response to the *Lotus v. Department of Transportation* decision, if an environmental protection action is not a feature described in the project plan or design and it meets the definition of a mitigation measure, it likely is one. The environmental analysis of a significant impact of a proposed project would not, then, assume the mitigation measure is already part of the project description. The mitigation measure's impact-reducing influence would be considered after an initial conclusion describing the proposed project's significant or potentially significant effect on the environment.

Regardless, the relevant environmental impact needs to be evaluated and disclosed. The analysis needs to include a threshold or standard of significance and the identified project description feature or mitigation measure (whichever it may be) must be evaluated for its effectiveness in reducing the impact.

As it has been said, "if it looks like a duck, and quacks like a duck, it is a duck."

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If you have any questions about this paper, please feel free to contact either of the authors:

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WIKIPEDIA

Coordinates: 40°47′59″N 121°56′35″W

Round Mountain, California

Round Mountain is a census-designated place in Shasta County, California, United States. The population was 155 at the 2010 census, up from 122 at the 2000 census.

Round Mountain

census-designated place

Location in Shasta County and the state of California

Coordinates: 40°47′59″N 121°56′35″W

Country	United States
State	California
County	Shasta
Area[1]	
• **Total**	1.684 sq mi (4.360 km²)
• **Land**	1.677 sq mi (4.343 km²)
• **Water**	0.007 sq mi (0.018 km²) 0.40%
Elevation	2,080 ft (635 m)
Population (2010)	
• **Total**	155
• **Density**	92/sq mi (36/km²)
Time zone	UTC-8 (Pacific (PST))
• **Summer (DST)**	UTC-7 (PDT)
ZIP code	96084
Area code(s)	530
FIPS code	06-63134
GNIS feature ID	1659552

Contents

Geography

Round Mountain is located at 40°47′59″N 121°56′35″W (40.799633, -121.943058).[2]

According to the United States Census Bureau, the CDP has a total area of 1.7 square miles (4.4 km²), 99.60% of it land and 0.40% of it water.

Round Mountain is the geographic center of the Achomawi and Atsugewi or "Pit River" first nation. The "Pit River" tribe has never signed a treaty with the federal government and remains a strong force of opposition to federal control.

Round Mountain is the home of Hill Country Health and Wellness Center, one of the most solvent clinics in California. It also has the highest awarded LEEDS construction certificates of any clinic in California. Hill Country maintains a large youth facility.

Some organic farmers in Round Mountain are members of the Shasta Regional Seed Cooperative and work together to maintain hundreds of heirloom food crops as well as bio-dynamic farming techniques. Many residents are off the grid, using hydroelectric, solar and wind resources for their home power. Some of these forward-thinking residents also maintain local crime-watch activities and network projects to advance the sustainability of the region.

P21-36 cont.

A large electrical substation is in the area, and power lines (Path 66 and a set of connecting wires to Path 15) run through the town.

A second substation was planned, then canceled, in 2009, along with 650 miles (1,050 km) of electrical lines from central California thru Round Mountain and then northbound. This plan, called TANC (Transmission Authority of Northern California), was halted by citizens who produced presentations statewide, showing that Department of Energy data conflicted with the project's stated goals. This 1.4 billion dollar TANC project was stopped (http://www.stoptanc.com) in about 90 days.

Cedar Creek Elementary School is not currently operating as most Round Mountain students are attending schools in the Mountain Union (K-8) District in nearby Montgomery Creek. Round Mountain Community Center is administered through the local Lion's Club/VFW and has capacity for about 200.

The geography in Round Mountain has been at times very unstable. Several homes, a store, and a nightclub have been among buildings destroyed in landslides. Many of the power lines in the area appear to be constantly repaired due to shifting foundations. After both the Fountain Fire and the introduction of power lines (which increased erosion due to construction as well as due to a program to maintain low or no vegetation under and alongside high-tension wires), slides in the area increased. The location of a major road reconstruction project in 2009 of "the fountain" (a set of curves leading into Round Mountain from the west) became the scene of major shifting, road buckling, and surface water eruptions in the first rain season after completion.

Local geography invites fishing, mountain climbing, and hiking as well as opportunities to experience some of California's wildest land.

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Demographics

2010

At the 2010 census Round Mountain had a population of 155. The population density was 92.1 people per square mile (35.5/km^2). The racial makeup of Round Mountain was 126 (81.3%) White, 2 (0.6%) African American, 12 (7.7%) Native American, 3 (1.9%) Asian, 1 (0.6%) Pacific Islander, 1 (0.6%) from other races, and 11 (7.1%) from two or more races. Hispanic or Latino of any race were 12 people (7.7%).[3]

The whole population lived in households, no one lived in non-institutionalized group quarters and no one was institutionalized.

There were 74 households, 14 (18.9%) had children under the age of 18 living in them, 27 (36.5%) were opposite-sex married couples living together, 4 (5.4%) had a female householder with no husband present, 5 (6.8%) had a male householder with no wife present. There were 4 (5.4%) unmarried opposite-sex partnerships, and 1 (1.4%) same-sex married couples or partnerships. 31 households (41.9%) were one person and 12 (16.2%) had someone living alone who was 65 or older. The average household size was 2.09. There were 36 families (48.6% of households); the average family size was 2.92.

The age distribution was 27 people (17.4%) under the age of 18, 12 people (7.7%) aged 18 to 24, 30 people (19.4%) aged 25 to 44, 55 people (35.5%) aged 45 to 64, and 31 people (20.0%) who were 65 or older. The median age was 47.8 years. For every 100 females, there were 98.7 males. For every 100 females age 18 and over, there were 106.5 males.

There were 82 housing units at an average density of 48.7 per square mile, of the occupied units 57 (77.0%) were owner-occupied and 17 (23.0%) were rented. The homeowner vacancy rate was 1.7%; the rental vacancy rate was 5.3%. 113 people (72.9% of the population) lived in owner-occupied housing units and 42 people (27.1%) lived in rental housing units.

2000

At the 2000 census there were 122 people, 57 households, and 33 families in the CDP. The population density was 71.7 people per square mile (27.7/km^2). There were 61 housing units at an average density of 35.9 per square mile (13.9/km^2). The racial makeup of the CDP was 85.25% White, 10.66% Native American, and 4.10% from two or more races. Hispanic or Latino of any race were 0.82%.[4]

Of the 57 households 22.8% had children under the age of 18 living with them, 43.9% were married couples living together, 7.0% had a female householder with no husband present, and 42.1% were non-families. 36.8% of households were one person and 12.3% were one person aged 65 or older. The average household size was 2.14 and the average family size was 2.82.

The age distribution was 23.8% under the age of 18, 4.1% from 18 to 24, 23.8% from 25 to 44, 31.1% from 45 to 64, and 17.2% 65 or older. The median age was 43 years. For every 100 females, there were 103.3 males. For every 100 females age 18 and over, there were 93.8 males.

The median household income was $18,250 and the median family income was $28,125. Males had a median income of $36,250 versus $28,750 for females. The per capita income for the CDP was $9,598. There were 25.9% of families and 28.0% of the population living below the poverty line, including no under eighteens and 13.3% of those over 64.

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Politics

In the state legislature Round Mountain is located in the 1st Senate District, represented by Republican Brian Dahle,[5] and the 1st Assembly District, represented by Republican Megan Dahle.[6]

Federally, Round Mountain is in California's 1st congressional district, represented by Republican Doug LaMalfa.[7]

History

On August 19, 1992, a fire called the Fountain Fire started off Buzzard Roost Road. It destroyed approximately 600 structures in Round Mountain and the surrounding towns. The fire burned 64,000 acres (260 km^2), and also burned most of Round Mountain's neighbor, Montgomery Creek.[8] The towns were declared a disaster area.[9] The town of Burney was threatened as well.

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WHEN WIND, WIND TURBINES, AND RADAR MIX —A CASE STUDY

COLONEL FELIX A. LOSCO AND MAJOR THOMAS F. COLLICK***

P21-36 cont.

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I. Unexpected Storms and Wind Turbines

On 12 December 2006, air traffic controllers at Travis Air Force Base (AFB), Calif., saw more than they expected when they switched on their Air Surveillance Radar 8 (ASR-8) system. During recent radar system upgrades, the older ASR-8 analog system was digitized to enhance system compatibility, which would allow for data to be fed from a digital radar system located in nearby Mill Valley. However, the digital upgrade, a temporary measure to enhance compatibility until the more modern digital ASR-11 radar system replaced the legacy ASR-8,[1] resulted in some unusual radar returns. For instance, Travis controllers began observing persistent but non-existent weather cells. More concerning, the controllers saw the tracks of aircraft they were following disappear and then reappear.[2] According to controllers, these phenomena did not occur with the analog version of the ASR-8. The disturbing returns appeared to be associated with the 700-plus electricity-generating wind turbines in the Montezuma Hills area southeast of the base.[3]

Through a case study of events occurring at Travis, this article hopes to familiarize legal professionals with the legal, operational, environmental and political issues that can arise when wind turbines and operational air space collide. Additionally, this article demonstrates the utility of early engagement with potential foes and highlights one tool to enhance collaborative efforts to fully understand and possibly resolve highly technological problems associated with civilian activities that could impact military operations. Lastly, it will also introduce the reader to legislation designed to streamline Department of Defense (DOD) review of wind turbine projects. P21-36 cont.

Wind-turbine development had been growing in the Montezuma Hills area since 1985.[4] Both the wind turbines and the base are in Solano County, and in 1987, county officials designated a sixty-eight-square-mile area as a Wind Resource Area, or WRA.[5] The turbines range in height from 91 to 351 feet,[6] with the closest one located 4.8 nautical miles from the base.[7] Over time, the WRA has developed into an important renewable energy resource for the citizens of Solano and neighboring counties and the state of California.

To better understand the situation as it arose at Travis, one must first have some understanding of how radar systems work. Air traffic control radars such as

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[1] *See* William J. Hughes Technical Ctr., U.S. Fed. Aviation Admin., Airport Surveillance Radar, Model 8 (ASR-8) Interim Digitizer Program 1, http://www.tc.faa.gov/its/cmd/visitors/data/ACT-300/asr-8.pdf (last visited Mar. 27, 2012) (discussing how the ASR-8 digitalization program is designed to temporarily support obsolete ASR-8 radars until the ASR-8 can be replaced).

[2] Letter from Colonel Steven J. Arquiette, Commander 60th Air Mobility Wing, to Solano County Department of Resource Management, (Mar. 8, 2007) (on file with authors).

[3] *Id.*

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[5] E-mail from Geoffrey Blackman, Westslope Consulting, LLC, to the author (July 19, 2010, 09:36 AM) (on file with authors).

[6] Solano County, *supra* note 3.

[7] Steven Hall, A. F. Flight Standards Agency, Wind Turbine Impact On Travis AFB ATC Radar (2008) (on file with authors).

Figure 1: ASR-11 radar illustrating the SSR and PSR radars. Photo courtesy of the FAA.

the ASR-8 and ASR-11 are really a combination of radar systems.[8] The concave bottom portion is the Primary Surveillance Radar (PSR), while the rectangular top component is the Secondary Surveillance Radar (SSR).[9] (See Figure 1.) Both systems emit energy pulses as the apparatus rotates. The PSR sends out high-frequency radio waves that bounce off or "illuminate" the target and returns to the radar.[10] By interpreting returns from successive pulses (known as primary returns), the radar is able to determine the range, bearing and altitude of objects in the radar's beam.[11] Return pulses are much weaker than the initial energy beams. The low-energy returns are susceptible to interference caused by ground objects (clutter), which can degrade the PSR's ability to provide location and altitude information.[12] The SSR, on the other hand, uses frequencies different from the PSR to send out a pulse that can be received by aircraft equipped with a transponder.[13] Transponder-equipped aircraft react to the SSR pulse by generating a relatively strong return signal containing the plane's location and altitude rather than relying on a low-energy reflection.[14] The stronger SSR return means that it is easier to receive and is less susceptible to interference caused by clutter.[15]

P21-36 cont.

As it pertained to Travis, experts found the PSR problem occurred only in areas that had both wind turbines and heavy traffic along a nearby highway.[16] The apparent "weather cell" changed fluidly based on the quantity and type of wind turbines that were rotating.[17] This area also generally overlapped with the area of dropped targets. Experts also noted a difference between radar returns from the PSR and the SSR, finding that the secondary radar was not affected by the WRA.[18] Fortunately, most planes have transponders and would be detectable; however, those planes without transponders remained a concern.[19]

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[8] Airport Surveillance Radar (ASR-11), U.S. FED. AVIATION ADMIN., http://www.faa.gov/air_traffic/technology/asr-11/ (last visited Mar. 27, 2012).

[9] *Id.*

[10] OFFICE OF THE DIR. OF DEF. RESEARCH AND ENG'G, REPORT TO THE CONGRESSIONAL DEFENSE COMMITTEE, THE EFFECT OF WINDMILL FARMS ON MILITARY READINESS 17 (2006), *available at* http://www.defense.gov/pubs/pdfs/windfarmreport.pdf. The report provides an excellent description of radar fundamentals.

[11] *Id.* at 22-24.

[12] *Id.* at 19.

[13] *Id.* at 18.

[14] *Id.* at 19.

[15] *Id.* at 19.

[16] Blackman e-mail, *supra* note 5.

[17] *Id.*

[18] *Id.*

[19] GENERAL AVIATION & PART 135 ACTIVITY SURVEYS—CY [sic] 2006, tbl. AV.9, at AV-28 (showing the aircraft with transponder equipment by the state where the aircraft is based), *available at* http://www.

Figure 2: Wind Turbines as seen from perimeter fence at Travis AFB.

Even though the digital ASR-11 was scheduled to replace the ASR-8 in 2008, Travis officials feared the same problem would impact the new radar.[20] The pending switch to the ASR-11 was part of a long-term Air Force and Federal Aviation Administration (FAA) plan to replace legacy systems such as the ASR-8 with more modern and efficient digital systems.[21] Leaders at Travis AFB and their parent command, Air Mobility Command (AMC), were concerned about the impact of this development on flight safety. The Travis AFB controllers believed there was an immediate and daunting air safety issue over the WRA.[22] To appreciate the situation as the Travis AFB controllers saw it, an understanding of Travis AFB's air space environment is necessary.

Aircraft transiting through controlled airspace must comply with the rules applicable to that airspace. Had the FAA designated the airspace over the WRA and Travis AFB as "Class C," planes traversing this area would have been required to have "an operable radar beacon transponder with automatic altitude reporting equipment."[23] As noted above, a transponder would have effectively eliminated the turbine interference. Using the SSR to receive signals from the plane's transponder, controllers would have been able to confidently track aircraft over the WRA irrespective of the wind turbines. Instead of Class C, the FAA determined the

P21-36 cont.

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faa.gov/data_research/aviation_data_statistics/general_aviation/CY2006/. According to the FAA, in 2006, almost eighty percent of general aviation aircraft were equipped with Mode C transponders capable of reporting altitude information. *Id.*

[20] Arquiette letter, *supra* note 2.

[21] FY2002 NAS Ann. Rep. Office of the Dir., Operational Test & Evaluation, Air Force Programs, at 287-28.

[22] Arquiette letter, *supra* note 2.

[23] *See generally* U.S. Fed. Aviation Admin., Aeronautical Information Manual: Official Guide to Basic Flight Information and ATC Procedures ch. 3 (2010) (explaining the various airspace classifications), *available at* http://www.faa.gov/air_traffic/publications/atpubs/aim/. In general terms, Class A space extends from 18,000 and 60,000 feet above the continental United States. Civilian carriers routinely fly in this area and operate under "instrument flight rules." Class B airspace is generally found around busy airports and extends from the surface to 10,000 feet. Class B airspace is specifically tailored to its location and includes a surface area and two or more layers in an "upside-down" wedding cake formation. Class C includes moderate-size airports with an operating control tower and an Air Traffic Control (ATC) facility. Aircraft in this airspace must have a transponder. Class D airspace extends from an airport's surface level to 2500 feet around an operational control tower. In Class D, neither an ATC facility nor transponders are required. Finally, Class E includes remaining areas of controlled airspace that is not included in the previous classes. Transponders are not required in Class E airspace. *Id.* at ch. 3, § 2, Para. 3-2-1 and Fig 3-2-1.

areas over Travis AFB and the WRA to be "Class D" and "Class E," respectively.[24] Neither classification requires a transponder, and Class E airspace does not require radio contact with the control tower.[25] Thus, with degraded PSR signals and some aircraft lacking transponders, controllers feared wind turbine interference would impair their ability to control traffic.

Additionally, the airspace environment around Travis and the WRA includes military tactical and operational training areas, two civilian airports and a high-level transit route between San Francisco and Sacramento.[26] For these reasons, controllers estimated a thousand general aircraft per day transited this area.[27] They further estimated high volumes of aircraft using both visual flight rules (VFR) and instrument flight rules (IFR).[28] Additionally, the controllers also believed a large number of aircraft were operating without transponders in this area due to flight training activities being conducted at nearby Concord and Rio Vista Airports.[29] However, subsequent investigation revealed the actual number of general aviation flights through this area averaged between thirty and sixty per day[30] and the number of aircraft transiting the area without operating transponders was minimal, perhaps as little as one a day.[31] Thus, controllers had overestimated the amount of general air traffic traversing this area, as well as the number of aircraft transiting the area without operating transponders.

Had the air traffic situation been as the controllers believed it to be—and knowing the turbine-generated anomaly decreased the ability of the ASR-8 to interpret the PSR's returns over this area—the safety concern would have been far more substantial. Specifically, controllers expressed concern about maintaining safe separation distances between the IFR aircraft or providing all aviators timely

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[24] U.S. Fed. Aviation Admin., Order JO 7400.9V, Airspace Designations and Reporting Points, Subparts D-E (2011) *available at* http://www.faa.gov/documentLibrary/media/Order/7400.9.pdf.
[25] U.S. Fed. Aviation Admin., Aeronautical Information Manual *supra* note 23.
[26] U.S. Fed. Aviation Admin., Sectional Raster Aeronautical Charts, San Francisco (2011) [hereinafter San Francisco VFR sectional chart], *available at* http://aeronav.faa.gov/index.asp?xml=aeronav/applications/VFR/chartlist_sect. A sectional raster aeronautical chart is a "scanned image" of an FAA VFR sectional chart. *Id.*
[27] Letter from Lieutenant General (Lt Gen) Vern M. Findley, the AMC vice commander, to Kevin Haggerty, Manager, Airspace and Rules Division at the FAA (Sept. 3, 2009) (on file with authors).
[28] VFR and IFR refer to rules pilots follow based on the type of flight plan and weather conditions. The requirements for VFR flights are set out in 14 C.F.R. 91.155. They vary depending upon the different type of airspace, visibility, and distance from clouds. Flight plans flown following VFRs permit pilots to follow a fixed object, such as a road or railroad tracks, to an airfield. VFRs are important should an aircraft's instruments fail or if a non-instrument rated pilot flies in adverse weather. Pilots who fly using IFR flight plans fly according to instruments in their cockpit.
[29] Travis ATC estimates at one time were 2,500 civil aircraft activities over the WRA from surface to 10,000 feet per day, including participating and non-participating (transponder not operating) aircraft. *See* U.S. Transp. Command, Coop. Research & Dev. Agreement, Operations Working Grp., Research Conclusions and Recommendations at 6 (2010) [hereinafter USTRANSCOM CRADA Report] *available at* http://www.co.solano.ca.us/civicax/filebank/blobdload/aspx?blobid=7939; E-mail from Lieutenant Colonel (Lt Col) Brian W. Lindsey, Director of Operations at 60th Operational Support Squadron, to Gregory Parrott (Aug.10, 2009, 13:15 CST) (on file with authors).
[30] E-mail from Ronald Morgan, Morgan Aviation Consulting, to the authors (July 14, 2010 13:38, PM) (on file with authors).
[31] USTRANSCOM CRADA Report, *supra* note 29.

safety alerts.[32] For these reasons, the controllers felt it was important to let affected pilots know of the reduced service over the WRA.[33]

Base authorities acted promptly after discovering this issue. To address immediate safety needs, the base issued a Notice to Airman (NOTAM), which provides pilots general information deemed essential for the safe and efficient operation of airplanes.[34] The NOTAM advised pilots flying in aircraft without transponders that Travis AFB's ability to provide air traffic control over the WRA was limited.[35] Additionally, the FAA placed this information on charts pilots used to navigate through this area.[36] Further, Travis AFB officials briefed this newly discovered condition to pilots at the nearby civilian airports.[37] On 8 March 2007, the wing commander formally notified the Solano County Department of Resource Management about the wind turbines' impact on Travis AFB's radar.[38] Hoping to forestall additional wind turbine construction in the WRA, he described the potential impact additional wind turbines could have on the new digital radar:

> While we have not yet reached a solid conclusion, we have evidence indicating the wind turbines will create significant interference with the base's radar and could lead to potentially serious flight safety hazards in terms of planes dropping off radar, flight tracks on radar different from actual tracks, and "false targets"—planes the radar sees but are not actually there. Ultimately, these safety concerns affect not only Air Force aircraft and crews but the general flying public as well, as 85% of the air traffic in the Travis AFB coverage area is civilian, and smaller planes are more susceptible than large military aircraft to some of the radar issues that result from the wind turbines.[39]

At the time, the three largest wind farm developers in the Montezuma Hills area, enXco, Florida Power and Light (FPL)[40] and the Sacramento Municipal Utility District (SMUD), each had pending construction projects. Each agreed to halt

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[32] *Id.* at 5.
[33] *Id.*
[34] Joint Chiefs of Staff, Joint Pub. 1-02, Department of Defense Dictionary of Military and Associated Terms 233 (2010), *available at* http://www.dtic.mil/doctrine/new_pubs/jp1_02.pdf.
[35] This caution is maintained in the current NOTAM regarding radar coverage over the WRA at M0817/11 NOTAMR M0672/11 issued on 28 December 2011.
[36] *San Francisco* VFR sectional chart, *supra* note 26. The San Francisco Visual Flight Rules sectional aviation chart provided the following cautions: Numerous windmills reaching a height of 645 feet above mean sea level. Radar is limited south east of Travis AFB. Traffic advisory may not be available to non-transponder-equipped aircraft.
[37] 60 AMW/JA enXco, FPL Windfarm Issues Timeline (2007) (on file with authors).
[38] Arquiette letter, *supra* note 2.
[39] *Id.*
[40] Florida Power and Light is a subsidiary of NextEra Energy Company. For convenience and consistency, we will refer to the subsidiary, FPL, rather than the parent company in this article. *See* http://www.nexteraenergy.com/pdf/form10k.pdf at page 4.

construction of additional turbines until the radar issue was resolved to the satisfaction of Travis officials.[41]

EnXco keenly felt the impact of this decision, as the company was within one week of obtaining final approval for "Shiloh II," a $350 million project to build about seventy-five turbines.[42] For at least two years, the company had been assiduously completing the lengthy process of obtaining the necessary governmental approvals to build the wind turbines.[43] This included technical siting studies, lease negotiations with land owners, an environmental review and electrical system network transmission upgrade activities. Travis AFB officials were made aware of enXco's plans in November 2006, during the Shiloh II Draft Environmental Impact Report (EIR) public comment period.[44] The company had already submitted its plans to the FAA, which issued a "Determination of No Hazard" (DNH) for each of the seventy-five turbines.[45] In its amended EIR, enXco observed that the FAA consulted the DOD before making its decision and that the FAA represented the interest of the Air Force in this matter.[46] Finally, enXco added, "The FAA determination of No Hazard to Air Navigation is the final conclusion about whether a project would or would not have an adverse effect on aeronautical safety."[47]

Despite the foregoing, the Solano County Airport Land Use Commission determined that enXco's project was inconsistent with the Commission's Travis Airport Land Use Compatibility Plan,[48] concluding that the final EIR did not adequately address the impact of the proposed development on Travis AFB's digital radar.[49] At a subsequent meeting of the Solano County Planning Commission, both FPL and enXco requested six-month continuances for the Montezuma Wind and Shiloh II projects respectively, which the Commission granted.[50]

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[41] SOLANO CNTY, DEP'T OF RES. MGMT., AMENDMENT TO FINAL ENVIRONMENTAL IMPACT REPORT, SHILOH II WIND PLANT PROJECT 4-35 (2007) *available at* http://www.co.solano.ca.us/resources/ResourceManagement/3_Exhibit%20B_Shiloh%20II%20FEIR%20Amendment_April%202007.pdf.

[42] Letter from Joseph B. Fahrendorf, Vice President, enXco, Escondido CA, to General (Gen) Lichte, Commander, Air Mobility Command, (Oct. 30, 2007) (on file with the authors).

[43] *Id.*

[44] 60 AMW/JA Windfarm bullet paper, *supra* note 35. On 9 November 2006, before a meeting of the Solano County Airport Land Use Commission, and again in a meeting enXco arranged with the 60 OG/CC, base officials were invited to state any concerns they may have. As these notifications occurred prior to the inclusion of the Mill Valley radar feed to the ASR-8, the base responded that it had no comment and the project would have an unknown impact on the planned DASR-11.

[45] On November 6, 2006, the FAA issued DNH rulings for the turbines. This was, of course, before the wind turbine-induced problems became evident. *See* Shiloh II Amended EIC, *supra* at note 41 at 4-33.

[46] Shiloh II Amended EIC, *supra* note 41.

[47] *See Id.* at 4-36. The content of the "Department of Defense" input will be discussed *infra*.

[48] The Airport Land Use Commission reviews development projects for consistency with Travis AFB's "maximum mission" as defined in the Travis Airport Land Use Compatibility Plan.

[49] Solano County Airport Land Use Commission, Cal., Resolution 07-01 (April 17, 2007) (on file with the author).

[50] 60 AMW/JA bullet paper, *supra* note 35.

II. A Temporary Fix Reveals Problems

To the credit of both the Air Force and enXco, the two entities resolved the impasse through cooperation and a joint study. Between October 2007 and February 2008, enXco partnered with the Air Force and civilian radar experts to form a Joint Technical Working Group to evaluate the impact of the proposed new turbines.[51] For a variety of reasons, including the expectations of improved performance of the ASR-11, possible improvements from additional feeds from other radars, and the location of the proposed turbines, the experts predicted enXco's project would not further degrade radar performance. Specifically, the experts found the probability the new radar would detect an aircraft (probability of detection, or Pd) at 4,000 and 10,000 feet was, respectively, 78.03 and 78.25 percent.[52] These percentages represented a discrete Pd loss that was not deemed to be a significant decrease from the 80 percent Pd the Air Force Flight Standards Agency (AFFSA) and Raytheon (the ASR-11's manufacturer) sought to achieve with the ASR-11.[53] For technical reasons, the experts believed the ASR-11 would perform better than this minimum standard.[54] On 3 March 2008, the base withdrew its objection,[55] Solano County issued enXco its use permit,[56] and enXco began construction of its turbines (a year later than it expected). The wing commander made it plain that the withdrawal was fact-specific to this particular group of turbines.[57]

Moving beyond this particular enXco project, the real challenge to the Air Force was the lack of a widely accepted and validated method to accurately gauge the cumulative impact further turbine construction could have on Travis AFB's digital radar. The FAA's evaluation system included analysis by the "Radar Support System (RSS)," a system that goes beyond "line of sight" screening and can evaluate the effect of both existing and proposed structures like buildings and chimneys.[58] Air Force officials, however, were concerned about the RSS' ability to accurately *predict* the impact, if any, of additional wind turbines with their rotating

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[51] *See generally*, Letter from Gen Arthur J. Lichte, Commander, Air Mobility Command, to Mr. Joseph B. Fahrendorf, V.P. enXco, (Nov. 30, 2007) (outlining the group's efforts and plans) (on file with the author).

[52] Letter from Geoffrey N. Blackman, Partner/Senior Eng'r, Regulus Grp., LLC., to the Solano County Planning Comm'n (Mar. 4, 2008) (on file with the author).

[53] *Id.* Eighty percent is the design standard Pd for the radar in areas free of clutter. U.S. Dep't of Def., Operational Requirements Document (ORD) for DOD Air Traffic Control and Landing Systems (ATCALS) in the National Airspace System (NAS) 8 (Mar. 16, 2005) (on file with the author).

[54] Blackman letter, *supra* note 52 (noting that the assembled panel of experts expected the ASR-11's Pd rate to outperform the ASR-8 by between two and twelve percent).

[55] Letter from Colonel (Col) Steven J. Arquiette, Commander 60th Air Mobility Wing, to the Solano County Dep't of Res. Mgmt. (Mar. 3, 2008) (on file with author).

[56] Press Release, enXco, enXco Announces the Permit Approval of Shiloh II Wind Energy Project (Apr. 17, 2008), http://www.enxco.com/about/press/enxco_announces_the_permit_approval_of_shiloh_ii_wind_energy_project/.

[57] Arquiette letter, *supra* note 55.

[58] The FAA utilized a "Radar Support System" (RSS) produced by the Technology Service Corporation to assist them in conducting their aeronautical studies. While useful in siting studies, RSS is not as helpful when used as a predictive tool to assess the turbines' impact on the ASR-11.

blades and unique electromagnetic effects on the ASR-11.[59] AMC officials noted, with some trepidation, that if the ASR-11 performed as expected, it would already be operating at close to the required minimum level of efficiency.[60]

While the Joint Working Group's detailed analysis revealed Shiloh II's turbines would not further degrade radar performance, it provided no basis for concluding the next group of turbines would likewise have a negligible effect. Thus, the issue became the point at which new turbine construction drop the ASR-11 below the eighty percent detection rate.[61] If not this group, maybe the next group of turbines would ultimately drop the radar below an acceptable performance level. To resolve these issues, AMC and Travis AFB officials sought a predictive modeling tool to evaluate the cumulative impact additional turbines would have on the ASR-11 and determine the ASR-11's minimally acceptable operational Pd standard.[62] Unbeknown to AMC and Travis, enXco and a radar consultant, Westslope Consulting, LLC, were also seeking a similar tool.[63] Unfortunately, the predictive modeling technology largely trailed the rate at which wind energy development was growing.[64] Time was of the essence, and the remaining developers, SMUD and FPL, had projects they were anxious to get approved.[65]

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III. A Wind Storm of Issues

A. Project Approval and *the* Voice for the United States on Issues of Air Navigation Safety

As the enXco Shiloh II project demonstrated, there was confusion as to who speaks on behalf of the United States on issues of air navigation safety. What are the respective roles of the Air Force and the FAA? The first step in evaluating the Air Force's role in the evaluation process is to determine whether enXco's position about the FAA's DNH with respect to their turbines was "the final conclusion" regarding its potential as a hazard to air navigation. Since the FAA delegated control of the navigable airspace around Travis AFB to the Air Force,[66] and the Air Force uses the airspace regularly, it has an obvious interest in air safety.

On the other hand, as the wind turbine developers were quick to point out, the FAA, the agency responsible for air safety, had expressly approved these turbines. The developers not only urged Solano County to follow the FAA's lead, but also contacted their U.S. senators, who in turn sent a letter to the Secretary of Defense.[67] In the letter, the senators expressed their concerns about the delay in

[59] "Thoughts Regarding Gen (R) Looney's Office Call w/ 60 AMW/CC" Lt Col Brian Lindsey, 60 OSS/DO, 14 Aug 09, (on file with author).
[60] *See, generally* Findley letter, *supra* note 27.
[61] *Id.*
[62] *Id.*
[63] E-mail from Geoffrey Blackman, Westslope Consulting, LLC, to Lt Col Brian Lindsey, 60 OSS/DO (Aug. 5, 2009 3:12 PM) (on file with the author).
[64] Findley letter, *supra* note 27.
[65] *Id.*
[66] USTRANSCOM CRADA report, *supra* note 27, at 3.
[67] Letter from U.S. Senators Dianne Feinstein, Charles Grassley, Ron Wyden, Barbara Boxer, Tom

the developers' projects, sought consolidated decision making and encouraged the DOD to participate in the FAA's review process.[68] The issue to resolve was whether delegating airspace control also delegated authority to determine whether construction in that area would impermissibly harm air navigation.

The FAA's supremacy in air navigation issues was established in legislation creating the organization. Before this legislation, the responsibility for controlling and apportioning the nation's airspace was divided between the DOD, the Department of Commerce (where the FAA's predecessor was located), the Civil Aeronautics Board and the President. The military air traffic control (ATC) system operated independently from the civilian system.[69] Communication between them was not automatic, leading to accidents.[70] While there had been prior reform efforts, three mid-air collisions, two of which were between military planes and civilian airliners, convinced then-President Dwight D. Eisenhower and Congress of the pressing need to centralize this cumbersome system. On 13 June 1958, President Eisenhower urged Congress to act swiftly in passing the bill that would create the FAA.[71] In his message, he emphasized the importance of unified "federal (sic) Aviation Agency charged with aviation facilities and air traffic management."[72] He wanted the new agency to have "paramount authority" over U.S. airspace.[73] Another top Eisenhower Administration official also recognized that the military would play an important role in the new regulatory scheme, but he strongly supported the legislation's goal to consolidate the authority to issue safety regulations in the new FAA.[74] In a letter to the committee, Elwood R. Quesada, the special assistant for aviation matters, wrote, "It is essential that one agency of government, and one agency alone, be responsible for issuing safety regulations if we are to have timely and effective guidelines for safety in aviation."[75]

On 23 August 1958, Congress passed the Federal Aviation Act (hereafter the "Act"), which created the FAA and gave it the President's desired "paramount authority" in issues of aviation safety.[76] The House Report accompanying this statute provided the following guidance in the section entitled "Division of Responsibility:"

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Harkin, Jeff Merkley, Jon Tester, Richard Durbin, and Max Baucus, to Robert M. Gates, Secretary of Defense, (May 19, 2009) (on file with the author).

[68] *Id.*

[69] H.R. Rep. No. 85-2360, (1958), *reprinted in* 1958 U.S.C.C.A.N. 3741.

[70] *Id.*

[71] Letter from Dwight Eisenhower, President of the United States, to the Congress of the United States (June 13, 1958), *available at* http://www.presidency.ucsb.edu/ws/index.php?pid=11091.

[72] *Id.*

[73] *Id.*

[74] H.R. Rep., *supra* note 69, at 3761. In addition to being President Eisenhower's special assistant, Quesada was also a retired Air Force Lieutenant General and was the first FAA Administrator. He was also one of the pilots of the legendary aircraft "Question Mark" which demonstrated the viability of refueling airplanes in flight.

[75] *See id.*

[76] Federal Aviation Act of 1958, Pub. L. No. 85-726, §72 Stat. 731, (codified as amended at 49 U.S.C. §§ 40101-49105 (2006)).

> Clearly an agency is needed now to develop sound national policy regarding use of navigable airspace by all users—civil and military. This agency must combine under one independent administrative head functions in that field now exercised by the President, the Department of Defense, the Department of Commerce and the Civil Aeronautics Board. It is also intended by this bill to eliminate divided responsibility that exist in other areas, particularly conflicts between civil and military agencies in the field of electronic aids to navigation.[77]

In short, the FAA retains the authority to make DNH decisions regardless of any delegation the agency may make regarding control of the airspace. In fact, as the situation at Travis evolved, Congress stepped in and cleared up any lingering doubts involving DOD and FAA roles in the review of alternative energy projects. This legislation, the 2011 National Defense Authorization Act,[78] will be discussed in greater detail later in this article.

B. The FAA's Obstruction Evaluation System and Criteria for a DNH Finding

The Act created a legislative and regulatory scheme requiring the FAA (vice the Air Force) to draft regulations pertaining to navigation and to assess the impact tall structures may have on air safety. Specifically, section 40103 of the Act requires the FAA's administrator to prescribe regulations for (a) navigating, protecting, and identifying aircraft; (b) protecting individuals and property on the ground; (c) using the navigable airspace efficiently; and (d) preventing collisions between aircraft, between aircraft and land or water vehicles, and between aircraft and airborne objects.[79] Section 44718 requires the owners of objects tall enough to impact air safety, like wind turbines, to notify the FAA, but the Act imposes no similar requirement to notify the Air Force.[80] Owners of structures tall enough to pose a threat to air safety are required to provide a public notice "in the form and way the Secretary prescribes" (referring to the Secretary of Transportation, the FAA's parent agency).[81] If the structure could obstruct navigable airspace or interfere with navigation facilities, the Act requires an "aeronautical study" to determine "the extent of any adverse impact on the safe and efficient use of the airspace."[82] In conducting the study, the FAA must consider, among other things, the cumulative impact resulting from the proposed construction or alteration of a structure when combined with the impact of other existing or proposed structures.[83]

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[77] H.R. Rep., *supra* at 3743-3744.
[78] Ike Skelton National Defense Authorization Act for Fiscal Year 2011, PL 111-383, § 358 (Jan. 7, 2011).
[79] 49 U.S.C. § 40103(b)(2)(A) – (D)(1994).
[80] 49 U.S.C. § 44718(a)(1) and (a)(2)(1994).
[81] 49 U.S.C. § 44718(a)(1994).
[82] *See id.* § 44718(b)(1).
[83] *See id.* § 44718(b)(1)(E).

Pursuant to these statutes, the FAA drafted detailed regulations and published a handbook for accomplishing these legislative goals.[84] Then existing regulations detailed how the FAA would evaluate objects affecting navigable airspace, described notice requirements, provided for the aeronautical studies as appropriate and explained how to request a review of the FAA's decisions.[85] Only a portion of the handbook described how the FAA was to evaluate structures that might affect air navigation and communication facilities.[86]

While recognizing that many structures may create interference, the FAA will only issue hazard notifications if the interference demonstrates a "substantial physical or electromagnetic adverse effect" on navigable airspace or navigation facilities.[87] A situation reaches this level when a proposed structure "causes electromagnetic interference to the operation of an air navigation facility or the signal used by an aircraft"[88] or when the interference's "adverse effects" impact a "significant volume" of aeronautical activity.[89] A structure would have an "adverse effect" if it exceeds the obstruction standards, impacts the physical or electromagnetic radiation of air navigation facilities and has one of six consequences, two of which apply to wind-turbine-induced radar degradation over the WRA: derogation of airport capacity/efficiency and affecting future VFR and/or IFR operations as indicated by the airport's plans already on file.[90] Determining how much activity constitutes a "significant volume" depends on the type of activity. For example, if one aeronautical activity per day were affected, this would indicate regular and continuing activity that would constitute a "significant" volume, regardless of the type of operation.[91] An affected instrument procedure or minimum altitude used on average only once per week would be significant if the procedure served as the sole procedure under certain conditions.[92] This background is crucial to understanding the FAA's DNH process and the role the Air Force played.

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[84] FAA, JO 7400.2G, Procedures for Handling Airspace Matters (Apr. 10, 2008). An earlier version, JO 7400.2F, was in effect at the time relevant to the events in this article. The earlier version contained similar provisions. Hereafter, it will be referred to as the Handbook. Moreover, on 10 March 2011, the FAA cancelled and replaced the Handbook with JO 7400.2H, Procedures for Handling Airspace Matters *(noting that wind turbines are a special case, in that they may cause interference up to the limits of the radar line of site or at a greater distance than other more routine obstructions)*.

[85] Objects Affecting Navigable Airspace, 14 C.F.R. §§ 77.1 – 77.75 (2004).

[86] FAA Procedures, *supra* note 84, at para. 6-3-10.

[87] *See id.* para 6-3-3 through 6-3-5.

[88] *Id.*

[89] *Id.*

[90] *See id.* para 6-3-3(a)-(f). The other four are: (1) requiring a change to an existing or planned IFR minimum flight altitude, a published or special instrument procedure, or an IFR departure use procedure for a public airport; (2) require a VFR operation, to change its regular flight course or altitude; (3) restrict the clear view of runways; and (4) affect the usable length of an existing or planned runway.

[91] *See id.*, para 6-3-4.

[92] *See id.*

C. Air Force Participation Before the 2011 National Defense Authorization Act

Before the 7 January 2011 passage of the Ike Skelton 2011 National Defense Authorization Act, and as illustrated by the enXco Shiloh II project, Air Force involvement with either the FAA or developers was usually minimal until very late in the DNH process.[93] While developers like enXco typically spent years investigating potential sites and invest substantial sums in obtaining local permits and environmental studies,[94] they were not required to formally notify the FAA or the Air Force of their construction plans until they were close to beginning turbine construction. Although recently revised FAA guidance now requires developers to provide up to forty-five-days notice of their construction plans, the previous regulation permitted notice as late as thirty days before construction.[95] While the majority of these regulatory provisions deal with physical obstructions, the FAA handbook recognized "an electromagnetic interference potential may create adverse effects as serious as those caused by a physical penetration of the airspace by a structure" and required that those effects be identified and, if possible, resolved.[96]

Because modern turbines exceed the height standard, the FAA presumes the turbines to be a hazard unless a subsequent study by the FAA proves otherwise.[97] As part of that review, the FAA contacts the Air Force for its evaluation of the proposed projects.[98] The Air Force's program manager for Obstruction Analysis/Airport Airspace Analysis (OE/AAA) then forwards the FAA's request for information to functional experts for their input regarding the proposed wind turbines.[99] At the time the Travis issue arose, the Air Force practice was to evaluate a proposed structure's potential for physical obstruction and its impact only on long-range radars air defense radars.[100] The Air Force did not provide the FAA with guidance on the potential impact the structure could have on ATC radars like the one at Travis.[101] As explained later, this deficiency was the source of considerable consternation to officials at Travis and AMC.[102] To illustrate this point, this article next discusses the Air Force's role in evaluating FPL's thirty-turbine project for the WRA.

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[93] Skelton Act, *supra* note 78. The impact of the new statute will be discussed *infra*.
[94] See, e.g., enXco Wind Energy, *Project Development*, www.enxco.com/wind/development (last visited May 13, 2012).
[95] Notice Requirements, 14 C.F.R. § 77.7 (2004). The 45-day notice requirement became effective January 18, 2011. The superseded notice requirement was located at 14 C.F.R. §§ 77.17(b) (2004).
[96] Handbook, *supra*, note 84, at paras. 6-3-10(a) and (f).
[97] *See id*, para. 6-3-2.
[98] *See id*, para. 6-3-6(f).
[99] E-mail from Lt Col Brian W. Lindsey, 60 OSS/DO, to Raymond Crowell, 60 AMW/DS (June 17, 2009, 9:17 AM) (on file with author); e-mail from Terri Johnson, USAF OE/AAA Program Manager, A3O-AAN USAF Liaison, Eastern Service Area, to Lt Col Brian Lindsey, 60 OSS/DO, Travis AFB (Aug. 10, 2009,10:38 AM) (on file with the author).
[100] E-mail from Shawn Jordan, 84 RADES/SCMD, to the author (Aug. 10, 2009, 9:16 AM) (on file with the author).
[101] Johnson e-mail, *supra* note 99.
[102] E-mail from Colonel (Col) James C. Vechery, 60 AMW/CC, to Lt. Colonel Brian Lindsey, 60 OSS/DO (Aug. 14, 2009, 3:57 PM) (on file with author).

To put the FPL project into context, Travis AFB and AMC officials were aware SMUD and FPL planned to pursue new turbine projects following approval of enXco's Shiloh II and the February 2009 installation of Travis' new digital radar, the ASR-11.[103] As noted earlier, these officials were still concerned about the cumulative impact of turbine development and the lack of a predictive model to assess new projects. Additionally, ongoing efforts to find a validated predictive modeling tool revealed that any such effort was at least a year from being fielded.[104] Further, on 4 May 2009 Travis and AMC officials learned the FAA issued DNH findings for SMUD's forty-nine-turbine project.[105] Consequently, Travis and AMC officials monitored the progress of FPL's application to the FAA very closely and with heightened interest.

On 1 June 2009, the Air Force's OE/AAA manager forwarded the FAA's requests for inputs on FPL's project to the 84th Radar Evaluation Squadron (84 RADES) at Hill AFB, Utah, and AMC's Terminal Instrument Procedures or "TERPS" Branch of its Operations Division (AMC/A3AT)[106] This duty section addresses issues of physical obstruction, that is, whether the height of the turbines would intrude or come close to intruding on flight paths near Travis.[107] The AMC Operations Division reported the height of the turbines would not hazard planes using Travis[108]—a logical conclusion since the WRA itself was more than 4.5 nautical miles from the base.

While 84 RADES does evaluate a structure's potential for electromagnetic interference, the squadron does not evaluate all radar systems. Its primary focus is on homeland defense. Specifically, it evaluates radars that feed data into a North American Aerospace Defense Command (NORAD) Region Operations Center or Air Defense Sector radar.[109] These are basically long-range air-defense radars (rather than ATC radars). For that reason, 84th RADES *did not evaluate* the turbines' impact on Travis' ATC radar.[110] The 84 RADES did, however, evaluate the turbines' potential impact on long-range radars from Mill Valley, Stockton and Sacramento.[111] On 15 June 2009, 84 RADES reported FPL's turbines would have a "minimal" impact on these radars.[112] The Air Force OE/AAA program manager relayed both

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[103] Letters from Col Steven J. Arquiette, 60 AMW/CC, to SMUD and FPL (both Mar. 24, 2008); Letter from Colonel Mark C. Dillon, 60 AMW/CC, to Solano County Planning Comm'n (Apr. 16, 2009).
[104] E-mail from Dr. Donald R. Erbschloe, AMC/ST, to Raymond Crowell, 60 AW/DS and author (May 29, 2009, 12:11 PM) (on file with author).
[105] Determination of No Hazard to Air Navigation, 2009-WTW-2379 through 2009-WTW-2428, (May 4, 2009). The FAA published a separate DNH for each of SMUD's 49 turbines.
[106] Lindsey e-mail, *supra* note 99.
[107] E-mail from John F. Tigue, AMC/A3AR, to the author (Aug. 13, 2009, 9:21AM) (on file with author).
[108] *Id.*
[109] U.S. Dep't of Air Force, Instr 13-101, Evaluation of Ground Radar Systems para. 1.3.1 (Oct. 29, 2004).
[110] Jordan e-mail, *supra* note 100.
[111] *See id.*, Mr. Jordan added that 84 RADES "... did not assess this project against the Travis (ASR-11) since it is not integrated into the Air Defense or AMOC [Air and Marine Operations Center] air pictures."
[112] *Id.*

the AMC/A3AT and 84 RADES input to the FAA.[113] Though the FAA considered this input the definitive Air Force position regarding this project,[114] neither AMC's obstruction analysis nor 84 RADES' electromagnetic analysis addressed Travis and AMC concerns about the wind turbines' impact on the ASR-11.[115]

In an effort to ensure their concerns were considered, Travis and AMC officials engaged with permitting officials in Solano County, the developers, and the FAA. During these interactions, which included a teleconference with the FAA's OE/AAA manager, Air Force officials from both locations unambiguously stated their concerns about the impact additional turbines could have on the ASR-11.[116] Despite these efforts, the FAA issued a DNH determination to FPL on 7 August 2009 regarding the ASR-11,[117] stating:

> This determination included evaluation of the potential impacts to the radar coverage of the new Travis AFB ASR-11commissioned in February 2009. Potential impacts to both the military mission and provision of services to civilian aircraft in the Bay-Delta area were considered. Understanding the fact that the Montezuma Hills Wind Resource Area (WRA) has approximately 815 wind turbine generators established and the petitioner is requesting to build an additional 31 turbines, the results of this study concluded that there was "no significant impact" to the airspace and air traffic control services provided to aircraft in the vicinity of the WRA. The USAF confirmed that coordination was accomplished through the 84th RADES and the Air Mobility Command (AMC), the parent command to the military mission at Travis AFB.[118]

During their analysis, FAA technicians noted the problem created by the wind turbines, but the FAA ultimately decided the problem was not sufficiently serious to issue a presumption-of-hazard-to-air-navigation determination.[119] The FAA concluded the VFR sectional cautions (mentioned earlier) sufficiently mitigated the hazard.[120] As quoted above, the FAA's rationale within the DNH suggested it was at least partially premised on the fact the WRA already had almost 815 turbines.[121]

P21-36 cont.

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[113] Johnson e-mail, *supra* note 99.
[114] *Id.*
[115] Findley letter, *supra* note 27.
[116] E-mail from John F. Tigue, AMC/A3AR, to Colonel William A. Malec, AMC/A3A (June 29, 2009, 4:36 PM) (on file with author.)
[117] Determination of No Hazard to Air Navigation, 2009-WTW-3043 through 2009-WTW-3073, 7 Aug 2009. The FAA published a separate DNH finding for each of FPL's 30 turbines.
[118] The quoted language was included in each of the FAA's DNH determinations for all of FPL's turbines.
[119] E-mail from Lt Col Brian W. Lindsey, Director of Operations, 60 Air Mobility Wing, to the author (Major (Maj) Thomas F. Collick) and to John Tigue, Air Mobility Command, Air Traffic Systems and Resource Manager, (August 13, 2009, 10:43 CST) (on file with the author).
[120] *Id.*, and *see* note 35, *supra*, for contents of notice.
[121] Quoting from Aeronautical Study # 2009-WTW-3044-OE, "This determination included evaluation of the potential impacts to the radar coverage of the new Travis AFB ASR-11 commissioned in

The FAA's DNH determinations for both the SMUD and FPL projects, despite objections by Travis AFB and AMC, convinced Lieutenant General (Lt Gen) Vern M. Findley, the AMC vice commander at the time, to write directly to the FAA's OE/AAA program manager. In his 3 September 2009 letter, Lt Gen Findley reiterated AMC's concern about the safety impact of the FAA's recent DNH decisions on the SMUD and FPL turbine projects. He observed the existing turbines in the WRA already caused Travis' ATC radar to lose primary surveillance radar on general aviation aircraft in the WRA "at least" fifteen percent of the time.[122] Lt Gen Findley warned that additional WRA development that further reduced Travis' ability to track aircraft among the Air Force's large, fast-moving planes "invite[d] catastrophe."[123] In emphasizing the need for a way to assess the impact of future turbine construction, he wrote:

> At some point, the construction of additional turbines *will* impact aviation safety. Neither we nor the FAA, I assume, know when we've reached that threshold. While the construction of 76 wind turbines may not, in itself, *appear* to pose a safety problem, the fact that this would be a ten percent increase in the number of turbines already operating in the WRA is troubling because *we currently have no way to assess their cumulative impact*. As a possible solution, we suggest the FAA and the Air Force join interested wind energy developers to develop an assessment capability.[124]

Lt Gen Findley closed his letter by explaining he had "no choice" but to object to additional WRA development absent a method of assessing the impact of future turbine construction on the Travis radar. The general sent a copy of this letter to Solano County officials, who then attached his letter to a next-day request that the FAA reconsider the DNH decision in FPL's case.[125]

On 15 October 2009, the FAA notified Solano County that it was denying the reconsideration request.[126] The FAA stated it had followed its procedures and

P21-36 cont.

February 2009. Potential impacts to both the military mission and provision of services to civilian aircraft in the Bay-Delta area were considered. Understanding the fact that the Montezuma Hills Wind Resource Area (WRA) has approximately 815 wind turbine generators established and the petitioner is requesting to build an additional 31 turbines, the results of this study concluded that there was "no significant impact" to the airspace and air traffic control services provided to aircraft in the vicinity of the WRA . . . ."

[122] Findley letter, *supra* note 27.

[123] *Id.*

[124] *Id.* (emphasis in original).

[125] Letter from Mr. Lee Axelrad, Deputy Cnty. Counsel, Solano Cnty., to Manager, Air Space Rules Div., FAA, (Sept. 4, 2009) (on file with author). Solano County's request included only FPL's turbines. Any review petition must be filed within thirty days of the FAA's decision. Because more than thirty days had elapsed since the FAA's DNH decision for SMUD, Solano County could not request review of that decision. In the absence of a petition for review, the FAA's decision becomes final 40 days after issue. If a petition is filed, the decision's effective date is delayed until the matter is resolved. See 14 CFR § 77.37(a) and the Handbook, para 7-1-5(b) and 7-1-5(c).

[126] Letter from Elizabeth L. Ray, Dir. of Syss. Operations Airspace and Aeronautical Info. Mgmt., Air

confirmed the results of the original evaluation. While the FAA acknowledged the turbines would impact the ASR-11, the agency found "no substantial adverse impact" and no hazard to navigation.[127] The agency also stated that it considered the Air Force to be "team members" when conducting aeronautical studies and that the agency regularly met with Air Force officials concerning the obstruction evaluation program. The FAA further stated the Air Force "sets their own parameters and standards for the cases it wants to evaluate."[128] Finally, the agency correctly noted that the Air Force received a copy of the study and the "USAF" responded with no objection.[129]

The FAA's denial left the DNH actions in place and Travis and AMC in a quandary. Neither Travis nor AMC officials were satisfied with the FAA's decision. They remained concerned the FAA reached its conclusion without a validated tool to assess the cumulative impact future turbine projects could have on the ASR-11. Additionally, this experience exposed deficiencies in how the Air Force responded to FAA requests for inputs into the obstruction evaluation process. In determining how to proceed, they wanted to address both issues. Before deciding on a final course of action, they considered but ultimately rejected other options, discussed next.

IV. Rejected Options to a Squally Problem

A. Internal Resolution through the U. S. Attorney General

Aside from repeatedly bringing its concerns to the appropriate FAA officials and elevating them as necessary, the Air Force had limited options in such a disagreement between federal agencies. While the U.S. Attorney General is authorized to decide issues of law between different executive departments, this authority does not extend to questions of fact.[130] The issue between the Air Force and the FAA was one of fact, not law. AMC's and Travis' review of the wind turbines' impact on the ASR-11 concluded that future development had the potential to degrade its performance below acceptable levels. The FAA's aeronautical study came to the opposite conclusion. Resolving this dispute would require an assessment of

P21-36 cont.

Traffic Org., to Lee Axelrad, Office of Solano Cnty. Counsel, (Oct. 15, 2009) (on file with the author).

[127] *Id.*

[128] *Id.*

[129] *Id.* By "USAF" the FAA is apparently referring to the 84 RADES and AMC/A3AT studies referenced *infra*. This is an understandable conclusion. The FAA provided the Air Force's OE/AAA with a request for Air Force inputs about the FPL turbine project. Just over two weeks later, the Air Force's OE/AAA provided the requested response indicating FPL's project would have "minimal impact" on long-range radar and would not physically obstruct aircraft at TAFB. It was natural for the FAA to conclude that response—and not the later contrary comments of TAFB, AMC or Lt Gen Findley—as the final and considered Air Force opinion on the FPL turbine project. As the FAA noted in their response to Solano County, the Air Force is "responsible for its internal coordination and for notifying the appropriate offices."

[130] 28 U.S.C. §§ 511-513 (2006). The provision applicable to the military services is 28 U.S.C. § 513. The Attorney General has delegated this authority to the Office of the Legal Counsel. *See* Department of Justice website, http://www.justice.gov/olc/opinions.htm (last visited May 13, 2012).

the merits of the different studies—precisely the sort of dispute excluded from the Attorney General's review.[131]

B. Solano County Option

As noted earlier, Solano County delayed enXco's wind farm project when the Air Force could not[132]—an occurrence that suggested the two agencies should explore other ways the county could assist the Air Force when their interests coincided. Though the Air Force's interest in Travis' continued operation is manifest, state law also gives Solano County a statutory basis for the same interest. While California recognizes federal supremacy regarding the operation, control and safety of the airways,[133] state law also requires county officials to encourage development around military airports that is consistent with the safety and noise standards developed by the installation.[134] Responding to base closures due to development that interfered with base operations, the California legislature noted the military is a "key component of California's economy" and that protecting military installations was "in the public interest."[135] Solano County thus was legitimately interested in preventing further degradation of Travis' radar, which in turn could lead to decreased or abolished flying operations at the base. Because the Air Force is part of the executive branch, it could not contest the FAA's DNH decisions in court.[136] Solano County, however, as a state entity, could request the FAA to review its decision.[137] If not satisfied, the county could challenge the FAA's decisions in federal court, as a Nevada county had done in a case that set out the issues such a challenge would have to confront to be successful.[138]

P21-36 cont.

In *Clark County v. FAA*, county officials succeeded in overturning no-hazard determinations for wind turbines that both presented a physical obstruction and degraded radar performance.[139] A wind farm developer planned to construct eighty-three four-hundred-foot wind turbines ten miles southwest of a proposed new airport.[140] Clark County studies revealed the turbines intruded into the runway's departure slope.[141] In addition, another study showed the turbines could impact aviation safety by creating false and/or intermittent targets on the airport's radar.[142] Two offices within the FAA raised concerns about the turbine's impact on the radar, but the FAA dismissed them.[143] As in the Travis situation, the FAA conducted its

[131] Obstruction to Navigation, 21 Op. Att'y Gen. 594 (1897).
[132] *See supra* text accompanying notes 55-77.
[133] CAL. PUB. UTIL CODE § 21240 (DEERING 2010).
[134] CAL. PUB. UTIL.CODE § 21675 (DEERING 2010).
[135] Muzzy Ranch Co. v. Solano Cnty. Airport Land Use Comm'n, 164 Cal.App.4th1, 16 (Cal.App. 1 Dist., 2008).
[136] U.S.C., *supra* note 130.
[137] 14 CFR § 77.37(a) (2010).
[138] 49 U.S.C. § 46110 (2005).
[139] *See generally* Clark County, Nev. v. FAA, 522 F.3rd 437 (D.C. Cir. 2008).
[140] *Id.* at 438.
[141] *Id.* at 440, 442.
[142] *Id.* at 442.
[143] *Id.*

own aeronautical study, concluded there was no problem, and issued a DNH for each of the eighty-three turbines.[144] When Clark County sued, the FAA responded by urging the court to dismiss the case because Clark County lacked standing to bring the action and its petition was not ripe.[145] The FAA also claimed that even if it did not prevail on the first two issues, its no-hazard determinations were reasonable and appropriate[146].

The court rejected all the FAA's contentions. Clark County established standing by demonstrating the radar problems created by the turbines and then showing it would suffer injury because the FAA's DNH rulings would allow construction of those same problematic wind turbines.[147] In denying the ripeness claim, the court noted that the FAA's DNH rulings were the only decisions the FAA would make. At oral argument, the FAA conceded that though the determinations are subject to review and renewal, a later challenge likely could not object to the initial DNH decision. The court found this concession persuasive on the "ripeness" issue.[148] To assess the reasonableness of the FAA's decision, the court reviewed the FAA's decision in accordance with the Administrative Procedures Act to determine if the agency's action was "arbitrary, capricious, an abuse of discretion, or otherwise not in accordance with the law."[149] Finding that the FAA had failed to adequately explain its decisions regarding either the physical obstruction evidence or provide "any coherent explanation countering the concerns about radar interference," the court vacated the FAA's determinations.[150]

Like Clark County, Solano officials probably could have demonstrated they had standing and a ripe case and quite possibly that no convincing evidence supported the FAA's decision. Solano County had standing because it could first establish that the existing wind turbines had adversely affected Travis' radar. Then, the county could show it suffered injury because the FAA's DNH rulings would permit the construction of turbines that could further degrade the radar and imperil Travis AFB operations—which Solano County had a statutory duty to protect.[151] For the same reasons stated in the Clark County case, this matter would also be ripe for decision.

In addressing whether the FAA's decision was arbitrary, capricious or an abuse of discretion, Solano County could have pointed out that, as in Clark County's case, the FAA's own technicians identified a problem with the wind turbines that

P21-36 cont.

[144] *Id.* at 441.
[145] *Id.* at 440.
[146] *Id.*
[147] *See id.* at 440. If the FAA had determined the wind turbines would hazard air navigation, Solano County officials (like their counterparts in Clark County NV) would have been compelled to stop the project as further construction would not be compatible with operations at Travis AFB. *See* Shutt Moen Assocs., Travis Air Force Base Land Use Compatibility Plan: Solano County, California, Table 2A (2002) *available at* http://www.co.solano.ca.us/civicax/filebank/blobdload.aspx?blobid=3929. (adopted by Solano County Airport Land Use Commission).
[148] *See id.* at 441.
[149] *See id.* at 441 (referencing the standard defined at 5 U.S.C. § 706(2)(A) (2006)).
[150] *Id.* at 443.
[151] *See supra* notes 133, 134 and 138 and text accompanying note 147.

the agency ultimately disregarded. It also would have had the benefit of radar studies showing the ASR-11 was missing at least fifteen percent of PSR or Primary Surveillance Radar from general aviation aircraft over the WRA. Significantly, the FAA's lack of a validated predictive model to assess the impact of further turbine construction would weaken the FAA's case—as would Lt Gen Findley's opinion that further development without such a tool would "invite catastrophe." With these facts, a court could conclude that the turbines' effect was not only "adverse" but so considerable as to have a "substantial adverse" effect on the Travis ATC radar. Based on these circumstances, the FAA should have issued a notice of hazard,[152] and failing to do so could be construed as an abuse of discretion. In sum, Solano County might have prevailed on this last point unless the FAA could explain how it arrived at its DNH ruling despite the demonstrated decrease in detection and radar performance over the WRA. However, shortly before the 15 October 2009 FAA decision denying the County's request for reconsideration, the winds of change began to blow . . . .

V. A Cooperative Solution But Not "The" Solution

Because officials at both AMC and Travis had extensive involvement with Solano County and the wind-farm developers, all parties trusted each other. As noted above, with the DNH in hand, the developers could have made a strong case for their projects before Solano County. Even so, enXco, FPL and SMUD voluntarily agreed not to proceed with turbine construction until the radar issue was resolved. The willingness of all parties to work with the base to resolve this issue led to a more cooperative, sustained approach without resort to litigation.[153] During ongoing discussions with wind-farm developers and the County, Air Force officials, with the assistance of the U.S. Transportation Command (USTRANSCOM),[154] formally invited developers to help the Air Force find a solution to the radar issue by participating in a Cooperative Research and Development Agreement (CRADA).[155] P21-36 cont.

[152] *See* text accompanying notes 121 and 125.

[153] One option Air Force officials considered was the creation of a second "Joint Technical Working Group" as was done for enXco's Shiloh II project. This approach was tempting because it had worked previously, but it had drawbacks, too. First, resolution of the issue took almost one year and stalled development of this important renewable energy source. Second, and more important, adopting this approach would not address the concerns expressed by AMC and Travis to the FAA. The FAA reached its DNH finding for FPL's and SMUD's projects without a verifiable means to assess the cumulative impact additional turbines may have on the ASR-11's performance. While not rejecting a joint technical team, AMC and Travis AFB wanted to ensure any solution to the present wind turbine issues also included a means to assess the impact of further development in the WRA.

[154] The United States Transportation Command, located at Scott Air Force Base, Ill., was established in 1987 and is one of 10 U.S. unified commands. As the single manager of America's global defense transportation system, USTRANSCOM is tasked with the coordination of people and transportation assets to allow our country to project and sustain forces, whenever, wherever, and for as long as they are needed. USTRANSCOM has a Technology Transfer and Cooperative Research and Development Agreements Division with the capability to enter into technology exploration partnerships with non-federal entities. *See* U.S. Transportation Command, http://www.transcom.mil (last visited May 13, 2012).

[155] On 30 Sep 2009, Solano County officials hosted a "Travis AFB Radar—Wind Turbine Co-

A CRADA permits the federal government to collaborate with nonfederal entities on research projects of mutual interest.[156] While CRADA participants share personnel and resources, non-federal collaborating parties do not receive federal funds.[157] Because CRADAs can be executed quickly,[158] they are an effective means of quickly bringing together talented people and resources. In this case, enXco, FPL, and SMUD all participated.[159] Additionally, other CRADA collaborators provided technical support, including commercial companies Westslope Consulting, JDA Aviation Technology Solutions and Morgan Aviation,[160] and two governmental entities—the Air Force Flight Standards Agency and the Department of Transportation's Volpe National Transportation Center. The Department of Energy's Idaho National Laboratories provided an independent review of the technical work done under the CRADA.[161] The FAA did not participate in the CRADA.

The CRADA created two working groups, a Radar Working Group and an Operations Working Group.[162] To assess the ASR-11's performance, the Radar Working Group first obtained baseline radar and display data, then simulated the impact of the pending wind turbine projects.[163] With this data, the group used Westslope's innovative (and proprietary) methodology to manually manipulate components of the ASR-11, thus quantifying the pending projects' best- and worst-case scenarios on the radar.[164] The worst-case scenario (no radar returns from the

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Existence Workshop" where then Brigadier General (Brig Gen) Steven J. Lepper, AMC's Staff Judge Advocate at the time, personally extended an invitation to developers in attendance.

156 15 U.S.C § 3710a (2006).

157 *Id.* at § 3710a(d)(1).

158 The government first proposed the CRADA concept at a meeting on 30 September 2009 (E-mail from Colonel James C. Vechery, 60 AMW/CC, to Brig Gen Steven J. Lepper (Oct. 2 2009 8:47AM) (on file with author). By 7 December 2009, the wind turbine industry partners had signed the agreement; (E-mail from author to Brig Gen Steven J. Lepper (Dec. 9, 2009, 10:27AM) (on file with author).

159 U.S. TRANSP. COMMAND COOP. RESEARCH AND DEV. AGREEMENT, ASSESSMENT OF WIND FARM CONSTR. ON RADAR PERFORMANCE,(2009), (on file with the author). enXco Development Corporation, a U.S. subsidiary of enXco Incorporated is an affiliate of EDF Energies Nouvelle. The latter is a French company and therefore required special permission to join the CRADA. While awaiting formal approval, enXco was permitted to provide information on their construction and participate where possible.

160 Westslope Consulting, JDA Aviation and Morgan Aviation provided radar technical expertise, federal aviation air space use and regulation and traffic service requirements at developer expense. USTRANSCOM CRADA Report, *supra* note 29.

161 AFFSA, Volpe Transportation Systems Center and the 84th RADES represented the government's radar technical expertise. Idaho National Labs provided a government requested independent review of the Radar Working Group's results. USTRANSCOM CRADA, Radar Working Group Out-Brief, (19 Jan. 2010) [hereinafter USTRANSCOM CRADA Out-Brief] (on file with author).

162 U.S. Transportation Command Cooperative Research and Development Agreement, Assessment of Wind Farm Construction on Radar Performance, Attachment A, Proposed Joint Technical Activities and Milestones, 7 December 2009, (on file with the author).

163 USTRANSCOM CRADA Out-Brief, *supra* note 161.

164 *Id.*

affected area) yielded a cumulative Pd drop on the radar display of 3.2 to 3.5 percent in the airspace above the WRA.[165]

The second group, the Operations Group, developed and recommended an operationally acceptable radar Pd rate.[166] This was one of the CRADA's major accomplishments, because the baseline Pd value provided a minimum standard "necessary to maintain aviation safety and efficiency of flight operations."[167] When used with the predictive simulation developed by the CRADA, a baseline provides a meaningful way to assess the impact of future wind farm development on the ASR-11 that the Air Force did not have before.[168]

After careful analysis, the groups determined that the three pending projects would not significantly degrade the ASR-11's performance nor would they impact air safety or flight operations.[169] The results proved to support the FAA's earlier finding that the proposed developments would not create an air safety hazard.[170] Based on these results, the Travis AFB commander notified Solano County and the wind farm developers about the results of the CRADA working groups. He informed them the Air Force was withdrawing its objections to the projects.[171]

While the CRADA achieved impressive and valuable results,[172] it was not "the" solution" nor a way to do an "end run" around the FAA. A near-term solution for Travis and nearby developers would include creating a system that could unilaterally analyze future development near Travis AFB, without the need for future CRADA collaborations. To date, the CRADA has not produced these results, although its work continues. Additionally, any solution should include FAA adoption—or at least consideration—of the CRADA's baseline Pd rate when assessing further WRA development. As discussed earlier, the FAA, the final arbiter on air safety in the navigable airspace, uses its own process to evaluate wind turbine effects.

Further, the CRADA cannot evade the FAA's process for the simple reason that the CRADA's results are not legally binding—which becomes especially important as additional developers who are not CRADA collaborators seek project approvals. Moreover, the CRADA's critical component was the willingness of the

P21-36 cont.

[165] *Id.*

[166] USTRANSCOM CRADA report, *supra* note 29.

[167] Letter from Col James C. Vechery, Commander 60th Air Mobility Wing, to Solano County Department of Resource Management (Jan. 19, 2010) (on file with the author); (The CRADA team determined a minimum average probability of detection (Pd) over the WRA at the radar scope of 75.3 percent surface to 4000 feet and 79.2 percent surface to 10,000 feet are the baseline values necessary to maintain aviation safety over the WRA).

[168] USTRANSCOM CRADA report, *supra* note 29.

[169] *Id.*

[170] *See generally*, Determination of No Hazard to Air Navigation, *supra* note 117.

[171] Letter from Col James C. Vechery, Commander, 60th Air Mobility Wing, Travis AFB CA, to Michael G. Yankovich, Solano Cnty. Dep't of Res. Mgmt.(19 Jan. 2010) (on file with the author).

[172] In October 2010, USTRANSCOM and the Volpe National Transportation Systems were selected as the winner of the 2010 Federal Laboratory Consortium for Technology Transfer (FLC) Mid-Atlantic Region Interagency Partnership Award for the collaborative work in transferring technology accomplished under the CRADA.

developers, Solano County, Travis and AMC to cooperate in fashioning a solution. The developers did not limit their legal options by participating in the CRADA. Only the FAA, exercising its authority governing safety issues in navigable airspace, can make the proposed Pd rates enforceable.

The CRADA results did vindicate the decision of all involved to cooperate rather than litigate. Based on the FAA's DNH findings, the developers could have tried in court to force Solano County to issue construction permits for their turbines. With AMC and Travis fearful of the potential consequences of further WRA development, Solano County might have acted to protect the county's interest in the base by seeking to overturn the FAA's DNH rulings. Based on the analysis in Section IV above, Solano County might have prevailed against the FAA and forced a "Determination of Hazard," but this would have been only a temporary setback for the developers. After obtaining data similar to that the CRADA provided, the developers would have been able to demonstrate to the FAA that their projects would not substantially degrade the ASR-11. By joining the CRADA, the parties avoided time-consuming and expensive litigation to arrive at the same point as they did otherwise. Travis and AMC withdrew their objections, Solano County issued the construction permits, and the developers built and are now operating the new turbines.

In November 2011, the CRADA partners extended the collaboration agreement for two years.[173] Collaborators continue to collect flight data for validating the predictive tool. Additionally, through various techniques, radar experts have continued to make software enhancements to Travis' radar performance using actual traffic and pre-planned test flights directly over the WRA. The improvement has been significant, even with construction and operation of the additional turbines.[174] Significantly, the dialog among all parties has continued with the prospect that future issues, if any, can be expeditiously resolved.[175]

P21-36 cont.

VI. New Problem, New Legislation, New Procedures

Meanwhile, developments, largely centered around a long-range radar facility in Fossil, Ore., convinced Congress to change how the Air Force and the DOD respond to the challenges wind turbines present. This article next provides the context for the creation of these new procedures, set out in Section 358 of the 2011 NDAA[176]

[173] E-mail from USTRANSCOM ORTA, to USTRANSCOM CRADA (5 Dec. 2011) (Subj Draft Modification 2).

[174] *See generally* Karen Parrish, *Pentagon Streamlines Approval for Energy Projects*, Am. Forces Press Service, July 26, 2011, *available at* http://www.defense.gov/news/newsarticle.aspx?id=64814 (noting the CRADA effort and how its results may be the model moving forward).

[175] E-mail from Greg Parrott, 60 AMW/JA, to Maj Thomas F. Collick, 43 AG/JA (12 Dec. 2011, 12:39 PM) (on file with the author).

[176] Skelton Act, *supra* note 78.

A. Long-Range Radar Problem in Oregon Generate Congressional Interest in FAA Process

As with the situation at Travis AFB, the controversy in Oregon involved the potential impact of a wind farm developer's plan to add new turbines to an area already congested with them. The Shepherds Flat area, near Fossil, contained approximately 1800 wind turbines.[177] To this number, the developer, Caithness Energy, planned to add 338. Like the developers around Travis, Caithness Energy notified Air Force officials about the proposal, to which officials responded they had no objection to the proposed development.[178] Erroneously, but understandably, believing this local endorsement indicated Air Force-wide approval for the project, the company continued expensive site preparation.[179] When this work was complete and Caithness was ready to begin construction, the company gave the FAA the required thirty-day notice.[180]

As part of the FAA evaluation process, Air Force officials first considered the possibility the new turbine project could negatively impact their radars. Specifically, the Air Force worried that the additional turbines could degrade the ability of radars at Whidbey Island Naval Air Station, Wash., and Mountain Home AFB, Idaho, to track aircraft.[181] In addition, the North American Aerospace Defense Command (NORAD) and the U.S. Northern Command (NORTHCOM) were particularly concerned about the proposed development's effect on the long-range Air Surveillance Route radar at Fossil.[182] NORAD relies on this site to provide detection and tracking information that allows the command to decide whether to deploy fighter aircraft in response to a threat.[183]

P21-36 cont.

Like their counterparts at Travis AFB, the DOD radar experts had no way to assess the impact, if any, the additional turbines would have on their radar. Declining to accept the unknown level of degradation risk this set of turbines posed, Air Force officials advised the FAA of their concerns.[184] Based on the Air Force's objections, the FAA issued a "Notice of Presumed Hazard" on 1 March 2010—devastating news for Caithness Energy.[185] Not anticipating an issue at this late stage of the project, Caithness Energy had to cancel long-standing plans to begin turbine construction

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177 *Impact of Wind Farms on Military Readiness: Hearings Before the Subcomm. on Readiness of the H. Comm. on Armed Servs.*, 111th Cong., at 43 (2010) (statement of Dr. Dorothy Robyn, Deputy Under Secretary of Defense for Installations and Environment), *availale at* http://www.gpo.gov/fdsys/pkg/CHRG-111hhrg61770/pdf/CHRG-111hhrg61770.pdf

178 *Id.*

179 *Id.*

180 *Id.*

181 *Id.*

182 *Id.*

183 *Id.*

184 Scott Learn, *Air Force Concerns About Radar Interference Stall Huge Oregon Wind Energy Farm*, OregonLive.Com, April 14, 2010, http://www.oregonlive.com/environment/index.ssf/2010/04/air_force_concerns_about_radar.html.

185 *Id.*

in May 2010.[186] The FAA's decision and the resulting $2 billion Caithness' project cancellation attracted significant Senate and media attention.[187]

Ultimately, the Caithness Energy's turbine project was approved. As with the wind turbines in Solano County's WRA, DOD's further study of Caithness Energy's proposed turbine project revealed new turbines would have less impact than initially thought.[188] In late April 2010, the DOD commissioned a sixty-day study by the Massachusetts Institute of Technology to develop mitigation measures. The study suggested two near-term mitigation measures—an adjustment of the radar settings for optimal performance at the Fossil radar and adding software to essentially edit out false targets (The DOD has since implemented some of these measures).[189] Based on the DOD study and the expected mitigation measures, the Air Force withdrew its objections to the project on 30 April 2010.[190] Approximately one year later, deliveries of the first large turbines began in May 2011, with construction of the 338-turbine site scheduled for completion in 2012.[191]

B. Congressional Focus on Long-Range Radar Drives Legislation

Two months after the Air Force withdrew its objections regarding Shepherds Flat, in June 2010, the Readiness Subcommittee of the House Armed Services Committee held a hearing on the impact of wind turbines on military readiness. Perhaps because the Shepherds Flats situation was fresh in their minds, subcommittee members took testimony on the national security issues raised by wind turbine development and its impact on long range radars.[192] Then subcommittee chairman, former Rep. Solomon Ortiz, a Texas Democrat, noted wind energy's growing importance coupled with increasing military objections to these projects based on conflicts with radars and existing training routes. He added that he was concerned

P21-36 cont.

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[186] *Id.*

[187] *Id.*; Juliet Eilperin, *Pentagon Objections Hold Up Oregon Wind Farm*, WASH. POST, Apr. 16, 2010, *available at* http://www.washingtonpost.com/wp-dyn/content/article/2010/04/15/AR2010041503120.html; Parrish article, *supra* note 174.

[188] Press Release, Office of the Deputy Under Secretary of Defense - Installations and the Environment, Department of Defense notifies Federal Aviation Administration - wind turbine development plans in Northern Oregon and Southern Washington pose no additional risk to national security (1 Oct. 2010), *available at* http://www.acq.osd.mil/ie/download/20101001-turbines.pdf.

[189] *Id.*

[190] *Id.*

[191] Caleb Denison, *Big Wind Farm Gets Big Turbine Delivery*, EARTHTECHLING (May 31, 2011), http://www.earthtechling.com/2011/05/big-wind-farm-gets-big-turbine-delivery/.

[192] Impact of Wind Farms hearing, *supra* note 177 Statement of Rep. John Garamendi, *available at* http://democrats.armedservices.house.gov/index.cfm/hearings?ContentRecord_id=f0755a71-d039-491f-a724-fe4778cabc7c. Rep Garamendi represents California's 10th District which includes Solano County. He noted the hearing focused on long-range radar and attempted, with limited success, to elicit testimony from Ms. Robyn concerning the ATC radar at Travis AFB. Rep. Garamendi took the opportunity to express his approval of the way wind developers and the military worked together to resolve issues at Travis AFB.

by the "lack of a coordinated, well-established review process within the Department of Defense to provide timely input for these green energy initiatives."[193]

Dorothy Robyn, deputy undersecretary of defense for installations and environment, testified before the committee and expanded on Rep. Ortiz's comment. She recommended the subcommittee support creating a single DOD point of contact for developers on renewable energy sitings, describing the proposed point of contact as a sort of "1-800-Butterball"—the equivalent of a turkey-cooking hotline that wind developers could consult to receive an authoritative and comprehensive DOD position.[194] Because technological solutions were critical, Robyn urged federal agencies to "realign their research and development priorities to give greater emphasis to this issue."[195] Though her focus was primarily long-range radars, she did observe that wind-turbine-induced degradation of ATC radars could adversely affect DOD training missions.[196]

Wind-energy developers were represented by Stu S. Webster, director of wind development, permitting, and environmental at Iberdrola Renewables.[197] Webster told the subcommittee that a "better system for engaging federal agencies on radar and airspace issues" was necessary to avoid jeopardizing wind projects and meeting the nation's energy goals.[198] He added that the wind industry supported establishing a "single entity" to review wind projects in DOD.[199] To help the industry achieve the nation's energy goals, he urged the subcommittee to develop an improved process for early consultation, establish a proactive plan to upgrade existing radars and invest in significant research and development.[200] P21-36 cont.

The final witness was from the FAA—Nancy Kalinowski, vice president for system operations services of the FAA's Air Traffic Organization, whose office is responsible for assessing the impact of development that impinges on the country's navigable airspace.[201] During her testimony, Kalinowski pointed out the steep rise in wind turbine cases from 3030 in 2004 to 25,618 in 2009, before dropping to 18,685 cases in 2010. While the FAA reviews each turbine separately, she acknowledged the wind turbines' cumulative effect will "obviously be more significant based on the total number grouped together."[202] Kalinowski questioned the adequacy

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[193] *Id.* Statement of Rep. Solomon Ortiz, Chairman, Subcommittee on Readiness.

[194] *Id.* Testimony of Dr. Dorothy Robyn, Deputy Under Secretary of Defense (Installations and Readiness).

[195] *Id.*

[196] *Id.*

[197] According to its website, Iberdrola Renewables, Inc. is headquartered in Portland, OR and is the second-largest wind operator in the U.S. and is generating power from more than 40 renewable energy projects for its utility-scale customers in the United States, *see* Iberdrola Renewables, http://www.iberdrolarenewables.us/business-overview.html (last visited May 13, 2012).

[198] Impact of Wind Farms hearing, *supra* note 177 Statement of Mr Stu S. Webster, Director of Wind Development Permitting and Environmental, Iberdrola Renewables.

[199] *Id.*

[200] *Id.*

[201] *Id.* Statement of Ms. Nancy Kalinowski, Vice President, Systems Operations Services, Air Traffic Organization, Federal Aviation Administration.

[202] *Id.*

of the forty-five year-old requirement that her agency receive notice no later than thirty days before construction. That standard, she stated, was appropriate when the FAA evaluated the impact of single, stationary structures—but not in complex wind-turbine cases.[203] As discussed next, many of the concerns highlighted by these witnesses were incorporated into new legislation that formalized DOD's role in the obstruction review process.

C. Section 358 of the Ike Skelton NDAA and its Implementing Regulation

The legislation quickly changed how the Air Force and DOD respond to renewable energy projects that have the potential to impact their operations. The statute made it a DOD objective to ensure that the "robust development of renewable energy sources" and the "increased resiliency of the commercial electric grid" move forward while "minimizing or mitigating" adverse impacts on military operations and readiness.[204] To this end, the statute created an executive agent, imposed two sets of requirements to be implemented within 180 and 270 days, respectively, and required the DOD to surmount new, and higher, hurdles before deciding a renewable energy product presents an "unacceptable risk." Each will be discussed below.

The statute required the Secretary of Defense to appoint an "executive agent"[205] and a lead organization from the DOD to carry out the reviews required by the new law.[206] The executive agent's role is to oversee a clearinghouse to coordinate DOD review of renewable energy projects' effects on military capability.[207] The new law unequivocally makes the executive agent the one person (senior officer as discussed later) who will speak to the FAA for the Air Force and DOD on wind turbine and other renewable energy issues. Additionally, the executive agent is responsible for developing "planning tools" necessary to determine the acceptability of proposals that are ultimately submitted to the FAA for review. Once fully developed, the planning tools will likely include predictive models or simulation tools like the one being developed by Westslope.[208]

Not later than 180 days after enactment, the statute required the executive agent review OE/AAA applications received from the FAA that could adversely impact military operations or readiness.[209] In addition to assessing the scope and duration of the impact, if any, the project might have on operations and readiness,

P21-36 cont.

[203] *Id.*

[204] Ike Skelton Act, *supra* note 78.

[205] As noted in Karen Parrish's *Pentagon Streamlines Approval for Energy Projects*. Mr. David Belote, a retired United States Air Force Colonel and the former air base wing commander at Nellis AFB NV, had considerable experience responding to the challenge of renewable energy projects near an active military base and major test and training range.

[206] *See supra* note 78 at § 358(b).

[207] Parrish article, *supra* note 174.

[208] *See supra* note 163 and accompanying text.

[209] *See* Skelton Act, *supra* note 78 at § 358 (c). The requirements of the "preliminary review" described in this section are set out in Section 358(c)(1)-(4).

the executive agent must identify "feasible and affordable actions"[210] that DOD, the developer or "others"[211] could take to mitigate adverse impact and minimize risk to national security. The executive agent was required to work with other federal agencies to ensure his or her response to the FAA was "integrated" and "timely."[212]

Further, the executive agent was required to establish procedures for a "coordinated consideration" of responses to or review requests from local officials and developers, including guidance to each military installation on implementing these procedures. Finally, the statue imposed a public notice requirement on the executive agent. The statute required the executive agent to develop procedures to conduct early outreach to parties submitting applications to the FAA's OE/AAA for projects that could impact operations or readiness, as well as extending the outreach to the "general public."[213] Both the general public and developers must receive clear "notice on actions being taken"[214] and be given the opportunity to comment.[215]

Beginning no later than 270 days from enactment, the executive agent was required to develop a "comprehensive strategy for addressing the military impacts" of projects requiring OE/AAA analysis.[216] In addition to assessing the "magnitude of interference"[217] created by these projects, the executive agent was required to identify geographic areas that are or may become likely sites for wind turbine projects.[218]

Under the new process, where development might adversely impact military operations or readiness, the executive agent will assess the threat. After assessment, the executive agent will categorize the area as high risk, medium risk, or low risk. The executive agent will share his assessment with interested parties and will also identify "feasible and affordable long-term actions"[219] to mitigate the adverse impacts of these projects. Potential mitigation actions could include reviewing DOD's research and development priorities, modifying military operations to accommodate these projects, recommending upgrades or modifications to existing DOD systems, acquiring new systems by the DOD or other federal agencies and modifying to the proposed project. P21-36 cont.

DOD hazard assessments begin with the executive agent's preliminary review previously described.[220] The DOD is required to complete its assessment and respond to the FAA no later than thirty days after a developer files an OE/AAA

[210] *See id.* § 358 (c)(1)(B).

[211] *Id.*

[212] *Id.* § 358 (c)(3).

[213] *Id.* § 358 (c)(4).

[214] *Id.*

[215] *Id.*

[216] *See id.* § 358(d)(2). The elements of the "comprehensive strategy" discussed here are set out in Section 358(d)(1) and Section 358(d)(2).

[217] *Id.* § 358(d)(2)

[218] *See infra* notes 222-227 and accompanying text for a discussion of the progress made to date in complying with the act.

[219] Skelton Act, *supra* note 78 at § 358(d)(2)(C).

[220] *See id.* at § 358(e). The assessment requirements discussed in this paragraph are detailed in Section 358(e)(1)-(4)

request with the FAA. The DOD's preliminary assessment will describe the risk of adverse impact on military operations and readiness and the mitigation needed to address the risk. The Secretary of Defense cannot object to a developer's OE/AAA filing on the basis of "unacceptable risk" unless the Secretary determines—after full consideration of mitigation actions—that approval of the project would "result in an unacceptable risk to the national security of the United States."[221] Moreover, the Secretary must notify congressional defense committees of his action. The notification must include the basis for the decision, discuss the operational impact that led to the decision and explain the mitigation options considered why they were not adequate or feasible.

Interestingly, the DOD, other federal agencies, alternative energy associations and nongovernmental organizations had already been collaborating on new review procedures.[222] In early December 2010, industry representatives had agreed to approach Congress with DOD officials in an effort to establish review guidelines, but that effort was cut short with the passage of the authorization act in early January 2011.[223] Perhaps their efforts and prior partnerships helped the newly created clearinghouse to move quickly.

Consistent with the legislation, the clearinghouse has reached several significant milestones. On 26 July 2011, officials reported that the clearinghouse identified 249 backlogged projects in thirty-five states and Puerto Rico.[224] Of those, 229 were approved representing ten gigawatts of wind-generated energy.[225] The clearinghouse worked with all branches of the services, the FAA and the Bureau of Land Management in reaching this conclusion. Further, after being posted for public comment in October 2011,[226] the strategy and the requisite "procedures" have since largely been outlined in a section of federal regulations titled "Mission Compatibility Evaluation Process."[227]

The new procedures provide for informal and formal project reviews.[228] The informal review triggers when the clearinghouse receives a request from a project proponent. The proponent is to supply as much information about the project as possible, including the geographic location with coordinates, the nature of the project and any other information that would assist the Clearinghouse to accurately and reliably review the proposed project.[229] Within five days, the clearinghouse is to forward the information to those DOD components that may have an interest in reviewing the project.[230] Within forty-five days (fifty days after first contract), the clearinghouse must notify the project proponent of its determination that the proposal

P21-36 cont.

[221] *Id.* at § 358(e)(2).

[222] Parrish article, *supra* note 174.

[223] *Id.*

[224] *Id.*

[225] *Id.*

[226] Mission Compatibility Evaluation Process, 76 FR 65112-02, 65115 (Oct. 20, 2011).

[227] See 32 C.F.R. §§ 211.1 – 211.12 (2002).

[228] *Id.* at §§ 211.7 and 211.6.

[229] *Id.* at § 211.7(a).

[230] *Id.* at § 211.7(b).

will or *will not* have an adverse impact on military operations and readiness.[231] If the clearinghouse expects an adverse impact, it must immediately notify the proponent, seek discussions regarding project mitigation and designate a DOD component to serve as an agent to discuss mitigation.[232] Parties are then to seek mitigating solutions.[233] The regulation is silent regarding an impasse at this point, but the steps should at least ensure the parties have met and identified issues early in the review process should the proponent continue toward a formal review.

Formal review begins when the clearinghouse receives a properly filed application pursuant to 49 U.S.C. §44718 from the Secretary of Transportation.[234] The clearinghouse then forwards the proposal to DOD components it believes has an interest in the project, and those offices must then respond within twenty days.[235] Additionally, the DOD offices responsible for installations and environment, readiness and operational test and evaluation must provide a preliminary assessment of the level of risk of an adverse impact on military operations and readiness and the extent mitigation may be needed.[236] No later than thirty days from receiving a proposal, the clearinghouse must notify the Secretary of Transportation that the proposal *may* or *may not* have an adverse impact on military operations and readiness.[237]

Like the informal procedures, for those projects that may have an impact, the clearinghouse must seek discussions regarding project mitigation and designate a DOD component to serve as an agent to discuss mitigation.[238] The applicant then has five days to respond to the invitation to discuss recommendations and mitigation measures. Additionally, the clearinghouse is to notify the Secretaries of Transportation and Homeland Defense[239] and invite the administrator of the FAA and the Secretary of Homeland Security to the discussions.[240]

Unlike the informal procedures, the formal process does provide for an impasse. Absent a written agreement to extend discussions between the designated DOD component and the applicant, the discussions shall not extend beyond ninety days from initial notification to the applicant.[241] If the designated DOD component and applicant remain in a stalemate, the clearinghouse must determine that the proposal, as it may have been modified by the applicant, would result in an

P21-36 cont.

[231] *Id.* (As defined in the regulation, "adverse impact on military operations and readiness" is defined as "[a]ny adverse impact upon military operations and readiness, including flight operations, research, development, testing, and evaluation, and training that is demonstrable and is likely to impair or degrade the ability of the armed forces to perform their warfighting missions.")

[232] *Id.*

[233] *Id.*

[234] *Id.* at § 211.6.

[235] *Id.*

[236] *Id.* at § 211.5(c).

[237] *Id.*

[238] *Id.*

[239] *Id.*

[240] *Id.*

[241] *Id.*

unacceptable risk to national security.[242] Whether or not the clearinghouse concurs with the DOD component, the clearinghouse forwards its recommendation to the senior official. The senior official then makes his independent recommendation to the senior officer.[243] At this point, the senior officer ultimately makes a determination on behalf of the DOD regarding whether or not the applicant's project, including mitigation measures of the DOD and the applicant, would result in an unacceptable risk to the national security and notifies the Secretary of Transportation of his decision[244] If an unacceptable risk determination is made, the senior officer must identify which of the three criteria creates the unacceptable risks to national defense.[245] At this time, the senior officer must report this determination to Congressional defense committees along with supporting rationale.[246] If necessary, the senior official and senior officer may seek an extension of time from the Secretary of Transportation.[247]

In November 2011, in another significant milestone, the DOD partnered with the National Resources Defense Council to release a new mapping tool to help steer renewable energy projects away from areas where they would interfere with military activities or environmentally sensitive areas.[248] The Renewable Energy and Defense Database (READ) uses geospatial data to show if a potential site conflicts with installations, flight training routes, testing and training ranges or other military activities, including sites where projects such as wind turbines could interfere with technical radar systems.[249] It allows developers to enter geographic coordinates for potential projects early in the planning process.[250]

P21-36 cont.

[242] *Id.* (An unacceptable risk to the national security of the U.S. is defined as, "the construction, alteration, establishment, or expansion of a structure or sanitary landfill that: (1) endangers safety in air commerce, related to DOD activities; (2) interferes with the efficient use and preservation of the navigable airspace and of airport traffic capacity at public-use airports, related to the activities of the DOD; (3) Will significantly impair or degrade the capability of the DOD to conduct training, research, development, testing, and evaluation, and operations or maintain military readiness.")

[243] *Id.* (As outlined in 32 C.F.R. § 211.5 "Responsibilities," the "senior officer" is the Deputy Secretary of Defense and is the only DOD official that may convey to the Secretary of Transportation a determination that a project would result in an unacceptable risk to the national security. The Under Secretary of Defense for Acquisition, Technology, and Logistics is designated as the "senior official." Only the senior official can recommend to the senior officer that a project would result in an unacceptable risk to the national security.

[244] *Id.*

[245] *Id.*

[246] *Id.* at § 211.10.

[247] *Id.* at § 211.

[248] Donna Miles, *Database Helps Identify Renewable Energy Sites*, AMERICAN FORCES PRESS SERVICE, Nov 9, 2011, *available at* http://www.defense.gov/news/newsarticle.aspx?id=66019.

[249] *Id.*

[250] *Id.*

VII. MOVING FORWARD

Under the new statute, the DOD and the Air Force were forced to fine-tune their response procedures in relatively short order. While this undoubtedly caused a lot of work for clearinghouse pioneers, the DOD and the Air Force are already reaping benefits.[251] Ironically, as mentioned in the letter from nine senators[252] and the subsequent Congressional testimony,[253] a source of frustration to the developers—the lack of a single voice speaking on behalf of the DOD (much less the Air Force)—was similarly frustrating for officials at Travis and AMC.[254] The new procedures should curb situations like those involving FPL's turbine project, where one pair of Air Force organizations tells the FAA that FPL's turbines' impact will be "minimal," while another pair warns the FAA that the same turbine project "invites catastrophe." But perhaps more important is the synergy this clearinghouse will bring to all proposal reviews.

When Travis encountered this relatively new phenomenon nearly five years, legislation had not yet outlined DOD review procedures. As the highly technical issues surfaced, personnel in the field were not equipped to deal with identifying specific causes, much less mitigation measures to limit impacts. At that time, they dealt with the issue while seeking out assistance within the Air Force, DOD and beyond. Building that network took valuable time. Many times during the process, personnel working the wind-turbine issues learned of capabilities as projects were being approved. A CRADA involving multiple agencies to study this phenomena was still nearly two years off. Scientist from MIT, like those that assisted in developing mitigation measures at Sheppard's Flat, were not readily available. Despite the seemingly tight regulatory timelines imposed on the DOD to identify problems and possible solutions, establishing the DOD-level clearinghouse, with its supporting capabilities, vast experience and readily identifiable chain of command from installation to the clearinghouse, has in and of itself markedly enhanced the response.[255] P21-36 cont.

Yet another source of frustration for developers was also, ironically, again frustrating for officials at Travis—the timing of the Air Force involvement. As demonstrated by the Shiloh II project, developers were well on their way to project approval when the issue surfaced. On the flip side, once the problem surfaced, Travis and AMC had very little time to understand the extent of the issue before making comments within the timeframes of the California environmental review process. As in the FPL case, the Air Force raised its concerns after the FAA issued the DNH opinions to the developer. Such belated involvement, however unknowing and

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[251] *See generally*, Parrish article, *supra* note 174 (noting the CRADA effort and how its results may be the model moving forward).

[252] Letter from U.S. Senators, *supra* note 67.

[253] Impact of Wind Farms hearing, *supra* note 177; *see supra* at notes 192 - 203.

[254] Findley letter, *supra* note 27.

[255] *See generally*, Parrish article, *supra* note 174 (noting the CRADA effort and how its results may be the model moving forward).

unintentional, is not in the Air Force's interest and also tests the Air Force's good relations with local permitting authorities. Where, as was the case, the Air Force could not bring suit on its own behalf, overturning an erroneous DNH was a virtual impossibility. The Air Force's best opportunity to influence this process is to be engaged as a full partner with the developers as *early* as possible. The Renewable Energy and Defense Database, with its specific information regarding installations and their military activities, will go far towards alerting developers of these issues in the early planning phases.

Looking to the future, there are other solutions on the horizon to resolve air safety issues over wind farms. The FAA's Next Generation Air Transportation System modernization initiative includes overhauling radar surveillance. This technology involves on-board Global Positioning System receivers transmitting location and altitude to other nearby aircraft and air traffic controllers. After this system is fully operational (scheduled for 2020), many secondary surveillance radars will eventually be shut down. Ultimately, the Next Generation system offers a potential long-term solution for some ATC radar problems,[256] but its requirements do not apply to "see and avoid" airspace (operating without transponders) and to primary radar for homeland defense purposes.[257] Such a system could be complemented with regulations requiring planes transitioning immediately above places like the WRA to be equipped with the requisite GPS systems.[258] Other options explored have included the development of "stealth" turbines, which can absorb instead of reflect radar energy.[259] In the near term, a possible solution at other DOD installations could involve employing Westslope's methodology and the review process used and honed in CRADA collaboration for an independent predictive analysis. This would enhance the earliest stages of turbine planning, not only at Travis AFB, but for other potentially affected DOD installations and developers alike. As the CRADA research suggests, even if a predictive modeling or simulation tool is never fully honed, optimizing radar performance and software enhancements may mitigate the extent of this problem.[260] Hopefully, these and other potential solutions will be fielded and improved upon as both wind energy and aviation, including unmanned aviation, only continue to grow.

P21-36 cont.

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[256] 14 C.F.R. pt. 91, *available at* http://edocket.access.gpo.gov/2010/pdf/2010-12645.pdf (site last visited June 25, 2010).

[257] *Id.*; *see also Air Traffic Services and Technology*, AOPPA Online, http://www.aopa.org/whatsnew/air_traffic/ads-b.html (last visited May 13, 2012).

[258] U.K. Civil Aviation Auth., Airspace Change Proposal Framework Briefing: Establishment of Transponder Mandatory Zone(s) around the London Array (LA) and the Thanet Offshore (TOW) Windfarms in the Eastern Thames Estuary (Mar. 26, 2010) *available at* http://www.ukfsc.co.uk/files/Consultations%20CAA%20DAP/NATMAC%20Informative%20Framework%20Briefing%20March%202010.pdf (discussing the United Kingdom Civil Aviation Authority exploring "Mandatory Transponder Zones").

[259] *See, generally* Martin LaMonica, *Wind Power Growth Limited by Radar Conflicts*, Cnet (Feb. 4, 2010) http://news.cnet.com/8301-11128_3-10447450-54.html.

[260] *Id.*

VIII. Conclusions

The wind turbine-induced radar issue was as unexpected as it was difficult to fully resolve. It demonstrated how one technological change—receiving a new radar feed—exposed an operational vulnerability base officials could not have foreseen. In such cases, it is difficult to be proactive and get ahead of such a technological puzzle. With wind energy as an important and fast growing resource to our nation, the Air Force is becoming a proactive partner in promoting safe, responsible wind energy development. In time, working through the relatively newly established "executive agent" and continuing to bring bright, talented people to bear should solve this problem will be solved. Equally important, and perhaps for an unforeseen technology of tomorrow, this difficult situation showed the benefits that can accrue to all parties where there is a willingness to try new ideas and cooperate with each other (versus litigate) toward a common goal.

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HOW THE ROC ANALYSES WIND TURBINE SITING PROPOSALS

The ROC learns of wind farm developments through both formal and informal methods. Formally, the Department of Commerce's National Telecommunications and Information Administration (NTIA) acts as clearinghouse for developers to voluntarily submit wind farm proposals for review by several federal agencies, including NOAA. This formal process is recognized by the wind industry in the American Wind Energy Association's (AWEA) Wind Siting Handbook (AWEA 2008). Informally, the ROC occasionally receives notifications directly from developers, or learns of wind farm projects from local forecast offices who email news articles or web links to stories about planned wind farms. The ROC typically receives 10 to 15 notifications per month through the NTIA and 1 to 3 per month directly from developers or third parties. The ROC tries to proactively contact the developers if a third party notifies the ROC of a wind project that has the potential to significantly impact a nearby WSR-88D.

Based on the wind farm proposal the ROC receives, the ROC provides a case-by-case analysis of potential wind farm impacts on WSR-88D data and forecast/warning operations. The ROC uses a geographic information system (GIS) database that utilizes data from the Space Shuttle Radar Topography Mission to create a RLOS map with delineated areas corresponding to a turbine height of 160 m AGL. Multiple radar elevation angles are considered for projects close to the radar.

The ROC then performs a meteorological and engineering analysis using: distance from radar to turbines; maximum height of turbine blade tips; the number of wind turbines; radar azimuths impacted; elevation of the nearby WSR-88D antenna; an average 1.0 degree beam width spread; and terrain (GIS database). From this data the ROC determines if the main radar beam will intersect any tower or turbine blade based on the Standard Atmosphere's Refractive Index profile.

Finally, the ROC estimates operational impacts based on amount of turbine blade intrusion into RLOS, number of radar elevation tilts impacted by turbines, location and size of the wind farm, number of turbines, orientation of the wind farm with respect to the radar (radial vs azimuthal alignment), severe weather climatology, and operational experience. The ROC also compares the wind farm to other operational wind farms to estimate impacts.

The ROC has developed a four zone scheme that takes terrain, distance, and the number of elevation angles impacted into account while. The four zones use terminology that communicates to wind farm developers the desired action. These zones, defined below, are: no build, mitigation, consultation and notification.

1. The No Build Zone is a 4 km radius red circle around the WSR-88D. The ROC is requesting that developers do not build turbines in the RLOS within 4 km of the radar due to the potential for serious impacts, including turbine nacelles blocking the radar beam and potential receiver damage if sited in the radar's near field.

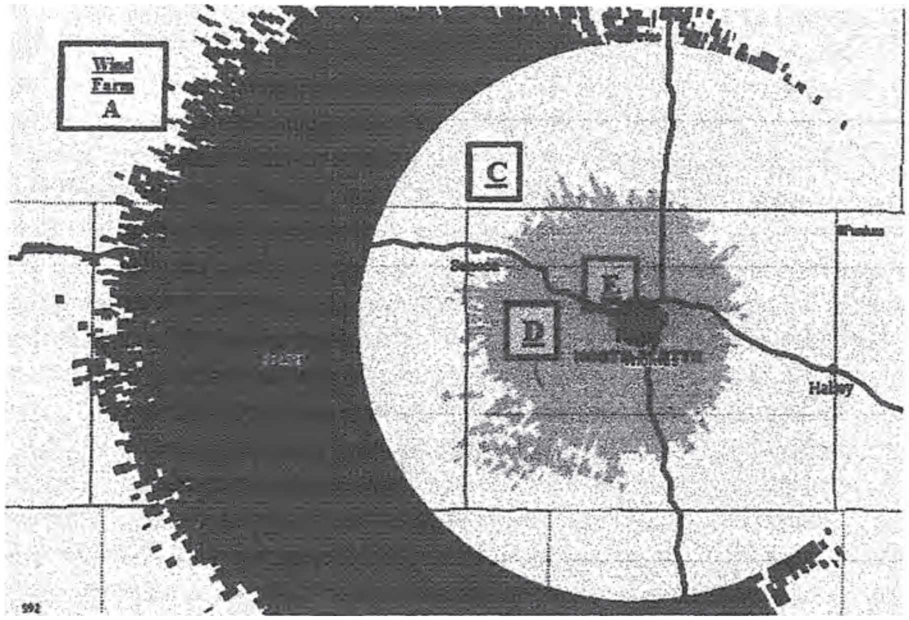
2. The Mitigation Zone, orange areas on the map, is tha area between 4 km and 36 km where a 160-meter turbine would penetrate more than one elevation angle. Wind farms sited within the mitigation zone have the potential for moderate to high impacts. Therefore, the ROC will work with the developer to get detailed project information, do a thorough impact analysis, and discuss potential mitigation solutions.

3. The Consultation Zone, yellow areas on the map, is the area between 4 km and 36 km where a 160-meter turbine only penetrates the 1st elevation angle or when a 160-meter tall turbine will penetrate more than one elevation angle between 36 km and 60 km. Due to the increased potential for impact to operations the ROC is requesting consultation with the developer to track the project and acquire additional information for a thorough impact analysis.

4. The Notification Zone, green areas on the map, is the area between 36 km and 60 km where a 160-meter tall turbine will only penetrate one elevation angle, or any area beyond 60 km that a 160-meter tall turbine is in the RLOS. Since impacts are typically minimal beyond 60 km and workarounds are available for penetration of only one elevation angle, the ROC is making consultation optional; however, NOAA would still like to know about the project.

The figure depicts an example of the primary categories of wind farm analysis requests/replies.

P21-36 cont.



P21-36 cont.

An example radar line of sight (RLOS) map generated by the NEXRAD ROC for a wind farm analysis. Four hypothetical proposals: W, X, Y, and Z as described in the text are shown.

Wind Farm A: clearly out of the RLOS, would have no impact on the radar data, except in some anomalous propagation conditions, in which case impacts would be low.

Wind Farm B: Notification zone - low impact on the radar data if turbines were built in the western portion of the proposal area. The ROC would suggest that the developer locate most/all wind turbines in the western portion of the proposed area.

Wind Farm C: Consultation Zone - low impact on the radar data if turbines were built in the western portion of the proposal area. The ROC would suggest that the developer locate most/all wind turbines in the western portion of the proposed area.

Wind Farm D: Mitigation Zone - low to moderate impacts on the radar. The ROC would seek to consult with the developer to determine if there is flexibility to consider impact mitigation techniques and to ensure the developers are aware of potential impact on forecast/warning operations.

Wind Farm E: Encroaches into No-Build Zone. Potentially high impacts on the NEXRAD for the portion of the proposal in the red area. The ROC would seek to consult with the developer to ensure they are aware of the likely impact on forecast/warning operations, the NEXRAD system, and the wind turbines/personnel.

LINKS

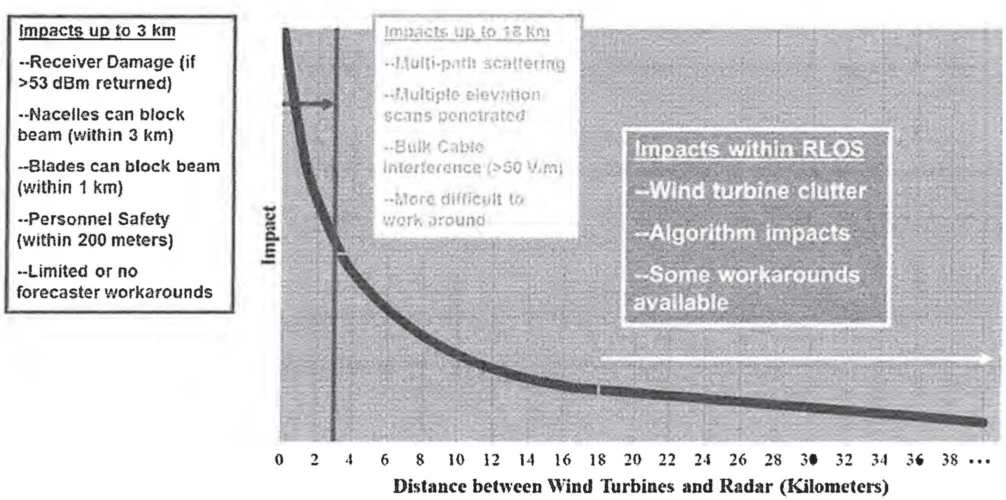
- INTRODUCTION
- HOW ROTATING WIND TURBINE BLADES IMPACT THE NEXRAD DOPPLER WEATHER RADAR
- HOW THE ROC ANALYSES WIND TURBINE SITING PROPOSALS
- RADAR IMAGERY
- FREQUENTLY ASKED QUESTIONS (FAQs)
- ADDITIONAL LINKS AND RESEARCH PAPERS
- FEEDBACK

HOW ROTATING WIND TURBINE BLADES IMPACT THE NEXRAD DOPPLER WEATHER RADAR

Rotating wind turbine blades can impact the radar in several ways. Wind turbines can impact the NEXRAD radar base data, algorithms, and derived products when the turbine blades are moving and in the radar's line of sight (RLOS); and, if turbines are sited very near to the radar their large nacelles and blades can also physically block the radar beam or reflect enough energy back to the rader to damage the radar's receiver hardware.

- **Radar Receiver:** The NEXRAD radar has a very sensitive receiver. The radar's Receiver Protector prevents damage from strong reflected signals; however its upper limit is 53 dBm. Large objects sited very near the radar (< 4 km), such as turbine nacelles, have the potential to return signals that exceed the limit of receiver protector and render the radar inoperable.
- **Beam Blockage:** If sited within a few kilometers of the radar, wind turbines can partially or fully block the radar beam. This beam blockage attenuates the strength of the beam and impacts data beyond the wind farm, causing shadows or spikes in the data through the entire range of the radar (460 km for reflectivity data, and up to 300 km for velocity and spectrum width data).
- **Radar Base Data:** Turbines in RLOS can reflect energy back to the radar and visually contaminate the reflectivity, velocity, and spectrum width data. Forecasters look for certain "signatures" in the data that indicate the severity of the storms. The wind farm clutter can sometimes look just like showers and thunderstorms, or can alter the appearance of a storm (e.g. hook echoes). This visually corrupted data adds uncertainty to the analysis and could cause forecasters to delay/miss a severe weather warning or to warn unnecessarily.
- **Algorithms and Derived Products:** The base reflectivity, velocity, and spectrum-width data are also used by many algorithms in the radar processor to detect certain storm characteristics, such as mesocyclones, relative storm motion, hail, turbulence, etc. Corrupted base data can cause the radar algorithms to generate false alerts or to miss alerts. The radar also generates many additional products using this base data, such as wind profiles and rainfall estimates. Wind turbine clutter can impact the accuracy of these derived products.

The graph below depicts the relative impact of wind turbines (or wind farms) on NEXRAD radars and forecasters as a function of distance (on level terrain) if wind turbines are in the RLOS.



Impacts increase greatly as wind turbines are sited closer to the rader, especially within 18 km (assuming level terrain), as radar operator workarounds become more difficult. Turbines sited at least 18 km from the radar generally only impact the lowest radar scan at 0.5 degrees elevation, and clutter is confined to the wind farm area. Within 18 km wind turbines cause additional impacts including: clutter on multiple elevation scans above 0.5 degrees, multipath clutter down range of the wind turbines, and greater impacts to radar algorithms. Multipath scattering from wind turbines can extend the contaminated data up to 40 km beyond the wind farm. Turbines sited within 4 km of the radar may also cause significant (>10%) attenuation/blockage of the radar beam impacting data throughout the entire range (460 km-reflectivity, 300 km-velocity) of the radar. When turbines are sited within 200 m, construction or maintenance personnel may be exposed to microwave energy exceeding OSHA (Occupational Safety and Health Administration) thresholds. The above distances assume a level terrain and a Standard Atmosphere Index of Refraction profile. Therefore, actual impacts may occur closer or further away from the radar than this chart indicates depending on the terrain and current atmospheric refraction. Accurate determination of the RLOS and impact distances requires a detailed site-by-site analysis.

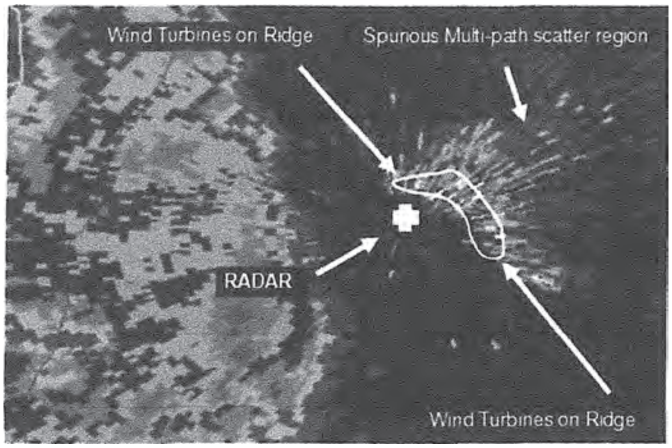
You may wonder why we can't filter out this clutter since we know where the wind farms are located. The NEXRAD has a sophisticated clutter removal scheme. Since weather is usually in motion, the scheme was designed to filter returns that have essentially no or very low motion. This is effective for removing the returned signals from terrain, buildings, and other non-moving structures. However, the radar sees rotating wind turbine blades as targets having motion, hence processes these returns as weather. At this time there is no filtering scheme available to identify and remove wind turbine clutter while preserving real weather returns.

Wind turbine clutter has not had a major negative impact on forecast or warning operations, yet. However, with more and larger wind turbines coming on line, radars in some parts of the country will have multiple wind farms in their line of sight. Cumulative negative impacts should be anticipated – which, at some point, may become sufficient to compromise the ability of radar data users to perform their missions.

Examples of Wind Turbine Clutter

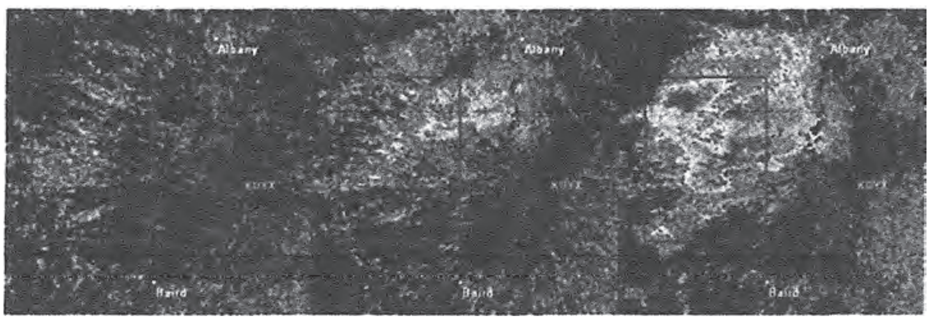
Zoomed-in Display of WTC-contaminated data from Fort Drum NEXRAD

P21-36 cont.

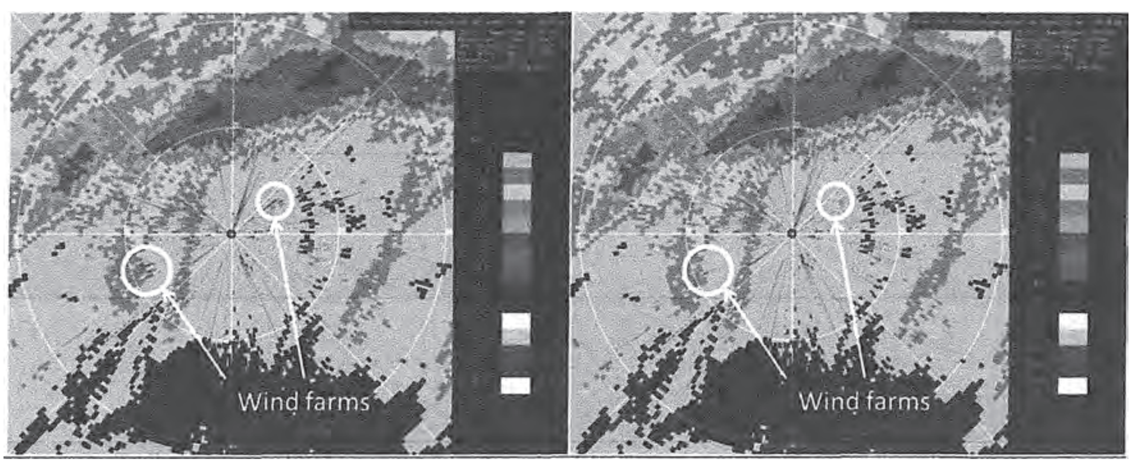


The image above is a zoomed 0.5 degree elevation Reflectivity product from the Ft Drum, NY NEXRAD. There is a large wind farm nearby with turbines oriented from due north through southeast of the radar. The turbines are close enough (within 18 km) to cause spurious multipath scattering that extends well beyond the wind farm and contaminates data at multiple scanning elevation angles.

Display of WTC-contaminated data from the Dyess AFB, TX NEXRAD

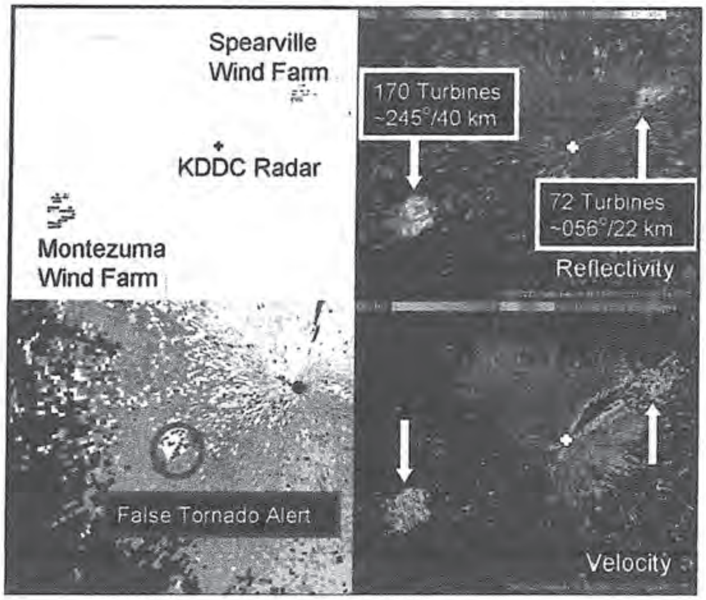


Sequence (left to right) of 0.5 deg reflectivity images showing thunderstorms developing over a wind farm (purple rectangle) 18–30 km (10-16 nm) west of Dyess AFB, TX WSR-88D. Left: thunderstorms have not yet developed, high reflectivity values due to wind turbines alone. Middle and Right: storm has developed to where in right image a distinct notch structure, indicative of severe weather, formed – note: turbine and weather echoes indistinguishable.



This radar-estimated Storm Total Precipitation accumulation product from the Dodge City, Kansas NEXRAD on April 22, 2010 at 1403 GMT depicts how wind farms can impact radar-derived products. Erroneous 4+ inch radar-estimated Storm Total Precipitation accumulations (indicated by the arrows) in the image on the left are due to wind farms northeast and southwest of the NEXRAD. The anomalous accumulations make estimates of rainfall over an area/river basin more difficult to determine. However, radar operators can apply exclusion zones to mitigate these anomalous accumulations, as seen on the right. (Radar precipitation algorithms do not use the returns from the exclusion zone to accumulate precipitation.)

P21-36 cont.



Dodge City, KS NEXRAD (KDDC) reflectivity (upper right) and mean radial velocity (lower right) imagery for 0150 UTC on 23 Feb 2007 showing two wind farms within the radar's line of sight. The yellow area in the upper left image depicts areas where the radar line of sight is within 130 m of the ground. The reflectivity and velocity values are anomalous and can confuse users. The lower left panel shows the effects of the wind farm to the southwest whose influence has resulted in a false tornado alert generated by the NEXRAD algorithms. The Weather Forecast Office did not issue a warning because, in this case, other data indicated that there was no severe weather in the wind farm area.

Radar Line of Sight Graphs

The WSR-88D radar performs 360° scans of the atmosphere with elevation angles between 0.5° and 19.5°. The WSR-88D samples up to 14 different elevations angles for each complete scan of the atmosphere. The radar beam increases in height and in diameter as it moves away from the radar, with most of the beams energy at the beam center height. The bottom and top heights of the beam are defined as the points where there is a 50% reduction in the transmitted energy. Below the beam bottom height and above the beam top height the energy drastically decreases. The area between the beam bottom and beam top is referred to as the "beam". There is reduced impact on the radar if the rotating blades are below the beam bottom, especially at "close" distances.

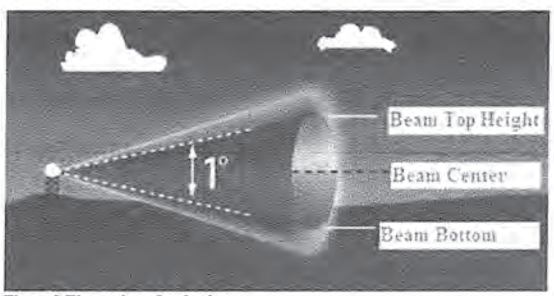


Figure 1 Illustration of radar beam

Figure 2 Illustration of the total elevation angle coverage of the radar

Any object within the beam reflects energy back to the radar. The WSR-88D uses a complex algorithm, called a clutter filter, to perform an analysis on the data to determine if the returned energy is from a desirable target (weather) or not (non-weather clutter). One factor used in the clutter filter process is the motion of the return. Clutter mitigation filters within the WSR-88D can not filter rotating wind turbines due to the motion of the blades. When the turbines are close to the radar, they penetrate more of the beam increasing the amount of energy returned to the radar, resulting in higher reflectivity values, potentially at multiple elevation angles.

LINKS

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P21-36 cont.

NOAA's National Weather Service
Radar Operations Center

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About The ROC
Field Requirements Branch
Engineering
Operations
Program Branch
Current Weather
Level II Data
Level III Data
Related Links
ROC Papers
Safety & Environmental
Site ID / Maps
Software Build Information
SPG
System Documentation
WSR-88D Program
Questions & Comments

USA.gov

P21-36 cont.

FREQUENTLY ASKED QUESTIONS (FAQs)

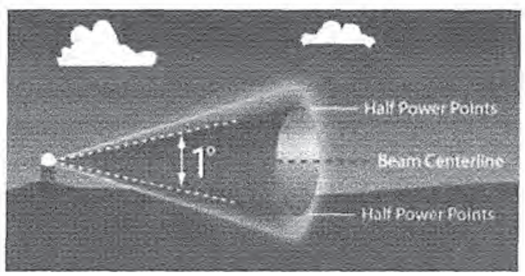
Q1. How far away from the NEXRAD should we site a wind farm? Do you have a benchmark distance? If so, what is it?
Q2. What is the "Radar-Line-of-Sight" and why is that important?
Q3. Does the RLOS ever change?
Q4. How can NEXRAD systems "see" wind towers/turbines when I can't visually see the radar from the wind farm?
Q5. How powerful is the NEXRAD's transmitted microwave energy?
Q6. Why can't the NEXRAD be reprogrammed to filter out returns from wind turbines?
Q7. Can't you just move the NEXRAD to a new location, or build a new one?
Q8. Can the NEXRAD impact a wind turbine or its maintenance personnel?
Q9. Has the National Weather Service ever missed a weather warning to public, or given a false weather warning to the public as a result of the wind turbine clutter problem?
Q10. Has the FAA diverted aircraft as a result of wind turbine clutter?

Q1. How far away from the NEXRAD should we site a wind farm? Do you have a benchmark distance? If so, what is it?

REPLY: Our benchmark distance is terrain dependent and varies from site to site, but on flat terrain the distance would be approximately 18 km (10 nm). This benchmark is based on the distance at which turbines begin to penetrate the radar line of site (RLOS) of the second scanning elevation angle (0.9 deg.). We have also established a benchmark no-build zone of 4 km. For a more detailed description of how the ROC analyses wind farm proposals visit: HOW THE ROC ANALYZES WIND TURBINE SITING PROPOSALS.

Q2. What is the "Radar-Line-of-Sight" and why is that important?

REPLY: The radar line of sight/radar beam width can be considered analogous to the beam of light coming from a flash light. Most of the energy of the flashlight, just as with the radar, is in the beam of light/radar beam. In radars this is the distance between the "half power" points or where the energy in the beam is down 3 dB from that at the center of the beam. For the NEXRAD the beam width is approximately 1 degree. As the beam propagates away from the radar, its width increases. For NEXRADs, at 111km (60 nm) from the radar the beam is approximately 2km (1 nm) wide. Obstacles in the radar line of sight can block the radar signal and reduce the ability of the radar to see targets further downrange. The figure below is a depiction of the radar line of sight.



Main beam/radar line of sight is defined by half-power points

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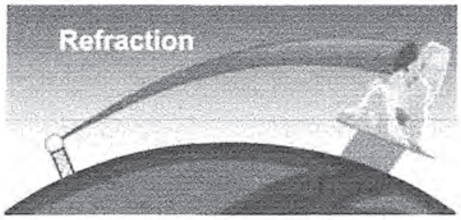
Q3. Does the RLOS ever change?

REPLY: Yes. The actual RLOS (not the RLOS based on the Standard Atmosphere, but the RLOS based on actual day to day weather) changes during the day as a result of temperature and humidity changes. It also changes as fronts pass or with nearby thunderstorm outflows. Typically after sunset, the surface temperature cools causing the radar beam to bend more towards the earth's surface. This is called super-refraction or "ducting". The net result is that wind farms that are normally out of the RLOS may be in the RLOS at certain times of the day and during certain weather conditions. So, even if wind farm developers site their projects outside the benchmark RLOS, the weather forecasters will occasionally "see" the wind farms on the radar imagery.

Q4. How can NEXRAD systems "see" wind towers/turbines when I can't visually see the radar from the wind farm?

REPLY: The path that emitted radar energy (i.e., the radar line of sight) takes, depends upon atmospheric density. Density differences are caused by variations in pressure, temperature and moisture. In a "standard atmosphere" representative of the atmosphere on a day with enough wind to mix the lower atmosphere well, the radar beam takes a path that is approximately 4/3 of the Earth's radius. This bending is called "refraction." So, the NEXRAD, like other radars, can "see" targets well beyond the optical line of sight. The figure below is a depiction of the beam's path in a standard atmosphere.

Comment Letter P21



Q5. How powerful is the NEXRAD's transmitted microwave energy?

REPLY: The NEXRAD radar transmits a pulsed signal at 750 kilowatts (peak power). The maximum time-averaged power (transmitting and listening periods) is about 1500 watts.

Q6. Why can't the NEXRAD be reprogrammed to filter out returns from wind turbines?

REPLY: The NEXRAD's clutter filter scheme only removes clutter that is stationary, such as buildings, trees, and terrain. Unfortunately, both precipitation and wind turbine blades are moving and the filter is not applied to them. Trying to filter out moving blades will inevitably alter how the radar sees real precipitation. Here's why. A single radar volume sample (gate) at 48 km (26nm) from the radar is approximately a square kilometer. Thus, for a typical wind farm, the radar may receive reflected energy from many turbines within that gate, each with multiple rotating blades. These numerous rotating blades appear similar to precipitation, which is also made up of numerous distributed moving targets. Yes, there are fewer blades than raindrops within a sample volume, but the blades make up for their smaller numbers by reflecting significantly more energy back to the radar. However, the radar has no way to determine the number of targets it is sampling within a particular gate. Also, the reflected energy is constantly changing as the blades change their pitch and orientation relative to radar, with some blades moving towards the radar, some moving away, and some not appearing to move at all (perpendicular). This is analogous to the movement of precipitation within a volume sample.

Q7. Can't you just move the NEXRAD to a new location, or build a new one?

REPLY: Moving a NEXRAD radar is very expensive—$1.5Million(M) to $4M—and a new weather radar with similar NEXRAD capabilities could be $10M depending on site acquisition costs and other site-specific costs like radar tower height. In general, moving a radar is not a good solution since these radars were strategically sited to work as a national network with proper coverage while minimizing operating costs. Moving one radar can affect coverage relative to surrounding radars in the network. Given the ever increasing number of wind farms being installed, this can quickly become a costly and futile exercise as new wind farms encroach on the moved radar.

Q8. Can the NEXRAD impact a wind turbine or its maintenance personnel?

REPLY: Yes, if a wind turbine is sited very close to the radar. When wind turbines are sited very close to NEXRAD radars, the turbines can be adversely affected by the high power, 750 kW, radar transmission. Within 200 m (600 ft) of a NEXRAD and in the transmitted beam, this energy can exceed the OSHA (29 CFR Part 1910–Subpart G-Occupational Health and Environmental Control Ch.1910.97) threshold for occupational exposure to microwave energy for construction, operation, and maintenance personnel. Within 18 km (10 nm) of a NEXRAD, the microwave radio frequency field strength can cause bulk cable interference (inductive coupling) with the turbines electronic controls if they are not properly shielded (MIL-STD-461D).

P21-36 cont.

Q9. Has the National Weather Service ever missed a weather warning to public, or given a false weather warning to the public as a result of the wind turbine clutter (WTC) problem?

REPLY: A warning has not been missed yet, but there have been some false warnings issued due to WTC. Operational forecasters can often distinguish WTC from weather signals using their experience. However, WTC can be a distraction and can take forecasters' time away from evaluating developing weather. Another major concern is the effect of these echoes on automated detection algorithms and users (e.g. media and public) not as experienced or used to the appearance of WTC. And, while the WTC problem is causing relatively minor operational impacts at this time, the expected exponential increase in the number of wind farms near NEXRAD radars is cause for concern. It is easy to envision some NEXRADs becoming surrounded by many wind farms and forecasters and other users having to work around significantly large areas of contaminated radar data.

Q10. Has the FAA diverted aircraft as a result of wind turbine clutter?

REPLY: Yes. The FAA has re-routed air traffic due to false returns from wind turbine clutter. NEXRAD data streams are fed directly into the FAA's Weather and Radar Processor System at Air Route Traffic Control Centers (ARTCC) and FAA controllers use the data to route aircraft safely around weather. ARTCCs have contacted the NEXRAD Radar Operations Center asking about NEXRAD radar data showing what appeared to be significant weather that required rerouting, but pilots reported not seeing weather in the area. This confusion causes unnecessary and expensive aircraft re-routing and excess fuel consumption.

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- ADDITIONAL LINKS AND RESEARCH PAPERS
- FEEDBACK

Gmail

Elizabeth L Lattin <elizabethllattin@gmail.com>

ridgeline construction

Kelly Tanner <kwillett2@hotmail.com> Fri, Oct 9, 2020 at 12:41 PM
To: Elizabeth L Lattin <elizabethllattin@gmail.com>

Sb 901 Chapter 626 (2018), there was another similar one that was passed in September but vetoes

Section 9 4290

(b) The board shall, on and after July 1, 2021, periodically update regulations for fuel breaks and greenbelts near communities to provide greater fire safety for the perimeters to all residential, commercial, and industrial building construction within state responsibility areas and lands classified and designated as very high fire hazard severity zones, as defined in subdivision (i) of Section 51177 of the Government Code, after July 1, 2021. These regulations shall include measures to preserve undeveloped ridgelines to reduce fire risk and improve fire protection. The board shall, by regulation, define "ridgeline" for purposes of this subdivision. P21-36 cont.

If you go to Section 51177 - it is listed there as well

From: Elizabeth L Lattin <elizabethllattin@gmail.com>
Sent: Friday, October 9, 2020 1:21 PM
To: Kelly Tanner <kwillett2@hotmail.com>
Subject: ridgeline construction

Got an AB #?

Boundary-Layer Meteorology (2020) 176:251–269
https://doi.org/10.1007/s10546-020-00522-z

RESEARCH ARTICLE

Check for updates

Effects of Two-Dimensional Steep Hills on the Performance of Wind Turbines and Wind Farms

Luoqin Liu[1] · Richard J. A. M. Stevens[1]

Received: 18 September 2019 / Accepted: 3 April 2020 / Published online: 19 May 2020

Abstract
We use large-eddy simulations with an immersed boundary method to study the performance of wind turbines and wind farms in hilly terrain. First, we analyze the performance of wind turbines in the vicinity of a two-dimensional hill. For turbines that are significantly taller than the hill, the performance improves as the flow speeds up over the hill. For turbines that have approximately the same or a smaller height than the hill, the impact of the hill on the turbine performance depends on the positioning of the turbine in relation to the hill. For these turbines, the performance is better at the hilltop. However, the power production of these turbines is reduced due to blockage effects when they are placed at the base of the hill. The performance of turbines placed on the windward side of the hill is well predicted by superimposing the wind-turbine wake profile for the flat terrain on the hilly-terrain flow field. In contrast, we show that this approach is invalid when the turbine is placed on the leeward side of the hill where flow separation occurs. Subsequently, we consider wind farms with a hill in the middle. The hill wake is very pronounced due to which the performance of turbines located behind and close to the hill is mainly determined by the flow dynamics induced by the hill instead of the wind-turbine wakes. Finally, we study a wind farm located between two hills. We find that, for this particular configuration, there is a unique turbine spacing that maximizes the wind-farm power production in the valley.

Keywords Atmospheric boundary layer · Power production · Steep hill · Wind farm · Wind turbine

P21-36 cont.

1 Introduction

Energy provision is one of the greatest challenges facing our society today. Wind energy will likely provide a significant contribution to the growing need for clean and renewable energy (van Kuik et al. 2016). There is no doubt that more and larger onshore and offshore

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arated behind the ridges. They found that the wind-turbine wakes did not follow the terrain topography, but instead were deflected slightly upwards.

The review of Porté-Agel et al. (2020) explained that topography affects the development of wakes in three ways, namely, due to (1) non-zero pressure gradients, (2) variable elevation of the wake-centre trajectory, and (3) flow separation. Hyvärinen and Segalini (2017b) showed that the Jensen wake model cannot accurately capture the wake modulations induced by the hills. However, reasonable results were still obtained by merely superposing the turbine wake for the flat terrain case and the flow over the hilly terrain without turbines. Feng and Shen (2014) proposed an adapted Jensen wake model by assuming that the wake centreline follows the terrain rather than staying at a constant elevation above sea level. This model was later used to optimize the wind-farm layout in complex terrain. In their study, the flow field for the terrain under consideration without turbines was obtained by numerical simulations. Shamsoddin and Porté-Agel (2018a) developed an analytical model of turbulent axisymmetric planar wakes under pressure gradient conditions, with the assumption that the mean velocity-deficit profiles are self-similar and have a Gaussian shape function. The model was validated by comparison with an LES dataset. Later, Shamsoddin and Porté-Agel (2018b) developed an analytical modelling framework to model wake flows over two-dimensional shallow hills, with the effect of the hill-induced pressure gradient accounted for by the analytical model discussed above (Shamsoddin and Porté-Agel 2018a) and the effect of the hill-induced streamline distortion by a linearized perturbation approach (Hunt et al. 1988).

Based on these and other results, Porté-Agel et al. (2020) concluded that modelling approaches can be successfully employed to predict the effect of shallow hills on the performance of wind turbines and wind farms. However, for steep hills, the effects are much more difficult to model due to the flow separation that occurs. Few works have systematically investigated the performance of wind turbines and wind farms on such complex topography. The objective of the present study is to gain insight into the effect steep hills may have on the performance of nearby turbines. For simplicity, we only consider truly neutral atmospheric boundary-layer (ABL) flow over a two-dimensional steep hill. The mean slope of the hill is assumed to be greater than 0.3, such that significant flow separation occurs (Mason and King 1985). This means that no analytical modelling approach is available to consider this situation (e.g., Shamsoddin and Porté-Agel 2018b; Porté-Agel et al. 2020). While we find that the performance of turbines placed on the windward side of the hill is well predicted by superimposing the wind-turbine wake profile for the flat terrain on the hilly-terrain flow field (Hyvärinen and Segalini 2017b), this approach does not work for turbines on the leeward side of the hill.

The remainder of the paper is structured as follows: in Sect. 2 we discuss the adopted numerical method and provide a validation of this method against wind-tunnel measurements by Cao and Tamura (2006). We note that there are also other measurements for flow over steep two-dimensional hills, such as Ross et al. (2004) and Loureiro et al. (2007, 2009). We selected the measurements by Cao and Tamura (2006) because their study is well documented and thus often used for validations. In Sect. 3, we analyze the effect of a two-dimensional hill on the performance of a nearby wind turbine and its influence on the wake recovery. In Sect. 4 we study the performance of a wind farm with a hill in the middle and a wind farm located between two hills. We conclude with a summary of the main findings in Sect. 5.

P21-36 cont.

wind farms will be commissioned, with most onshore sites located in complex terrain due to the lack of alternatives (Alfredsson and Segalini 2017). Because complex terrain strongly influences flow dynamics and wake development, it is crucial to understand the effects of complex terrain on wind-farm performance (Stevens and Meneveau 2017; Porté-Agel et al. 2020).

Taylor and Smith (1991) presented a wind-tunnel investigation on the performance of turbines situated on a two-dimensional flat-topped hill. They found that the wakes generated by wind turbines on the hilltop could delay the flow separation on the leeward side of the hill. Tian et al. (2013) performed measurements on an array of five turbines located on a two-dimensional shallow hill, and compared the power production and fatigue loads for turbines in flat and hilly terrains. They found that the wind speed was much higher and the turbulence intensity was relatively low on the top and the windward side of the hill. Thus, they recommended placing turbines in these locations. Howard et al. (2015, 2016) experimentally studied the performance of a wind turbine located downstream of a three-dimensional steep hill or another wind turbine. They observed that the performance of the downstream turbine was reduced when it was in the wake of the upstream hill or turbine, where the thermal stability conditions also played a significant role. Hyvärinen and Segalini (2017a), Hyvärinen and Segalini (2017b) and Hyvärinen et al. (2018) measured the thrust and power coefficients for turbines located on top of a series of sinusoidal hills. They showed that the turbine wakes recovered more rapidly in hilly terrain than on flat terrain, and concluded that the undulating hills could have a favourable effect on the measured thrust and power coefficients of turbines, especially further downstream in the wind farm. P21-36 cont.

Morfiadakis et al. (1996) measured the turbulence characteristics in a wind farm on the island of Andros, Greece. The measured spectra of the three velocity components were analyzed by applying the von Kármán formulation. The analysis revealed that the von Kármán spectrum was suitable for the structure of the turbulence measured at some locations when the wind turbines were not operational. However, the pronounced topography and turbine wake effects were not adequately modelled by this formulation. Subramanian et al. (2016) measured the wake evolution downstream of multi-MW wind turbines of the Mont Crosin wind farm in complex terrain and the Altenbruch II wind farm on flat terrain. Results showed that the near-wake region in complex terrain extended up to two rotor diameters and was about 35% shorter than that over flat terrain. However, the further downstream wake evolution in flat and complex terrains revealed similar wake characteristics. Hansen et al. (2016) performed measurements on a wind farm in Shaanxi, China, and showed that in hilly terrain wind-turbine wakes were deflected upwards or downwards depending on the thermal stability conditions. During the daytime, the wakes were deflected upwards, while at night-time wakes were deflected downwards and followed the terrain topography. A similar dependence of the wake propagation was observed in the field measurements conducted in Perdigão, Portugal (Menke et al. 2018; Barthelmie and Pryor 2019).

Apart from wind-tunnel and field measurements, various numerical simulations have also been used to investigate the effect of complex terrain on wind-turbine and wind-farm performance. Generally, the simulation results agree well with measurements (see, for example, Shamsoddin and Porté-Agel 2017; Berg et al. 2017; Sessarego et al. 2018; Yang et al. 2018). In particular, Shamsoddin and Porté-Agel (2017) performed large-eddy simulations (LES) of turbulent flows over five wind turbines sited on a two-dimensional shallow hill under neutral stratification conditions. In that study the streamwise velocity and turbulence intensity profiles from the simulations agree well with the wind-tunnel measurements of Tian et al. (2013), and wind-turbine wakes were observed to follow the terrain topography. In contrast, Berg et al. (2017) presented simulations of the Perdigão site in Portugal where the flow sep-

2 Numerical Method and Validation

We use LES in combination with an immersed boundary method to simulate the turbulent flow over two-dimensional hills. We consider a truly neutral ABL such that the flow can be simulated by solving the filtered incompressible Navier–Stokes equations,

$$\nabla \cdot \widetilde{\mathbf{u}} = 0, \tag{1}$$

$$\partial_t \widetilde{\mathbf{u}} + \widetilde{\omega} \times \widetilde{\mathbf{u}} = \mathbf{f} - \nabla \widetilde{p} - \nabla \cdot \boldsymbol{\tau}. \tag{2}$$

Here, $\widetilde{\mathbf{u}}$ is the velocity, $\widetilde{\omega} = \nabla \times \widetilde{\mathbf{u}}$ is the vorticity, $\mathbf{f}$ is the external force (which includes the constant pressure gradient, the force exerted by turbines, and the force caused by the immersed boundary), $\widetilde{p}$ is the modified pressure, and $\boldsymbol{\tau}$ is the subgrid-scale stress tensor, which is modelled using the Smagorinsky model (Smagorinsky 1963; Mason and Thomson 1992). We use a pseudo-spectral discretization, and thus periodic boundary conditions in the horizontal directions. In the vertical direction, we use a staggered second-order finite difference method. At the top boundary, we enforce a zero vertical velocity and a zero shear stress boundary condition, and we use a classic wall-layer model at the bottom surface and the immersed boundary to determine the wall stress at grid points closest to the solid boundaries (Moeng 1984; Bou-Zeid et al. 2005; Chester et al. 2007). Time integration is performed using the second-order Adams–Bashforth method (Canuto et al. 1988). The projection method is used to ensure the divergence-free condition of the velocity field (Chorin 1968), and we use the concurrent precursor method to simulate finite-size wind farms and to generate turbulent inflow conditions that match atmospheric turbulence (Stevens et al. 2014). P21-36 cont.

The wind turbines are modelled using a filtered actuator disk model (Shapiro et al. 2019). In short, when the freestream velocity U_∞ is used to calculate the turbine force F_t, it is given by

$$F_t = -\frac{1}{2}\rho C_T U_\infty^2 A, \tag{3}$$

where ρ is the density of fluid, C_T is the thrust coefficient based on the free-stream velocity U_∞, and A is the area of the disk. However, if a turbine is behind another turbine or in complex terrain, the freestream velocity is no longer easily available. Meyers and Meneveau (2010) pointed out that in such a case the disk-averaged velocity u_d is a better candidate and then actuator disk theory gives that the force can be written as

$$F_t = -\frac{1}{2}\rho C_T' u_d^2 A, \tag{4}$$

and that the power output is given by (Stevens and Meneveau 2014)

$$P = -F_t u_d = \frac{1}{2}\rho C_T' u_d^3 A, \tag{5}$$

where C_T' is the thrust coefficient based on u_d. In our study, we retain a constant thrust coefficient $C_T = 0.75$, which is equivalent to $C_T' = 4/3$.

In all simulations, we consider the following two-dimensional steep hill, which was used in the experimental study by Cao and Tamura (2006):

$$z_w(x) = h\cos^2\left(\frac{\pi x}{2l}\right), \quad -l \le x \le l, \tag{6}$$

where h and l are the height and half-width of the hill, respectively. The maximum slope is $\pi/5$ such that a significant separation region exists on the leeward side of the hill. The

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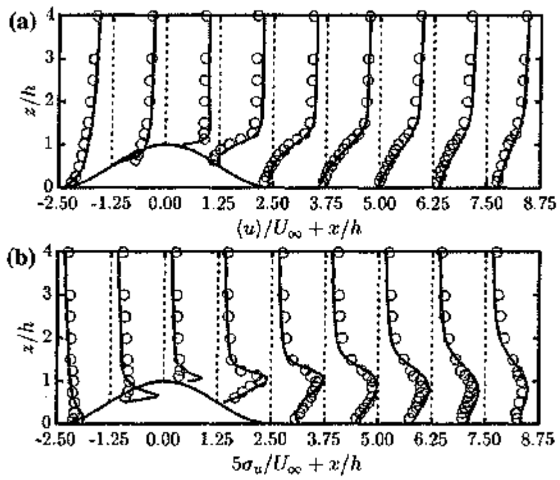

Fig. 1 Time-and spanwise-averaged, **a** streamwise velocity component and **b** its variance as function of height for the ABL flow over a two-dimensional steep hill. Solid lines: simulation results; Open circles: experimental data by Cao and Tamura (2006)

experiments were conducted in an open circuit wind tunnel. The height and half-width of the hill are $h = 40$ mm and $l = 100$ mm, respectively, the roughness length is $z_0 = 0.004$ mm, and the boundary-layer height is $\delta = 250$ mm. We use a domain of $5\delta \times \delta \times \delta$, in the streamwise, spanwise, and wall-normal direction, respectively. The used grid resolution is $192 \times 64 \times 97$. P21-36 cont.

Figure 1 shows that the vertical profiles of the streamwise velocity component and its variance obtained by the simulations agree well with the measurements at all downstream locations. To further illustrate the characteristics of the hill wake, we show the time-averaged streamwise velocity component and its variance in the streamwise–vertical plane in Fig. 2. A significant feature of the flow is the recirculation zone, which is established on the leeward side of the hill. As a result, the velocity downstream of the hill is significantly reduced, while the velocity fluctuations increase. The edge of the recirculation zone, which is identified by $\langle u \rangle = 0$, where $\langle \cdot \rangle$ denotes the time average, intersects with the ground at $x/h \approx 5.4$, which is in good agreement with the result obtained from the wind-tunnel measurements (Cao and Tamura 2006).

Hereafter, we use the same hill and numerical resolution as used in the validation case discussed above, to ensure that the essential flow features are captured accurately. As mentioned above, this hill geometry is widely used in the literature, and allows us to study the effects that steep hills have on the performance of turbines. We do not study the effect of the hill shape, which will be investigated in future.

3 A Wind Turbine Near a Hill

To investigate the performance of a wind turbine located close to a steep hill, behind which significant flow separation takes place, we use the hill geometry given by Eq. 6. The roughness length z_0 is set to $z_0/D = 10^{-4}$, where D is the diameter of turbines equal to the hill height

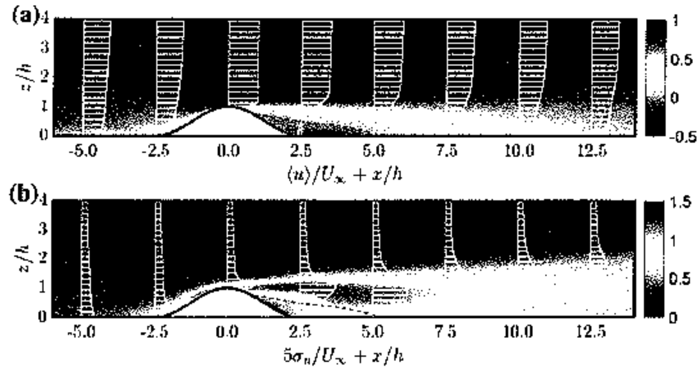

Fig. 2 Time- and spanwise-averaged, **a** streamwise velocity component, and **b** its variance for the ABL flow over a two-dimensional steep hill. The white lines indicate the profile at various downstream locations and the black dashed line indicates the edge of the recirculation zone

h. To keep the discretization of the hill identical that one used in Sect. 2 we use a domain size of $30D \times 6D \times 6D$ and a grid resolution of $192 \times 64 \times 97$ in the streamwise, spanwise, and vertical directions, respectively. We perform simulations with the turbine located at various streamwise locations, i.e., $x_t/D = -2.5, -1.25, 0, 1.25, 2.5, 7.5$, where $x_t = 0$ indicates the location of the hilltop. This means that we test the performance of the turbine at the base, top, and the end of the hill. Besides, we test the performance for turbines placed halfway on the windward and leeward sides, respectively so the tested turbine locations are distributed uniformly over the extent of the hill. We also test the turbine performance further downstream at $7.5D$ behind the hill to obtain more insight into the long-range effect of the hill wake. P21-36 cont.

To study the effect of the ratio of the turbine hub height to hill height we vary the turbine height between $0.75D$ and $3D$. The lower limit ensures that the turbine blades do not hit the ground. The maximum hub height allows us to explore the limit for which the turbine is much taller than the hill. The selected hill heights are distributed equidistantly over this interval. We note that the maximum hub height pushes the limit of the ratio of hub height versus diameter that is seen in practical applications, but we consider it here since it allows us to see what happens when the turbines are much taller than the hill. For each hub height, we perform a reference simulation in flat terrain to normalize the results. This means that 70 simulations are performed, i.e., ten different hub heights for six different streamwise locations and the corresponding reference simulation in flat terrain. This comprehensive set of simulations allows us to investigate the effect of the relative location and height of the turbine compared to the hill.

3.1 Effect of a Steep Hill on the Power Production of Wind Turbines

Figure 3 compares the power production of the turbine located at the different streamwise locations and for various turbine heights with the production of the corresponding reference turbine located in flat terrain. The symbols and solid lines indicate the measured power production by the turbines. The hill has a large effect on the performance of nearby wind turbines. For turbines that are significantly taller than the hill, i.e., $h_{hub}/D \geq 1.75$, the power production of a turbine that is placed close to the hill is higher than that on flat terrain, and is

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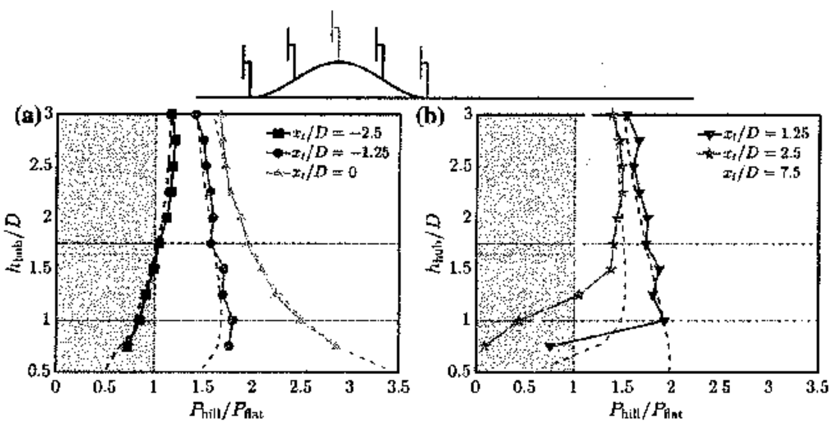

Fig. 3 The power production for turbines located at the, **a** windward, and **b** leeward side of the hill compared to the power production for a turbine on flat terrain P_{hill}/P_{flat}. The symbols and solid lines indicate the measured power production by the turbines. The top panel indicates a sketch of the used turbine locations. The vertical dotted–dashed line denotes the unit ratio of power. The upper dotted–dashed line denotes the ratio of height above which the ratio of power is greater than unity. The lower dotted–dashed line denotes the unit ratio of height. As we assume that the thrust coefficient is constant, a prediction for the expected power production can be obtained by determining $(U_{hill}(z)/U_{flat}(z))^3$, where $U_{hill}(z)$ and $U_{flat}(z)$ are the streamwise velocity profiles, for the hill and the flat terrain cases, respectively. The coloured dashed lines give this prediction

P21-36 cont.

due to the speed-up of flow over the hill, which benefits turbines placed on the hilltop most. The situation is more complicated for shorter wind turbines for which the hub-height is the same as the hill height, i.e., $h_{hub}/D = 1$. Due to the blockage effect of the hill, a turbine located at $x_t/D = -2.5$ produces less power than on flat terrain. The production of a turbine on the hilltop can be about 2.5 times higher than on flat terrain. Interestingly, turbines on the leeward side ($x_t/D = 1.25$) produce more power than turbines on the windward side ($x_t/D = -1.25$). Due to the hill wake, the performance of turbines located downstream of the hill is severely affected. The worst position is at the end of the hill at $x_t/D = 2.5$, where the turbine produces almost no power when $h_{hub}/D = 0.75$. However, further downstream the performance loss is still notable (at $x_t/D = 7.5$ the production loss is about 50% compared to the flat terrain case). Figure 3 reveals that the effect of the hill on the turbine performance increases when the turbine height is reduced compared to the hill height. This effect is most pronounced at the leeward side ($x_t/D = 1.25$) as at this location a drastic drop in the power production of the turbine is observed for $h_{hub}/D < 1$, because the turbine is then in the recirculation zone behind the hill.

As we assume that the thrust coefficient of the turbines is constant, we can compare the measured power production of the turbines with a prediction that is obtained from a comparison of the flow profile obtained from the simulations of the flat terrain and the hill case, respectively. Under the given assumptions the prediction for the effect of the hill can be determined from $(U_{hill}(z)/U_{flat}(z))^3$, where $U_{hill}(z)$ and $U_{flat}(z)$ indicate the streamwise velocity profile for the hill and the flat terrain case with z the distance from the ground. The prediction for the different turbine locations is obtained by determining this ratio for the respective turbine positions. Figure 3a shows that the measured power production agrees very well with these predicted values for turbines placed on the windward side of the hill. However, Fig. 3b reveals that on the leeward side, the production of several of the shorter turbines is

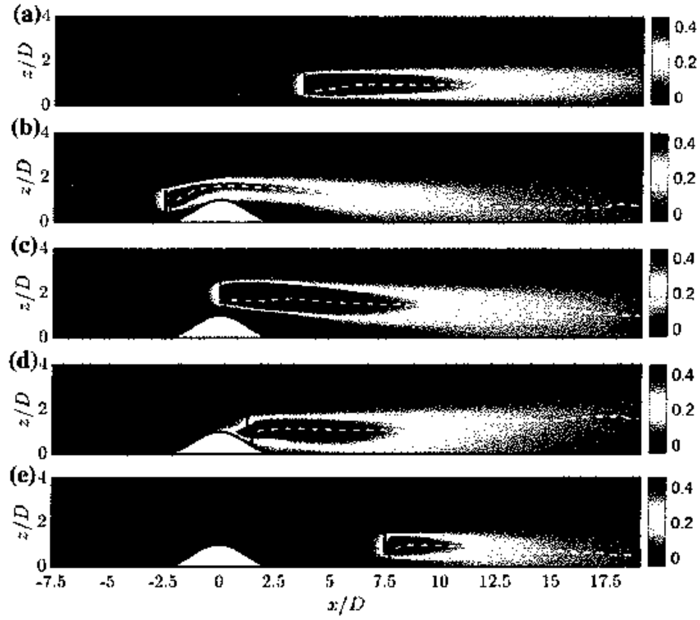

Fig. 4 Normalized velocity deficit $\langle u_{def}\rangle/u_d$ in the mid-plane of the turbine for, **a** the flat terrain case, and **b–e** for flow over a steep hill at $x/D = 0$ with the turbine located at **b** $x_t/D = -2.5$, **c** $x_t/D = 0$, **d** $x_t/D = 1.25$, and **e** $x_t/D = 7.5$. The hill height is $h/D = 1$. The hub-height is (**a–c**, **e**) $h_{hub}/D = 1$ and **d** $h_{hub}/D = 0.75$. The white dashed lines denote the location of the wake-centre trajectory

significantly lower than predicted. For turbines located at $x_t/D = 1.25$, this happens when the turbine hub-height is smaller than the hill height $h = D$. For $x_t/D = 2.5$ and $x_t/D = 7.5$ this effect is significant for hub-heights smaller than approximately $1.5D$ and $2D$, respectively. This is because both the hill and the turbine have a significant effect on the flow. Their combined effect is different than what would be predicted by a simple superposition of their effects. To illustrate this, we compare the flow field from the simulations with the turbine with the flow field when the turbine is not present. Figure 3b shows that when the turbine located at $x_t/D = 1.25$ and the hub-height $h_{hub}/D = 0.75$ the turbine power production is much lower than predicted. The positive values in front of the turbine in Fig. 4d, which will be explained in more detail below, reveal that the velocity there is much lower when the turbine is present than when the turbine is not present. The reason is that the flow is forced around the turbine, and in this particular case, there is a pronounced effect due to geometry. This confirms that the effect of steep hills on the performance of nearby wind turbines cannot be estimated by using a simple superposition approach. For this hill, we find that the power production of a turbine on the leeward side of the hill can be significantly lower than the production estimate that is obtained from the flow field over the hill without the turbine.

3.2 Effect of a Steep Hill on Wake Recovery

Figure 4 shows the normalized velocity deficit in the vertical mid-plane of the domain for a turbine on flat terrain and four different turbine positions. Similar to Shamsoddin and

P21-36 cont.

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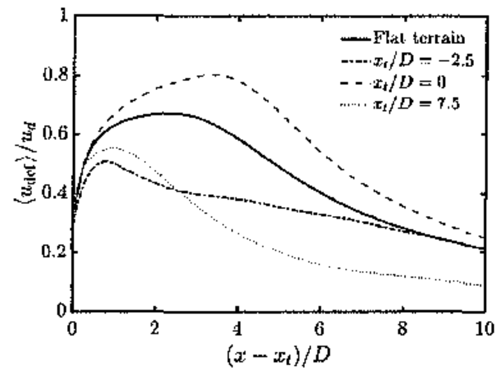

Fig. 5 Normalized velocity deficit $\langle u_{\rm def}\rangle/u_d$ along the wake-centre trajectory for a wind turbine on flat terrain (solid line) and for flow over a steep hill at $x/D = 0$ with the turbine located at the base of the hill ($x_t/D = -2.5$: dashed–dotted line); on the hilltop ($x_t/D = 0$: dashed line); or behind the hill ($x_t/D = 7.5$: dotted line)

Porté-Agel (2018a), the velocity deficit is defined as

$$\langle u_{\rm def}\rangle = \langle u_{\rm nw}\rangle - \langle u_{\rm w}\rangle, \tag{7}$$

where $\langle\cdot\rangle$ denotes the time average, and $u_{\rm w}$ and $u_{\rm nw}$ are the streamwise velocity components over the same terrain with and without a wind turbine, respectively. We normalize the velocity deficit $\langle u_{\rm def}\rangle$ by the disk-averaged velocity u_d, which is related to the power output P of a wind turbine as follows $P \propto u_d^3$ when the turbine thrust coefficient is assumed to be constant (Calaf et al. 2010). The benefit of selecting this characteristic velocity is that it allows us to compare the wake recovery for the different cases in which the turbine power production is not the same. Figure 4 also shows the location of the wake centre as a function of the downstream location. We determine the location of the wake centre in the symmetry plane behind the turbine by determining the location of the maximum velocity deficit (Shamsoddin and Porté-Agel 2018a), P21-36 cont.

$$z_c(x) = \arg\max_z \langle u_{\rm def}(x, y_t, z)\rangle, \tag{8}$$

where z_c is the z-coordinate of the wake centre and y_t is the spanwise location of the turbine. Evidently, the hill can significantly affect the wake development when the turbine is placed in the vicinity of the hill. We find that the wake tends to follow the terrain. To be specific, the wake moves upwards when generated upstream of the hill and moves down a bit afterwards. Interestingly, the wake also is deflected downwards when the turbine is located downstream of the hill, which does not happen for the flat-terrain case. These findings are qualitatively similar to the theoretical analysis and numerical observations of Shamsoddin and Porté-Agel (2018b) for the development of wakes over two-dimensional shallow hills.

Figure 5 shows the normalized velocity deficit $\langle u_{\rm def}\rangle/u_d \propto \langle u_{\rm def}\rangle/P^{1/3}$, again under the assumption that C_T is constant, along the wake-centre trajectory. We see that when the wind turbine is located upstream or downstream of the hill, the turbine wake recovers more rapidly than for the flat terrain reference case. However, when the turbine is located on the hilltop the wake recovery is much slower. These wake recovery characteristics are a result of two competing effects. First of all, the hill significantly increases the turbulence level downstream of the hill (see Fig. 6), which enhances momentum diffusion and therefore promotes wake recovery (Yang et al. 2015). However, the wake recovery is also affected by the pressure gradients created by the hill. The hill generates a favourable pressure gradient on its windward side and an adverse pressure gradient on its leeward side. These pressure effects enhance the wake recovery for turbines in front of the hill and reduce the wake recovery

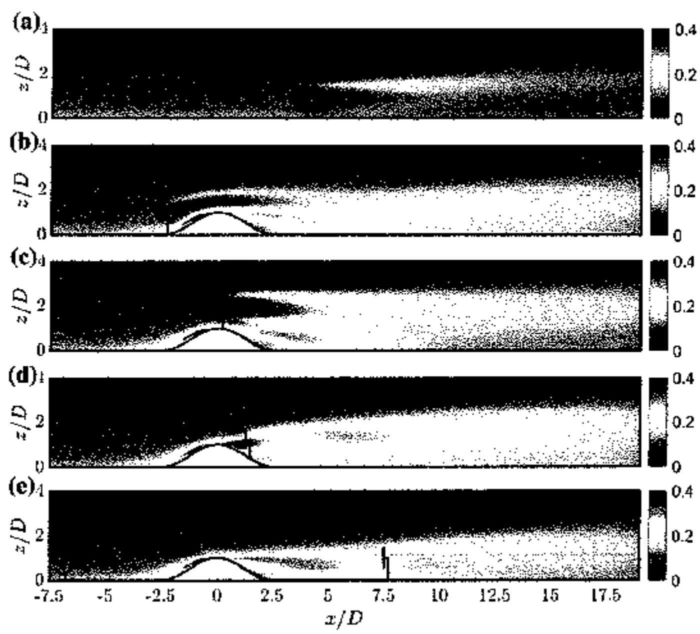

Fig. 6 The normalized streamwise velocity variance σ_u/U_h in the mid-plane of the turbine for, **a** the flat-terrain case, and (**b–e**) for flow over a steep hill at $x/D = 0$ with the turbine located at **b** $x_t/D = -2.5$, **c** $x_t/D = 0$, **d** $x_t/D = 1.25$, and **e** $x_t/D = 7.5$. The hill height is $h/D = 1$. The hub-height is (a, b, c, e) $h_{\mathrm{hub}}/D = 1$ and **d** $h_{\mathrm{hub}}/D = 0.75$

for turbines located on the hilltop (e.g., Politis et al. 2012; Yang et al. 2015; Shamsoddin and Porté-Agel 2017, 2018a, b). In this case, the pressure effects are so large that the wake recovery is slower for a turbine located on the hilltop than for a turbine on flat terrain, even though the velocity fluctuations are significantly higher downstream of the hill (see Fig. 6).

Figure 6 shows the normalized streamwise velocity variance σ_u/U_h, where σ_u is the standard deviation of the streamwise velocity component and U_h is the flow speed at hub-height over a flat terrain without any turbines (Shamsoddin and Porté-Agel 2018b). One can observe that the velocity fluctuations introduced by the hill are high compared to the velocity fluctuations in the wake behind the turbine on flat terrain. Figure 6b, c shows that the velocity fluctuations behind the hill are reduced due to the existence of an upstream turbine (Shamsoddin and Porté-Agel 2017). Figure 6e shows that the region with higher velocity fluctuations that is formed behind the hill can extend more than $7D$ downstream. This means that even turbines that are placed far downstream of a steep hill may be subjected to higher velocity fluctuations, which increases the unsteady turbulence loading experienced by the turbine (Stevens and Meneveau 2017; Porté-Agel et al. 2020).

4 Wind Farm in Hilly Terrain

To investigate the performance of wind farms located close to a steep hill, we analyze the performance of a wind farm with a steep hill in the middle in Sect. 4.1 and a wind farm

P21-36 cont.

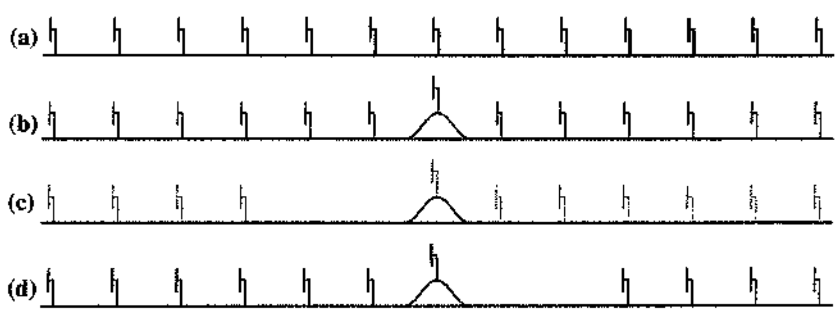

Fig. 7 Sketch of wind-turbine arrangement in different cases for the aligned wind farm. **a** Flat terrain (case 1), **b** wind farm located around a steep hill (case 2), **c** the two turbine rows upstream of the hill removed (case 3), and **d** the two turbine rows downstream of the hill removed (case 4). The colours of the turbines are the same as the colours of the corresponding results presented in Fig. 8. The hill height and hub-height are equal to the turbine diameter, $h = h_{hub} = D$

between two parallel steep hills in Sect. 4.2. For simplicity, the rotor diameter, the hub-height, and the hill height are the same, i.e., $D = h_{hub} = h$. We use the same hill geometry as before, which is given by Eq. 6 with $l/h = 2.5$, and $z_0/D = 10^{-4}$. To keep the discretization of the hill the same, we use a domain size of $100D \times 25D \times 8D$ and a grid resolution of $768 \times 192 \times 193$ in the streamwise, spanwise, and vertical directions, respectively. P21-36 cont.

4.1 Wind Farm with a Hill in the Middle

To evaluate the influence of a hill on the performance of wind farms, we performed simulations of aligned and staggered wind farms, which consist of 13 rows of five turbines. Both the streamwise and spanwise spacings between the turbines are set to $5D$. We consider a reference wind farm on flat terrain (case 1) and a case in which row number 7 is located on the hilltop (case 2). We also consider a wind farm in which the two rows in front of the hill are removed (case 3), and one in which the two turbine rows behind the hill are removed (case 4). Sketches for these different wind farm cases are provided in Fig. 7.

Figure 8 shows the normalized power production P/P_1 for the different cases as a function of the downstream position x for the aligned and staggered wind farms. Here P_1 is the power output of the first row of turbines, which is located at the origin such that the centre of the hill is at $x/D = 30$. Far upstream of the hill ($x/D \leq 20$), the performance of wind farms of case 1 and case 2 is nearly identical, which indicates that the hill has no significant effect on the flow in this region. However, for the aligned wind farm of case 2, the power production of row 6 is about 14% lower than the corresponding row in the reference wind farm (case 1). For the staggered wind farms, this difference is about 18%. This production loss is caused by the flow blockage induced by the hill and is similar to the effect we observed in Sect. 3. The production of the turbine on the hilltop, i.e., row 7, is obviously much higher than in the reference wind farm. This is in agreement with the results obtained in Sect. 3.

Another interesting result is that the power production for rows 8 and 9, i.e., the rows just downstream of the hill, is almost the same for the aligned and staggered wind farms of case 2. The reason is that the hill wake dominates the flow in this region. This conjecture is confirmed by the results of cases 3 and 4. In particular, removing turbines upstream of the hill (case 3) does not significantly affect the performance of turbines downstream of the hill,

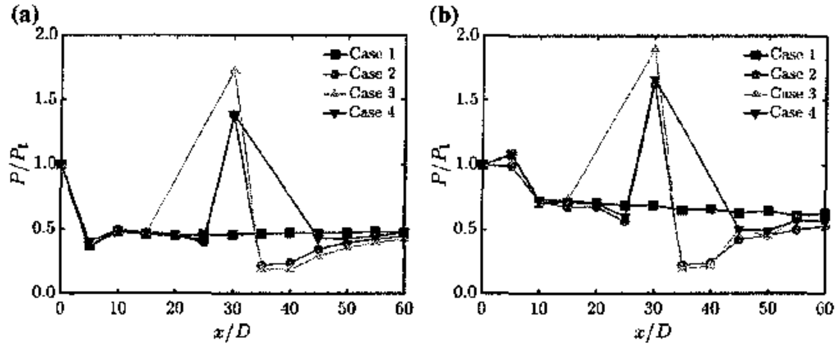

Fig. 8 The normalized power P/P_1 as a function of the downstream position x/D, a aligned, and b staggered wind farms. Case 1: flat terrain; case 2: wind farm located around a steep hill; case 3: the two turbine rows upstream of the hill removed; case 4: the two turbine rows downstream of the hill removed. The hill height and hub-height are equal to the turbine diameter, $h = h_{hub} = D$. See Fig. 7 for a sketch of the different cases

even though it increases the power production of the turbines on the hilltop. At the same time, removing turbines just downstream of the hill (case 4) does not affect the performance of rows even further downstream. This indicates that the hill wake is the dominating flow feature for a very significant region behind the hill. Interestingly, the power production in the last turbine row, which is located $30D$ behind the hilltop, is still lower than the flat-terrain case. This indicates that the flow requires a very long distance to recover fully. P21-36 cont.

To analyze the impact of the hill on the flow further, we show the normalized mean streamwise velocity $\langle u\rangle/U_h$ at a fixed distance D above the ground for the aligned wind farms in Fig. 9. The velocity profiles upstream of the hill are almost the same as for the reference wind farm. This finding is in agreement with the power production data shown in Fig. 8, which is nearly identical for all cases for the first four rows. The figure shows the flow acceleration over the hill due to which the power production of the turbines in row 7 is much higher. Removing the two turbine rows upstream of the hill (case 3) significantly increases the power output of the turbines on the hilltop compared to case 2. However, the wake effect of the upstream rows is still visible as the normalized power production of the turbines on the hilltop is still about 30% lower than for an isolated turbine located on top of the hill (see Fig. 3). Downstream of the hill, the hill wake overshadows the effect of the wakes created by turbines upstream of the hill. Due to the dominant effect of the hill wake removing the two turbine rows downstream of the hill (case 4) does not significantly affect the velocity downstream of the hill. In agreement with the power production results, we find that at $30D$ behind the hill the effect of the hill wake is still visible.

Figure 10 shows the corresponding normalized streamwise velocity variance σ_u/U_h at a fixed distance D above the ground. Upstream of the hill, the velocity fluctuations are nearly the same as that in flat terrain. Just behind the hill, the velocity fluctuations increase significantly due to the flow separation. Further downstream of the hill ($x/D > 50$), the velocity fluctuation contours in complex terrain are almost the same again, which is very similar to the streamwise velocity case (see Fig. 9). This indicates that the wind-farm performance downstream of the steep hill is also independent of the turbines upstream of the hill. Removing the two turbine rows upstream (case 3) or downstream (case 4) of the hill does not significantly affect the velocity fluctuations downstream of the hill. In agreement with the single turbine case (see

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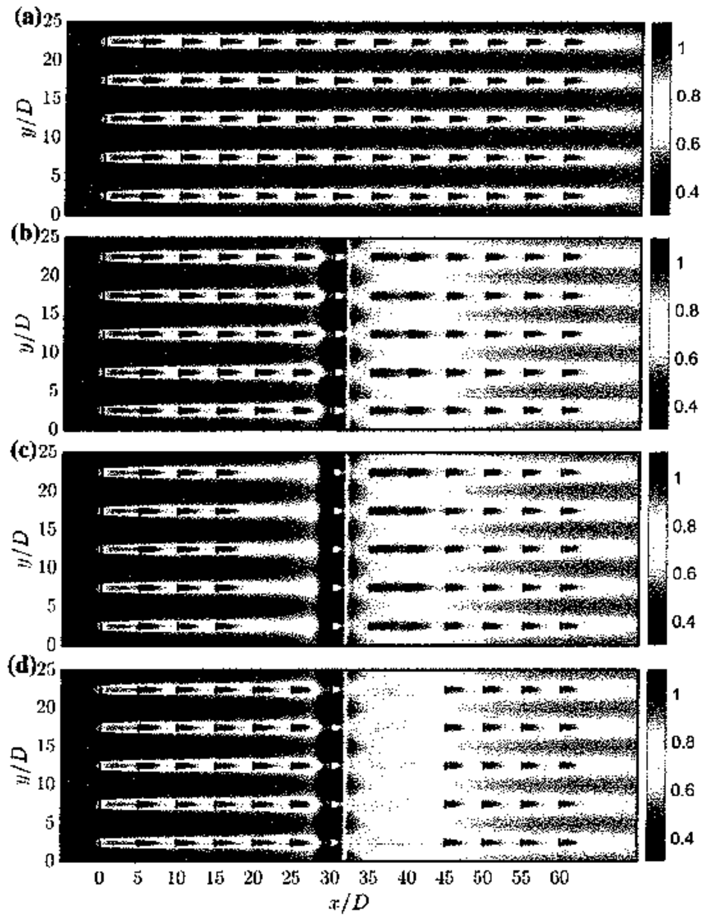

Fig. 9 Normalized mean streamwise velocity component $\langle u\rangle/U_h$ at a fixed distance D above the ground for the aligned wind farm, **a** flat terrain (case 1), **b** wind farm located around a steep hill (case 2), **c** the two turbine rows upstream of the hill removed (case 3), and **d** the two turbine rows downstream of the hill removed (case 4). The hill height and hub-height are equal to the turbine diameter, $h = h_{\text{hub}} = D$. The hilltop is located at $x = 30D$. Small solid lines indicate the turbine positions. See Fig. 7 for a sketch of the different cases

Fig. 6), we find the velocity fluctuations can also be significantly reduced via the interaction with mainly the hilltop turbine.

Figure 11 shows the normalized vertical kinetic energy flux, $-\langle u\rangle\langle u'w'\rangle/U_h^3$ at a fixed distance $2D$ above the ground, where u' and w' indicate the streamwise and vertical velocity fluctuations. For the flat terrain case, the increase of the vertical kinetic energy flux with downstream location is determined by the increased turbulence induced by the wake and the growth of the internal boundary layer that forms at the start of the wind farm. The figure also reveals that the vertical kinetic energy flux more than doubles downstream of the hill. This increased vertical flux ensures that the flow behind the hill recovers and thus compensates for the flow disruption caused by the hill. We notice that although removing the two turbine

P21-36 cont.

Comment Letter P21

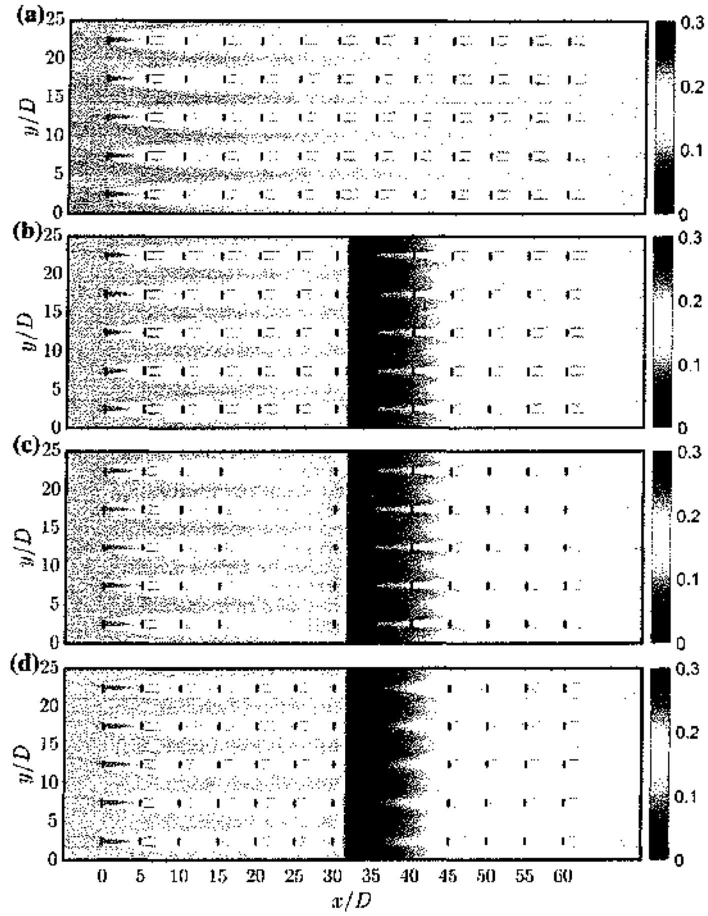

Fig. 10 Normalized streamwise velocity variance σ_u/U_h at a fixed distance D above the ground for the aligned wind farm, **a** flat terrain (case 1), **b** wind farm located around a steep hill (case 2), **c** the two turbine rows upstream of the hill removed (case 3), and **d** the two turbine rows downstream of the hill removed (case 4). The hill height and hub-height are equal to the turbine diameter, $h = h_{\text{hub}} = D$. The hilltop is located at $x = 30D$. See Fig. 7 for a sketch of the different cases

rows downstream of the hill (case 4) does not significantly affect the streamwise velocity and the velocity fluctuations further downstream, it does decrease the vertical kinetic energy flux when compared to cases 2 and 3. Nevertheless, the vertical kinetic energy fluxes downstream of the hill are significantly larger than the flat terrain case, which indicates the strong effect of the hill.

P21-36 cont.

Comment Letter P21

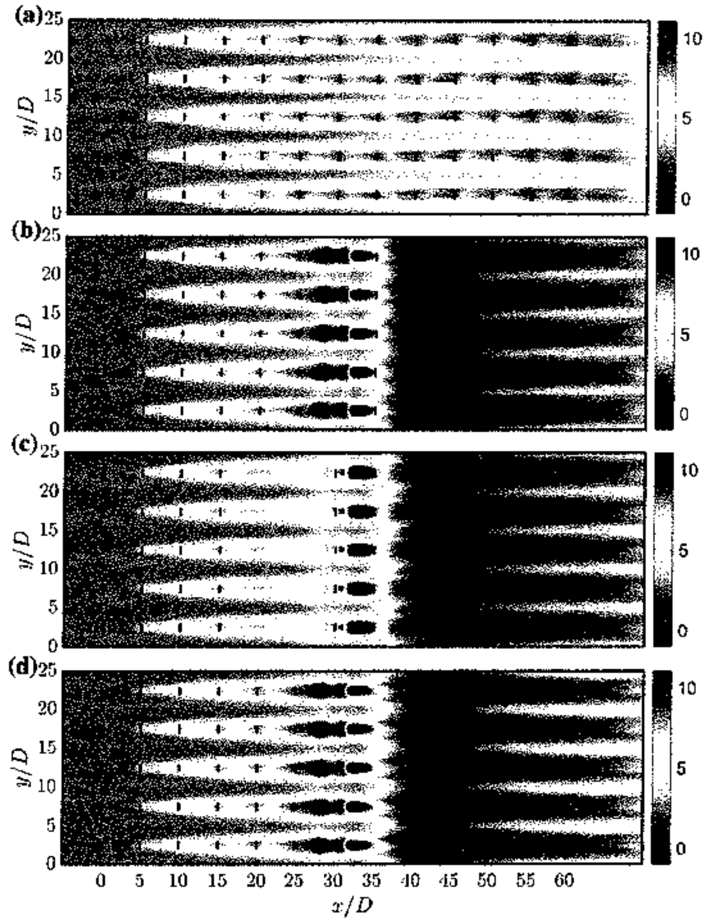

Fig. 11 Normalized mean vertical kinetic energy flux $-10^3\langle u\rangle\langle u'w'\rangle/U_h^3$ at a fixed distance $2D$ above the ground for the aligned wind farm, **a** flat terrain (case 1), **b** wind farm located around a steep hill (case 2), **c** the two turbine rows upstream of the hill removed (case 3), and **d** the two turbine rows downstream of the hill removed (case 4). The hill height and hub-height are equal to the turbine diameter, i.e. $h = h_{hub} = D$. The hilltop is located at $x = 30D$. See Fig. 7 for a sketch of the different cases

4.2 Wind Farm Between Two Parallel Hills

In this section, we consider an aligned wind farm located between two parallel hills, separated by $60D$, with seven rows of five turbines. As the optimum turbine performance is obtained at the hilltop, the first and last turbine rows are located on hilltops. The spanwise spacing between the turbines is $5D$. We vary the streamwise spacing s_x between the turbines in the valley, as indicated in the sketch provided in the top panel of Fig. 12. We place the turbines closer to the second hill to prevent turbines being placed in the wake of the upstream hill as much as possible. We do this as we have seen that upstream hills have an enormous effect on

P21-36 cont.

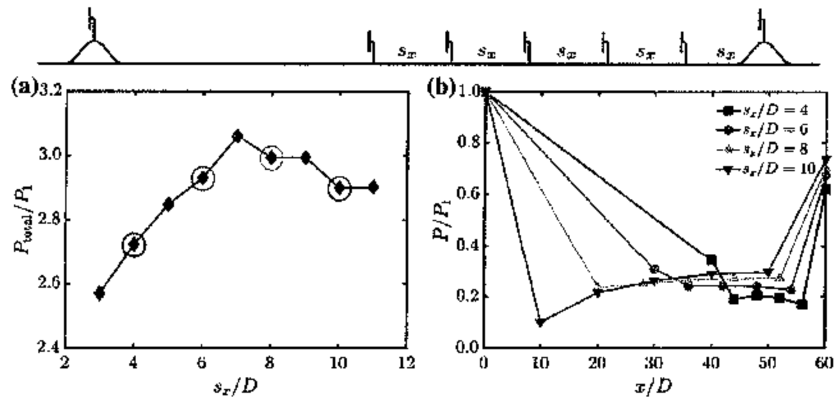

Fig. 12 **a** The normalized total power P_{total}/P_1 as a function of the streamwise spacing s_x/D and **b** the normalized power P/P_1 as a function of the downstream position x/D. The circles in **a** corresponds to the curves in **b**. The top panel sketches the wind turbine arrangement for the wind farm between two steep hills. The hill height and hub-height are equal to the turbine diameter, $h = h_{hub} = D$

the performance of downstream turbines. Thus the streamwise distance between all turbine rows is the same, except for between the first two turbine rows. The results below confirm the view that in a case like this — in which space is limited — it is beneficial for the wind-farm power output that the turbines are placed in the wake of an upstream hill as little as possible. P21-36 cont.

Figure 12a shows that the normalized total wind farm power production P_{total}/P_1 reaches a maximum value when $s_x = 7D$. Here, P_1 denotes the time-averaged power production of the first row and P_{total} the output of the entire farm. Figure 12b shows the power production as a function of the downstream position x for four typical cases indicated in Fig. 12a. The figure shows that with decreasing s_x the power production of the first turbine in the valley increases, but the production of all other turbines in the valley and the turbine on the top of the second hill significantly decreases due to the inter-turbine wake effects. For $s_x \geq 7D$ the power production of the first turbine in the valley decreases rapidly with increasing s_x, while the turbines in the valley only marginally benefit from the increased inter-turbine distance. Thus, the maximum wind-farm power production for $s_x = 7D$ is a result of two competing effects: When s_x is too small, the effect of the wind-turbine wakes affects the power production of the turbines too much. However, when s_x is too large, the second turbine row is located too closely behind the first hill, and this severely limits its power production.

In this case, the existence of a unique spacing for which the total power production of the wind farm reaches a maximum value is a result of the space limitation and the flow separation downstream of the hill. Although this is an interesting observation, it is hard to generalize as it depends on many parameters and considerations. Nevertheless, we confirm that the steep hill has a significant effect on the wind-farm performance.

5 Conclusions

We used LES to study the effect of two-dimensional steep hills on the performance of wind turbines and wind farms. Throughout the entire study, we assume that the turbine thrust coefficient $C_T = 3/4$. We find that steep hills have a significant impact on the power production of turbines, and turbines that are significantly taller than the hill benefit from the speed-up of the flow over the hill. For shorter turbines, the power production strongly depends on the turbine location with respect to the hill but reaches its maximum value on the hilltop while locations just downstream of the hill are worst. While previous studies have shown that it is possible to obtain reasonable predictions for the effect of a shallow hill on the performance of nearby turbines, it is much more challenging to model the effect of a steep hill (Porté-Agel et al. 2020). Here we find that the performance of turbines placed on the windward side of the hill is well predicted by superimposing the wind-turbine wake profile for the flat terrain on the hilly-terrain flow field (Hyvärinen and Segalini 2017b). However, we show that such a prediction is not accurate for turbines placed on the leeward side of the hill.

The hill wake effect is very pronounced when the hill is located in the middle of the wind farm. In particular, removing turbines upstream of the hill has no significant effect on the power production of turbines downstream of the hill. Even removing turbines just downstream of the hill only leads to a minimal benefit for turbines located further downstream. This indicates that the recirculation zone of the hill is the dominant flow feature, and the wind turbines have only a limited effect on the development of the hill wake. The effect of the hill wake is observed up to at least $30D$ behind the hill, implying that steep hills influence the performance of turbines in a significant region.

Furthermore, we find that there is a unique turbine spacing for the wind farms located between two parallel hills such that the power production of the wind farm reaches its maximum value. The existence of such a unique spacing is the result of two competing effects created by the existence of a steep upstream hill and a limited available downstream space.

P21-36 cont.

Acknowledgements We appreciate very much the valuable comments of the anonymous referees. We thank Srinidhi Nagarada Gadde, Anja Stieren, and Jessica Strickland for stimulating discussions. This work is part of the Shell-NWO/FOM-initiative Computational sciences for energy research of Shell and Chemical Sciences, Earth and Live Sciences, Physical Sciences, FOM and STW and an STW VIDI grant (No. 14868). This work was carried out on the national e-infrastructure of SURFsara, a subsidiary of SURF cooperation, the collaborative ICT organization for Dutch education and research.

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OSTI.GOV / Conference: *Effects of wind shear and turbulence on wind turbine power curves*

Effects of wind shear and turbulence on wind turbine power curves

Abstract

It is a common practice to use wind speeds at hub height in determining wind turbine power curves. Although the possible influence of other variables (sub as turbulence and wind shear) is generally neglected in power curve measurements, we discovered the importance of other variables in an analysis of power curves for three 2.5 MW wind turbines. When the power curves were stratified by turbulence intensity. Such a large sensitivity to turbulence was not expected, and further analyses were conducted to determine if other factors accompanying the change in turbulence level could cause or contribute to the observed sensitivity of the power curves to turbulence. In summary, the sensitivity of the observed power curves was largely due to two factors: (1) an actual sensitivity to turbulence in determining the power curve and (2) the deviation of the disk-averaged velocity from the hub-height velocity under low turbulence conditions that were most prevalent at the site. An examination of the wind shear profiles over the height of the rotor disk revealed that low turbulence conditions were characterized by strong shear in the lower half of the rotor disk and weak or negative shear in the upper half. Implications of this analysis are that significant errors in power curve measurements can result if the effects of wind shear and turbulence are ignored. 7 refs., 6 figs. « less

P21-36 cont.

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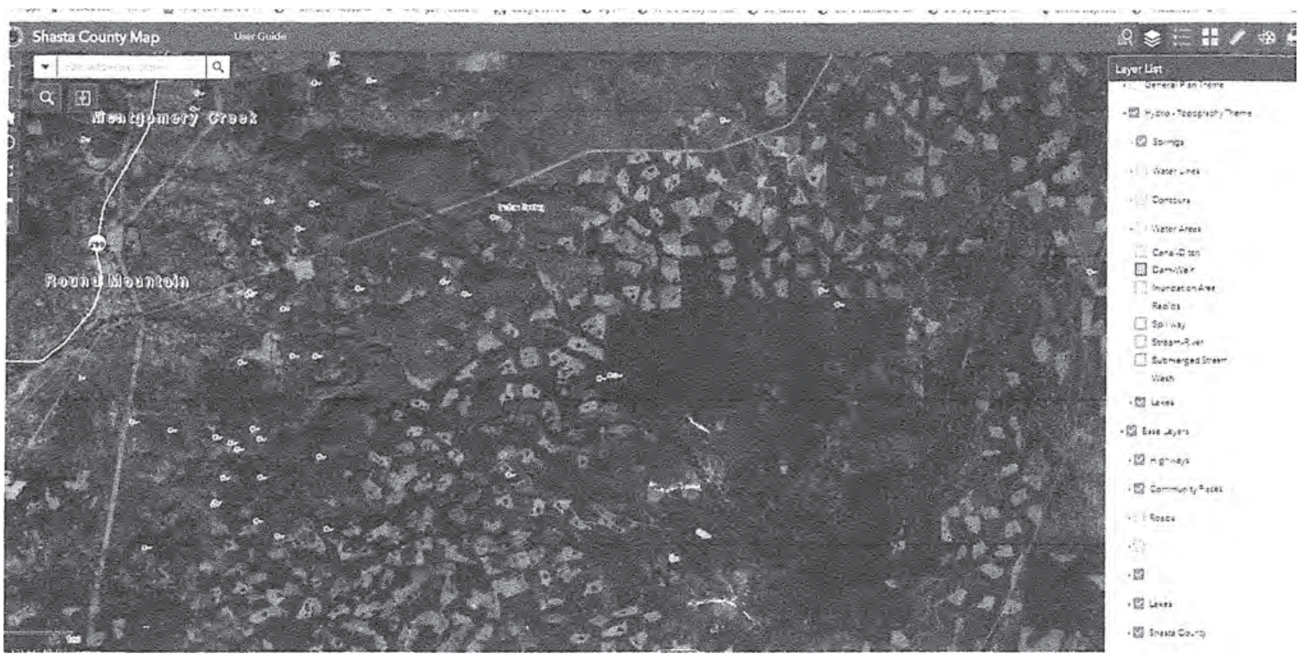
10/13/2020 Springs map closer up round mountain montgomery creek.JPG



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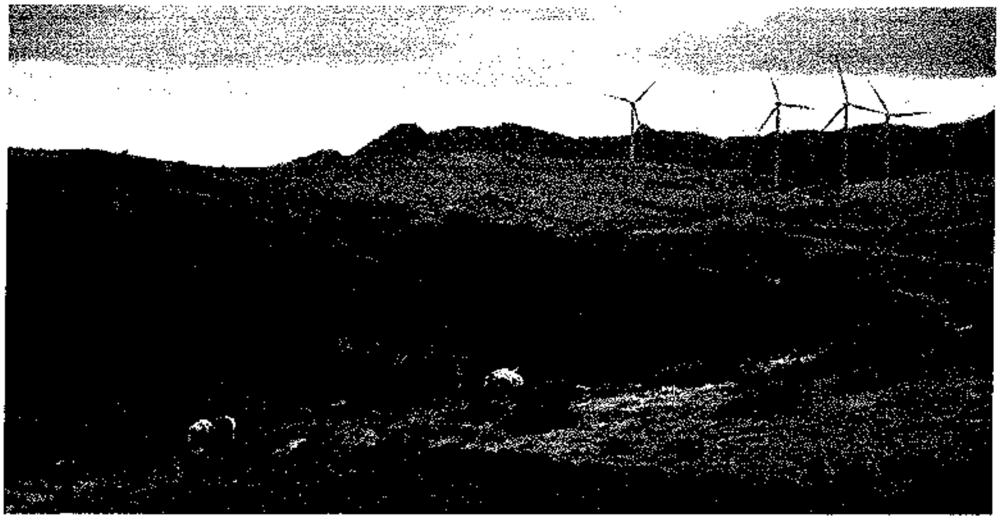
SECURITY

First-of-a-kind U.S. grid cyberattack hit wind, solar

Blake Sobczak, E&E News reporter

Published: Thursday, October 31, 2019



sPower's Pioneer Wind Park in Glenrock, Wyo. Several sPower solar and wind sites experienced communications outages as a result of a cyberattack on Cisco equipment this year. sPower

This story was updated at 2:55 p.m. EDT.

A Utah renewable energy developer was hit by a first-of-its-kind cyberattack that briefly cut contact to a dozen wind and solar farms this spring, according to documents obtained by E&E News under the Freedom of Information Act.

Salt Lake City-based sPower suffered "denial of service" attacks on March 5 that left grid operators temporarily blinded to generation sites totaling 500 megawatts, the documents show.

Hackers did not cause any blackouts or generation outages, according to sPower, which says it's the biggest private solar power operator in the United States. The cyberattack took advantage of a known weakness in Cisco firewalls to trigger a series of five-minute communications outages over a span of about 12 hours, according to an emergency report sPower filed with the Department of Energy at the time of the disruption that was not publicly released. Denial-of-service attacks flood target devices or websites with bogus traffic to crash them.

The cybersecurity incident is the first confirmed to have caused "interruptions of electrical system operations," based on DOE records. Experts say the hackers behind the attack may not have known they were affecting the power grid, based on the fact that Cisco firewalls are used in a range of industries and are a popular target of opportunity when left exposed to the internet.

In September, the North American Electric Reliability Corp. posted a document revealing that the attack created blind spots at a grid control center, but it was not known until now which specific company was affected (*Energywire*, Sept. 6).

"sPower has reviewed log files and has found no evidence of a breach beyond the [denial-of-service] attack," said Matthew Tarduogno, an official in DOE's Office of Cybersecurity, Energy Security and Emergency Response, in a March 8 email obtained by E&E News. "Additionally, the incident did not have any impacts on operations."

Tarduogno said he was providing DOE's intelligence officials with updates "and they are ready to investigate any indicators, as appropriate, and have been checking for any related incidents."

A DOE official said in a statement today that while the agency offered to investigate, "the reporting entity did not provide any further data to DOE."

"Additionally, at this time, DOE is not aware of any related incidents in the energy sector," the official said, adding that grid security officials outside the agency also issued a bulletin on the event. "Overall, the incident did not

P21-36 cont.

impact generation, the reliability of the grid, or cause any customer outages."

Lara Hamsher, government relations and communications manager at sPower, said in a statement that the company investigated the case and improved its systems since March 5 to "help ensure as much uptime as possible."

"These interruptions had no impact to generation and did not cause electrical system separation," she said in an emailed statement.

'Pain' possible

Cybersecurity experts say the March 5 attack underscores emerging dangers to power companies worldwide (*Energywire*, May 6).

In 2015, hackers knocked out electricity to several hundred thousand people in Ukraine in an unprecedented cyberattack. The attackers, later linked to the Russian government, also swamped their targets' phone lines with calls in a "telephone denial of service" aimed at hampering recovery. The three power companies hit in that attack managed to restore electricity in a few hours.

"In isolation, impacting network communications is probably not that huge of a deal," said Joe Slowik, principal adversary hunter at industrial cybersecurity firm Dragos Inc."But as a sort of pop-up or amplifying effort, things can get really interesting."

He pointed to the record-smashing electricity demand in Texas this summer as the state experienced a heat wave (*Energywire*, Aug. 14). Given the region's heavy reliance on wind power, any communications outages there "would have been a big deal, because that could have resulted in a generation gap that would have led to some pain," Slowik said.

For its part, the sPower wind and solar sites affected by the March 5 cyber event spanned Wyoming, California and Utah, where the company's 24/7 grid control center and headquarters are located. sPower's 106.3-MW Solverde project in Lancaster, Calif., and its 80-MW Pioneer Wind Park in Glenrock, Wyo., were among the sites to face communications problems.

sPower is owned as a joint venture between Virginia-based utility AES Corp. and Canadian investment manager AIMCo. Neither parent company responded to requests for comment yesterday.

Wind and solar projects aren't designed to stop feeding power into the grid if operators lose contact with them. Communications outages of 30 minutes or more are fairly common because of power outages and other glitches, even at much larger grid control centers, and rarely lead to blackouts, based on DOE grid disturbance records.

Still, wind and solar generation sites pose some unique challenges compared with natural gas, coal or nuclear plants that are staffed around the clock.

"They rarely have anyone on-site," said Patrick Miller, managing partner at Archer Energy Solutions. "Any troubleshooting for things like this will often require a fair amount of windshield time for someone or several people. This could easily exacerbate the impacts to incident response and forensic capabilities."

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The essential news for energy & environment professionals

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Article

Computational Fluid Dynamics (CFD) Investigation of Wind Turbine Nacelle Separation Accident over Complex Terrain in Japan

Takanori Uchida

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Abstract: We have developed an unsteady and non-linear wind synopsis simulator called RIAM-COMPACT (Research Institute for Applied Mechanics, Kyushu University, COMputational Prediction of Airflow over Complex Terrain) to simulate the airflow on a micro scale, i.e., a few tens of km or less. In RIAM-COMPACT, the large-eddy simulation (LES) has been adopted for turbulence modeling. LES is a technique in which the structures of relatively large eddies are directly simulated and smaller eddies are modeled using a sub-grid scale model. In the present study, we conducted numerical wind diagnoses for the Taikoyama Wind Farm nacelle separation accident in Japan. The simulation results suggest that all six wind turbines at Taikoyama Wind Farm are subject to significant influence from separated flow (terrain-induced turbulence) which is generated due to the topographic irregularities in the vicinity of the wind turbines. A proposal was also made on reconstruction of the wind farm.

Keywords: complex terrain; terrain-induced turbulence; LES

P21-36 cont.

1. Introduction

At Taikoyama Wind Farm (located on Mt. Taikoyama, Kyoto Prefecture, Japan) at around 19:30 on 12 March 2013, a major accident occurred in which a portion of Wind Turbine (WT) No. 3 constituting the generator and blades (height: approximately 50.0 m; weight: approximately 45.0 t) fell to the ground. The base of the nacelle, which connects the tower and the blades, was fractured. Since the wind speed at the time of the accident was about 15.0 m/s and was within the design limit, investigations were conducted based on a standpoint that metal fatigue was the main cause of the accident. A report [1] on the investigation results has already been made available to the public, and the results are also reported in the literature [2].

There are six 750 kW wind turbines manufactured by Lagerwey in the Netherlands at Taikoyama Wind Farm. The maximum output of the wind farm is 4500 kW. The annual energy output of the wind farm projected in the planning stage was 8549 MWh. The wind farm has been operated by a government affiliated public utility organization in Kyoto Prefecture since November 2001. The total operating cost of the wind farm is approximately 1.5 billion yen. The annual mean wind speed evaluated at the time of the detailed investigation of the wind conditions was 5.4 m/s at the height of 20.0 m above the ground surface. (The annual mean wind speed corrected to the 50.0 m height with a power law exponent of 1/7 was 6.2 m/s.) Figures 1–3 show the location of the Taikoyama Wind Farm, a still image of the wind farm from the time of the accident, and a schematic diagram of the wind turbines, respectively.

Liu and Ishihara [2] did not report details of the airflow characteristics at each wind turbine site. Accordingly, the present study focused on the effect of the terrain-induced turbulence which is generated in the vicinity of the wind turbines, and conducted unsteady, numerical wind diagnoses for Taikoyama Wind Farm using LES technique [3–9]. Based on the numerical simulation results, relative comparisons were made of the airflow characteristics among the wind turbine locations. In particular, the present study focused on: (1) the three-dimensional structure of the airflow; and (2) the standard deviations of the three components (i.e., streamwise, spanwise, and vertical components) of the wind velocity that were evaluated from time-series data. In the present paper, "terrain-induced turbulence" is defined as "temporal and spatial fluctuations of airflow which are generated by topographic irregularities."

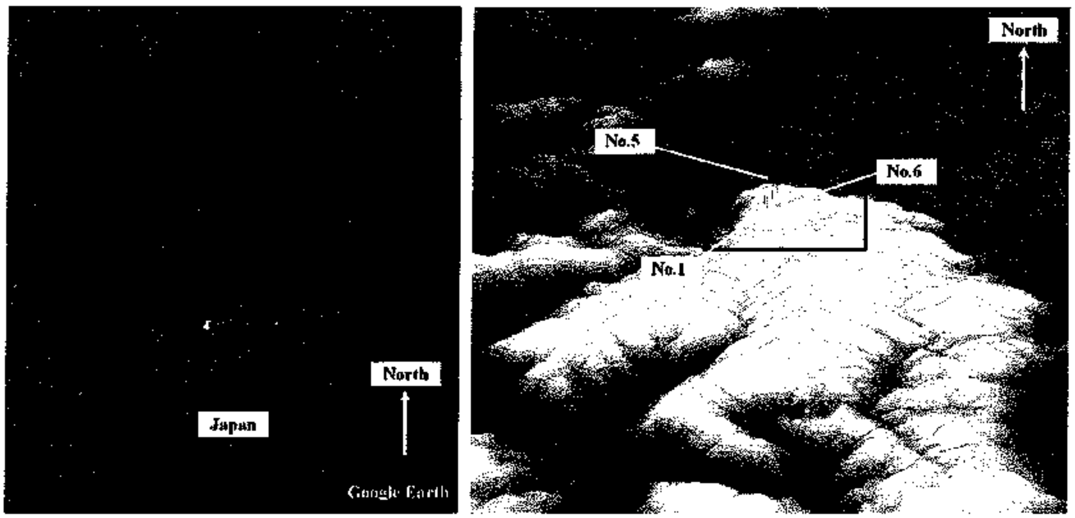

Figure 1. Location of Taikoyama Wind Farm in Kyoto Prefecture, Japan.

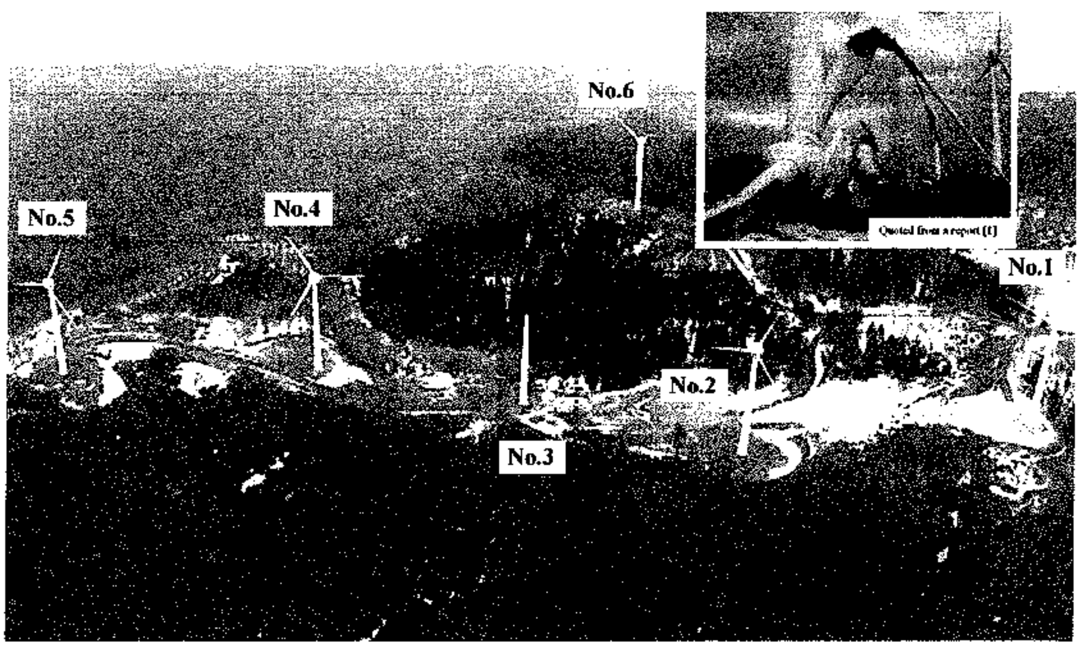

Figure 2. Still image of wind turbine accident, taken from a video by RKB Mainichi Broadcasting Corporation.

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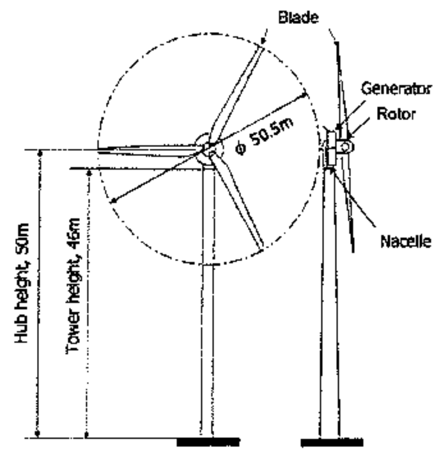

Figure 3. Schematic diagram of the wind turbine.

2. Overview of Numerical Simulation Method

The present study used the RIAM-COMPACT natural terrain version software package [3–9], which is based on a collocated grid in a general curvilinear coordinate system, to numerically predict local wind flow over complex terrain with high accuracy while avoiding numerical instability. In this collocated grid, the velocity components and pressure are defined at the grid cell centers, and variables that result from multiplying the contravariant velocity components by the Jacobian are defined at the cell faces. For the numerical technique, the finite-difference method (FDM) was adopted, and a large-eddy simulation (LES) model was used for the turbulence model. In the LES model, a spatial filter is applied to the flow field to separate eddies of various scales into grid-scale (GS) components, which are larger than the computational grid cells, and sub-grid scale (SGS) components, which are smaller than the computational grid cells. Large-scale eddies, i.e., the GS components of turbulence eddies, were directly numerically simulated without the use of a physically simplified model. In contrast, dissipation of energy, which is the main effect of small-scale eddies, i.e., the SGS components, was modeled according to a physics-based analysis of the SGS stress. P21-36 cont.

For the governing equations of the flow, a filtered continuity equation for incompressible fluid (Equation (1)) and a filtered Navier–Stokes equation (Equation (2)) were used. Because high wind conditions, with mean wind speeds of 8.0 m/s or higher, are considered in the present study, the effect of vertical thermal stratification (atmospheric stability), which is generally present in the atmosphere, was neglected. As in Uchida et al. [3–9], the effects of the surface roughness were considered by reconstructing surface irregularities in high resolution. For the computational algorithm, a method similar to a fractional step (FS) method [10] was used, and a time marching method based on the Euler explicit method was adopted. The Poisson's equation for pressure was solved by the successive over-relaxation (SOR) method. For discretization of all the spatial terms except for the convective term in Equation (2), a second-order central difference scheme was applied. For the convective term, a third-order upwind difference scheme was applied. An interpolation technique based on four-point differencing and four-point interpolation by Kajishima et al. [11] was used for the fourth-order central differencing that appears in the discretized form of the convective term. For the weighting of the numerical diffusion term in the convective term discretized by third-order upwind differencing, $\alpha = 3.0$ is commonly applied in the Kawamura–Kuwahara scheme [12]. However, $\alpha = 0.5$ was used in the present study to minimize the influence of numerical diffusion. For LES subgrid-scale modeling, the standard Smagorinsky model [13] was adopted with a model coefficient of 0.1 in conjunction with a wall-damping function.

$$\frac{\partial \overline{u}_i}{\partial x_i} = 0 \quad (1)$$

$$\frac{\partial \overline{u}_i}{\partial t} + \overline{u}_j \frac{\partial \overline{u}_i}{\partial x_j} = -\frac{\partial \overline{p}}{\partial x_i} + \frac{1}{Re}\frac{\partial^2 \overline{u}_i}{\partial x_j \partial x_j} - \frac{\partial \tau_{ij}}{\partial x_j} \quad (2)$$

$$\tau_{ij} \approx \overline{u_i' u_j'} \approx \frac{1}{3}\overline{u_k' u_k'}\delta_{ij} - 2\nu_{SGS}\overline{S}_{ij} \quad (3)$$

$$\nu_{SGS} = (C_s f_s \Delta)^2 |\overline{S}| \quad (4)$$

$$|\overline{S}| = (2\overline{S}_{ij}\overline{S}_{ij})^{1/2} \quad (5)$$

$$\overline{S}_{ij} = \frac{1}{2}\left(\frac{\partial \overline{u}_i}{\partial x_j} + \frac{\partial \overline{u}_j}{\partial x_i}\right) \quad (6)$$

$$f_s = 1 - exp(-z^+/25) \quad (7)$$

$$\Delta = (h_x h_y h_z)^{1/3} \quad (8)$$

3. Outline of the Numerical Simulation Set-Up

The computational domain used in the present study extends over the space of 10.0 km (x) × 5.0 km (y) × 3.3 km (z), where x, y, and z are the streamwise, spanwise, and vertical directions, respectively. The maximum surface elevation within the computational domain is 681.0 m, and the minimum surface elevation is 8.0 m. Terrain elevation data with a 10.0 m spatial resolution from the Geospatial Information Authority of Japan (GSI) were used. The total number of computational grid points, 401 (x) × 201 (y) × 41 (z), is approximately 3.3 million. The grid points in the x- and y-directions are distributed non-uniformly so that the density of the grid points is high in the vicinity of the wind turbines. The grid points are also distributed non-uniformly in the z-direction so that the density of grid points increases smoothly toward the ground surface. The minimum horizontal and vertical grid spacings are 10.0 m and 2.0 m, respectively. Figure 4 shows the computational grid in the vicinity of the wind turbines. The Wind Power Utility Evaluation Board of Kyoto Prefecture reports that the prevailing wind direction in the area of Taikoyama Wind Farm is west-southwesterly. Accordingly, the present numerical simulation investigated a case of west-southwesterly flow. As for the boundary conditions, a vertical wind profile which follows a power law (N = 7) was assigned at the inflow boundary. For the lateral and upper boundaries, free-slip conditions were used. For the outflow boundary, a convective outflow condition was used. On the ground surface, a no-slip boundary condition was imposed. The non-dimensional parameter Re in Equation (2) is the Reynolds number (= U_{in} h/ν) and was set to 10^4 in the present simulation. The characteristic length scales adopted for the simulation are shown in Figure 5. In the present study, h (=673.0 m) is the difference between the minimum and maximum surface elevations in the computational domain, U_{in} is the wind velocity at the inflow boundary at the height of the maximum terrain in the computational domain, and ν is the coefficient of dynamic viscosity. The time step in the present simulation is set to Δt = 2 × 10^{-3} h/U_{in}.

P21-36 cont.

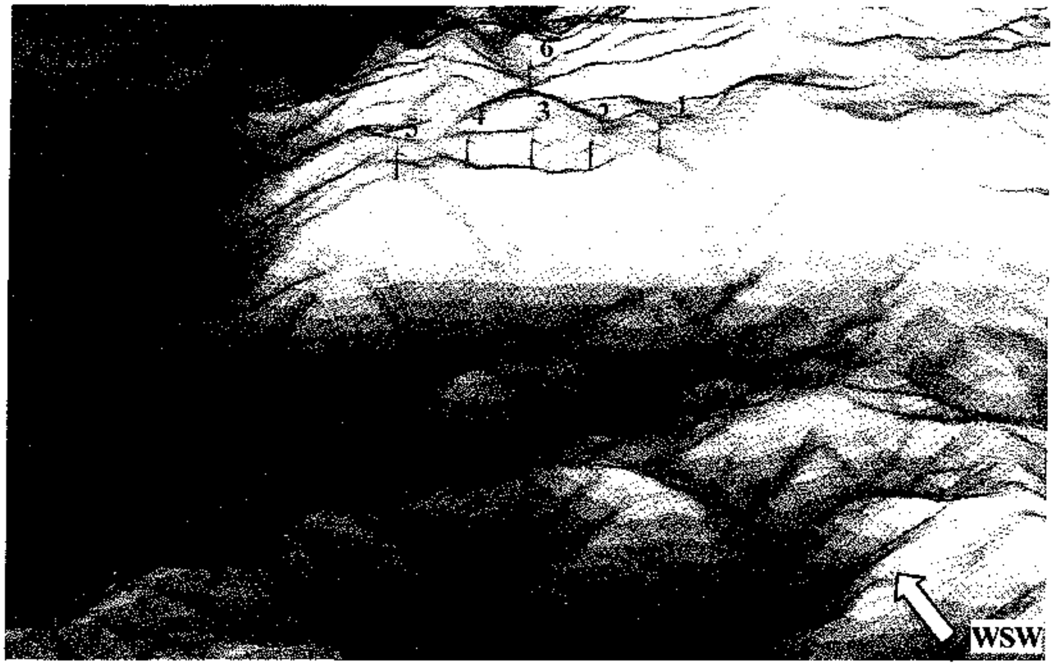

Figure 4. Computational grid in the vicinity of the wind turbines.

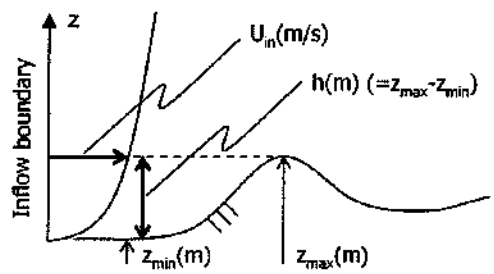

Figure 5. Characteristic velocity and length scales (U_{in} and h).

P21-36 cont.

4. Simulation Results and Discussion

Figure 6 shows the temporal changes of the non-dimensional scalar wind speed based on the three components of the wind velocity, U_{scalar}/U_{in} ($=(u^2 + v^2 + w^2)^{1/2}/U_{in}$), which were calculated at the hub heights (50.0 m above the ground surface, refer to Figure 3) of all wind turbines, WTs No. 1 to No. 6. In Figure 6, the horizontal axis indicates non-dimensional time ($=T/(h/U_{in})$). For a hypothetical value of U_{in} = 5.0 m/s for the actual wind velocity, the duration of time on the horizontal axis is approximately 45.0 min. An examination of Figure 6 reveals that an anomalous flow phenomenon is generated in the vicinity of the wind turbines, that is, the trends of the temporal change of the non-dimensional scalar wind speed are almost the same at all turbines, WTs No. 1 to No. 6. The wave pattern in the trends changes by alternating between low velocities and high velocities. As discussed in detail below, this wave pattern changes periodically, suggesting that terrain-induced turbulence is generated due to the topographic irregularities in the vicinity of the wind turbines passing through the wind turbines. Therefore, it can be speculated that all wind turbines, WTs No. 1 to No. 6, were subject to the effect of terrain-induced turbulence which originated from topographic irregularities, on a regular basis. Although it happened to be the nacelle of WT No. 3 that fell to the ground at the time of the accident, it may be claimed that this accident was bound to happen at one of the wind turbines on the wind farm and that it would have been no surprise even if the nacelle of a different

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wind turbine had fallen to the ground. Note that, in post-accident inspections, cracks similar to those on WT No. 3 were detected on all the turbines except for WT No. 1.

In a Reynolds-Averaged Navier–Stokes (RANS) model, the governing equations are Reynolds-Averaged (ensemble-averaged). Therefore, in a numerical wind simulation which uses a RANS model as the turbulence model, unsteady flow phenomena such as the one in Figure 6 cannot be simulated. Figure 7 shows the vertical profiles of streamwise wind velocities from all the wind turbine sites. These profiles were obtained by time-averaging (frame-averaging) the wind field over t = 100–120 in the non-dimensional time period shown in Figure 6. The results in this figure correspond to output from a RANS model. The variable z^* on the vertical axis represents the height above the terrain surface (m), and the horizontal axis shows the normalized wind velocity. In regard to interpreting Figure 7, the following point should be noted. Figure 7 shows that large velocity shears are not present at any of the wind turbine sites at Taikoyama Wind Farm, i.e., WTs No. 1 to No. 6, although the mean streamwise wind velocities are locally enhanced due to topographic effects at all these sites. Judging from Figure 7 alone, one may tend to conclude that, from the point of view of wind conditions, serious problems are not expected to occur at any of the wind turbine sites WTs No. 1 to No. 6. Therefore, to examine the topographic effects on airflow at wind turbine sites, an examination that considers unsteady flow phenomena is crucial.

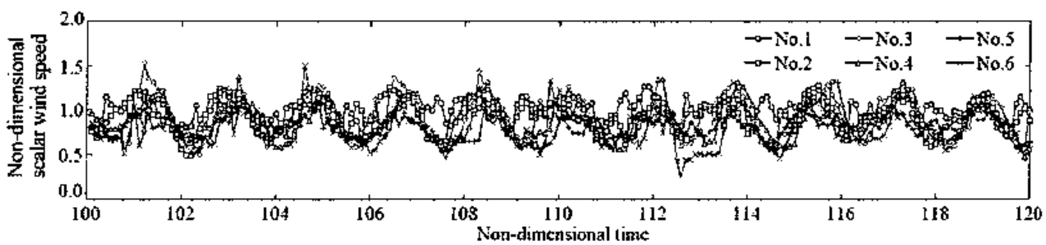

Figure 6. Temporal changes of scalar wind speed at the hub height (50.0 m). Duration of time shown on the horizontal axis is approximately 45.0 min (for U_{in} = 5.0 m/s).

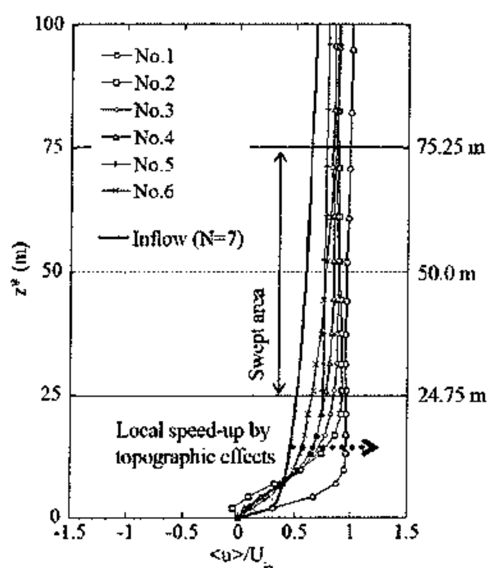

Figure 7. Profile of mean streamwise wind velocity at each wind turbine site.

Henceforth, the discussion focuses on WT No. 3, the nacelle which fell to the ground in the present accident. Figure 8 shows the temporal changes of the angle of the wind on horizontal (yaw direction)

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and vertical cross-sections at the wind turbine hub height (50.0 m above the terrain surface), which are represented by the symbols ○ and □, respectively. The definitions of the two angles are also illustrated in Figure 8. The figure indicates that both angles change periodically with time in conjunction with the temporal changes of the non-dimensional scalar wind speed shown in Figure 6. An examination of the temporal change of the angle of the wind on the vertical cross-section, shown with the symbol □, reveals that wind blowing with angles close to ±25° occurs frequently. As indicated by points A (+28.5°) and B (+28.2°) in the figure, wind blowing upward with a large angle even exceeding 25° also occurs. Subsequently, the temporal change of the angle of the wind on the horizontal cross-section (yaw direction), shown with the symbol ○, is examined. As is the case for the angle of the wind on the vertical cross-section, wind blowing with angles of approximately ±25° occurs periodically. Figure 9 depicts the velocity vectors at WT No. 3 for the times indicated by points C (+28.1°, non-dimensional time: 106.0) and D (−40.4°, non-dimensional time: 107.5) in Figure 8. The corresponding vertical profiles of the streamwise wind velocity are shown in Figure 10. An examination of the side view of the vertical profile of the wind velocity vectors in Figures 9 and 10 together leads to the following finding: within the swept area at both instances indicated by points C and D, the vertical profiles of the wind velocity do not deviate significantly from the vertical profile of the inflow wind velocity which follows a power law (N = 7) (heavy black line in Figure 10). In contrast, an examination of the rear view in Figure 9a shows that, at the time indicated by point C, the velocity vector rotates rapidly with height across the entire vertical profile. At the time indicated by point D, the velocity vector rotates gradually with height between the ground surface and the upper end of the swept area (Figure 9b). In this case, the rotation angle of the wind vector over the entire height is much smaller than that for the time indicated by point C.

The rotations of the wind velocity vector with height in the vertical profiles are attributable to the three-dimensional structure of the terrain-induced turbulence. It can be speculated that, as a result of the change of direction of the wind velocity vector with height, additional load was imposed in the vicinity of the base of the nacelle of WT No. 3, which connected the wind turbine tower and the blades. This condition, in turn, increased metal fatigue in the bolts on WT No. 3. The simulation results of the present study also show, across the height between the center of the wind turbine hub and the lower end of the swept area, the presence of multiple time periods characterized by large velocity shear, in which the vertical profile of wind velocity deviates significantly from that of the inflow wind velocity which follows a power law (N = 7) (not shown due to space limitations). P21-36 cont.

Figure 11 shows the vertical profiles of the standard deviations of the three components of the wind velocities evaluated from the wind field at each of the wind turbine sites. Specifically, the standard deviations were calculated with respect to the time-averaged (frame-averaged) values of wind velocities from the non-dimensional period t = 100–120 shown in Figure 6. The present study evaluates only the airflow fluctuations caused by terrain-induced turbulence which originates from the topographic irregularities and does not consider the fluctuating component of the inflow wind field (wind gusts). The values of the standard deviation of each component of the wind velocity are relatively large across the range of the swept area at all the wind turbine sites (Figure 11). It should also be noted that the values of the standard deviations of the x- and y-components (Figure 11a,b, respectively) are approximately the same. This result indicates that the temporal and spatial fluctuations of the airflow in the horizontal cross-section direction (yaw direction) are large at all of the wind turbine sites, as discussed for Figures 8 and 9. It can be speculated that vertical and horizontal exciting forces were generated at and around the base of the nacelle of WT No. 3 due to the phenomena discussed above: (1) relatively large values of the standard deviation of the x-component of the wind velocity; (2) large values of the standard deviation of the z-component of the wind velocity; and (3) the standard deviation of the y-component of the wind velocity being approximately the same as that of the x-component. This leads to a possible explanation for the accident: the generated exciting forces damaged the bolts at the joint between the wind turbine body and the tower, which in turn would increase the exciting forces, resulting in the fatigue breakdown of the upper portion of the tower.

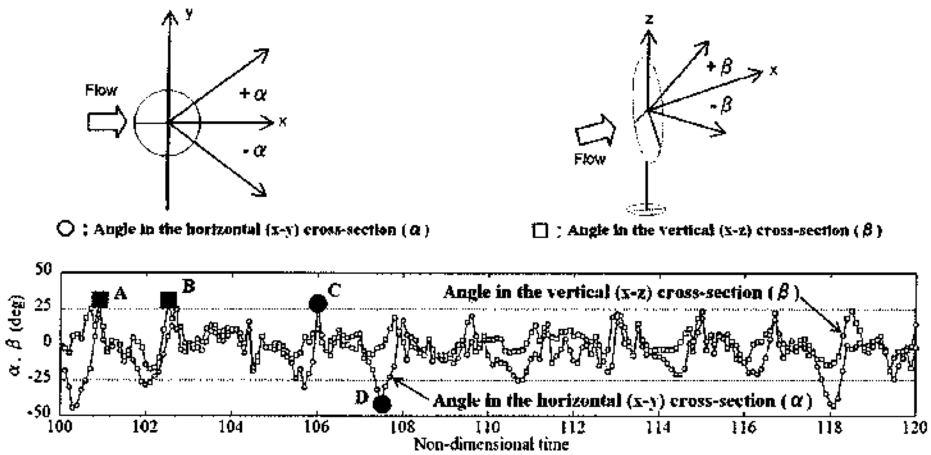

Figure 8. Temporal changes of the angle of the wind on the horizontal (x–y) and the vertical (x–z) cross-sections at the hub height (50.0 m above the terrain surface) in the case of WT No.3. Duration of non-dimensional time on the horizontal axis is approximately 45.0 min (for U_{in} = 5.0 m/s).

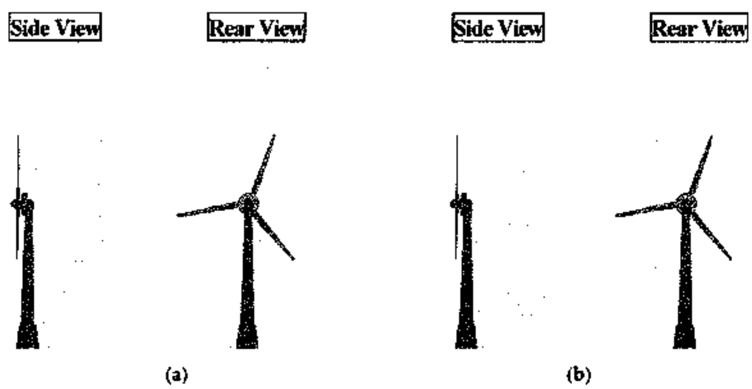

Figure 9. Instantaneous velocity vectors at WT No. 3. **(a)** Time = 106.0, marked by point C in Figure 8, **(b)** Time = 107.5, marked by point D in Figure 8.

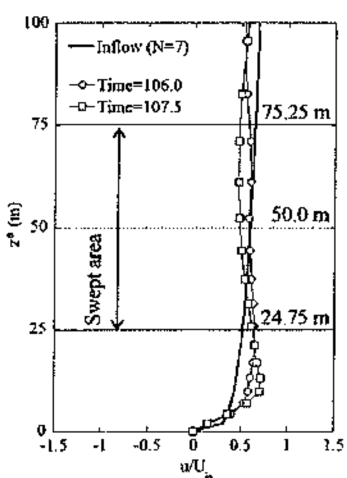

Figure 10. Profiles of instantaneous streamwise wind velocity corresponding to Figure 9 (WT No.3).

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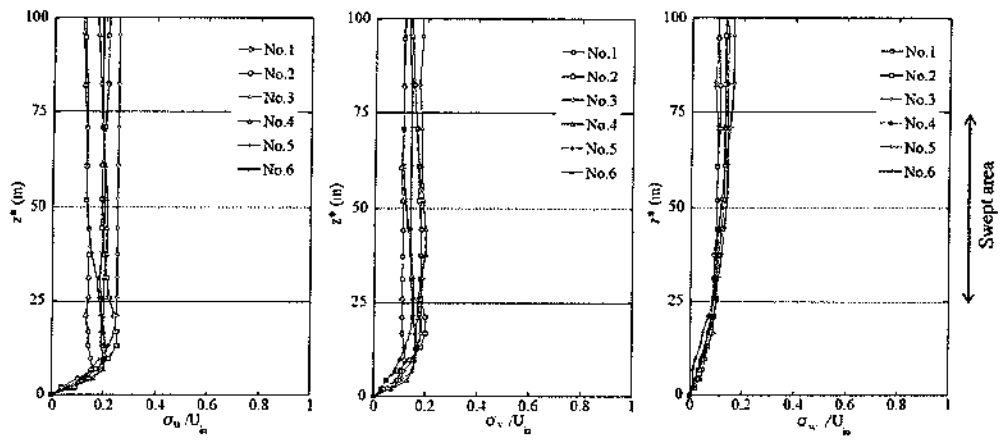

(a) x-component (b) y-component (c) z-component

Figure 11. Profiles of the standard deviations of the three components of the wind velocities at each of the wind turbine sites.

In the present study, an additional analysis was performed on the characteristics of the wind conditions at, and in the vicinity of, Taikoyama Wind Farm with the use of the surface level (10.0 m height above the ground surface) of the MSM (Meso Scale Model)—GPV (Grid Point Value) data distributed by the Japan Meteorological Agency (JMA). The analysis results reveal that southerly wind as well as westerly wind, which were described earlier, occurred frequently throughout the year for the three years from 2010 to 2012. As an example, Figure 12 shows analysis results of wind conditions in the area of Taikoyama Wind Farm during one of the three years, 2012. All the wind roses show that southerly is a frequently occurring wind direction. P21-36 cont.

In light of the analysis results above, an unsteady, numerical wind diagnosis is conducted for southerly wind conditions using RIAM-COMPACT (Figure 13). This figure infers that all the wind turbines at Taikoyama Wind Farm are strongly affected by terrain-induced turbulence generated in the vicinity of the site marked by arrow A and that they operate immersed in airflow which fluctuates significantly in time both in wind speed and direction. Furthermore, the present diagnosis reveals the following additional concern: since WTs No. 1 to No. 5 are on a nearly straight line in the south-to-north direction, mutual interference between the wakes of the wind turbines (turbulence generated by the rotation of the blades of an upstream wind turbine affects downstream wind turbines, causing breakdown of the downstream wind turbines and/or reduction in electric power generated by the downstream turbines) may arise in the case of southerly wind appearing aloft over Taikoyama Wind Farm (see the conceptual figure in Figure 14).

To summarize, the results of the numerical wind diagnosis infer that, in the case of southerly wind appearing over Taikoyama Wind Farm, additional load was imposed in the vicinity of the base of the nacelle, which connected the tower and the blades, due to the effects of both terrain-induced turbulence and turbulence caused by the rotation of the blades of the wind turbines (mutual interference between wakes of wind turbines). It can be speculated that the additional load, in turn, increased metal fatigue in the bolts at the base of the nacelle.

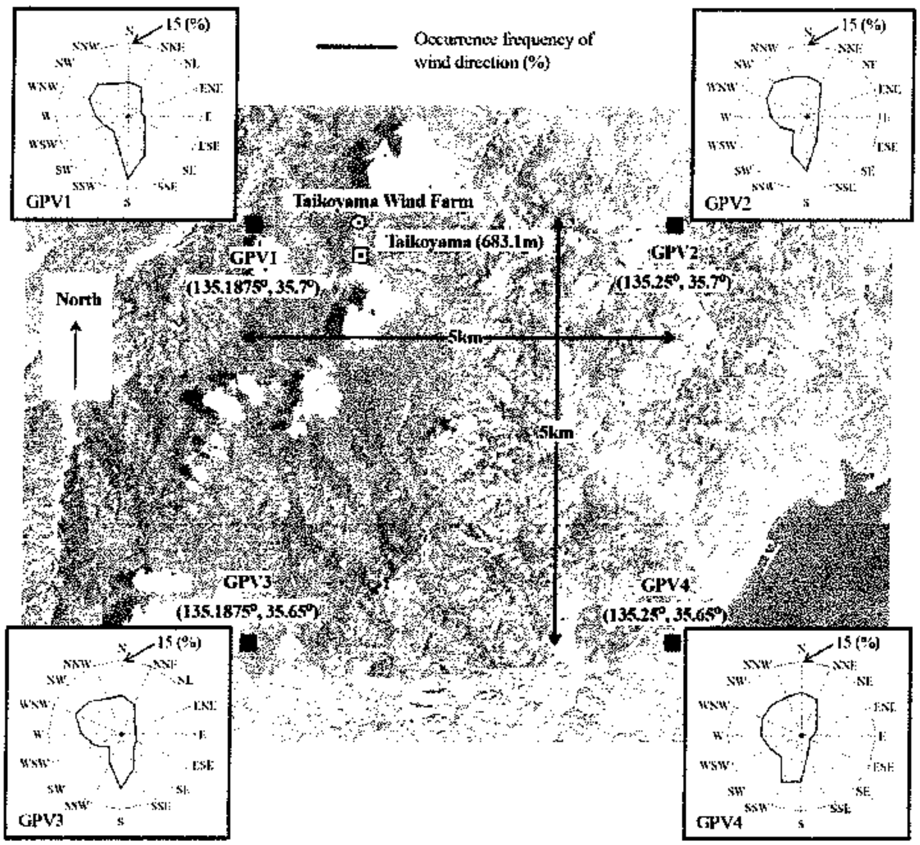

Figure 12. Wind characteristics in the vicinity of Taikoyama Wind Farm based on MSM-S GPV data for 2012.

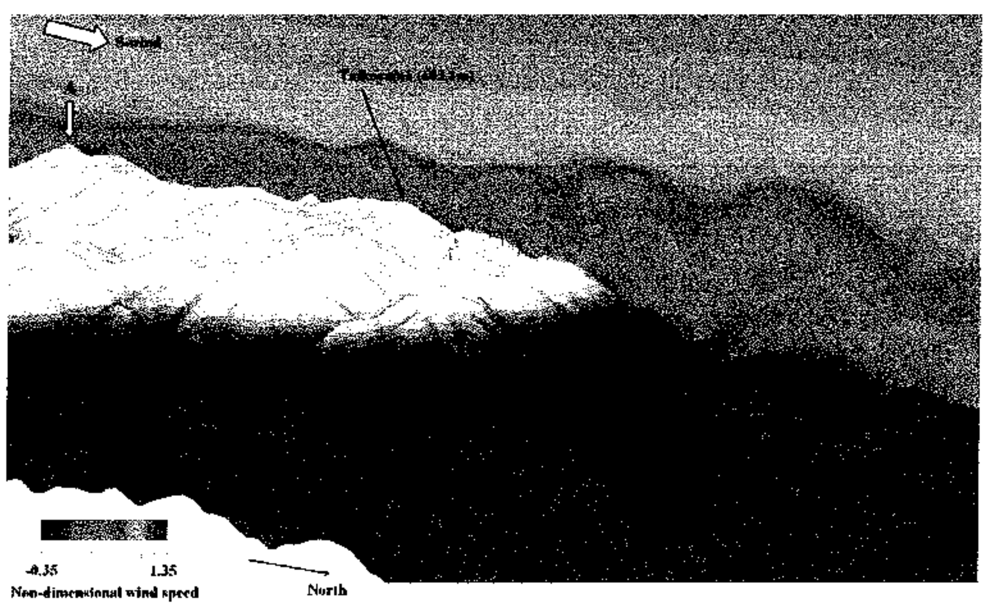

Figure 13. Distribution of instantaneous streamwise velocity along the vertical cross-section.

P21-36 cont.

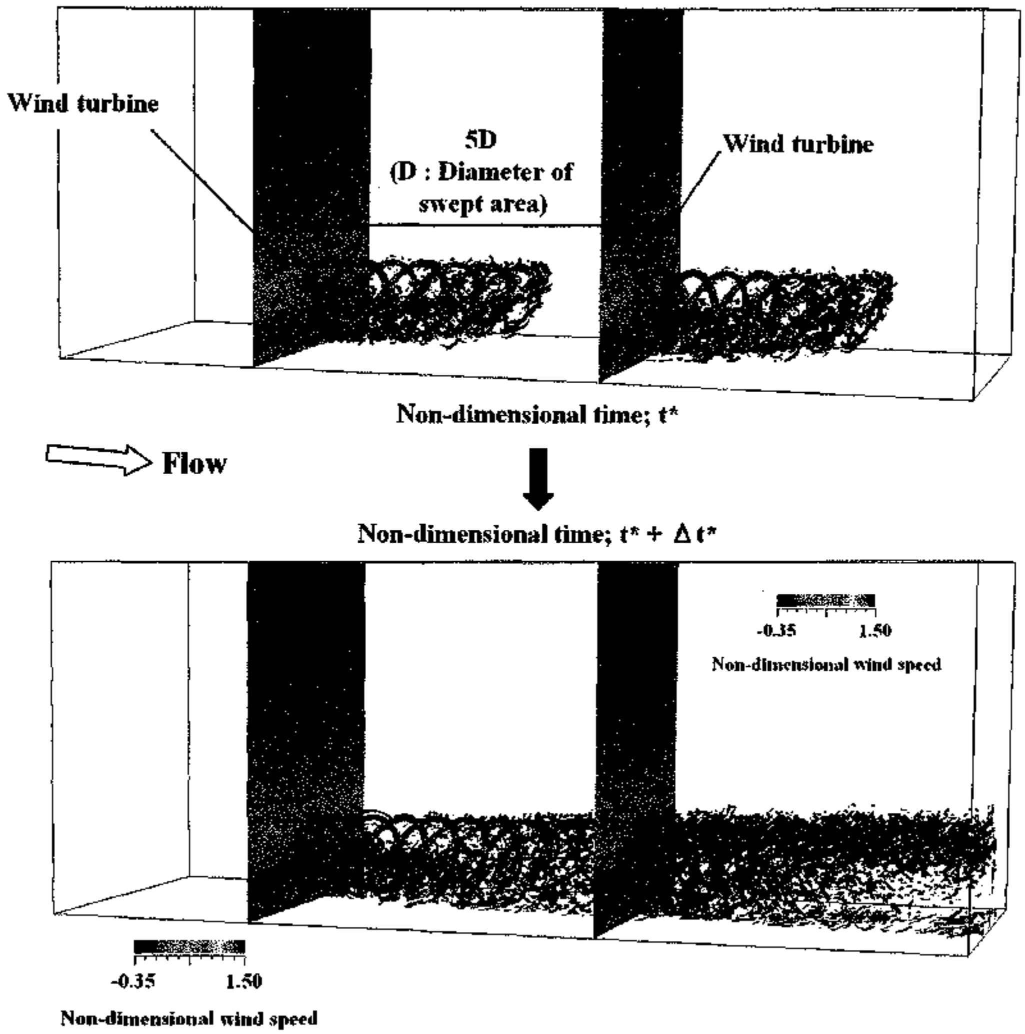

Figure 14. Conceptual figure of wake interaction between two wind turbines by visualization of the Laplacian of the pressure field.

Finally, if a decision is to be made based on the results of the numerical wind simulation in the present study for "reconstruction" of the Taikoyama Wind Farm, the following course of action is worthy of consideration. All existing wind turbines are to be removed, a wind turbine model which is highly resistant to terrain-induced turbulence is to be selected, and one or two wind turbines of this model are to be constructed. During construction, it is preferable to make the towers as tall as possible. Since terrain-induced turbulence is generated and develops close to the ground surface fundamentally, the effect of terrain-induced turbulence on the wind turbine and supporting structure decreases dramatically with increasing tower height. Subsequently, a preliminary calculation is made on the economics for the case in which a single wind turbine is deployed on a 70.0 m tower (Figure 15). In this calculation, the time-series data of the wind velocity (10.0 m above the ground surface) at grid point GPV1, shown in Figure 12, from 2012 are used after being height-corrected. The results of the calculation reveal that the economics of the proposed future Taikoyama Wind Farm is typical in comparison to other wind farms in Japan. Therefore, it can be claimed that "reconstruction" of the Taikoyama Wind Farm is quite plausible if, in addition, appropriate maintenance and management are performed as laid out in the accident report [1].

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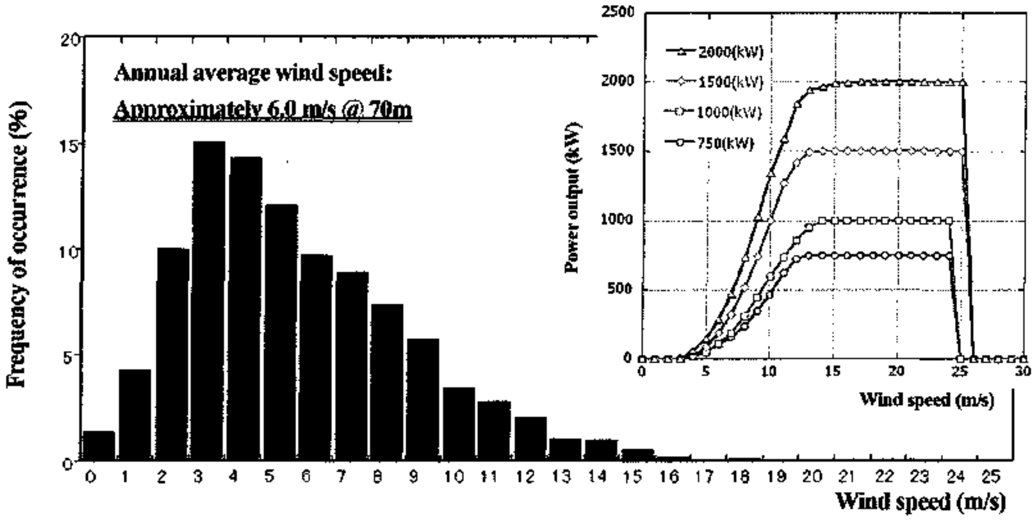

Annual energy production (kWh)

750kW	1,000kW	1,500kW	2,000kW
1,469,944	1,783,586	2,931,726	4,022,902

Capacity factor (%)

750kW	1,000kW	1,500kW	2,000kW
22.3	20.3	22.3	22.9

Income from sales of electric power (yen)

750 kW	1,000 kW	1,500 kW	2,000 kW
29,104,891	35,315,003	58,048,175	79,653,460

Remarks) We assume availability = 90% and feed-in tariff = 22 yen/kWh.

Figure 15. Results of a preliminary calculation of economic feasibility for the case of one wind turbine (hub height = 70.0 m), based on the MSM-S GPV data from the location labeled GPV1 in Figure 12.

P21-36 cont.

5. Conclusions

In the present study, unsteady numerical wind diagnoses were performed for Taikoyama Wind Farm with the use of an LES turbulence model. Based on the simulation results, with a focus on the effect of terrain-induced turbulence generated in the vicinity of the wind turbines, and from the viewpoint of numerical wind analysis, an examination was made of the Taikoyama Wind Farm nacelle separation accident, in which the nacelle of Wind Turbine (WT) No. 3 fell to the ground. The examination led to the following finding for all the wind turbine sites including WT No. 3: in the case of west-southwesterly wind conditions, the wind velocity shear deviated from the wind velocity shear in the vertical profile of the wind velocity that followed a power law (N = 7). For the same wind conditions, it was also found that large temporal changes in the angle of the wind on the hub height horizontal (yaw direction) cross-section occurred frequently at all wind turbine sites. Furthermore, an analysis of the airflow fluctuations caused by terrain-induced turbulence revealed additional characteristics of the wind across the heights of the swept area at all wind turbine sites. Specifically, the standard deviation of the streamwise (x) component of the wind velocity was relatively large, and that of the vertical (z) component was large. In addition, the values of the standard deviation of the spanwise (y) velocity component were approximately the same as those of the streamwise (x) velocity component. From the findings above, it can be speculated that the exciting force on WT No. 3 increased due to the effect of terrain-induced turbulence. The increased exciting force then imposed additional load in the vicinity of the base of the nacelle of the wind turbine, which connected the tower and blades, and thus increased metal fatigue in the bolts at the base of the nacelle. In the case of southerly wind conditions, it was found that the wind turbines were subject to, in addition to the effects of terrain-induced turbulence, the effects of turbulence caused by the rotation of blades of wind turbines (mutual interference between wakes of wind turbines).

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Conflicts of Interest: The authors declare no conflict of interest.

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Wind Turbine Accidents: A Data Mining Study

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Dr. Gürdal Ertek's Publications

Wind turbine accidents: A data mining study

Sobhan Asian, Gurdal Ertek, Cagri Haksoz, Sena Pakter, Soner Ulun

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Wind Turbine Accidents: A Data Mining Study

Sobhan Asian, *Member,* Gurdal Ertek, Cagri Haksoz, Sena Pakter, Soner Ulun

Abstract— While the global production of wind energy is increasing, there exists a significant gap in the academic and practice literature regarding the analysis of wind turbine accidents. Our paper presents the results obtained from the analysis of 240 wind turbine accidents from around the world. The main focus of our paper is revealing the associations between several factors and deaths and injuries in wind turbine accidents. Specifically, the associations of death and injuries with the stage of the wind turbine's life cycle (transportation, construction, operation, and maintenance) and the main cause factor categories (human, system/equipment, and nature) were studied. To this end, we conducted a detailed investigation that integrates exploratory and statistical data analysis and data mining methods. The paper presents a multitude of insights regarding the accidents and discusses implications for wind turbine manufacturers, engineering and insurance companies, and government organizations.

Index Terms—Wind energy, Wind power generation, Accidents, Data Mining, Data analysis.

I. INTRODUCTION

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The world demand for energy is expected to grow by more than two-thirds over the period 2011-2035 [1]. This demand will be met by a combination of nonrenewable (coal, fossil fuel, nuclear) and renewable (wind power, hydropower, solar energy, biomass, biofuel, geothermal) energy sources. The share of renewable energy sources in total power generation is expected to rise from 20% in 2011 to 31% in 2035, and renewables are expected to eventually surpass gas and coal and become the primary energy source in the world [1]. This global trend for the increasing usage of renewable energy is motivated mainly by the undesired global climate change due to carbon emissions as well as the depletion of fossil fuels. Furthermore, perceived notion of sustainability of renewable energy sources is driving governments to introduce legislations that promote use of renewable energy [2].

Wind energy has a long history [3], and is currently among the leading sources of renewable energy in terms of production capacity [4]. According to 2013 market statistics released by The Global Wind Energy Council (GWEC), the cumulative global wind energy capacity more than tripled in 6 years [5]. The cumulative installed wind energy capacity in the USA has increased more than 22-fold between 2000 and 2012 [6].

While wind energy industry and the installation of wind turbines are growing, the drawbacks of wind energy are not always considered and evaluated. One particular problem with wind energy is wind turbine accidents. Wind turbine accidents include a multitude of ways in which wind turbines fail due to mechanical problems, nature, or humans. In this paper we use the term "wind turbine accident" to

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describe any event involving a commercial wind turbine that was sufficiently noteworthy that it was reported in the public news media; it includes events where there was an injury or fatality, or where the wind turbine suffered significant damage, or both. Our literature review show that while there are several academic studies that primarily focus on the mechanical aspects of wind turbine accidents, the literature has fallen short of systematically analyzing wind turbine accidents (except report [7]).

There is a significant gap of knowledge and insights throughout the world with regards to wind turbine accidents. Specifically, there does not seem to exist any research that investigates the wind turbine accidents throughout the world and associates these accidents with cause factors and the stage of the wind turbine's life cycle. Investigating these two specific types of associations constitute the focus of our paper. Our main motivation to conduct a comprehensive analysis of wind turbine accidents is the significance of their occurrence as well as the variety of negative impacts they impose. They can result not only in technical failures and financial losses, but also and more importantly, human deaths and injuries.

To the best of our knowledge, one of the reasons for shortage of research on wind turbine accidents is the lack of publicly available data. While wind turbine manufacturers, owners, and contractors collect data about their operations, including data on accidents, they do not publicly share most of this data, especially the accident data. The reason for keeping these data private might be not only due to confidentiality, but also for preserving a positive public perception of wind energy [8]. Industry organizations, such as American Wind Energy Association (AWEA) also have not made a significant collection of data on wind turbine accidents publicly available.

As of January 2016, the most extensive data available on the Internet on wind turbines accidents was published by the Caithness Windfarm Information Forum (CWIF) [9], a UK-based grassroots organization opposing wind turbine installations. When we conducted our data collection in late 2013, the CWIF list contained more than 1400 wind turbine accidents. As of January 2015, the list contained more than 1500 accidents. While the list is impressive in magnitude, the quality and reliability of the list is questionable because of the following reasons: 1) Most of the web links to the news sources are not valid, and some of the accidents appear in multiple lines of the data. 2) In spite of containing much more magnitude of data, the data available in other online sources also exhibit similar deficiencies.

P21-36 cont.

Given the growth of the wind turbine industry, and considering the lack of academic as well as industry research, we inspired to perform the first such study and contribute to the literature. To this end, we carried out a rigorous search of the news on wind turbine accidents (with confirmed references to the news sources) and implemented a variety of data analysis techniques to provide with critical and impactful insights on the topic. One innovation of the paper is the fact that a well-planned data mining approach and process has been applied for the first time in the wind turbine accidents literature. Furthermore, the applied data mining process has been documented in detail within the paper, so that future studies would benefit from an initial methodological benchmark, enabling them to propose methodological improvements, as well as novel empirical findings.

There are two critical and fundamental concepts in our paper, which shape the structure of our methodology and analysis: First, the stage of the wind turbine's life cycle, at which the accident took place. Figure 1 displays four possible stages when an accident may occur, namely, during the transportation, construction, operation, and maintenance. Second, the cause of the wind turbine accident, namely nature, system/equipment, and human (Figure 1). We investigate the association between these two categories of factors and two major effects (outcomes), i.e., Death and Injury (Figure 1). Thus, the main hypotheses of our paper are as follows:

Hypothesis 1. There exists association between deaths and predictor attributes (factors).
Hypothesis 2. There exists association between injuries and predictor attributes (factors).
These hypotheses are tested using formal statistical methods.

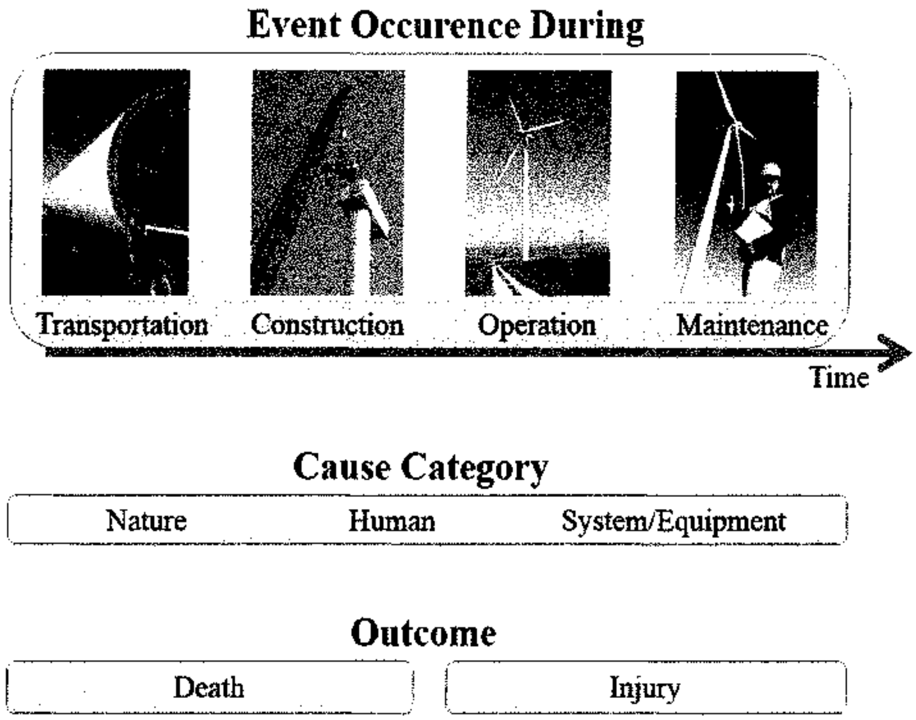

Fig. 1. The cause-effect relationship and stages where an accident occurs.

P21-36 cont.

The remainder of the paper is organized as follows: Section 2 provides a brief review of some relevant literature as the background. Section 3 discusses the methodologies used in the data analysis, including the flowchart of the process for statistical hypothesis testing. Section 4 describes the data collection and cleaning process and describes the collected data. Section 5 presents the analysis and results. It begins with the exploratory analysis of the data, and continues with the application of statistical tests and data mining methods. Section 6 discusses the discovered insights. Finally, Section 7 concludes the paper and suggests future research directions.

II. Literature

Wind turbine accidents and wind energy risks have drawn certain attention of the academic community [10]-[20]. However, our review of the literature showed that none of existing studies have done a comprehensive analysis of the associations between factors (predictive attributes), and Death and Injury [14]-[16]. Furthermore, none of the papers we found in the literature combine formal statistical methods with data mining approach to analyze a dataset that contains multiple accidents.

In this section, we first briefly review the existing work on the analysis of individual wind turbine accidents. Then, we discuss studies that analyze multiple wind turbine accidents. This is followed by a review of works that conduct risk analysis regarding wind turbines, farms, or electricity grids. Finally, we survey the application of a specific type of data mining, namely text mining, on wind energy and turbines.

A. Analysis of Individual Wind Turbine Accidents

There are a number of studies which focus on the failure of a single wind turbine. These studies, in chronological order, are as follows:

[16] reports the post-disaster inspection of a collapsed wind turbine during a typhoon in Taiwan. The study presents fresh insights into the causes of wind turbine failure, as well as lessons for the future. The authors also include a summary of 62 accidents of tower collapse that occurred between 1997 and 2009. However, the paper does not provide an analysis of the mentioned 62 accidents. The study draws insightful conclusions and generalized guidelines that should be considered by practitioners in the wind turbine industry.

[17] presents the fracture analysis of a wind turbine main shaft. The study determines that high stress concentrations were the cause behind the fracture.

[18] analyzes the failure of a large turbine blade. The study identifies the material and mechanical reasons behind the failure.

The above studies analyze a single turbine, mainly from a mechanical engineering or materials science perspective. We, on the other hand, analyze the outcomes of multiple accidents, and the association between cause factors and outcomes (Death and Injury).

B. Analysis of Multiple Wind Turbine Accidents

The most extensive report on multiple wind turbines is "Handboek Risicozonering Windturbines" [7], a handbook on wind turbine accidents, published in Dutch. The handbook was originally developed on the order of and updated annually for NOVEM (Netherlands Agency for Energy and the Environment). It aims at presenting the procedures for the risk assessment of wind turbines, and provides detailed statistics for different types of risks for wind turbines. The handbook firstly categorizes the different kind of failures of turbines (referred to as "scenarios") that should be considered in a risk analysis. Then, the handbook presents the occurrence frequency for each scenario, based on the analysis of over 200 severe incidents and accidents in Denmark, Germany and the Netherlands. Braam and Rademakers [19] provide a general description for the project and the handbook in English.

While the mentioned handbook is extensive, it does not address theoretical research questions that we answer in our paper. Furthermore, the data that we collected and analyzed covers not only three countries, but the globe. Finally, our data covers 240 accidents, which is more than what the handbook covers.

A study that analyzes multiple accidents is presented in Yasuda et al. [20]. The authors focus on wind turbine blade incidents and present a new classification of such incidents. The authors also classify lightning damages and their possible causes, as well as recommending countermeasures.

C. Risk Analysis Regarding Wind Turbines and Farms

We encountered two recent sample studies where risk analysis is conducted in a more general context. Similar studies can be found by referring to the references listed in these two studies. De Andrade Vieira and Sanz-Bobi [21] introduce a new method for estimating the health condition of components of a wind turbine based on real-time sensor data, which enables the rescheduling of planned maintenance. The contribution of their developed method is the maintenance of the wind turbine at lower cost. Gonzalez et al. [22] introduce a novel approach to the problem of optimal design of wind farms (selection of the

P21-36 cont.

turbines location, turbine type, and hub height) including decision making under risk. However, compared to our paper where the risk of accidents is the core of research, the main focus of Gonzalez et al. [22] is the uncertainty from wind direction and speed.

D. *Text Mining for Wind Energy and Wind Turbines*

Text mining refers to the application of data mining methods to text data. In the literature, text mining has been applied to wind energy industry and wind turbine systems in a few ways:

1. First, it is used to summarize the reasons of technical development constraints and suggest the research directions needed to be emphasized. For instance, the study in [23] discovers the key factors limiting the wind turbine scaling by mining textual reports, standards, and journals.
2. Second, text mining is applied to risk management by extracting information from the textual service records of wind turbines. For example, the inventions in [24] and [25] propose risk management systems with document classification capability for wind turbine service reports.
3. Lastly, text mining is used to identify technology trends and the promising technologies for technology transfer [26]-[28].

III. Methodology

A. *Exploratory Data Analysis*

Data analysis techniques can be grouped into three categories: Exploratory, Descriptive, and Predictive. The main goal in exploratory data analysis, which is implemented in our paper, is to obtain basic insights into the data. Exploratory data analysis includes the use of graphical techniques such as histograms, pie charts, geographical displays, besides basic summary tables. In our study, we start our data analysis with the graphical techniques and especially the mosaic display.

P21-36 cont.

B. *Statistical Hypothesis Testing*

In empirical research, statistical hypothesis testing is the conventional form of supporting or refuting proposed hypotheses. In our analysis, we use three principal types of hypothesis tests within a unified process (Figure 2): Goodness of fit test, sample mean comparison tests, and correlation tests [29].

The Shapiro-Wilk goodness-of-fit test suggests whether a data sample follows normal distribution [30]. This is a crucial information needed for the proper selection of the "comparison of means" test. The parametric t-test or the nonparametric Mann-Whitney test [31] is used for testing whether two data samples have same mean values. The parametric ANOVA or the nonparametric Kruskal-Wallis test is used for testing whether the mean of any sample among a group of samples (more than two data samples) is different from the others.

If the normality of the involved samples (in the comparison of means tests) is rejected with a high confidence level (test resulting in a low p-value), then nonparametric methods are used. Parametric tests are used only if all the samples follow the normal distribution [29].

Correlation tests that we employ are Pearson's Chi-Square test [32] for two numerical attributes, and Fisher's test [33] for two categorical attributes. In both of these tests, a low p-value suggests a significant association between the two selected attributes (a low p-value suggests that it is highly unlikely that the correlation would be zero). In our analysis, we selected the threshold p-value to be 0.05. The process followed is shown as a flowchart in Figure 2.

C. *Ranking of Attributes*

We employ the information gain (Kullback–Leibler divergence) measure to rank the importance of the attributes, when determining the occurrence of death and injuries. Information gain of an attribute A is the information gained about a response X based on observation of the values that A takes [34]. The information gain concept is used in information sciences to obtain a ranking among attributes [34], based on how much they help in the prediction of values of the response attribute. The higher the information gain value, the more information the attribute provides for predicting the response. In the context of our study, the attributes with the highest information gain values can be thought as those attributes that help us most in understanding and predicting whether death or injury will occur as a result of an accident.

P21-36 cont.

D. Classification Trees

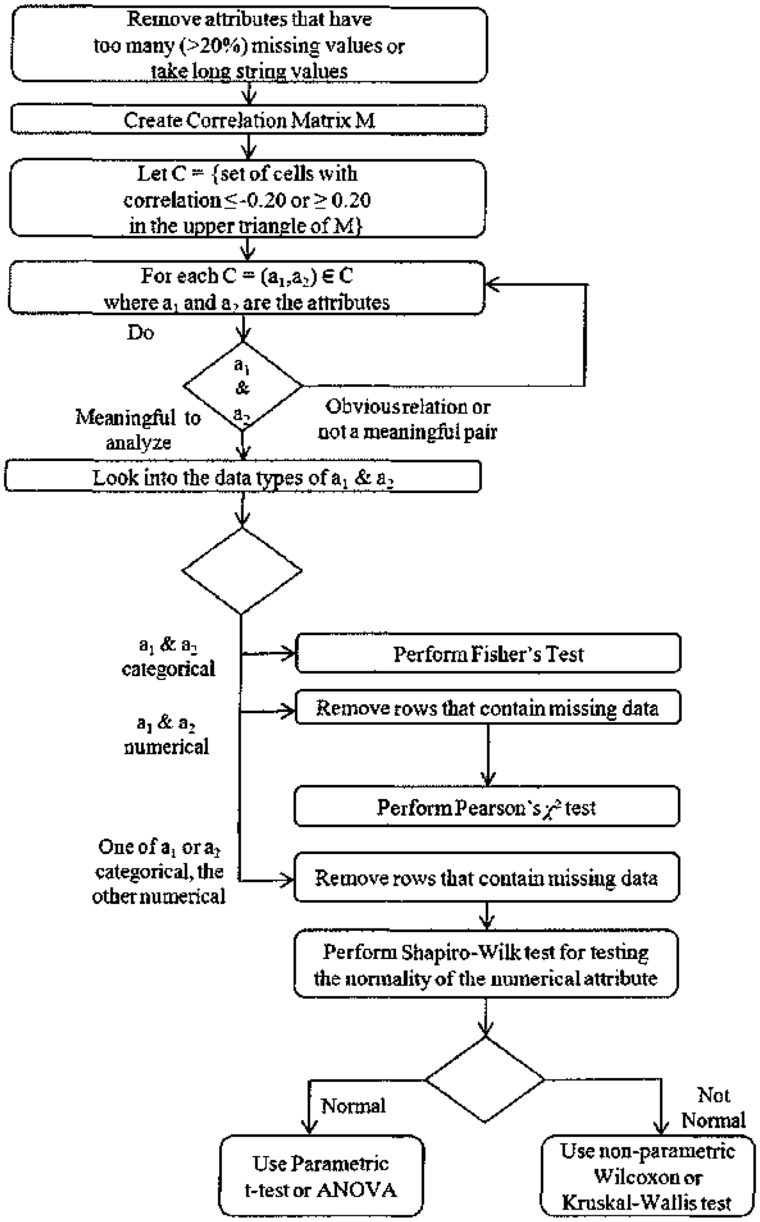

Fig. 2. Flowchart of the process for statistical hypothesis testing

Using classification tree models, one can summarize rule-based information about classification as trees. In classification tree, each node is split (branched) according to a criterion. Then, a tree is constructed with a depth until all the rules are displayed on the graph under a stopping criterion. At each level, the attribute that creates the most increase compared with the previous level is observed. The algorithms for decision tree analysis are explained in [35]. In classification trees, identifying the nodes that differ noticeably from the root node are important, because the path that leads to those nodes (represented as the antecedent of a rule) tells us how significant changes are observed in the subsample compared with

P21-36 cont.

the complete data. By observing the shares of slices and comparing with the parent and root nodes, one can discover classification rules and insights.

E. Classification Analysis

In classification analysis, the dataset is divided into two groups, namely, the learning and test datasets. Classification algorithms, also referred to as classifiers (or learners), use the learning dataset to learn from data and predict the class attributes in the test dataset. The prediction success of each classifier is measured through a variety of performance measures, two of which will be used in this study: Classification accuracy (CA) is the percentage of correctly predicted cases in the test dataset. Area under curve (AUC) corresponds to the area under the ROC curve (which will be discussed in detail later) and is a measure of prediction quality [36]. We applied in our study the following classification algorithms (classifiers), which are among the best-known classifiers in the data mining field: Logistic Regression, k-Nearest Neighbor (kNN), Classification Trees, Support Vector Machines (SVM), and C4.5 [37].

F. Data Mining Process

The data mining model is constructed in the Orange software [38]. The data mining process contains four main types of analysis, namely ranking analysis, classification analysis, classification tree, and mosaic display, applied on two models (Model 1 and Model 2).

IV. Data

A. Data Collection

The accident news dataset in this study was collected over a 9-month period, scanning the Ebscohost and Lexis Nexis databases and also using Google as the search engine. All publicly available newspaper or magazine reports were considered for selection. The search keywords were "wind turbine accidents" and "wind turbine failures". The search results were read and selected articles were checked by a graduate student. The main selection criteria were whether there was an impact on humans or the wind turbine. While reading the text of each news, only very certain statements describing specific outcomes were considered, and vague statements were ignored. P21-36 cont.

In total, more than 5,000 search results were scanned, more than 2,000 were read, and 247 were found highly related and were read in detail. Eventually, 216 news were found to directly report 240 wind turbine accidents, which were included in the dataset and analyzed in detail. Data on these 240 accidents was structured as a database table, containing the attributes explained below. All the original news articles, the word processor files that highlight the attribute fields in the data, and the structured database are well documented and are available upon request.

B. Data Cleaning

During the analysis of the news articles, it was firstly observed that some articles were either duplicates of other more extensive ones or were irrelevant to our study. These articles were removed from the data.

Data cleaning involved not only the verification and the validation of the data, but also the identification of missing values. While constructing the accidents dataset (Table 1), to the maximum possible extent, the data cells with missing values were eliminated through conducting additional search on the Internet. Specifically, search was conducted for finding the values of the attributes PowerOfWindFarm, Onshore/Offshore, TurbineModel, Manufacturer, PowerOfTurbine, Location, and Country.

C. Data Description

Selected columns in the constructed database, which contains the accident characteristics for the 240 accidents, are given below:

Accident No: Unique integer identification number for each accident (e.g. 1).

Country: Country where the accident took place (e.g. Denmark).

Turbine Model: Model of the wind turbine at which the accident took place; includes the manufacturer name, and the model name/code/number, and power (e.g. "Vestas, V80-2.0 MW").

Manufacturer: The company that manufactured the wind turbine (e.g. Vestas).

Power of Turbine (kW): Power of the wind turbine in kW (e.g. 2000), where 1 MW=1000 kW.

Power of Wind Farm (kW): Total power of the wind farm in which the wind turbine is located.

Death: Tells whether human death has occurred because of the accident; takes binary values (e.g. 0). It takes the value of 1 when death occurs.

Injury: Tells whether human injury has occurred because of the accident; takes binary values (e.g. 0). It takes the value of 1 when injury occurs.

Fire: Tells whether fire has occurred because of the accident; takes binary values (e.g. 0). It takes the value of 1 when fire occurs.

Mechanical: Tells whether mechanical damage has occurred because of the accident; takes binary values (e.g. 0). It takes the value of 1 when mechanical damage has occurred.

Structural Break: Tells whether a structural break has occurred because of the accident; takes binary values (e.g. 1). It i takes the value of 1 when structural break has occurred.

P21-36 cont.

TABLE I

DISTRIBUTION OF REASONS FOR ACCIDENTS CAUSED BY HUMANS

Cause	Count
Human (other)	23
Human (transportation)	18
Human (negligence)	4
Human (wrong action)	4
Human (interference in control systems)	2
Human (fall)	1
Human (heart attack)	1
Human (plane crash)	1

Affected Humans: Tells whether the accident has affected humans in the form of death or injury (e.g. 0). The value for this attribute is computed as the maximum of the values of the Death and Injury attributes.

Affected System/Equipment: Tells whether the accident has affected the turbine system or equipment (e.g. 1). The value for this attribute is computed as the maximum of the values of the Fire, Mechanical, StructuralBreak, and TransportAccident attributes.

Transport Accident: Tells whether the accident was a transport accident; takes binary values (e.g. 0). It takes the value of 1 when the accident was a transport accident.

Affected Component: All the major components affected because of the accident, summarized as a string (e.g. "Blade"). This string can contain more than one item, such as "Tower, Blade".

Cause: Tells the particular cause of the accident (e.g. "Human (interference in control systems)")

Cause Category: Tells the general cause category of the accident. Takes one of the following values: "Human", "Nature", "System/Equipment".

Onshore/Offshore: Tells whether the wind turbine is located onshore (inland) or offshore (in sea). Takes one of the values of "OnShore" or "OffShore".

EventOccurrence: The state of the wind turbine when the accident occurred. Takes one of the following values: "During construction", "During maintenance", "During operation", "During transportation".

Accident Year: Year in which the accident took place (e.g. 2002).

Accident Month: Month in which the accident took place (e.g. 11).

Accident Day: Day in which the accident took place (e.g. 4).

ANALYSIS AND RESULTS

In this section, we present the analysis of the constructed wind turbine accidents database using the introduced methodologies. The two processes that we apply are the statistical process (Figure 2), and the data mining process. The analysis has been conducted using five methods, namely, exploratory analysis, hypothesis tests, ranking analysis, classification tree analysis, and classification analysis.

D. Exploratory Data Analysis

Firstly, the values of different attributes (columns) were investigated. The Accident Year ranges from 1980 until 2013, except for two earlier accidents. The powers of the wind turbines mentioned in the news peak around certain points, such as 500 kW, 1500 kW and 2000 kW. These capacities are mainly because of the wind turbine capacities available in industry, where 500 kW, 1500 kW and 2000 kW are standard capacities, and many new wind turbine projects aim at developing turbines at these capacities. In the dataset, Danish wind turbine manufacturer Vestas is the wind turbine brand with the most accidents and GE coming as the second. USA has the largest number of wind turbine accidents, followed by Germany, China, and Australia. These statistics are consistent with the distribution of wind turbine installations.

P21-36 cont.

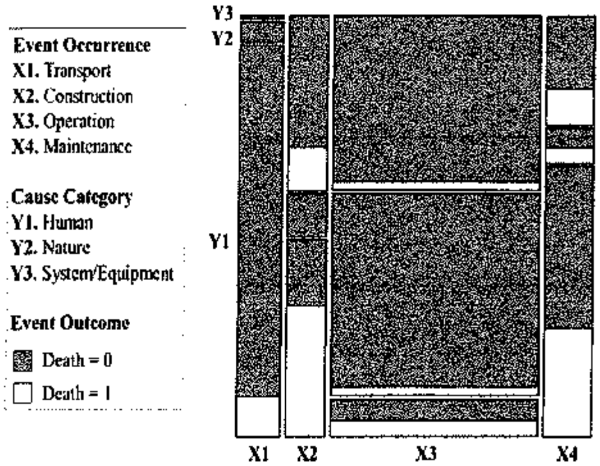

Fig. 3. Mosaic Plot Showing the Effect of Event Occurrence and Cause Category on Death.

TABLE II

DISTRIBUTION OF REASONS FOR ACCIDENTS CAUSED BY NATURE

Cause	Count
Nature (strong wind)	32
Nature (lightning strike)	9
Nature (storm)	4
Nature (other)	3
Nature (cyclone)	2
Nature (tornado)	2
Nature (cold)	1
Nature (due to collision)	1
Nature (strong wind, lightning strike)	1
Nature (strong wind, snow)	1
Structural (bolt failure)	1
Structural (smashed barge)	1

TABLE III

DISTRIBUTION OF REASONS FOR ACCIDENTS CAUSED BY SYSTEM/EQUIPMENT

Cause	Count
Mechanical	25
Mechanical (electrical)	8
Mechanical (faulty material)	5
Mechanical (due to collision)	4
Mechanical (material fatigue)	2
Mechanical (brake system failure)	1
Mechanical (cracks on blade)	1
Mechanical (failed transformer)	1
Mechanical (fire)	1
Mechanical (insufficient glue on blades)	1
Mechanical (lack of automatic braking system)	1
Mechanical (loose connections between the transformer's connection bars and the power cables from the generator circuit breaker)	1
Mechanical (low voltage ride through capability)	1
Mechanical (not properly secured foundation bolts)	1
Mechanical (platform collapse at construction site)	1

P21-36 cont.

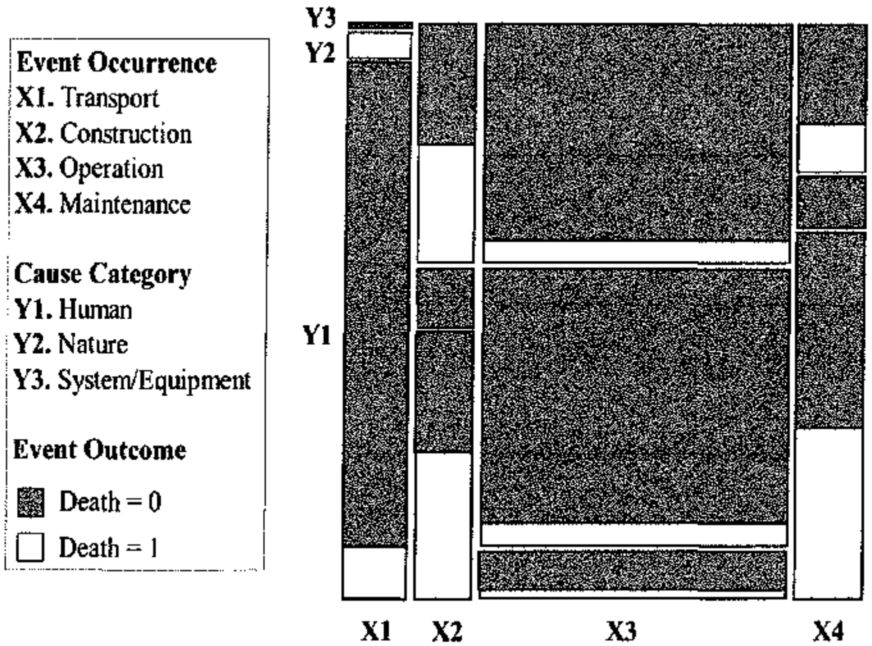

Fig. 4. Mosaic plot that shows the effect of Event Occurrence and Cause Category on Injury.

P21-36 cont.

Table 1 suggests that a human caused accident mostly occurs during transportation (18 accidents).

Table 2 suggests that natural causes are mostly related to strong wind (32 accidents) and lightning strikes (9 accidents). Even though the reasons for strong wind and lightning strike are categorized under natural causes, these may also be interpreted as indirect human-related causes. However, in this paper, we classify these causes as natural causes.

System/Equipment is also seen as a major cause for accident with its sub-causes mostly related to electric causes, material fatigue, and faulty material (Table 3). This analysis shows that not only the design, but also the maintenance and operation of a wind turbine are important. Electric problems may be attributed to not only the design of the system, but also to the electricity grid and the problems associated with it.

We analyzed the Distribution of values for the attributes AffectedHumans and AffectedSystem/Equipment. According to the results, wind turbine accidents mostly affect the system and equipment.

The distribution of values for the attribute AffectedComponents suggest that the case of a wind turbine accident, the components blade, tower, nacelle have the highest chances of being affected. When EventOccurrence is analyzed, it is revealed that accidents occurred overwhelmingly during operation.

The mosaic plot displays the stages of accident occurrence on the x axis, while the causes of accidents (human, nature, and system/equipment) are shown on the y axis. The width of the columns on the x axis and the height of the blocks on the y axis are proportional to the number of accidents in each category or cause, so the area of each of the rectangles represents the total number of accidents that meet its two criteria. Several patterns can be observed from the mosaic plot in Figure 3 for accidents and deaths (outcomes denoted by color).

First, let us summarize our findings from Figure 3 for accidents, regardless of whether they resulted in death or not (regardless of the color in the mosaic plot).

- It is seen that accidents during operation (the area above the label "X3. Operation") are more than the sum of accidents in the other three stages (transport, construction, maintenance).

Furthermore, the figure also illustrates which Cause Category is most influential in each stage.

- During transportation, the Cause Category is overwhelmingly Human.
- During construction, the cause categories System/Equipment and Human are much more influential than Nature.
- During operation, Nature is the most influential Cause Category, followed by System/Equipment.
- During maintenance, the most important cause category is Human.
- Most deaths occur during the Construction and Maintenance of the wind turbine.

The mosaic plot shown in Figure 4 is similar to Figure 3, and yields insights for the distribution of accidents and death occurrences in those accidents. However, Figure 4 shows the effect of Event Occurrence and Cause Category on Injury, rather than Death as displayed in Figure 3.

Let us summarize our findings from Figure 4 for injuries (white-colored regions denoting occurrence of injuries).

- During Transportation, the Cause Category that results in the most deaths is Human. However, percentagewise, the effect of Nature on Injury is the highest. All the cases during Transportation where Nature was the Cause Category, resulted in Injury=1.
- During construction, the pattern is exactly the same as in Figure 3. However, during operation, the most influential Cause Category is System/Equipment, both in quantity and percentage. This pattern for the Operation stage is different compared with that of Death.
- Finally, during Maintenance, all injuries occur because of the System/Equipment or Human. None of the accidents during Maintenance occur due to Nature.

E. Statistical Analysis

In our statistical analysis we will be exploring the relations between the predicted attributes of Death and Injury, and a set of predictor attributes. The first step was to compute the correlation matrix between all attributes, so that we could observe all such relations, and apply appropriate statistical tests of significance for the most promising relations. To this end, cells (pairs of attributes) of the correlation matrix which were found to have correlation values ≤ -0.20 or ≥ 0.20 were selected. Detailed statistical analysis was conducted for 12 of these 26 cells, while 14 of them could not be analyzed in detail because of too many categorical values, being too obvious or not being meaningful. Table 4 presents the detailed information on the hypothesis tests for these 12 cells. The table shows the pairs of attributes selected for the correlation tests, the corresponding correlation values, the statistical tests performed for each attribute pair, the resulting p-values (p-values less than the threshold p-value of 0.05 suggest statistically significant correlations) and the test results (+ means that the correlation observed between the two attributes is statistically significant at the selected p-value threshold of 0.05). As a result, statistically significant correlations were found between 10 out of 12 pairs of attributes, as can be read from the last column of Table 4. Table 5 presents the interpretation of the test results.

In Table 5, an important observation is for Test 5 (row 5), which is "There is association: Injury rate is lowest when the cause is nature induced (compared with System/Equipment or Human as the Cause Category)." This shows that our preliminary Hypothesis 2 that there may be a difference among the various causes (Nature, System/Equipment, Human) on how they affect Injury, is indeed statistically supported.

Tables 5 and 6 do not include an analysis of the effect of the various causes on Death, because the correlation value was not in the range [-0.20, 0.20].

P21-36 cont.

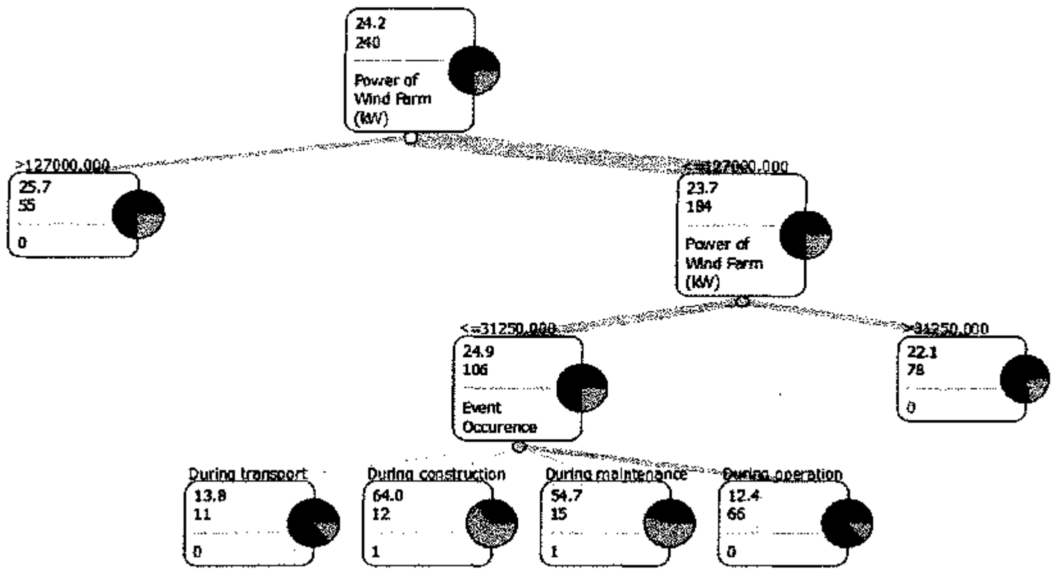

Fig. 5. Classification tree graph for Model 1, where Death is predicted.

F. Ranking of Predictor Attributes

TABLE IV

STATISTICAL TESTS PERFORMED AND THE RESULTING P-VALUES

Test No	Attribute1	Attribute2	Correlation	TestPerformed	p-value	Result
1	Structural Break	Death	0.39	Fisher's Test	2.07E-09	+
2	Structural Break	Injury	0.28	Fisher's Test	1.6E-05	+
3	Manufacturer	Mechanical	0.22	Fisher's Test	1.0000	-
4	Injury	Power of Turbine (kW)	0.20	Mann-Whitney test	0.0433	+
5	Cause Category	Injury	-0.22	Fisher's Test	0.0050	+
6	Cause Category	Power of Turbine (kW)	-0.24	ANOVA	0.0202	+
7	Mechanical	Death	-0.26	Fisher's Test	4.44E-06	+
8	Manufacturer	Structural Break	-0.26	Fisher's Test	0.6946	-
9	Death	Accident Year	-0.26	t-test	0.0013	+
10	Cause Category	Power of Wind Farm (kW)	-0.29	Kruskal-Wallis test	0.05	+
11	Event Occurrence	Power of Turbine (kW)	-0.32	Kruskal-Wallis test	0.05	+

The next analysis is the ranking of the predictor attributes, based on the information they provide in predicting Death or Injury. This analysis is important, since it helps us prioritize, among a multitude of attributes, the ones that potentially have the highest impact on the predicted attribute. To this end, two models have been constructed based on the same data mining process. The first model (Model 1) focuses on the occurrence of deaths, while the second model (Model 2) focuses on the occurrence of injuries.

The predictor attributes are Accident Month, Accident Day, Accident Year, Country, Event Occurrence, Onshore/Offshore, Power of Turbine (kW), and Power of Wind Farm (kW). The number of rows (corresponding to accidents) is 240. The predicted class attribute is Death, taking value of 1 (human death) or 0 (no human death) in the first model (Model 1), and Injury in the second model (Model 2).

P21-36 cont.

TABLE V

INTERPRETATION OF THE RESULTS OF STATISTICAL TESTS

Test No	Test Result
1	There is association: Less death when structural break
2	There is association: Less injury when structural break
3	No relation (when only Vestas and GE are considered)
4	There is difference: Higher power turbines in case of injury
5	**There is association: Injury rate is lowest when the cause is nature (compared with System/Equipment or Human as the Cause Category).**
6	There is difference: Higher power turbines when cause category is human.
7	There is association: Less death when mechanical
8	No relation (when only Vestas and GE are considered)
9	There is difference: Accident year is less when death (More recent years when no death)
10	There is no difference
11	There is difference: Higher power turbines when the accident is during construction or maintenance, compared with during operation.
12	There is association: More injuries during construction or maintenance, compared with during operation or transport.

P21-36 cont.

The results of ranking for Model 1 are displayed in Table 6, where the attributes are sorted according to their information gain values. Information gain is a measure of how much information is gained from a predictor attribute with respect to predicting a response attribute. The column titled Values tells the number of distinct discrete values that the attribute takes, where C denotes categorical attributes (which cannot be used in prediction).

TABLE VI

RANKING OF ATTRIBUTES FOR PREDICTING THE BINARY VALUE OF DEATH

Ran k	Attribute	Values	Information Gain
1	Event Occurrence	4	0.234
2	Country	25	0.156
3	Onshore/Offshore	2	0.109
4	Power of Turbine (kW)	C	0.098
5	Accident Month	C	0.089
6	Accident Day	C	0.062
7	Power of Wind Farm (kW)	C	0.060
8	Accident Year	C	0.030

Table 6 shows that Event Occurrence is the most important predictor attribute, with almost double the information gain value of the next attribute, Country. Therefore, Event Occurrence, in other words, the stage of wind turbine, is the attribute that provides the most predictive information on whether a human death occurs. Other attributes that follow include Onshore/Offshore, Power of Turbine, Accident Month, Accident Day, and Power of Wind Farm. The information gain value halves in the next attribute (Accident Year) that follows Power of Wind Farm, suggesting a large gap in the information provided by the first seven attributes and the last one. Therefore, the first seven attributes should be considered before the eighth one and those that come after. In Model 2, the same ranking analysis was conducted with the same eight predictors, but this time with Injury as the predicted class attribute. Table 7 shows the results of this analysis. The rank of Power of Turbine is now much higher, at the top of all the other attributes. The rank of Power of Wind farm is also higher ranked. In predicting Death, Power of Turbine and Power of Wind Farm do not play as much importance, while in predicting Injury, these two attributes make an important contribution. Country is still the second most important predictor. Event Occurrence is still important in predicting Injury, but ranks as the third most important predictor attribute, rather than first as in predicting Death. The rank of the attribute Onshore/Offshore is also different in Tables 6 and 7. In predicting Death, the Onshore/Offshore attribute of the wind turbine is important (ranked as the third most important predictor attribute), while it is the least important predictor in predicting Injury.

TABLE VII

RANKING OF ATTRIBUTES FOR PREDICTING THE BINARY VALUE OF INJURY

Rank	Attribute	Values	Information Gain
1	Power of Turbine (kW)	C	0.114
2	Country	25	0.093
3	Event Occurrence	4	0.068
4	Power of Wind Farm (kW)	C	0.048
5	Accident Year	C	0.030
6	Accident Month	C	0.011
7	Accident Day	C	0.003
8	Onshore/Offshore	2	-0.022

P21-36 cont.

Table 7 shows that Power of Turbine is the most important predictor attribute for injury, with almost double the information gain value of the third attribute, Event Occurrence. Therefore, Power of Turbine is the attribute that provides the most predictive information on whether a human Injury occurs. The information gain value also almost halves in the next attribute that follows AccidentYear, suggesting a large gap in the information provided by the first five attributes and the remaining ones. The data mining process can thus be modified to include only the first five attributes in Table 7 as predictors of Injury.

G. Classification Tree Analysis

In the classification tree analysis, information gain was used as the attribute selection criterion in the split in the tree Only the first seven attributes of Table 6 were included as predictors while predicting whether Death occurs (Death=1) or not. The results of the classification tree analysis for Model 1 are displayed in Figure 5. Each node (little box) represents the percentage of observations with the target class attribute value (Death) and also the count. Each pie shows the distribution of the values of the target class attribute.

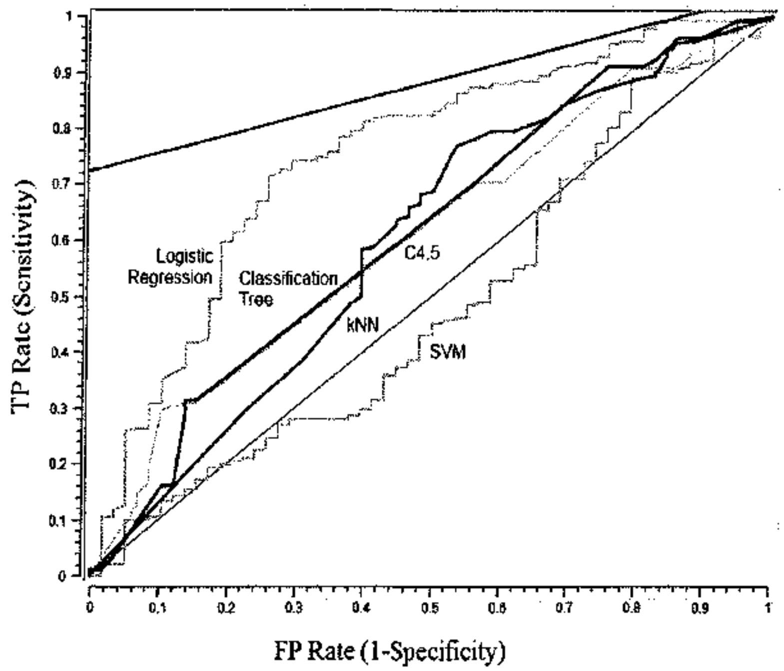

Fig. 6. ROC analysis for Death.

P21-36 cont.

In the analysis of classification trees (Figure 5), visually identifying the nodes that differ noticeably from the root node are important, because the path that leads to those nodes (represented as the antecedent of a rule) tells us how significant changes are observed in the subsample compared with the complete data. By observing the shares of slices and comparing with the parent and root nodes, one can discover classification rules and insights. While the first split (according to the value of information gain) is based on Power of Wind Farm, this does not create a significant change in slice shares. The most significant change from the root node occurs based on the third split, is based on the attribute Event Occurrence. Deaths are much less frequent during transportation and operation, while they are much more frequent during construction and maintenance (clearly, a larger share of the light-colored slice compared with the root).

The classification tree analysis did not yield any insights for Model 2, where Injury was predicted. This means that none of the five attributes from Table 7 that were put into Model 2 provided enough information to create a significantly different split of the sample into subsamples.

H. Classification Analysis

The final analysis of the data is the classification analysis. The task in classification analysis is to predict the predicted attribute with a high classification accuracy. The ultimate goal is to be able to predict the class values of the predicted attribute in new cases. To this end, the data is systematically split into training and testing datasets, the training dataset is used to "teach" the classification algorithms (or shortly "classifiers") about the data, and the performance of the classification algorithms is tested using the test dataset.

TABLE IX

EVALUATION OF THE PERFORMANCE OF VARIOUS CLASSIFICATION ALGORITHMS FOR PREDICTING THE BINARY VALUE OF INJURY.

Classifier	CA	AUC
Logistic regression	**0.829**	**0.777**
kNN	0.817	0.669
Classification Tree	0.850	0.500
SVM	0.850	0.500
C4.5	0.850	0.500

TABLE VIII

EVALUATION OF THE PERFORMANCE OF VARIOUS CLASSIFICATION ALGORITHMS FOR PREDICTING THE BINARY VALUE OF DEATH.

Classifier	CA	AUC
Logistic regression	**0.763**	**0.758**
SVM	0.750	0.728
Classification Tree	0.742	0.574
C4.5	0.738	0.565
kNN	0.642	0.605

P21-36 cont.

The most popular metric used in measuring the quality of the results obtained by classification algorithms is "classification accuracy", which is the percentage of observations in the test data set that are classified correctly. In our case, the classification is performed for Death and Injury, respectively. The goal is to predict whether Death or Injury will occur in a particular wind turbine accident. Tables 8 and 9 present the results of classification analysis. Among the five classifiers applied, Logistics Regression gives the best results for both models.

Figure 6 shows the receiver operating characteristic (ROC) curves for the first model. The ROC curve plots the true positive rate (TP-Rate) on the y-axis against the false positive rate (FP-Rate) on the x-axis, as a discrimination threshold is varied. The classifier predicts the class of the particular case in the testing dataset as "positive" (for example, predicting Death=1 in Model 1), if the function value for that classifier exceeds the discrimination threshold. TP-Rate refers to the percentage of cases which are correctly predicted to have positive class values (for example, cases which have Death=1 in Model 1 and have been correctly predicted as such by the classifier). FP-Rate refers to the percentage of cases which are predicted as positive, but are actually not positive (for example, cases with Death=0 in Model 1, that have been predicted as Death=1 by the classifier). Every single point on the ROC curve for a certain classifier (for example, logistic regression) reflects the (x,y)=(FP-Rate, TP-Rate) value pair corresponding to a particular value of the discrimination threshold. ROC curves with greater areas under the curve (AUC), which are closer to the upper left corner in the plot, correspond to better classifiers.

- In Model 1, it is possible to achieve a classification accuracy of at most 76.3%, using logistic regression. Logistic regression is a specific type of regression which is applicable in classification analysis, as logistic regression can be used to predict values of a categorical attribute (such as Death and Injury).

When the ROC curves in Figure 6 corresponding to logistic regression and SVM (Support Vector Machines) are compared, it is observed that logistic regression has a larger AUC value. Also, the ROC curve for SVM is mostly below the y=x line, showing that it results in a low TP-rate for the same FP-rate. Therefore, logistic regression is the most appropriate classifier to predict the occurrence of Death.

- In Model 2, for predicting Injury, the classification accuracy (CA) of the classifiers classification tree, SVM, and C 4.5 are the highest, reaching 85%. However, analyzing the confusion matrix reveals that these three predictors classify none of the Injury=1 cases correctly (The confusion matrix is a matrix that shows the distribution of correct and erroneous predictions; Each column of the matrix represents the observations in a predicted class, while each row represents the observations in an actual class). Obtaining a high value for CA, despite zero success in correctly classifying Injury=1 cases is interesting. This result is because of the high percentage of cases with Injury=0. So, even though CA is a good measure, it should be considered together with the confusion matrix and ROC curves.
- Logistic regression classifier, on the other hand, does classify some of the Injury=1 cases correctly. This is also revealed in the ROC curve (not given as a figure), where the AUC for logistic regression is the highest, followed by that of kNN. Therefore, logistic regression is the most appropriate classifier to predict the occurrence of the Injury, as well.

V. Conclusions and Future Work

For the first time in the literature, our research investigates the contents of news articles on wind turbine accidents to come up with multi-faceted insights and new knowledge. Specifically, we studied the association between the characteristic attributes of wind turbine failures and the outcomes of death and injury. A particular emphasis was on two factors, namely the stage of the wind turbine's lifecycle, and the cause of the accident. In the modeling and data collection phases of our research, a critical issue was the valid selection of the cause and effect categories. These selections have been tediously carried out through consulting with a well-known professor in the field, who was responsible of the design and development of a national wind turbine for Turkey in a research project which involved more than 100 researchers.

P21-36 cont.

Some of the insights that have been obtained, as well as their implications, can be summarized as below:

1) Human caused accidents mostly occur due to human errors in transportation. Possible novel practices can include the rehearsal of the route and/or use of virtual reality simulators before the actual transportation is executed.

2) Natural causes are mostly related to strong wind and lightning strikes. Considering the fact that continuous improvements are made on wind turbine designs, we hypothesize that high rates of accidents for lightning strikes in our data can be due the accidents in earlier make turbines (we do not have data on the make year of turbines).

3) Major causes of accidents within the category of Systems/Equipment are electric causes, material fatigue, and faulty material.

4) In wind turbine accidents, blade and tower have the highest probability of being affected. During construction the cause categories System/Equipment and Human are much more influential than Nature.

5) During maintenance, the most important cause is also Human.

6) In the accidents during Construction, if the cause category is System/Equipment or Human, the probability of Death is higher than 0.5.

7) Most deaths occur during the Construction and Maintenance of the wind turbine.

8) During Maintenance, the number of accidents (rather than the probability of accidents) is highest when the Cause Categories are Human and System/Equipment.

9) During Transportation, percentagewise, the effect of Human on Injury is highest.

10) Our paper has established the statistically significant associations between all the factors and Death & Injury (Tables 4 and 5).

11) When predicting the possible occurrence of Death, the most information is gained from EventOccurrence, that is, the stage of the wind turbine's lifecycle. Other informative attributes are listed in Table 7.

12) When predicting the possible occurrence of Injury, the most information is gained from PowerOfTurbine. From Table 4, it can be seen that the correlation is positive. Thus larger turbines are more likely to lead to injuries. Other informative attributes are listed in Table 8.

13) When predicting the possible occurrence of Death given that an accident of the type we have defined has occurred, one should use the logistic regression classification method, rather than other methods. For our test dataset, this method predicted Death with a classification accuracy of 0.763.

14) When predicting the possible occurrence of Injury given that an accident of the type we have defined has occurred, one should again use the logistic regression classification method, rather than other methods. For our test dataset, this method predicted Injury with a classification accuracy of 0.829.

One important limitation and threat to the validity of our study is regarding the collection of the data and selection of the relevant news. The data that we collected is not complete, but is just a sample obtained through Internet by the Google search engine. Our assumptions were that the significant accidents made it to the news and were indexed by Google search engine with a somewhat high ranking. Google search engine utilizes sophisticated natural language processing algorithms as well as the Page-rank and other algorithms to obtain a ranking among the search results. For example, the search term "wind turbine accident" results in approximately 300,000 results. We scanned through only the first 5,000 of these results. Therefore, our data is not complete and is only a sample. As in every study where sampling from a population is carried out, there is the risk that our sample may not in fact be a random sample that represents the true population.

P21-36 cont.

Future research on the topic can work with larger document collections, not necessarily coming from publicly available news articles, but maybe also from industry, NGO (non-governmental organization) and government sources, such as regulation bodies. Other research, from a methodological perspective, includes the automatic identification of documents that report particular outcomes, such as death and injuries by using data mining techniques such as classification.

As the wind turbine industry is growing, we believe that the stakeholders in the industry, as well as government organizations and the academic community, should put more emphasis on collecting and analyzing data on wind turbine accidents. Our study has provided a multitude of insights and also has outlined some possible suggestions regarding wind turbine accidents. These insights can be guidelines for a variety of studies and best practices to be developed for and implemented in the wind turbine industry.

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P21-36 cont.

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Do wind turbines have to brake themselves if the wind speed becomes too high?

2 Answers

Raunaq Shah, Sales executive in a Wind Turbine Manufacturer
Answered Dec 22, 2015

Since, I have answered a similar question, I will paste that same answer here with mild editing.

Every wind turbine is designed as per the wind density of that site (or area). Some wind turbines are designed for low wind sites while others are designed for efficient energy extraction from high winds. We put weather masts etc to collect 1-2 years of wind resource data for the proposed site. From the wind data we know with acceptable accuracy, the maximum wind speed as well as the minimum wind speed which helps us in deciding which wind turbine design is well-suited for efficient generation. P21-36 cont.

Now focusing on wind turbine specifically, every wind turbine (irrespective of the wind speeds its designed for) has a minimum wind speed below which it does not generate any appreciable electricity, called as cut-in wind speed and a maximum wind speed above which it has to shut down (stop rotation) to avoid the damage to mechanical parts, which is called as cut-off wind speed. The latter is the scenario where brakes jump in. So the direct answer to your question is a big fat YES!

The wind vane and anemomenter mounted on the WTG detect wind direction and speeds and the if the control system realises those speeds to be high then it sends signals to the braking mechanisms to stop the turbine to avoid damage.

Braking mechanisms in a wind turbine:

1. Aerodynamic Braking: This kind of braking (Pitch braking) is achieved by changing the flow of wind along the blade surface. The principle is exactly same as how aircrafts achieve lift while taking off and reduce the same while landing by changing the

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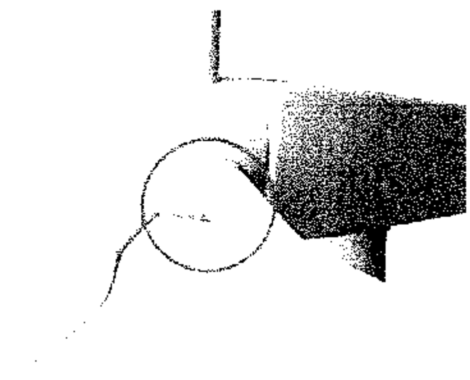
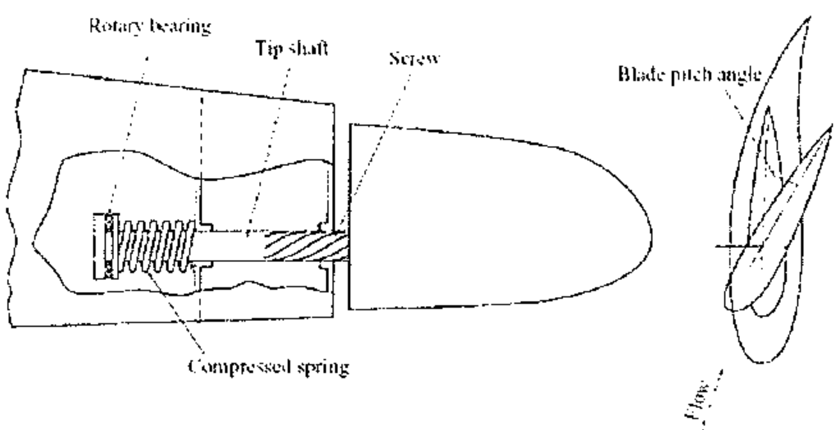
simply pass through without creating enough lift, hence no force moves the blade and the rotation dies out.



Note: There is a different version of pitch braking where the motor is placed close to the tip and only the tip spins out of the wind to brake the rotation as can be seen in picture below of the blade tip.



2. Mechanical Braking: In mechanical braking the rotation of the rotor is mechanically obstructed with appropriate mechanism. Since, the weight of rotor is high (in many-many tons for 2 MW and above capacity WTGs) the inertia is also huge and therefore, mechanically braking the turbine while the rotor is rotaing can damage (sometimes seriously) the working components. Hence, it is almost always employed after the rotor is aerodynamically stopped.

P21-36 cont.

Sign In

As can be seen in the picture above the cirular disc with holes on the outer rim is part of the mechanical braking mechanism (correct me if I am wrong). There will be a cylinder like stopper which will slide into one (or more depending on the design) of those holes to lock the rotor.

Note: There maybe alternative designs for mechanical braking.

3. Electrical Braking

There are a number of variations of electrical braking. This is similar to braking of electric motors in general. Main idea is to run the generator as motor by reversing the connections and thereby generating torques in opposite direction to reduce rotation until it dies out completely and switch out before reverse rotation starts. There are different types of electric braking methods. Main advantage is that the braking is very smooth and gradual thereby ensuring no damage to the involved components. P21-36 cont.

Note: There are also survival wind speeds. Above this the WTG simply cannot hold its ground, irrespective of any braking mechanisms and literally get blown away (sometimes even from the ground) as can be seen in the video posted in this answer - Don MacQuarrie's answer to In layman's terms, why do large windmills have brakes that keep them from spinning in too low or too high wind conditions?

But from the wind data, occurence of such scenarios can be efficiently detected and avoided. (well, for the most part :P)

Hope this helps :)

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What is the minimum wind speed for wind turbines to start turning?

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Can a wind turbine or wind mill be used at a place where the speed of the wind is above 35 mps?

James Quilter, Content marketer developer. Bringing code to content.
Answered May 28, 2015

Firstly the hub and the blades are turned so they're out of the wind. This is usually spring operated in case of electrical failure. Then there is also a mechanical brake as a back up.

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P21-36 cont.

Related Questions

Do small wind turbines normally have braking systems to slow or stop turbines in high winds?

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What is maximum wind speed turbine?

What is meant by tip speed ratio and designed wind speed of wind turbine?

Can a wind turbine or wind mill be used at a place where the speed of the wind is above 35 mps?

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What is aerodynamic braking in wind turbines?

Why is 3 the optimal number of blades on a wind turbine instead of say 5 or more?

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How is turbine output affected by wind speed?

Do wind turbines shadow the wind from other generators on a wind farm?

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Summary of Wind Turbine Accident data to 30 September 2020

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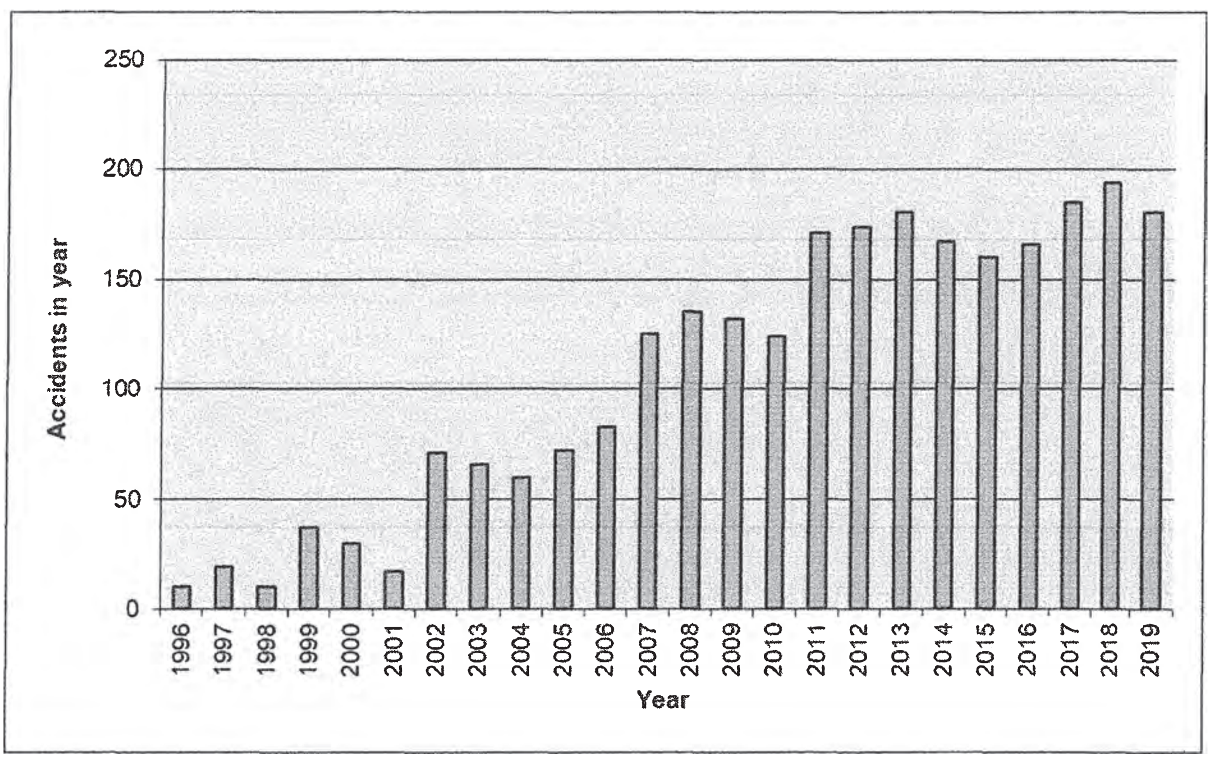
This is GLOBAL data - see Detailed Accident List with sources and locations

The attached **detailed table** includes all documented cases of wind turbine related accidents and incidents which could be found and confirmed through press reports or official information releases up to 30 September 2020. CWIF believe that this compendium of accident information may be the most comprehensive available anywhere.

Data in the detailed table attached is by no means fully comprehensive - CWIF believe that what is attached may only be the "tip of the iceberg" in terms of numbers of accidents and their frequency. Indeed on 11 December 2011 the **Daily Telegraph** reported that RenewableUK confirmed that there had been 1500 wind turbine accidents and incidents in the UK alone in the previous 5 years. In July 2019 EnergyVoice and the Press and Journal reported a total of 81 cases where workers had been injured on the UK's windfarms since 2014. The CWIF data has only 15 of these (<19%).

Additional evidence that CWIF data only represents the "tip of the iceberg" can be found in the 13 August 2018 publication by Power Technology **https://www.power-technology.com/features/golden-hour-paramedics-saving-lives-offshore-windfarms/** The article reports 737 incidents were reported from UK offshore windfarms during 2016 alone, with the majority occurring during operations rather than development. 44% of medical emergencies were turbine related. In comparison, only 4 UK offshore incidents are listed in the CWIF data - equivalent to 0.5%. P21-36 cont.

The CWIF data does however give an excellent cross-section of the types of accidents which can and do occur, and their consequences. With few exceptions, before about 1997 only data on fatal accidents has been found.



The trend is as expected - as more turbines are built, more accidents occur. Numbers of recorded accidents reflect this, with an average of 49 accidents per year from 2000-2004 inclusive; 109 accidents per year from 2005-2009 inclusive; 163 accidents per year from 2010-2014 inclusive, and 210 accidents per year from 2015-2019 inclusive.

This general trend upward in accident numbers is predicted to continue to escalate unless HSE make some significant changes - in particular to protect the public by declaring a minimum safe distance between new turbine developments and occupied housing and buildings.

In the UK, the HSE do not currently have a database of wind turbine failures on which they can base judgements on the reliability and risk assessments for wind turbines. Please refer to **http://www.hse.gov.uk/research/rrpdf/rr968.pdf.**

This is because the wind industry "guarantees confidentiality" of incidents reported. No other energy industry works with such secrecy regarding incidents. The wind industry should be no different, and the sooner RenewableUK makes its database available to the HSE and public, the better. The truth is out there, however RenewableUK don't like to admit it.

Some countries are finally accepting that industrial wind turbines can pose a significant public health and safety risk. In June 2014, the report of the Finnish Ministry of Health called for a minimum distance of 2 km from houses by concluding: *"The actors of development of wind energy should understand that no economic or political objective must not prevail over the well being and health of individuals."* In 2016 Bavaria passed legislation requiring a minimum 2km distance between wind turbines and homes, and Ireland are considering a similar measure.

The Scottish government has proposed increasing the separation distance between wind farms and local communities from 2km to 2.5km (**http://www.bbc.co.uk/news/uk-scotland-scotland-politics-26579733**) though in reality the current 2km separation distance is often shamefully ignored during the planning process.

Our data clearly shows that blade failure is the most common accident with wind turbines, closely followed by fire. This is in agreement with GCube, the largest provider of insurance to renewable energy schemes. In June 2015, the wind industry's own publication "WindPower Monthly" published an article confirming that "Annual blade failures estimated at around 3,800", based on GCube information. A GCube survey in 2013 reported that the most common type of accident is indeed blade failure, and that the two most common causes of accidents are fire and poor maintenance. A further GCube report in November 2015 stated that there are an average 50 wind turbine fires per year, and this remains unchanged in the latest 2018 GCube publication **http://www.gcube-insurance.com/reports/towering-inferno/**

The 50 fires per year is over double the reported CWIF data below, further underpinning that data presented here may only be "the tip of the iceberg".

The 2018 GCube report also notes the following:

- Wind turbine fires are greatly outnumbered by problems relating to blades and gear boxes;
- Failure of operators to undertake sufficient due diligence through maintenance checks is of increasing concern, and;
- Operating wind farms outwith their design parameters has been noted as a significant contributor to fires.

Data attached is presented chronologically. It can be broken down as follows:

P21-36 cont.

Number of accidents

Total number of accidents: 2744

By year:

Year	Before 2000	2000-2005	06	07	08	09	10	11	12	13	14	15	16	17	18	19	*20
No.	109	316	83	125	135	132	124	171	174	181	167	160	166	185	194	181	141

** to 30 September 2020*

Fatal accidents

Number of fatal accidents: 154

By year:

Year	Before 2000	2000-2005	06	07	08	09	10	11	12	13	14	15	16	17	18	19	*20
No.	24	16	5	5	11	8	8	15	17	5	3	8	6	9	3	5	6

** to 30 September 2020*

Please note: **There are more fatalities than accidents as some accidents have caused multiple fatalities.**

Of the 218 fatalities:

- 125 were wind industry and direct support workers (divers, construction, maintenance, engineers, etc), or small turbine owner/operators.
- 93 were public fatalities, including workers not directly dependent on the wind industry (e.g. transport workers, ecologists).

Human injury

183 accidents regarding human injury are documented.

By year:

Year	Before	2000-	06	07	08	09	10	11	12	13	14	15	16	17	18	19	*20

	2000	2005															
No.	5	17	10	16	18	9	14	12	15	9	9	9	10	13	4	7	6

** to 30 September 2020*

During the 183 accidents, 219 wind industry or construction/maintenance workers were injured, and a further 78 members of the public or workers not directly dependent on the wind industry (e.g. fire fighters, transport workers) were also injured. Eight of these injuries to members of the public were in the UK.

Human health

Since 2012, 185 incidents of wind turbines impacting upon human health are recorded.

By year:

Year	12	13	14	15	16	17	18	19	*20
No.	6	27	19	13	17	36	28	21	18

** to 30 September 2020*

Since 2012, human health incidents and adverse impact upon human health have been included. These were previously filed under "miscellaneous" but CWIF believe that they deserve a category of their own. Incidents include reports of ill-heath and effects due to turbine noise, shadow flicker, etc. Such reports are predicted to increase significantly as turbines are increasingly approved and built in unsuitable locations, close to people's homes.

Blade failure

By far the biggest number of incidents found was due to blade failure. "Blade failure" can arise from a number of possible sources, and results in either whole blades or pieces of blade being thrown from the turbine. A total of 454 separate incidences were found:

By year:

Year	Before 2000	2000-2005	06	07	08	09	10	11	12	13	14	15	16	17	18	19	*20
No.	35	65	17	23	20	26	20	20	29	36	32	22	21	18	27	24	19

** to 30 September 2020*

P21-36 cont.

Pieces of blade are documented as travelling up to one mile. In Germany, blade pieces have gone through the roofs and walls of nearby buildings. This is why CWIF believe that there should be a minimum distance of at least 2km between turbines and occupied housing or work places,in order to adequately address public safety and other issues including noise and shadow flicker.

Fire

Fire is the second most common accident cause in incidents found. Fire can arise from a number of sources - and some turbine types seem more prone to fire than others. A total of 399 fire incidents were found:

By year:

Year	Before 2000	2000-2005	06	07	08	09	10	11	12	13	14	15	16	17	18	19	*20
No.	7	77	12	21	17	18	16	22	23	26	19	21	28	25	27	23	17

** to 30 September 2020*

The biggest problem with turbine fires is that, because of the turbine height, the fire brigade can do little but watch it burn itself out. While this may be acceptable in reasonably still conditions, in a storm it means burning debris being scattered over a wide area, with obvious consequences. In dry weather there is obviously a wider-area fire risk, especially for those constructed in or close to forest areas and/or close to housing or work places. Five fire accidents have badly burned wind industry workers.

Structural failure

From the data obtained, this is the third most common accident cause, with 221 instances found. "Structural failure" is assumed to be major component failure under conditions which components should be designed to withstand. This mainly concerns storm damage to turbines and tower collapse. However, poor quality control, lack of maintenance and component failure can also be responsible.

By year:

Year	Before 2000	2000-2005	06	07	08	09	10	11	12	13	14	15	16	17	18	19	*20
No.	15	39	9	13	9	16	9	13	10	15	13	12	11	14	9	7	6

** to 30 September 2020*

While structural failure is far more damaging (and more expensive) than blade failure, the accident consequences and risks to human health are most likely lower, as risks are confined to within a relatively short distance from the turbine. However, as smaller turbines are now being placed on and around buildings including schools, the accident frequency is expected to rise.

Ice throw

46 reports of ice throw were found. Some are multiple incidents. These are listed here unless they have caused human injury, in which case they are included under "human injury" above.

By year:

Year	Before 2000	2000-2005	06	07	08	09	10	11	12	13	14	15	16	17	18	19	*20
No.	9	12	3	0	3	4	1	1	1	0	1	1	3	1	2	3	1

** to 30 September 2020*

Ice throw has been reported to 140m. Some Canadian turbine sites have warning signs posted asking people to stay at least 305m from turbines during icy conditions.

These are indeed only a very small fraction of actual incidences - a report* published in 2003 reported 880 icing events between 1990 and 2003 in Germany alone. 33% of these were in the lowlands and on the coastline.
**("A Statistical Evaluation of Icing Failures in Germany's '250 MW Wind' Programme - Update 2003", M Durstwitz, BOREAS VI 9-11 April 2003 Pyhätunturi, Finland.)*

Additionally one report listed for 2005 includes 94 separate incidences of ice throw and two reports from 2006 include a further 27 such incidences. The 2014 entry refers to multiple YouTube videos and confirmation that ice sensors do not work.

Transport

There have been 239 reported accidents - including a 45m turbine section ramming through a house while being transported, a transporter knocking a utility pole through a restaurant, and various turbine parts falling off and blocking major highways. Transport fatalities and human injuries are included separately. Most accidents involve turbine sections falling from transporters, though turbine sections have also been lost at sea, along with a £50M barge. Transport is the single biggest cause of public fatalities and injuries.

By year: P21-36 cont.

Year	Before 2000	2000-2005	06	07	08	09	10	11	12	13	14	15	16	17	18	19	*20
No.		13	6	19	12	11	11	24	17	14	17	14	16	19	14	18	14

** to 30 September 2020*

Environmental damage (including bird deaths)

287 cases of environmental damage have been reported - the majority since 2007. This is perhaps due to a change in legislation or new reporting requirement. All involved damage to the site itself, or reported damage to or death of wildlife. 97 instances reported here include confirmed deaths of protected species of bird. Deaths, however, are known to be far higher. At the Altamont Pass windfarm alone, 2400 protected golden eagles have been killed in 20 years, and about 10,000 protected raptors (Dr Smallwood, 2004). In Germany, 32 protected white tailed eagles were found dead, killed by wind turbines (Brandenburg State records). In Australia, 22 critically endangered Tasmanian eagles were killed by a single windfarm (Woolnorth). Further detailed information can be found at: **http://www.iberica2000.org/Es/Articulo.asp?Id=1228** .

600,000 bats were estimated to be killed by US wind turbines in 2012 alone. 1.4 million bird fatalities per annum are estimated if the US reaches it's 20% target for wind generation.

1,500 birds are estimated to be killed per year by the MacArthur wind farm in Australia, 500 of which are raptors.

By year:

Year	Before 2000	2000-2005	06	07	08	09	10	11	12	13	14	15	16	17	18	19	*20
No.	1	18	5	10	21	13	20	20	20	16	21	18	22	16	24	25	17

** to 30 September 2020*

Other (Miscellaneous)

576 miscellaneous accidents are also present in the data. Component or mechanical failure has been reported here if there has been no consequential structural damage. Also included are lack of maintenance, electrical failure (not led to fire or electrocution) etc. Construction and construction support accidents are also included, also lightning strikes when a strike has not resulted in blade damage or fire. A separate 1996 report** quotes 393 reports of lightning strikes from 1992 to 1995 in Germany alone, 124 of those direct to the turbine, the rest are to electrical distribution network.
***(Data from WMEP database: taken from report "External Conditions for Wind Turbine Operation - Results from the German '250 MW Wind' Programme", M Durstewitz, et al, European Union Wind Energy Conference, Goeteborg, May 20-24, 1996)*

By year:

Year	Before 2000	2000-2005	06	07	08	09	10	11	12	13	14	15	16	17	18	19	*20
No.	13	59	16	18	24	27	25	43	36	33	33	42	32	34	56	47	37

** to 30 September 2020*

Caithness Windfarm Information Forum
30 September 2020

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Wind Energy

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RESEARCH ARTICLE

Analysis of throw distances of detached objects from horizontal-axis wind turbines

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ABSTRACT

This paper aims at predicting trajectories of the detached fragments from wind turbines, in order to better quantify consequences of wind turbine failures. The trajectories of thrown objects are attained using the solution to equations of motion and rotation, with the external loads and moments obtained using blade element approach. We have extended an earlier work by taking into account dynamic stall and wind variations due to shear, and investigated different scenarios of throw including throw of the entire or a part of blade, as well as throw of accumulated ice on the blade. Trajectories are simulated for modern wind turbines ranging in size from 2 to 20 MW using upscaling laws. Extensive parametric analyses are performed against initial release angle, tip speed ratio, detachment geometry, and blade pitch setting. It is found that, while at tip speeds of about 70 m/s (normal operating conditions), pieces of blade (with weights in the range of approximately 7-16 ton) would be thrown out less than 700 m for the entire range of wind turbines, and turbines operating at the extreme tip speed of 150 m/s may be subject to blade throw of up to 2 km from the turbine. For the ice throw cases, maximum distances of approximately 100 and 600 m are obtained for standstill and normal operating conditions of the wind turbine, respectively, with the ice pieces weighting from 0.4 to 6.5 kg. The simulations can be useful for revision of wind turbine setback standards, especially when combined with risk assessment studies. Copyright © 2015 John Wiley & Sons, Ltd. P21-36 cont.

KEYWORDS
wind turbine accidents; blade element theory; blade detachment; ice throw; aerodynamic model; HAWT

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1. INTRODUCTION

The ever-growing number of wind turbines installed near inhabited areas, buildings and community facilities, such as bridges, power installations or highways, has resulted in an increasing concern by authorities to determine risk levels associated with wind turbine blade failure. From a safety point of view, the most serious failure is associated with splintering of rotor blades and detachment of debris, which could be thrown over long distances and damage people or property. Ice-throw from wind turbines installed in cold climate is also of high concern, especially for wind turbines erected near highways where the ice pieces thrown from a wind turbine may strike a passing car, which in the worst case may cause a fatal accident.

Various types of hazards regarding operation of wind turbines have recently been reported by Durstwitz and the Caithness Windfarm Information Forum.[2,3] According to a recent survey by the Caithness Windfarm Information Forum, blade failures resulting in either whole blades or pieces of blades being thrown from the turbine are the most important causes of turbine accidents.[3] A comparative graph showing the growth of wind turbine accidents over the past four decades is shown in Figure 1, where the share of blade accidents and accidents due to fire, which may eventually cause throw of fire patches, are also presented. Due to such accident data, energy authorities all over the world have tried to enforce safety distances around wind turbines and wind farms. The safety distance is a distance within which it is not allowed to build human structures such as buildings and roads. Shown in Table I is an example of the safety distance standards defined by different authorities. It can be seen from the table the values of offset safety distances fall within an extensive range of

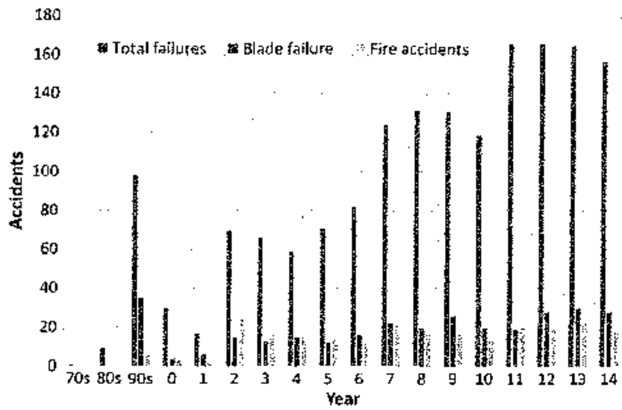

Figure 1. Comparison of wind turbine accidents and particularly blade failure data in a period from 1970s until 2014 (data taken from Caithness Windfarms[3]).

Table I. Safety distances of wind turbines from human structures as practiced in different regions of the world.[17]

Authority/source	Safety distance [m] (ft)
France	1609 (5280)
Germany	1609 (5280)
Rural Manitoba, Canada (1981)	(6500)
US National Research Council	762 (2500)
IL, USA	457 (1500)
Riverside County, CA, USA	**3218 (10560)**
MI, USA	**304 (1000)**

P21-36 cont.

scales between 3.2km and 300m, and that the setback standards are not even similar in different regions of the same country. To standardize such safety guidelines, it is useful to employ mathematical models of the throw in various conditions and risk assessment tools to associate the probability of failure in each particular setting.

Motions of solid particles in fluids were first addressed analytically by Kirchhoff.[4] He showed that the equations of motion for a solid body in an ideal fluid reduce to a set of ordinary differential equations (ODE) based on Euler's equations. Further experimental investigations on falling objects revealed, despite originating from Euler's equations, various states of chaotic motion. It was also mathematically shown that Kirchhoff's equations had been prone to yield chaotic solutions [5]. Tanabe *et al.*[6] developed a set of two-dimensional equations of motion (including rotation) based on simple mechanics in which plates of zero thickness were subject to lift, friction and gravity forces. Based on those assumptions, they found five different falling patterns, ranging from a periodic movement to chaotic random motions depending on the density ratio between the solid and the surrounding fluid and on the length of the object. Pesavento and Wang[7] and Andersen *et al.*[8] performed more detailed studies to determine the motion of a falling two-dimensional elliptic object using direct numerical simulation of the Navier–Stokes equations. They took added mass and added moment of inertia into account and analyzed the transient motion and local jumps of the falling object thoroughly.

Due to complications in a real-life blade accidents (erratic motions, high Reynolds numbers, complex geometries etc.), the fundamental studies mentioned above could only partially help understanding the physics of wind turbine blade throw patterns. To cope with the wind turbine problems, simplified approaches were used. Macqueen *et al.*,[9] for instance, studied the problem of blade-throw from wind turbines, using classical ballistics and also assumption of constant lift and drag. A lift coefficient of Cl = 0.8 and a drag coefficient of Cd = 0.4 were used for the gliding simulations, with Cl = 0.0 and Cd = 1.0 for the tumbling motion. However, the probability that gliding would occur was deemed very small. Their maximum throw studies using simple ballistic analysis, that is, by neglecting aerodynamic forces, showed that in the extreme throw velocity of approximately 310m/s, the maximum throw length reaches 10km.

One of the first detailed studies on the aerodynamics of a detached wind turbine blade was performed by Sørensen[1] using a blade element approach. In this approach, the detached blade is divided into a number of sections and the aerodynamic loads are determined for each section. The total external aerodynamic load on the whole blade would then be determined as the summation of the individual forces on each section.

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Recently, Rogers *et al.*[10] used a dynamic model employing quaternions instead of Euler angles and rotation vectors to form the orientation matrix and performed Monte Carlo simulations of a large set of initial conditions in order to obtain a range of the throw distances.

Ice throw has also been investigated, especially for the turbines erected in the cold climate. Seifert *et al.* measured ice-throw accidents together with a simple aerodynamic model and performed risk analysis of the ice fragments thrown from the blades.[11] Recently, a model of ice throw for a wind turbine in operation was presented by Biswas *et al.*,[12] in which calculations were carried out for ice pieces by neglecting lift and using a fixed drag coefficient of $C_d = 1.0$. It was also estimated that including the highest possible, lift increases the throw distance by approximately a factor of two.

The problem of blade/ice throw has also been investigated through the window of probabilistic methods. Such methods deal with risk levels and probabilities that a certain throw distance will occur. Such studies are typically performed together with a dynamic model for calculating the throw distances. Macqueen *et al.*,[9] Morgan,[13] Morgan and Bossanyi[14] and Rogers *et al.*[10] carried out risk analyses of ice throw to determine safety guidelines for wind developments in ice-prone areas. Sørensen[15] proposed a statistical model that determines risk levels of debris hitting people. Similarly, Carbone and Afferrante[16] performed a combined probabilistic and dynamic analyses to quantify hazards due to the blade throw.

In the present work, detailed aerodynamic analysis are performed for simulating flying debris. The cases include blade throw in which the blade together with its components is thrown, a case in which only a shell laminate is thrown and a case involving detachment of ice fragments. The governing equations of motion form a set of 18 ODEs responsible for the six degree-of-freedom motion. The resulting system of discretized equations are solved using an ordinary time integration method. Throw distances for four different turbine sizes ranging from 2.3 to 20 MW are compared, by employing simple upscaling rules. The computations are carried out for different wind and tip speeds.

2. MATHEMATICAL MODELING

P21-36 cont.

The equations of motion for a detached blade include equations of translation and equations of rotation. These are obtained using Newton's second law and Euler's equations of motion, with the aerodynamic forces obtained from tabulated airfoil data. To be able to quantify the rotational motion of the detached blade, the moments of inertia around the rotation axes are calculated. This, however, cannot be calculated in a fixed coordinate system (i.e., an inertial system) since both the moments of inertia and the rotational speeds are varying and a solution would become very complicated. Instead, the equations are computed around the body-fixed principal axis, and the obtained values are subsequently transformed to the global (inertial) coordinate system to represent the absolute location and orientations. Two coordinate systems are defined here: a global coordinate system $\mathbf{x} = (x, y, z)$ with the origin on the tower basement and orthonormal right-handed unit vectors $(\vec{i}, \vec{j}, \vec{k})$, with the y-axis in the wind direction and the z-axis in the upward direction. A body-fixed coordinate system $\mathbf{b} = (x_b, y_b, z_b)$ is defined by an orthonormal right-handed unit vector $(\vec{r}_1, \vec{r}_2, \vec{r}_3)$, with the origin located at the center of gravity of the detached blade fragment and the third axis parallel to the length axis of the blade (Figure 2).

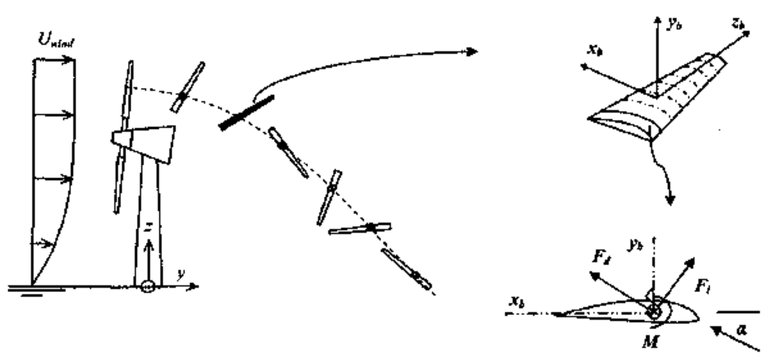

Figure 2. Sketch of the problem and definition of coordinate systems.

The orientation of the detached part is determined through a matrix **R**, which gives the transformation from global coordinates to the body-fixed coordinates

$$\begin{bmatrix} \vec{r}_1 \\ \vec{r}_2 \\ \vec{r}_3 \end{bmatrix} = [\mathbf{R}] \begin{bmatrix} \vec{i} \\ \vec{j} \\ \vec{k} \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \begin{bmatrix} \vec{i} \\ \vec{j} \\ \vec{k} \end{bmatrix} \text{ and similarly, } \begin{bmatrix} \vec{i} \\ \vec{j} \\ \vec{k} \end{bmatrix} = [\mathbf{R}^{-1}] \begin{bmatrix} \vec{r}_1 \\ \vec{r}_2 \\ \vec{r}_3 \end{bmatrix} \tag{1}$$

Equation (1) holds for transformation of any variable between the two coordinate systems. This way of defining a vectorized rotation matrix (as opposed to Euler's scalar angles) ensures uniqueness of orientation angles and avoids the problem known as gimbal lock.

The full six degree-of-freedom motion is governed by Newton's second law of motion and Euler's equations of motion:

$$m\ddot{\underline{x}}_g = \underline{F} + m\underline{g} \tag{2}$$

$$\underline{\underline{I}}.\dot{\underline{\omega}}_b = \underline{\omega}_b \times (\underline{\underline{I}}.\underline{\omega}_b) = \underline{M} \tag{3}$$

where m is the mass of the blade, $\underline{x}_g$ is the position vector of the center of gravity, $\underline{F}$ is the aerodynamic force acting on the center of gravity, g is the gravitational acceleration, $\underline{\underline{I}}$ is the moment of inertia tensor, $\underline{\omega}$ is the angular velocity in the rotating frame of reference, $\underline{M}$ is the aerodynamic force acting along the principal axis of the moment of inertia tensor and $(\dot{})$ denotes differentiation with respect to time. To close the system, the following relationship between the motion of the unit vectors of the body (the blade fragment) and the angular velocity is used:

$$\dot{\underline{r}} = \underline{\omega} \times \underline{r} \tag{4}$$

where $\underline{\omega}$ is the angular velocity of the blade fragment in the inertial coordinate system, which by equation (1) is transformed into the local body-fixed coordinate system. The total set of equations are solved using a fourth-order Runge–Kutta–Nystrom or a third-order Adams–Bashforth method. For more information about the mathematical and numerical treatment of the equations, readers are referred to the early work of Sørensen.[1]

P21-36 cont.

2.1. Aerodynamic modeling

For the solution of the system of ODEs, a blade element approach is employed in which each blade is divided into n sections along the span. In each section, the external forces and moments are calculated from airfoil data based on the local wind speed and relative velocities.

The three-dimensional edge effects are to some extent considered through the finite aspect ratio assumption of the blade, and the aerodynamic coefficients of lift and drag are calculated for all angles of attack based on flat-plate theory. The induced velocities are, however, neglected, and the Reynolds-number dependence of the airfoil data is disregarded. Once the aerodynamic coefficients are found, the lift, drag and moments on the blade fragment are computed as

$$L_i = \frac{1}{2}\rho v_i^2 A_i C_{Li}, \quad D_i = \frac{1}{2}\rho v_i^2 A_i C_{Di} \tag{5}$$

where L_i and D_i are lift and drag forces on the i-th section, ρ is the air density, v_i is the local relative airspeed, $A_i = c_i \Delta r_i$ is the local planform area where c_i and Δr_i are the local chord and the section lengths, and C_{Li} and C_{Di} are the sectional lift and drag coefficients at the desired angle of attack.

The static forces aerodynamic coefficients of the airfoil only depend on the angle of attack. Unsteady effects at high angles of attack are included by using the dynamic stall model of Øye.[18] In this model, the dynamic lift coefficient is obtained by interpolating between the lift coefficient of an airfoil in a fully attached flow and a lift coefficient of the airfoil when the flow around the airfoil is fully separated, i.e.,

$$C_{l,dyn} = f_s C_{l,inv}(\alpha) + (1 - f_s) C_{l,fs}(\alpha) \tag{6}$$

where $C_{l,inv}$ is the lift coefficient for a fully attached flow (i.e., inviscid flow assumption) and $C_{l,fs}$ is the lift coefficient for fully separated flow. The stall-changing rate is defined as

$$\frac{df_s}{dt} = \frac{f_s^{st} - f_s}{\tau} \tag{7}$$

where f_s is the time-dependent separation function, which can be thought of as the unsteady weighting function between the fully attached and the fully separated flow. f_s^{st} is a function of airfoil section,

$$f_s^{st}(\alpha) = \frac{C_{l,st}(\alpha) - C_{l,fs}(\alpha)}{C_{l,inv}(\alpha) - C_{l,fs}(\alpha)} \tag{8}$$

and τ is an empirically determined time constant giving the time lag between the dynamic value of f_s and its static value. It follows from equation (7) that

$$f_s(t+\Delta t) = f_s^{st} + \left(f_s(t) - f_s^{st}\right)\exp\left(\frac{-\Delta t}{\tau}\right) \quad (9)$$

2.2. The atmospheric boundary layer effects

The inlet wind is included as a velocity profile corresponding to the Atmospheric Boundary Layer (ABL). As a result, in addition to simulating uniform inflow,[1] it is possible to simulate throw distances for blades thrown in wind fields following a power or logarithmic law, depending on the specific site information. The ABL wind profile as a function of height and atmospheric conditions reads

$$u_z = \frac{u_*}{\kappa}\left[\ln\left(\frac{z}{z_0}\right) + \psi(z, z_0, L)\right] \quad (10)$$

where u_* is the friction velocity, κ is the von Karman constant (~ 0.41), z_0 is the roughness length, ψ is a function of atmospheric stability and L is the Monin–Obukhov stability parameter (see Wyngaard[19] for more details).

If no data are available in a specific site, and neutral ABL is assumed, a power law $u(z) = u_{hub}(z/z_{hub})^{\alpha}$, $\alpha \sim 0.14$ will be used for the wind velocity at different heights having the wind velocity at hub height as an input. The power-law method is used for the parametric studies in this paper.

Using the mentioned wind profile and denoting the local position vector of a point p on the wing as $\vec{r}_{pb}$, the local relative wind velocity $\vec{u}_{pb}$, as seen by the blade fragment, is given as

$$\vec{u}_{pb} = [\mathbf{R}].(\vec{u}_{wind} - \vec{u}_g) - \vec{\omega}_b \times \vec{r}_{pb} \quad (11)$$

where the wind vector is assumed to be $\vec{u}_{wind} = (0, u_y, 0)$, neglecting the vertical and lateral components. P21-36 cont.

3. SIMULATION RESULTS

Simulations of both blade-throw and ice-throw distances are performed by solving the equations derived in the previous sections using the in-house aerodynamic code *Savbal**. The overall procedure for the solution consists of three stages, comprising coordinate transformation, aerodynamics load assessment and time integration. The initial position, orientation and velocities of the detached part are first evaluated at their local coordinates. Based on these values, an iterative procedure starts where the local velocities are evaluated, according to exerted aerodynamic loads, and integrated to give the location and orientation of the fragment in global coordinates until the fragment reaches the ground level.

For the blade-throw analysis, cases with different detached lengths and tip speeds are compared in two sub-cases: (1) the whole blade together with its sandwich structure is thrown and (2) only the shell layer of the blade is thrown. For ice-throw analysis, it turns out that the drag to mass ratio plays an important role for the magnitude of the throw distance. As a result, a few cases with different $C_d A/m$ ratios (as discussed by Biswas *et al.*[12]) with both standstill and running turbine conditions are simulated. The analyses are performed for different wind turbine sizes.

3.1. Turbine upscaling laws

The throw distance analysis was initially performed for a 2.3 MW turbine using publicly available data. A series of empirical relations was then used to upscale the data for the larger turbines, and the analyses were performed for four different wind turbine sizes, i.e., 2.3, 5, 10 and 20 MW. The scale-up factors are first obtained for the blade length, which scales as the square root of the power ratio. Therefore, denoting the blade length, mass (applicable to both total sandwich structure and the shell laminate masses) and mass moment of inertia for the reference turbine with index a, i.e., r_a, m_a and $\mathbf{I}_a$, respectively, the corresponding values for the upscaled turbine, index b, can be obtained as

$$r_b = r_a\left(\frac{P_b}{P_a}\right)^{S_l}, \quad m_b = m_a\left(\frac{r_b}{r_a}\right)^{S_m}, \quad \mathbf{I}_b = \mathbf{I}_a\left(\frac{m_b}{m_a}\right)\left(\frac{r_b}{r_a}\right)^2 = \mathbf{I}_a\left(\frac{r_b}{r_a}\right)^{S_m+2} \quad (12)$$

*The computing code *Savbal* will be available upon request for further studies on this field.

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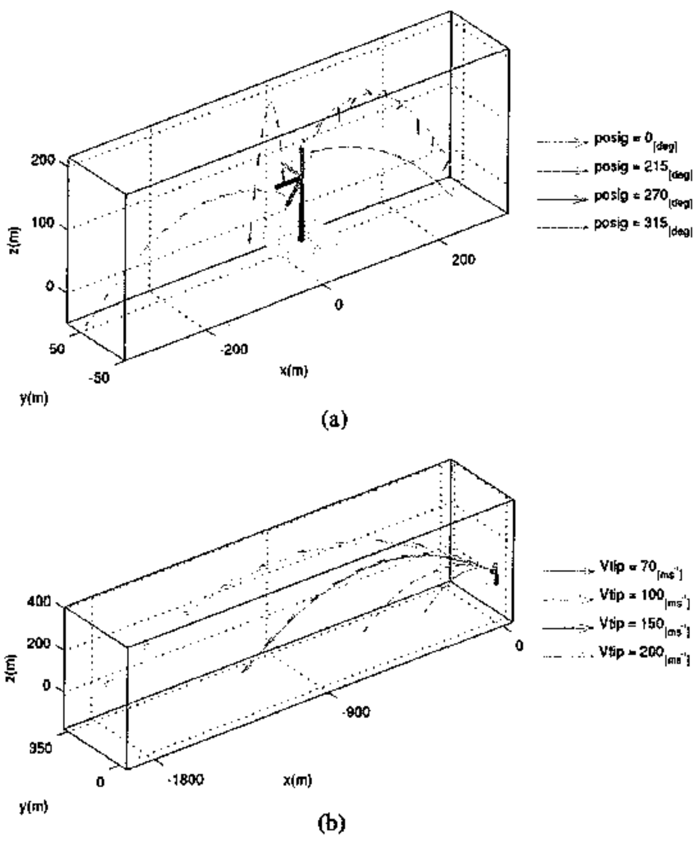
Table II. Characteristics of different turbine sizes considered in the throw analyses.

Size	$L^* = \frac{L}{R}$	L (m)	m (kg)	I_x (kg·m^2)	I_y (kg·m^2)	I_z (kg·m^2)
2.3 MW $R = 45$ m, $H = 100$ m	1.0	45	7.3E+3	0.1E+7	0.1E+7	0.3E+04
	0.5	22.5	2.4E+3	0.1E+6	0.1E+6	0.40E+03
	0.2	10	4.1E+2	0.4E+04	0.4E+04	0.2E+02
5 MW $R = 66$ m, $H = 147$ m	1.0	66	2.6E+04	0.9E+07	0.9E+07	0.2E+05
	0.5	33	8.2E+03	0.1E+07	0.1E+07	0.3E+04
	0.2	14	1.7E+3	0.3E+05	0.3E+05	0.2E+03
10 MW $R = 93$ m, $H = 208$ m	1.0	93	8.2E+04	0.5E+08	0.5E+08	0.1E+06
	0.5	46.5	2.7E+04	0.6E+07	0.6E+07	0.2E+05
	0.2	20	5.3E+3	0.2E+06	0.2E+06	0.1E+04
20 MW $R = 132$ m, $H = 294$ m	1.0	132	2.6E+05	0.3E+09	0.3E+09	0.9E+06
	0.5	66	8.7E+04	0.4E+08	0.4E+08	0.1E+06
	0.2	29	1.6E+04	0.1E+07	0.1E+07	0.8E+04



P21-36 cont.

Figure 3. Schematic graphs of the throw distances for half-blade detachment changing (a) the initial release angles (upward-clockwise reference) and (b) the tip speed velocities for the 2.3 MW reference turbine.

where $\mathbf{I} = (I_x, I_y, I_z)$. In the previous relations, $S_l = 1/2$ and S_m depends on actual scaling laws when increasing the size of the rotor. From simple upscaling rules, S_m would be equal to 3 , but because of more elaborate rotor designs, this parameter is usually found to be somewhat smaller. In the present work, we employ $S_m = 2.3$ (see UpWind[20] and TPI Composites[21] for more information on turbine scaling).

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3.2. Full-blade throw analysis

In this section, the throw distance analyses are performed for four different turbine sizes based on the upscaling rules presented previously. Here, the term full blade refers to the case of blade shell including stiffening members (upper and lower shells, spar, etc.). The dimensions and other characteristics of each turbine size are reported in Table II. In accordance with the copyright policies of the turbine manufacturers, the data for the reference turbine (2.3 MW) do not correspond to an existing turbine but are chosen to mimic a real turbine.

The analysis included a parametric study, where the effects of the length of the detached parts, incoming wind speeds, blade tip speeds and wind turbine size on the blade-throw distances were investigated. The height of the tower is in all considered cases assumed to be equal to the rotor diameter. Figure 3 shows three-dimensional visualizations of the throw distances of a half-blade piece thrown of the 2.3 MW machine for different initial conditions. The small colored patches in the figure shows the instantaneous orientation of the detached part. For the sake of clarity, only some selected curves are shown in the figure. Figure 3(a) shows the effect of release angle on the throw distance, and Figure 3(b) shows the effect

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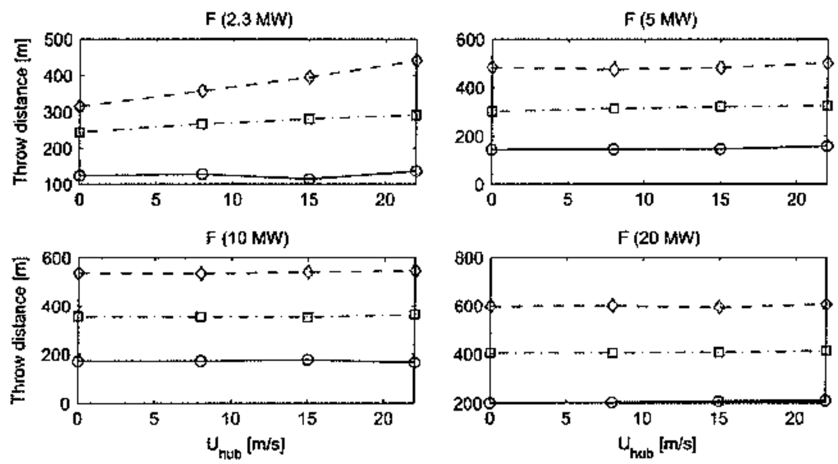

Figure 4. Throw distance calculations of full blade with three different detached lengths for 2.3, 5, 10 and 20 MW turbines at the normal operating condition of V_{tip} = 70 m/s. The horizontal axis shows the wind speed at the hub height and the vertical axis represents the throw distance. ◇ ◇ ◇: L^* = 0.2; □□□: L^* = 0.5; and o o o: L^* = 1.

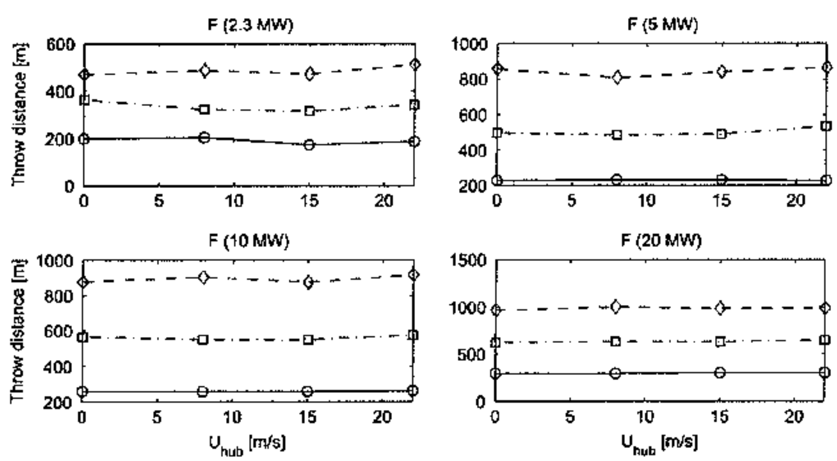

Figure 5. Throw distance calculations of full blade with three different detached lengths at a high tip speed of V_{tip} = 100 m/s. Legends are similar to those in Figure 4.

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of release tip velocity. As can be seen, the release tip speed is a very important factor influencing the maximum throw distances. Normal operating conditions with $V_{tip} = 70$ m/s result in throw distances of about 500 m long, whereas a tip speed of $V_{tip} = 150$ m/s may lead to throw distances up to 2 km.

For the quantitative analysis performed in the next section, the fragments are thrown at a release angle of 45° from the horizon (225° measured upward-clockwise) in all calculations. The full-blade and blade-shell throw calculations are performed using flat-plate assumption for the aerodynamic coefficients.

Figures 4, 5 and 6 show the throw distances for three different fragments of the full blade for a combination of three blade tip speeds ($v_{tip} = 70,\ 100\ 150$ m/s) and four different incoming wind velocities (with power-law profiles) ranging between 0 and 22 m/s at hub height.

The figures are divided into three groups, the first group (Figure 4) shows the throw distances, relative to the tower position, for different incoming wind speeds (shown on the horizontal axis) and different detachment lengths at a tip speed of $V_{tip} = 70$ m/s. The detachment length L^*, shown with markers, is the length of the detached piece, measured from the blade tip and normalized by the blade length. The throw distances are calculated and plotted for the four considered wind turbine sizes ranging from 2.3 to 20 MW. As can be seen, except for the 2.3 MW machine, the effect of the incoming wind on the throw distance is almost negligible. Similarly, the effect of turbine size on the throw distance is minimal and the main

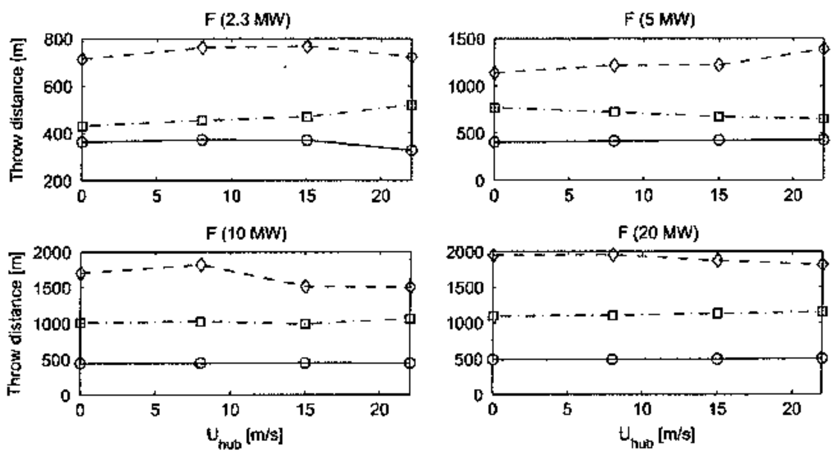

Figure 6. Throw distance calculations of full blade with three different detached lengths at an extreme tip speed of $V_{tip} = 150$ m/s. Legends are similar to those in Figure 4.

P21-36 cont.

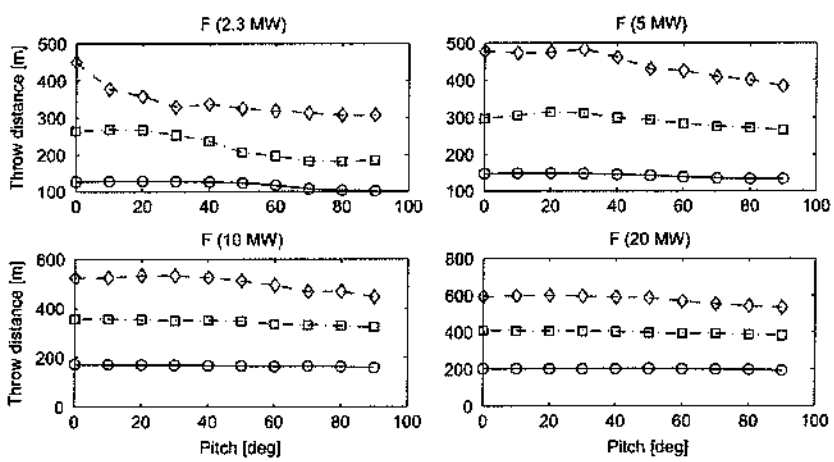

Figure 7. Sensitivity of throw distances of full blade to the initial pitch setting for 2.3, 5, 10 and 20 MW turbines operating at $V_{tip} = 70$ m/s. ◇ ◇ ◇: $L^* = 0.2$; □ □ □: $L^* = 0.5$; and o o o: $L^* = 1$.

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parameter governing the throw distance is the detachment length. The minimum throw distance is obtained for the heaviest fragment ($L^* = 0.2$) thrown from the 2.3 MW turbine, while the maximum throw distance of all cases at $V_{tip} = 70$ m/s is around 600 m for the lightest fragment ($L^* = 0.2$).

Figure 5 shows the same graphs for the higher tip speed of $V_{tip} = 100$ m/s, where the maximum throw distances for the smallest and largest turbines are about 500 and 1000 m, respectively, while the minimum throw distance is reached for a full-blade throw ($L^* = 1$) of a 2.3 MW turbine. Also, it is clear that the effect of the hub-height wind velocity is still very small. Figure 6 shows the same plots for the most extreme case considered, i.e., using a tip speed of $V_{tip} = 150$ m/s. Here, the thrown pieces reach throw distances ranging from approximately 350 m for the full-blade throw for a 2.3 MW turbine to about 2000 m for the lightest fragment thrown from the 20 MW turbine.

As can be seen from the red curve in Figure 6 for the 10 MW turbine (bottom-left), the throw distance has unexpectedly decreased when increasing the wind speed from 10 to 15 m/s. This behavior is somehow repeated to a smaller extent in other cases, especially at higher tip velocities. The unexpected results can happen because of the fact that a small change in the initial conditions can change the force/moment distributions on the fragments, thereby changing the trajectory drastically. To investigate the erratic motion further, the effect of initial pitch setting on the trajectory is analyzed in the next section.

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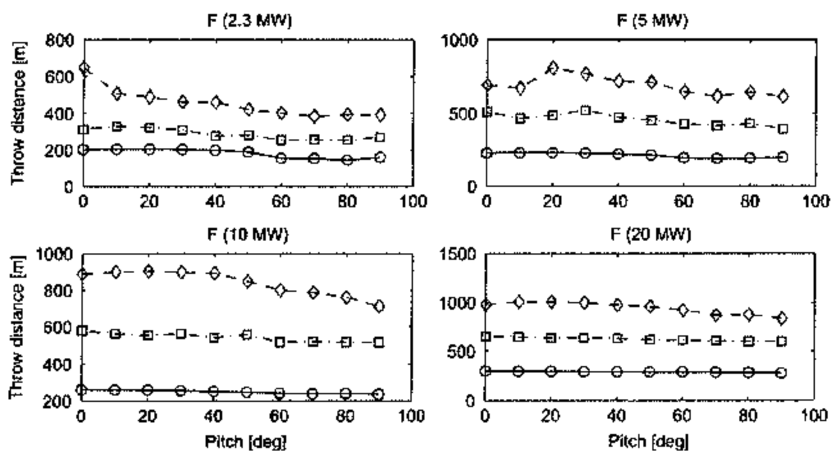

Figure 8. Sensitivity of throw distances of full blade to the initial pitch setting at $V_{tip} = 100$ m/s. Legends are similar to those in Figure 7.

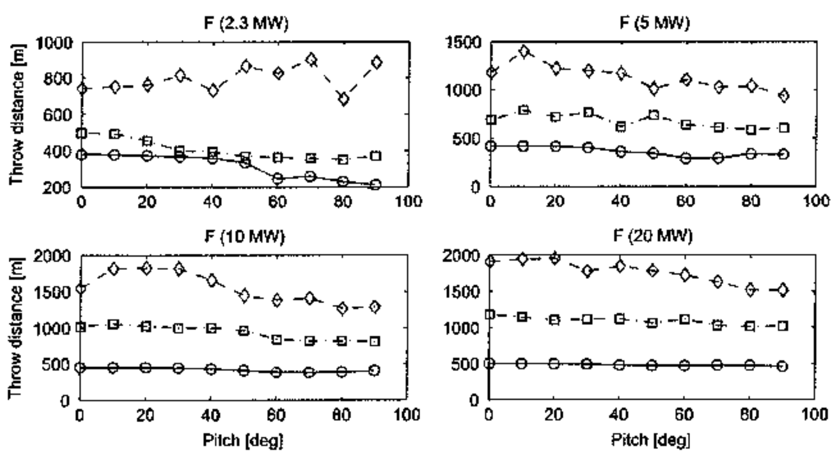

Figure 9. Sensitivity of throw distances of full blade to the initial pitch setting at $V_{tip} = 150$ m/s. Legends are similar to those in Figure 7.

3.2.1. Effect of initial pitch settings.

As explained earlier, analyses of the throw trajectories show that the throw distance for a particular wind turbine sometimes exhibits an erratic behavior going from one dominant solution to another with only a slight change in the initial conditions.

Table III. Aspect ratios, reference chord length C_{ref} and detached mass m of the blade shells (ρ_{shell} = 1700 kg/m^3) used for throw simulation from turbines of different sizes.

	2.3 MW		5 MW		10 MW		20 MW	
Cases – AR	C_{ref} (m)	m (kg)	C_{ref} (m)	m (kg)	C_{ref} (m)	m (kg)	C_{ref} (m)	m (kg)
AR = 1		34		83		184		408
AR = 5	1	170	1.5	415	2.1	920	3	2040
AR = 10		340		830		1840		4080

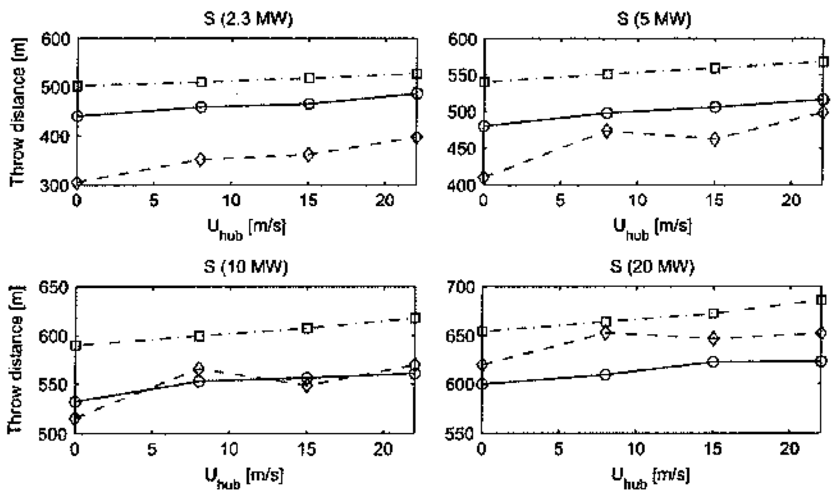

Figure 10. Throw distance calculations of blade shell with three different aspect ratios (invariant chord length for each turbine) for 2.3, 5, 10 and 20 MW turbines at a normal operating condition of V_{tip} = 70 m/s. ◇ ◇ ◇: AR = 1; □□□: AR = 5; and o o o: AR = 10.

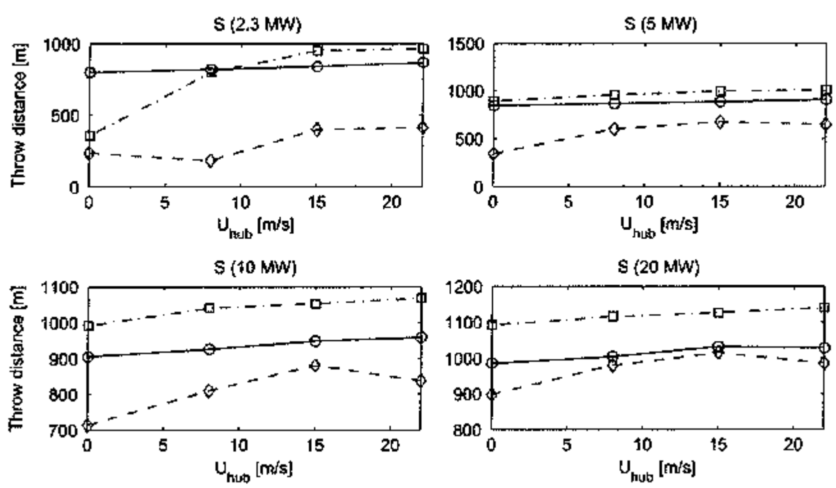

Figure 11. Throw distance calculations of blade shell at high tip speed of V_{tip} = 100 m/s. Legends are similar to those in Figure 10.

P21-36 cont.

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To understand this behavior, a sensitivity study is performed to investigate the effects of the initial pitch settings on the trajectory. Figures 7–9 demonstrate the pitch angle dependence of the full-blade throw distances for different turbine sizes and tip speeds, where the throw distances are obtained for release pitch angles ranging from 0° to 90°. As can be seen, the pitch setting has a substantial impact especially for the lighter parts. In general, higher throw distances are achieved using fragments thrown at lower pitch angles, which are due to the reduced drag. The effect of pitch angle on the heavier pieces (green and blue curves) is, however, smaller. The reason for this is that the aerodynamics plays a less significant role for the heavy parts in the throw distance calculation and the distance is mainly governed by the inertial forces. For the extreme tip velocity, and especially for the 2.3 MW turbine, increasing the pitch angle produces erratic throw distances for the lightest fragments. The exact reason for such erratic behavior has not been yet understood, but it is most likely explained by the physics of the problem, as explained earlier.

P21-36 cont.

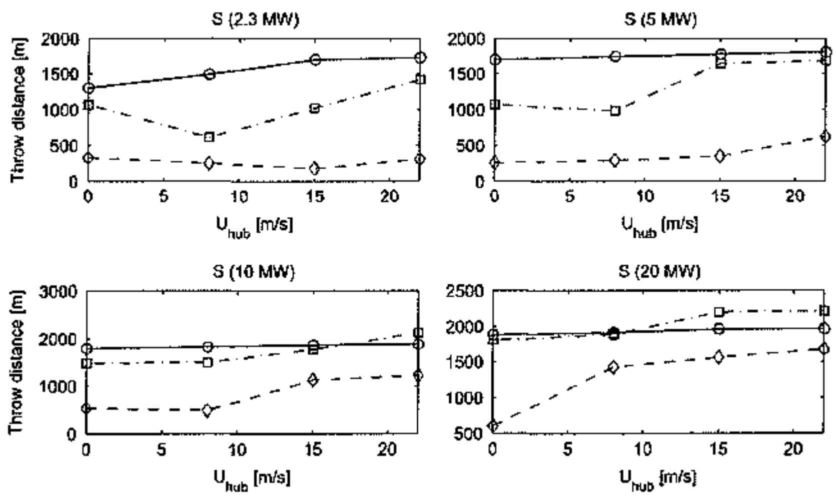

Figure 12. Throw distance calculations of blade shell at an extreme tip speed of V_{tip} = 150 m/s. Legends are similar to those in Figure 10.

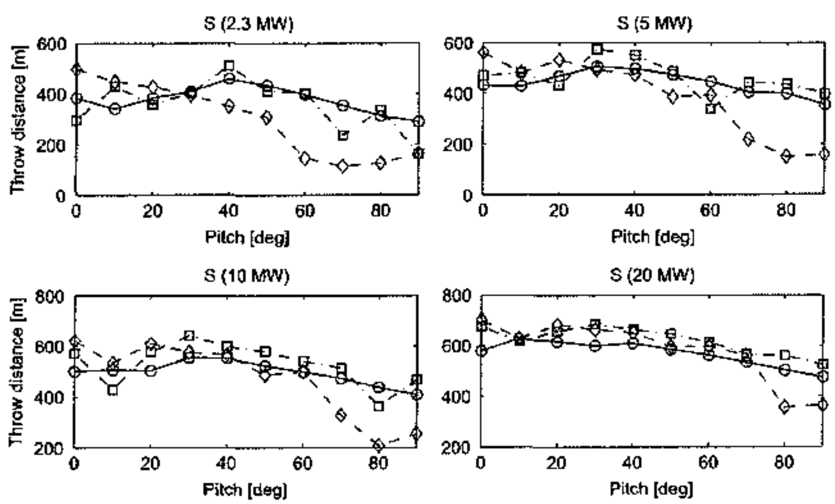

Figure 13. Sensitivity of throw distances of blade shell to the initial pitch setting at V_{tip} = 70 m/s. Legends are the same as in Figure 10.

3.3. Blade-shell throw analysis

An analysis of available data from blade failure accidents shows that depending on the manufacturing method and the structural integrity of the blade, it might first shatter into lighter parts, with the consequence that the shell layer is most likely to be thrown away. Three cases of different aspect ratios are considered for the shell throw analyses. For the reference case of 2.3 MW turbine, an average chord of 1 m and a shell thickness of 2 cm are chosen, and three aspect ratios (where *AR* is defined as the ratio of span to average chord) of 1, 5 and 10 are investigated. Then keeping the same *AR*, the analysis is repeated for each of the turbines introduced in the preceding sections. The density of the shell, consisting of fiber and glass, is assumed to be 1700 kg/m^3. Table III shows the test cases used for blade shell throw simulations.

Throw distances for the four different turbine sizes with the same working conditions as those for the full-blade case are plotted in Figures 10–12. Here, the non-dimensional length is replaced by the aspect ratio of the blade shell and three different aspect ratios are considered. As can be seen, increasing the hub-height wind speed and the turbine size generally results in larger throw distance. Nevertheless, an erratic behavior, as mentioned in the previous section, appears in the

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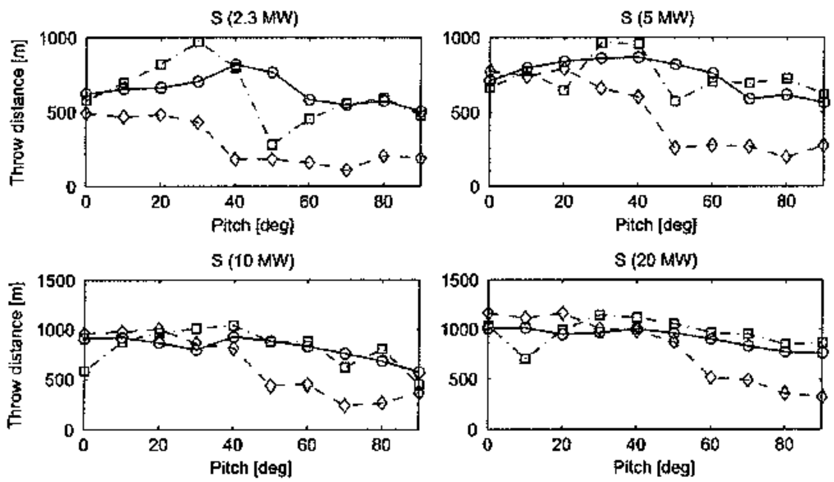

Figure 14. Sensitivity of throw distances of blade shell to the initial pitch setting at V_{tip} = 100 m/s. Legends are the same as in Figure 10.

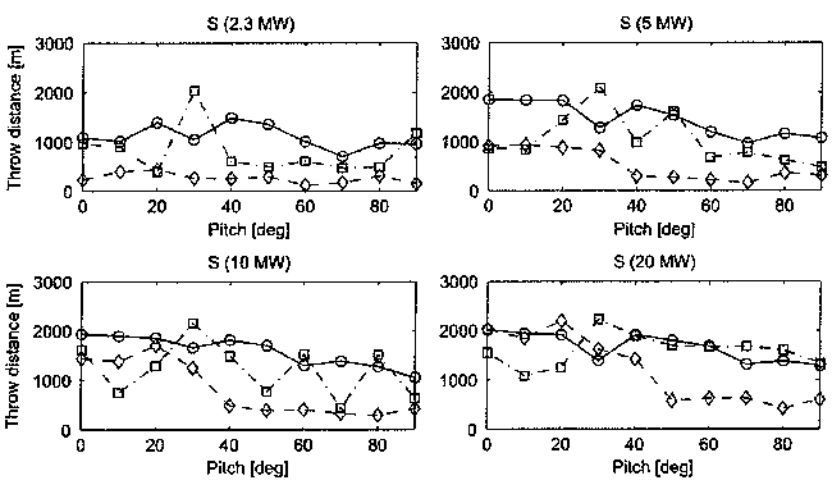

Figure 15. Sensitivity of throw distances of blade shell to the initial pitch setting at V_{tip} = 150 m/s. Legends are the same as in Figure 10.

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simulation results. By comparing the shell-throw graphs with the corresponding figures from the full-blade analysis, the throwing range of the blade shells and that of the full-blade structure are seen to be of the same order of magnitude. That is, the range is between 300 m for the 2.3 MW turbine operating at $V_{tip} = 70$ m/s and a maximum of 2200 m obtained for the 20 MW turbine in the extreme case of $V_{tip} = 150$ m/s. However, unlike the full-blade throw cases, the case with the smallest length ($AR = 1$) reaches the least throw distance, whereas for the full blade, the smallest fragment reaches the highest distance. This is most probably due to the fact that the small shell object is lighter and the corresponding inertial force is relatively small as compared with the drag forces.

As a comparison, the throw distances obtained for the ballistic motion of an equivalent particle in vacuum was also performed (results not shown), in which case there is no aerodynamic forcing on the objects. The results revealed that the ballistic throw distances are the most extreme cases in terms of throw distance.

3.3.1. Effect of initial pitch settings.

Similar to Section 3.2.1, the role of initial pitch setting on the trajectory of thrown blade-shell debris is assessed. Figures 13–15 show the pitch angle dependence of the throw distances for different turbine sizes and tip speeds for the blade-shell cases. Similar to the full-blade throw cases, the pitch setting has a substantial impact on the throw distance of thrown blade-shell structures. One major difference with the full-blade cases is, however, that the effect of the shell aspect ratios on the throw distance is much less significant and all of the cases show similar behavior with AR = 1 cases (red diamonds), predicting smaller throw distances in general.

3.4. Ice throw

For the analysis of the ice throw, the same procedure as for the blade throw is applied except that the throw analysis is not performed for the extreme tip speed conditions but only for the standstill where the tip speed is zero, and the running conditions, where the turbine is assumed to rotate in its normal operational mode at a tip speed of 70 m/s. For the icing case,

P21-36 cont.

Table IV. Aspect ratios, reference chord length C_{ref} and detached mass m of the ice fragments ($\rho_{ice} = 0.7$ kg/m^3) used for throw simulation of turbines of different sizes.

	2.3 MW		5 MW		10 MW		20 MW	
Cases – AR	C_{ref} (m)	m (kg)	C_{ref} (m)	m (kg)	C_{ref} (m)	m (kg)	C_{ref} (m)	m (kg)
$AR = 1$		0.18		0.43		0.97		2.16
$AR = 2$	0.1	0.36	0.15	0.87	0.2	1.95	0.3	4.33
$AR = 3$		0.54		1.31		2.94		6.49

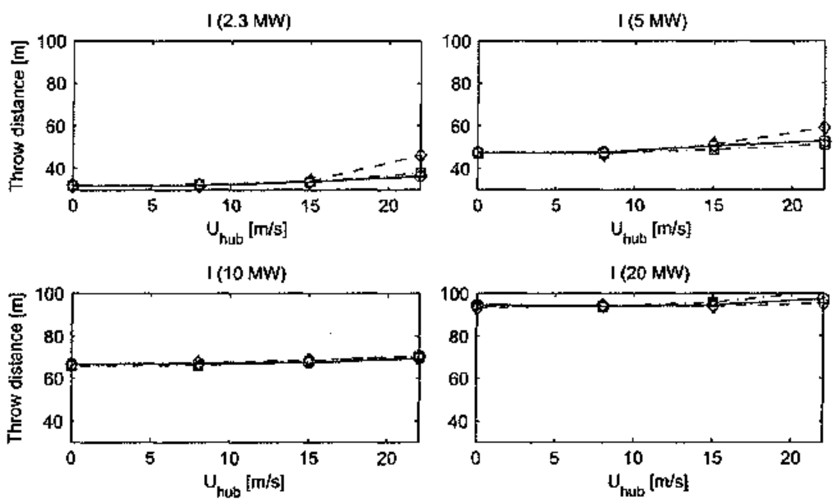

Figure 16. Throw distance calculations of ice fragments for three different aspect ratios for 2.3, 5, 10 and 20 MW turbines in standstill operation ($V_{tip} = 0$ m/s). ◇ ◇ ◇: $AR = 1$; □ □ □: $AR = 2$; and o o o: $AR = 3$.

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a density of 700 kg/m^3 is used (see also Seifert *et al.*[11]). The dimensions of the tested ice fragments and corresponding turbine sizes are shown in Table IV. According to field studies performed by, e.g., Cattin *et al.*,[22] most of the ice fragments thrown away from turbine are broken into objects that typically are smaller than 1 kg. However, fragments as heavy as up to 1.8 kg have also been observed. Because the pieces are so light, the throw distance of an ice piece is mainly governed by the drag forces applied on it (which are only functions of mass–area ratio) and the incoming wind.

Similar to the previous section, studies of the effects of different parameters on throw distances are performed and plotted in Figures 16 and 17 with the graphs structured in the same way as in the previous sections.

For the simulations, no lift is considered and the drag coefficient according to the flat-plate assumption is used. Figure 16 shows that the throw distances of the standstill case range from 30 to 100 m for different turbine sizes and incoming wind speeds. For the running conditions however, the fragments can reach distances up to 600 m. It is also clear from the figure that in many cases the aspect ratio does not play a significant role in the determination of throw distances.

3.5. Maximum throw distances

This section presents a summary of the previous results in terms of maximum throw distances. The maximum throw distances are obtained from the entire set of previous simulations regardless of the size and upcoming wind speed and plotted in Figure 18 for the full-blade and blade-shell cases and in Figure 19 for the ice-throw cases, respectively. In all

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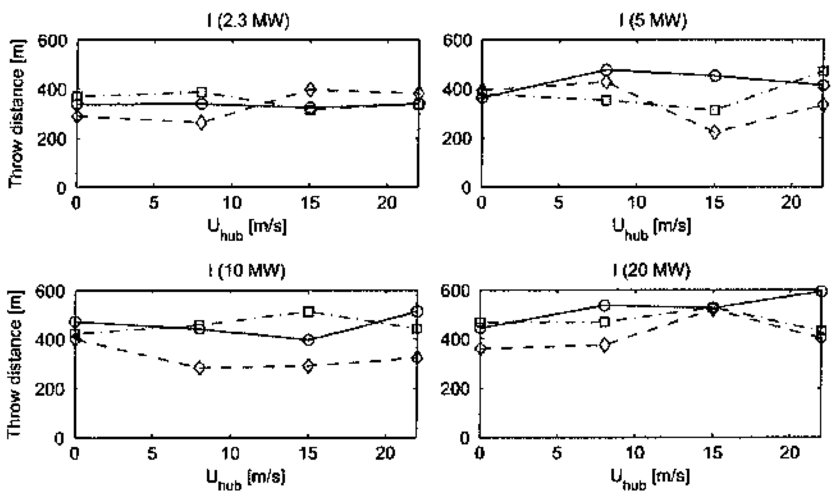

Figure 17. Throw distance calculations of ice fragments for three different aspect ratios for turbines in normal operation (V_{tip} = 70 m/s). Legends are the same as in Figure 16.

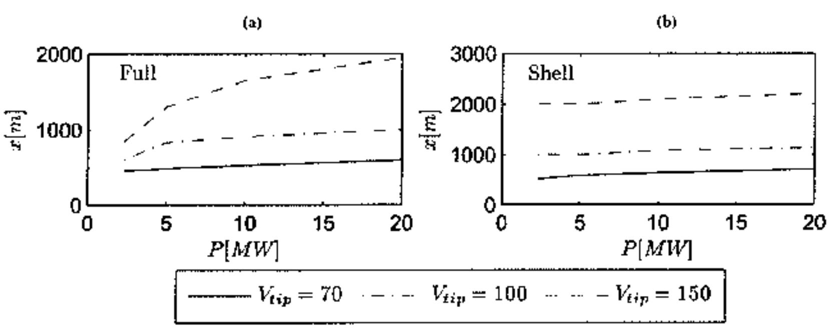

Figure 18. Maximum throw distances obtained for (a) full blade and (b) blade shell in different operating conditions. Blue line: V_{tip} = 70 m/s as a function of turbines power.

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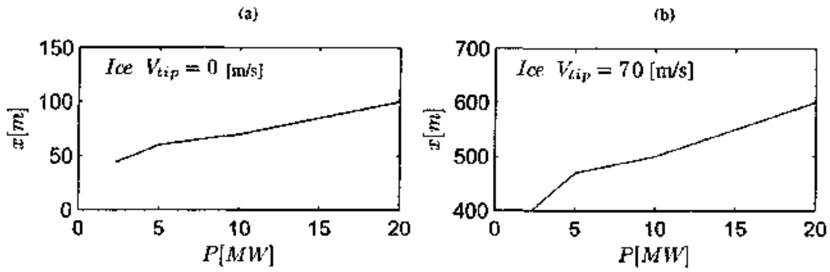

Figure 19. Maximum throw distances obtained for the ice throw in (a) standstill operation, i.e., $V_{tip} = 0$ m/s and (b) normal operating condition, i.e., $V_{tip} = 70$ m/s as a function of turbines power.

figures, the horizontal axis shows the turbine capacity and the vertical axis represents the maximum throw distance. It can be concluded that, in general, the tip speed has a large impact on the throw distances. From Figure 18(a), the turbine size does not affect the throw distances drastically for the lower tip speeds, whereas throw distances at high tip speeds experience a significant growth with increasing turbine size. Figure 18(b), on the other hand, shows that the effect of turbine size on the throw distance for the shell parts is almost negligible.

4. CONCLUDING REMARKS

Trajectory analysis of detached parts of blades and ice fragments thrown from horizontal-axis wind turbines was studied extensively using Newton's and Euler's equations of motion and rotation, employing a blade element approach for the aerodynamics. Full-blade and blade-shell analyses were performed for turbines running under different tip velocities. Turbine upscaling laws were derived, and simulations of throw distances were performed for four different turbine sizes, ranging from existing 2.3 MW machines to future 20 MW turbines. P21-36 cont.

In some cases, erratic behavior was observed in the computations, where a small change in one parameter could influence throw distance drastically. The behavior was believed to depend highly on the initial conditions. A likely explanation is that a small change in positioning and velocity components in some cases alters the distribution of forces on the detached objects and causes significant changes in the trajectory.

Maximum throw distances obtained at different tip speeds and detachment sizes were analyzed, and it was shown that the tip speed plays the most important role in the throw distance. From the full-blade throw analysis, it was shown that, when released at extreme tip speeds, throw distance picks up more rapidly with the tip speed rather than throw at lower tip speeds (looking at the absolute throw distances). The considered [thrown] full-blade pieces reached approximately 700, 900 and 2000 m at tip speeds of 70, 100 and 150 m/s, respectively. For the blade shell, throw distances were found to be approximately constant as turbine size escalates, and of the same order of magnitude as in the full-blade throw. Throw calculations were also obtained at the tip speeds of $V_{tip} = 0$ and $V_{tip} = 70$ m/s for ice pieces of three different aspect ratios and it was seen that the maximum throw distances scaled almost linearly with the turbine size irrespective of the tip speed. The ice-throw distances reached about 100 and 600 m in standstill $V_{tip} = 0$ m/s and normal operating conditions $V_{tip} = 70$ m/s, respectively. The throw distances presented by this study were obtained with respect to a set of initial parameters without taking into account their probabilities of occurrence. The authors are extending the current study to include the risk levels associated with each of the cases.

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ORIGINAL PAPER

Wind turbine rotor fragments: impact probability and setback evaluation

Scott Larwood · C. P. van Dam

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Abstract With increasing installation of wind turbines, the exposure to the hazard of impact from blade fragments increases. Local authorities use setbacks to reduce the risk by limiting the distance from wind turbines to adjacent property lines and dwellings. Unduly conservative setbacks are a deterrent to wind energy development. To determine appropriate setbacks, the authors developed a fragment trajectory model based on fragment rotation and aerodynamics. The model was used to simulate fragment trajectories at various rotor speeds, with randomly generated inputs for wind speed, wind direction, rotor azimuth, and rotor break position. Four sizes of wind turbines were studied, with rated power of 750 kW, 1.5, 3 and 5 MW. A sensitivity analysis showed that a fragment trajectory is highly dependent on the input parameters. However, for multiple trajectories from a given turbine and rotor speed, the sensitivity of the impact probability to most inputs was negligible. The results indicate that the range increased with turbine rating and rotor speed. When the range was normalized by overall turbine height, the probability of impact at a particular normalized range decreases with turbine rating. Planning agencies use the normalized range for setbacks, and the results indicate that using a common setback for all turbine sizes would be reasonable. Existing setback standards of 2–3 overall turbine heights offer better than 1 in 1,000,000 probability of impact per year; however, setbacks approaching 1 turbine height will have an order of magnitude higher probability of impact.

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Keywords Wind energy · Permitting · Hazards

Introduction

Background

Although in use for centuries, wind power became a provider of utility-scale electricity in the late 1980s (Gipe 1995). Worldwide installation of wind turbines has grown at an exponential rate, as shown in the latest US Department of Energy report on wind energy (Wiser and Bolinger 2013). Wind turbines produce the largest percentage of renewable energy in California [6.3 % of total system energy in 2012; the next highest renewable is 4.4 % for geothermal (Nyberg 2014)].

Wind turbines have become ubiquitous symbols of sustainability, with many societal benefits. However, as with any form of sustainable technology, wind power has associated risks. Huesemann (2003) discusses unavoidable negative environmental impacts of sustainable technologies; for wind power, this includes land use and manufacturing wastes. Fritzsche (1989) states that the main risks with wind energy are associated with the equipment manufacture and installation, which compares to environmental risks from battery production and disposal in electric vehicles (Ramoni and Zhang 2013). However, this work is about risk during the operation phase. A primary hazard of wind turbines during operation is the failure of a portion of the rotor resulting in fragments being thrown from the turbine (Larwood and van Dam 2006). Due to the rotational speeds of the rotor, the fragments could travel long distances. Dramatic photos and videos of wind turbine failures on the World Wide Web have increased the public visibility of this hazard.

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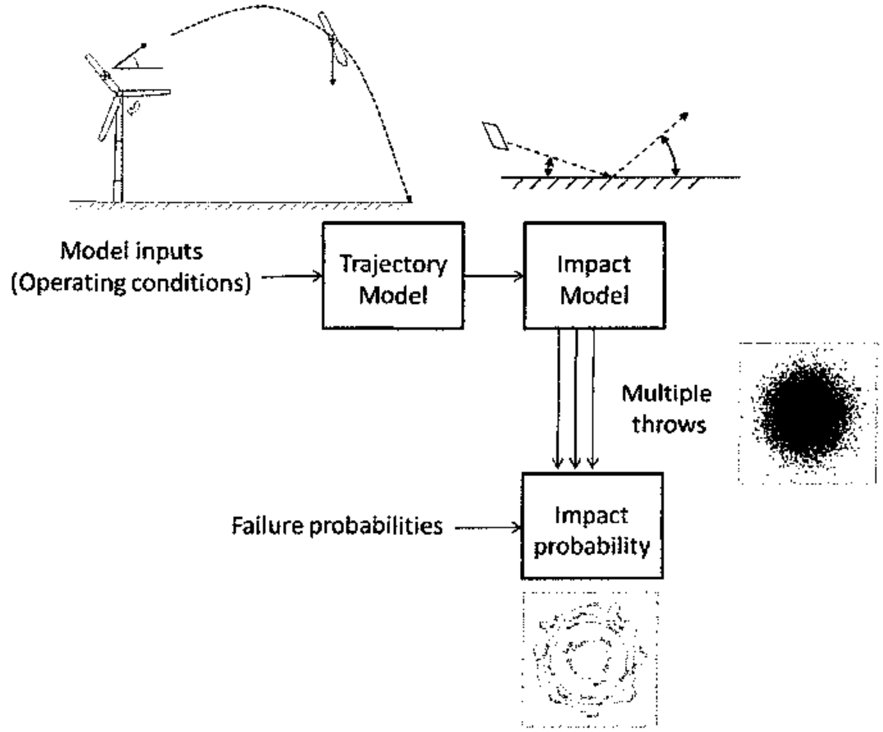
Fig. 1 Rotor fragment analysis block diagram



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Wind energy ordinances

Concerns over public exposure to the rotor fragment hazard led communities to develop setbacks from adjacent property lines and structures/dwellings. In California, the development of these setback ordinances took place in the 1980s (Larwood and van Dam 2006). In general, the setbacks were based on the overall height of the turbines, which is the height to the wind turbine hub plus the length of one blade. A typical setback from a property line with a dwelling is three times the overall turbine height.

Utility-scale, land-based turbines have evolved from 50 kW machines of 25 meter (m) overall height to 3.0 MW machines of 126 m overall height. The nature of that evolution, in general, is that manufacturers stopped production of smaller turbines due to improved economics of the new larger turbines. With increased overall height, increased setback distance is required, which constricts development for modern turbines. Because of this restriction, the California Energy Commission asked the authors to study the wind energy permitting issue of safety setbacks, which is reported in Larwood and van Dam (2006). The current work is an outcome of the report recommendations.

Analysis of the rotor fragment risk

In previous studies of rotor fragment risk, the probability of impact for various setback distances was not explicitly evaluated and would be of limited use to planning officials. Our contribution is the development of methodology that combines (1) a numerical technique to predict the distance a rotor fragment travels based on a range of wind turbine, fragment, and atmospheric parameters and (2) a probability assessment technique. This methodology allows users to determine the probability of an impact by a wind turbine rotor fragment based on the distance from the turbine and the probability of turbine rotor failure. As wind turbines further develop in terms of size and their technology further matures in terms of reliability, this methodology provides authorities a tool to (re-)analyze setback distances for wind turbines in their jurisdiction. A diagram of the analysis methodology is shown in Fig. 1.

Rotor failure probabilities

Larwood and van Dam (2006) have details regarding wind turbine rotor failures. The probability of a rotor failure from various studies ranged from 1.2×10^{2} (1.2 in 100) per turbine per year to 5.4×10^{-3}. Braam et al. (2005) [in Dutch, Appendix A translated in Larwood and van Dam (2006)] reports on rotor failure probabilities; the authors determined that these probabilities are the most representative of modern turbines and are used in the current work.

Fragment trajectory

The analysis starts by computing the trajectory of the fragment after it has been released from the turbine. This work is similar to risk assessment of windborne debris (Lin and Vanmarcke 2008); however, the wind turbine analysis differs due to the momentum (linear and angular) at release. Several authors discussed below have studied the rotor fragment hazard, with the majority of these studies originating from the 1980s when very large multi-MW research turbines were being considered.

The simplest theory is vacuum ballistics (Macqueen et al. 1983), which assumes no aerodynamic friction. Vacuum ballistics is a classic problem in mechanics, with an exact solution. The solution for range X is:

$$X = \frac{V_0^2}{g} \sin 2\theta \qquad (1)$$

where V_0 is the release velocity, g is gravitational acceleration, and θ is the release angle. Note that the range is dependent on the release velocity squared and the release angle. The release velocity depends on the rotor rotation speed and the radial location of the fragment mass center. The release angle (0° is blade at 12 o'clock position) is considered random with uniform probability; 315° results in maximum range. A large majority of the fragments land near the turbine with $90° \leq \theta \leq 270°$.

A more complex model is drag ballistics (Eggers et al. 2001), where a drag force D is modeled that opposes the relative wind velocity V_∞ as in:

$$D = \frac{1}{2} C_D \rho V_\infty^2 A \qquad (2)$$

where C_D is the drag coefficient, ρ is the atmospheric density, and A is the reference area for the drag coefficient. The model reduces the maximum range compared to vacuum ballistics and allows for downwind travel. The range is highly dependent on the value of the drag coefficient.

The next level of complexity has fragment rotation and translation along the trajectory, with calculation of aerodynamic forces and moments (Slegers et al. 2009). The authors' trajectory model is based primarily on Sørensen (1984).

Impact probability

Turner (1986) determined probability of impact around the turbine, along with the possibility of bouncing and sliding of the fragment after impact. The authors used his methods in the setback evaluation; however, several turbine sizes are considered. Like Turner, impact probability was determined with a Monte Carlo simulation of thousands of fragment throws with randomly determined inputs. A sensitivity analysis of the model was performed by varying the inputs separately. The model was insensitive to many of the parameters studied; the most important was the mass of the blade.

Probability of impact was determined for a point target and a target representing a family-size dwelling. The authors studied four turbine models of 750 kW, 1.5 MW, 3.0 MW, and 5.0 MW size, with nominal blade tip speeds that correspond to current turbine models. The authors compared the models for their range that results in a 1 in 1,000,000 impact probability. Macqueen et al. (1983) provided the inspiration for this probability, which is one order of magnitude more probable than being struck by lighting in the UK. The range for this probability increased with both model rating and tip speed. However, if the range is normalized by turbine overall height, the normalized range generally decreases with turbine rating. The change in normalized range is not very dramatic; therefore, authorities having jurisdiction may prefer to retain a single setback for all sizes of turbines. P21-36 cont.

Table 1 Rotor failure probabilities from Braam et al. (2005)

Operating condition	Probability per turbine per year
Nominal operating rpm	4.2×10^{-4}
Braking (1.25 times nominal rpm)	4.2×10^{-4}
Emergency (2.0 times nominal rpm)	5.0×10^{-6}

Methods

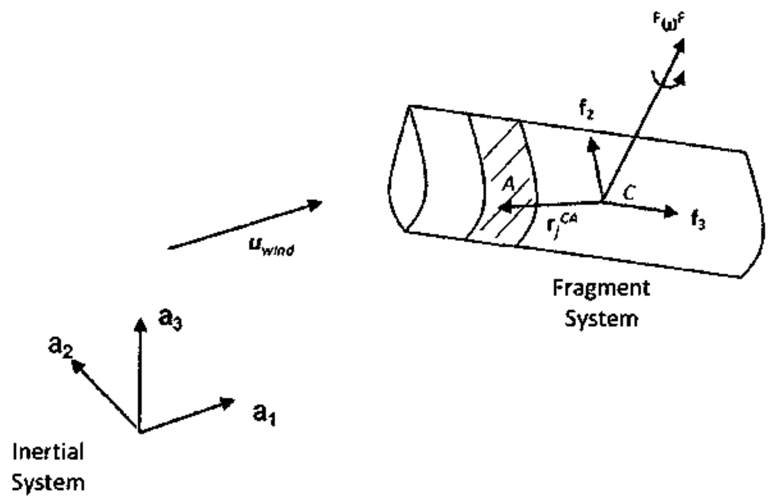
This section summarizes the modeling as shown in Fig. 1.

Blade failure probability

For the probability that a rotor failure has occurred, the authors used the analysis results from Braam et al. (2005). These resulting failure probabilities are shown in Table 1.

Nominal operating rpm is regular operation during power production, from the lowest wind speed that the turbine turns on (3–5 m/s) to the highest wind speed that the turbine turns off (22–27 m/s). Braking refers to the condition when the turbine is shutting down, for any reason except an overspeed condition. Emergency refers to a rotor overspeed condition. The failure probability consists of the time spent in each operating condition along with the

Fig. 2 Blade fragment showing fragment **f** system (Body F; $\mathbf{f}_1$ not shown for clarity) with position vector r_j^{CA} from the fragment mass center to the element aerodynamic center, along with the fragment angular velocity vector ${}^F\omega^F$ in the fragment **f** system



P21-36 cont.

potential for high loads (and thus failure) at each condition. The amount of time spent in each condition decreases from nominal to emergency, but the potential for high loads increases.

The setback evaluation does not include fragment failures when the turbine is parked, such as from 50-year extreme gust. Besides being a rare event, the range from a possible failure is much lower compared to an operating failure due to release velocities below that of normal operating speeds. Ranges for this condition were determined and are shown in the "Sensitivity analysis" section.

Fragment trajectory

The analysis assumes that the rotor breaks at a radial location along the blade and the outboard portion is released, remaining in one piece. Realistic fragments would probably have breaks with rough edges that would increase drag. Therefore, the ranges in this study are considered conservative. For the trajectory, the authors used the method developed by Montgomerie (1982) and further elaborated by Sørensen (1984). The analysis breaks the fragment into strips (Fig. 2), with each strip having separate aerodynamic and inertia properties. The forces are computed on each strip and then combined to determine the total forces and moments at the fragment center of mass (point C).

The equations of motion as a complete system of first-order differential equations are listed in three blocks below and are similar to those in Sørensen (1984). The simulation uses a Runge–Kutta scheme to numerically solve the equations of motion. Equation block 3 represent the translational velocities and accelerations of the fragment mass center C in the inertial frame **E** (a-system unit vectors) according to Newton's second law. Equation block 4 represent the change in the orientation matrix from the inertial frame **E** to the fragment frame **F**. This formulation avoids potential singularities from using Euler angles. Equation block 5 are the Euler equations in the fragment frame **F**.

$$
\begin{aligned}
\dot{r}^{DC}_{a1} &= {}^{E}v^{C}_{a1}\ {}^{E}\dot{v}^{C}_{a1} = F^{C}_{a1}/m \\
\dot{r}^{DC}_{a2} &= {}^{E}v^{C}_{a2}\ {}^{E}\dot{v}^{C}_{a2} = F^{C}_{a2}/m \\
\dot{r}^{DC}_{a3} &= {}^{E}v^{C}_{a3}\ {}^{E}\dot{v}^{C}_{a3} = F^{C}_{a3}/m - g
\end{aligned}
\qquad (3)
$$

$$
\begin{aligned}
\dot{T}_{FE\_11} &= {}^{F}\omega^{F}_{f3}T_{FE\_21} - {}^{F}\omega^{F}_{f2}T_{FE\_31} \\
\dot{T}_{FE\_12} &= {}^{F}\omega^{F}_{f3}T_{FE\_22} - {}^{F}\omega^{F}_{f2}T_{FE\_32} \\
\dot{T}_{FE\_13} &= {}^{F}\omega^{F}_{f3}T_{FE\_23} - {}^{F}\omega^{F}_{f2}T_{FE\_33} \\
\dot{T}_{FE\_21} &= -{}^{F}\omega^{F}_{f3}T_{FE\_11} + {}^{F}\omega^{F}_{f1}T_{FE\_31} \\
\dot{T}_{FE\_22} &= -{}^{F}\omega^{F}_{f3}T_{FE\_12} + {}^{F}\omega^{F}_{f1}T_{FE\_32} \\
\dot{T}_{FE\_23} &= -{}^{F}\omega^{F}_{f3}T_{FE\_13} + {}^{F}\omega^{F}_{f1}T_{FE\_33} \\
\dot{T}_{FE\_31} &= {}^{F}\omega^{F}_{f2}T_{FE\_11} - {}^{F}\omega^{F}_{f1}T_{FE\_21} \\
\dot{T}_{FE\_32} &= {}^{F}\omega^{F}_{f2}T_{FE\_12} - {}^{F}\omega^{F}_{f1}T_{FE\_22} \\
\dot{T}_{FE\_33} &= {}^{F}\omega^{F}_{f2}T_{FE\_13} - {}^{F}\omega^{F}_{f1}T_{FE\_23}
\end{aligned}
\qquad (4)
$$

$$
\begin{aligned}
{}^{F}\dot{\omega}^{F}_{f1} &= M^{C}_{f1}/I^{F/C}_{f1} - {}^{F}\omega^{F}_{f2}\,{}^{F}\omega^{F}_{f3}(I^{F/C}_{f3} - I^{F/C}_{f2})/I^{F/C}_{f1} \\
{}^{F}\dot{\omega}^{F}_{f2} &= M^{C}_{f2}/I^{F/C}_{f2} - {}^{F}\omega^{F}_{f1}\,{}^{F}\omega^{F}_{f3}(I^{F/C}_{f1} - I^{F/C}_{f3})/I^{F/C}_{f2} \\
{}^{F}\dot{\omega}^{F}_{f3} &= M^{C}_{f3}/I^{F/C}_{f3} - {}^{F}\omega^{F}_{f1}\,{}^{F}\omega^{F}_{f2}(I^{F/C}_{f2} - I^{F/C}_{f1})/I^{F/C}_{f3}
\end{aligned}
\qquad (5)
$$

The loads on the fragment are weight and aerodynamic loads. The aerodynamic loads (lift, drag, and pitching moment) are computed at the aerodynamic centers (point A) of the individual strips. These loads are then transformed to the fragment **f** system and then combined to determine the resulting forces (F) and moments (M) about

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Table 2 Input variable probability for setback evaluation

Input variable	Probability
Wind speed	Rayleigh distribution between 4 and 25 m/s
Blade pitch	Based on wind speed
Rotor rotational speed	Can be based on wind speed, but fixed
Rotor azimuth at break	Uniform between 0° and 360°
Blade break position	Uniform between hub radius and blade tip
Wind direction	Uniform between 0° and 360°, or wind rose
Yaw error	Uniform between −10° and 10°

the fragment mass center C. The loads are then transformed to the Earth a system for application into the equations of motion. The model assumes steady aerodynamics as in Sørensen (1984), who determined that unsteady effects significantly complicate the analysis for slightly reduced trajectory range. There is no aerodynamic interaction between elements and there are no effects at the ends of the fragment. In addition to the forces in the plane of the chord, the simulation includes a spanwise force with a skin friction coefficient, similar to Turner (1989).

With some fragments, the speed of rotation about the fragment long axis (${}^{F}\omega^{F}_{f3}$) would increase unbounded. This was due to a combination of airfoil pitching moment along with the moment resulting from the location of the aerodynamic center relative to the mass center. Realistically, an unsteady aerodynamic phenomenon would not allow the rotation to increase unbounded. Therefore, the authors included a switch in the analysis to change the model to a purely drag ballistics model when the rotation exceeded a user input value that was proportional to the fragment inertia.

Fragment impact

The flying trajectory completes when the vertical component passes through zero. This is considered the impact point; however, the simulation reduces the impact distance to account for the size of the fragment and the height of a target.

The travel of the fragment after impact is based on models proposed by Turner (1986), which includes a model of fragment bouncing and sliding. The probability of impact with a point or target on the ground is also the same as Turner (1986).

Model inputs

A given run was typically 10,000 throws with inputs from Table 2 below. The program generated random numbers with the system clock as the seed.

The program also accepts inputs for a wind rose, which is a graph of the probability of a particular wind speed range from a particular compass sector. The wind rose feature can also be used to fix the simulation at a particular wind direction, which is similar in the analysis of Rogers et al. (2012).

Sensitivity analysis

Similar to Sørensen (1984), a sensitivity analysis of the model inputs was performed on a single throw of a 10-m fragment from a 1.5-MW turbine. Additional single throw runs were performed to determine the range of 10-m fragment from a non-operational turbine in a 50-year gust [70 m/s for IEC Class I (Anonymous 2005)]. The azimuth and pitch were fixed at 90° (parked), and the wind direction was changed from 0° to 270° in 90° increments.

A sensitivity analysis was also performed on the impact probability (10,000 throw baseline) of the 1.5-MW turbine, where the range for 1×10^{-6} probability was determined for each run. Table 4 in the "Results" section lists the inputs and their settings for the analysis. The "mass multiplier" is a factor that the blade mass was multiplied by to increase or decrease the blade mass. The "mass location multiplier" was a factor that multiplied the distance between the section center of mass and pitch axis to move the center of mass forward or aft of the baseline position. P21-36 cont.

Setback evaluation

The authors based the setback evaluation on the following parameters and assumptions:

- Four wind turbine models were used from a National Renewable Energy Laboratory study Malcolm and Hansen (2006) that represented current and future utility-scale turbines. Table 3 lists the model details.
- The turbines operated at nominal tip speeds of 70, 80, and 90 m/s. These values represented the range of current turbine tip speeds.
- Each set consisted of three runs of 10,000 throws each with inputs according to Table 2. The three runs were for the nominal operating rpm (corresponding to the tip speed), the emergency braking speed, and the overspeed condition as described in Table 1.
- The average wind speed of the Rayleigh distribution for a run was 8.5 m/s, which is typical of USA wind turbine installations
- The blade pitch was 0° until 10 m/s and varied linearly to 20° at 25 m/s
- Results were for point probability and for a 625 m^2 target, which could represent a typical dwelling footprint

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Table 3 Turbine models used for setback evaluation

Model	Rated power	Rotor radius (m)	Hub height (m)	Overall height (m)
WP750	750 kW	23	60	83
WP1500	1.5 MW	35	80	115
WP3000	3.0 MW	49.5	119	168.5
WP5000	5.0 MW	64	154	218

- Additional sets of runs were performed with a fixed wind direction (as in Rogers et al. 2012) to determine upper bound of ranges

Results

Figure 3 shows the trajectory and orientation in the crosswind view for a 10-m fragment from the baseline 1.5 MW model. As in Sørensen (1984), the initial rotation dies down after the first-third of the flight with the heavy end of the fragment pointing down for the remainder. The trajectory for a drag ballistics model (0.15 drag coefficient) is also shown for comparison. The trajectory for a drag ballistics model with $C_D = 0$ (vacuum) would have twice the range; therefore, using drag ballistics alone for the analysis is highly dependent on the value of C_D.

The plot on the right-hand side of Fig. 1 shows the impact points for a typical 10,000 case run with a dense cloud centered around the turbine with several outliers. This is typical of all runs. Figure 4a, b shows scatter plots for the wind rose case and the fixed wind direction case. The wind rose is from a Northern European site with prevailing South–Southeast direction. The fixed wind direction case is similar in shape to a plot shown in Rogers et al. (2012). The figures do not display a uniform distribution; therefore, the risk probability will depend on the compass bearing from the turbine.

Figure 5 shows a contour plot of probability for point impact, based on the impacts shown in Fig. 1. The lines of constant probability for a run are roughly circular, indicating the uniform distribution of wind direction.

Sensitivity analysis results

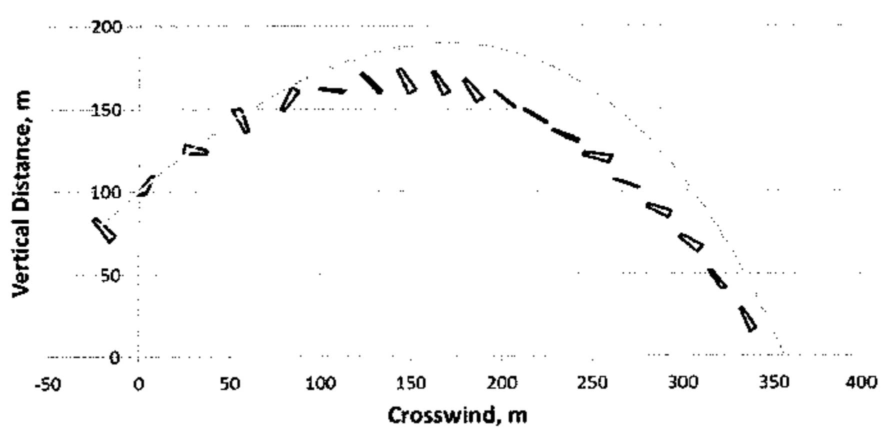
The outcome of the single throw sensitivity analysis was very similar to Sørensen (1984). Changing the input parameters could have a dramatic effect on the range and bearing for a single trajectory; however, over several thousand random throws the change in impact probability was mostly negligible.

The results of the 50-year gust (70 m/s) showed a maximum range less than one-third of the range of the baseline throw during operation. The authors therefore do not include throws from extreme wind events in the setback evaluation due to comparatively low ranges.

Table 4 shows the results of the multi-throw "Sensitivity analysis" section. The analysis showed that 10,000 throws were sufficient for the range to converge for 1×10^{-6} impact probability. For the range of parameters tested, several had negligible effect, such as average wind speed, hub height, altitude, and number of blade elements. Skin friction (for spanwise drag) had no effect and could be removed from the model. Increasing mass increases the range; therefore, the mass of the blade should be known. However, the baseline represents most turbines in production, and current design trends are lowering blade mass. The airfoil had no effect on the range, as long as the ballistics switch ("Fragment trajectory" section) was set to 0.1 for the SERI-airfoil (has high pitching moment). In summary, the results of the baseline should be representative of most 1.5 MW wind turbine installations.

P21-36 cont.

Fig. 3 Full-model trajectory and orientation. *Line* represents drag ballistics model with $C_D = 0.15$. Baseline 1.5-MW model, 10-m fragment released at 315° azimuth and 26.3 rpm.



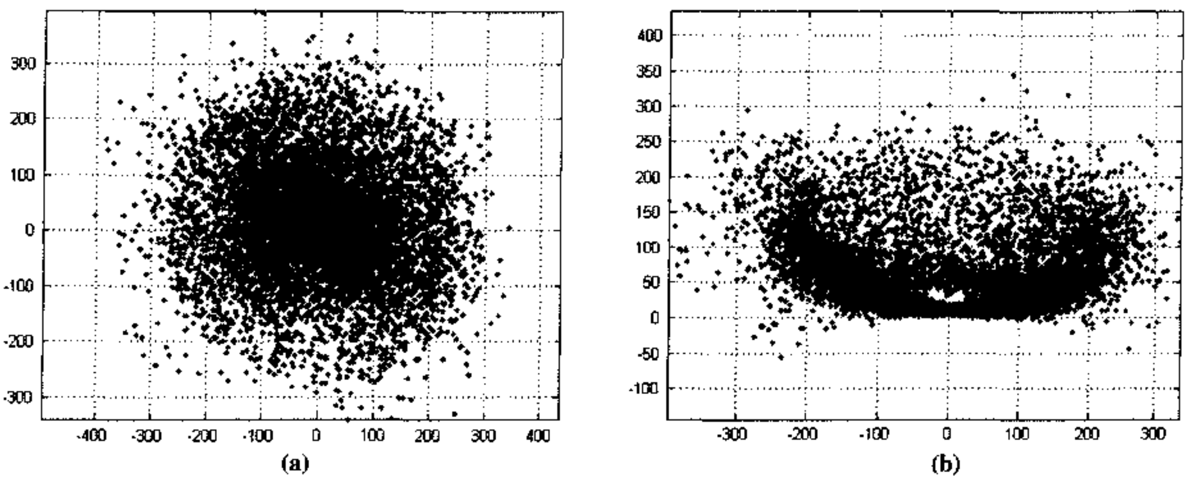


Fig. 4 Scatter plots of impacts for wind rose and fixed wind direction. **a** WP1500 with wind rose, **b** WP1500 with fixed wind direction (wind from *bottom*)

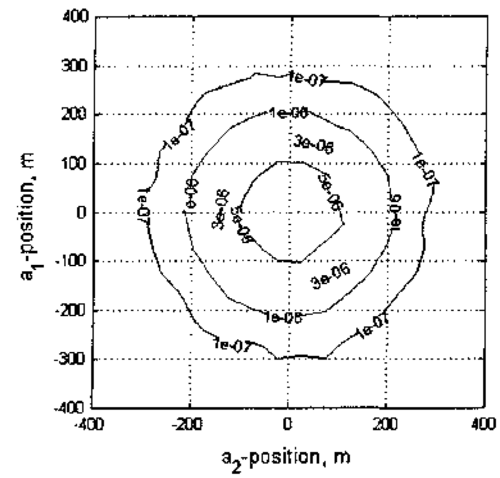


Fig. 5 Point probability for WP1500 at nominal 70 m/s tip speed

Table 4 Multi-throw sensitivity analysis results

Variable	Settings	Range
Number of cases	100/1K/5K/10K(*b*)/20K	Converges to 215 m at 5 K
Average wind speed	7.5/8.5/10(*b*) m/s	Respective range 215/190/215 m
Hub height	54/60(*b*)/66 m	No change in range
Time step	0.05/0.01/0.005(*b*)/0.001s	Unstable at 0.05, else no change
Density (altitude)	0(*b*)/1,000/2,000 m	No change in range
Ballistics switch	0.1/0.5/0.9/1.0(*b*)/1.1/2.0/10.0	Unstable at 10, else no change
Ballistics C_D	0.1/0/7/1.2//1.35(*b*)/1.5/2.7/13.5	No change in range
Airfoil section data	NACA(*b*)/SERI/flat/Go420	See text for SERI, else no change
Number of blade elements	10/15(*b*)/20/30	No change in range
Mass multiplier	0.5/0.9/1.0(**b**)/1.1/2.0	Respective range
Mass location multiplier	0.9/1.0(*b*)/1.1	No change in range
Skin friction coeff.	0.0/0.002(*b*)/0.02	No change in range
Wind direction probability	Fixed/uniform(*b*)/rose	Respective range 325/215/226 m

The baseline setting is indicated by (*b*). Baseline range for 1×10^{-6} impact probability is 215 m

The results of the wind direction analysis showed that the assumption of uniformly distributed wind direction gives the lowest range (215 m) for 1×10^{-6} impact probability, as expected. A longer range (325 m) is obtained with fixing the wind direction, which is similar to method of Rogers et al. (2012). The maximum range for 1×10^{-6} impact probability increases compared to the uniform direction case because of impact concentrations within particular sectors. With a realistic wind rose, the range (226 m) is relatively close to the uniform wind direction range. The authors therefore conducted the setback evaluation with both uniform wind direction and fixed wind direction, noting that the fixed wind direction results are a conservative upper bound. A realistic site would have a range close to the uniform results.

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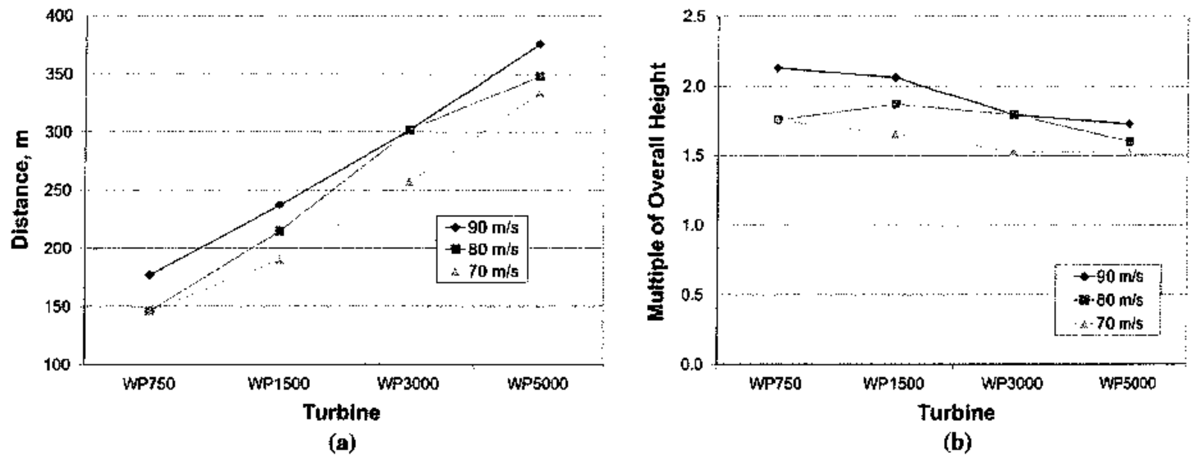

Fig. 6 1×10^{-6}/year probability of impacting a point. a Distance in meters, b distance as a multiple of overall height

Table 5 Distance for 1×10^{-6}/year probability from risk analysis, with fixed wind direction results in parentheses

Model	Nominal tip speed (m/s)	Point		625 m^2 Target	
		Distance (m)	Multiple of height	Distance (m)	Multiple of height
WP750	70	146 (176)	1.8 (2.1)	257 (302)	3.1 (3.6)
	80	146 (190)	1.8 (2.3)	276 (302)	3.3 (3.6)
	90	177 (22s6)	2.1 (2.7)	285 (325)	3.4 (3.9)
WP1500	70	190 (257)	1.7 (2.2)	334 (369)	2.9 (3.2)
	80	215 (285)	1.9 (2.5)	355 (382)	3.1 (3.3)
	90	237 (285)	2.1 (2.5)	376 (431)	3.3 (3.7)
WP3000	70	257 (333)	1.5 (2.0)	443 (432)	2.6 (2.6)
	80	302 (348)	1.8 (2.1)	437 (437)	2.6 (2.6)
	90	302 (382)	1.8 (2.3)	476 (475)	2.8 (2.8)
WP5000	70	334 (395)	1.5 (1.8)	481 (506)	2.2 (2.3)
	80	348 (431)	1.6 (2.0)	506 (580)	2.3 (2.7)
	90	376 (443)	1.7 (2.0)	567 (637)	2.6 (2.9)

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Setback evaluation

Figure 6a shows absolute distance for 1×10^{-6}/year probability of impacting a point. The distances increase with turbine rating and nominal tip speed. The turbines have the same tip velocities and conceivably should have similar range. However, higher fragment inertia for larger turbines results in longer ranges, which was indicated in the sensitivity analysis for mass. Figure 6b shows the distance as a multiple of overall turbine height for 1×10^{-6}/year probability of impacting a point. The distance as a multiple of overall height, in general, decreases with turbine rating.

Table 5 summarizes the results for 1×10^{-6}/year fragment impact probability in terms of absolute distance and multiple of overall height. The values for the fixed wind direction case are in parentheses and are greater than the uniform wind direction by 0.3–0.6 multiples of overall height.

Figure 7 shows the probability of impacting a point versus multiple of turbine height for 70 and 90 m/s tip speeds. The probability for impacting a 625 m^2 target is approximately one order of magnitude higher. The plots show the value and slope of the probability decreasing as the turbine size increases. The data from these figures including target probabilities and fixed wind direction probabilities are listed in Table 6.

Conclusions

The authors have developed a model to determine the probability of impact from wind turbine fragments at

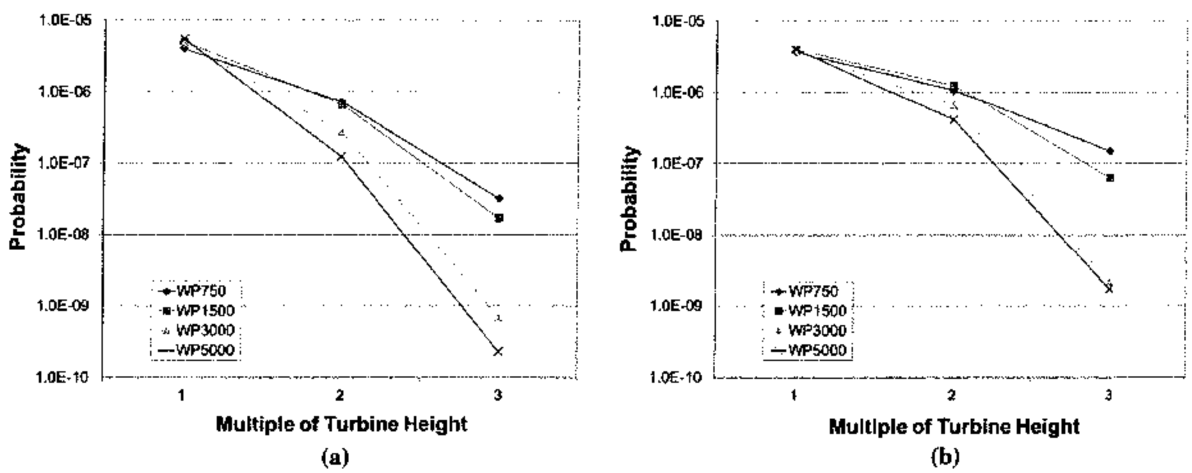

Fig. 7 Probability of impacting a point versus multiple of overall height. **a** Nominal tip speed 70 m/s, **b** nominal tip speed 90 m/s

Table 6 Probability of impact for multiples of turbine height

Model and tip speed (m/s)	Baseline height	2× Baseline height	3× Baseline height
WP750			
70	4.0×10^{-6} (1.1×10^{-5})	7.1×10^{-7}(2.6×10^{-6})	3.2×10^{-8} (8.5×10^{-8})
	1.0×10^{-4} (2.9×10^{-4})	1.8×10^{-5} (6.7×10^{-5})	8.2×10^{-7} (2.2×10^{-6})
80	3.6×10^{-6} (1.1×10^{-5})	9.1×10^{-7} (2.6×10^{-6})	8.8×10^{-8} (1.2×10^{-7})
	9.3×10^{-5} (2.7×10^{-4})	2.3×10^{-6} (6.7×10^{-5})	2.6×10^{-6} (3.0×10^{-6})
90	3.7×10^{-6} (9.9×10^{-6})	1.1×10^{-6} (3.6×10^{-6})	1.5×10^{-7} (1.8×10^{-7})
	9.5×10^{-5} (2.6×10^{-4})	2.8×10^{-5} (9.2×10^{-5})	3.9×10^{-6} (4.5×10^{-6})
WP1500			
70	5.1×10^{-6} (9.1×10^{-6})	6.6×10^{-7} (2.8×10^{-6})	1.7×10^{-8} (5.1×10^{-8})
	1.3×10^{-4} (2.4×10^{-4})	1.7×10^{-5} (7.2×10^{-5})	4.4×10^{-7} (1.3×10^{-6})
80	4.5×10^{-6} (5.5×10^{-6})	9.2×10^{-7} (4.3×10^{-6})	4.0×10^{-8} (1.1×10^{-7})
	1.2×10^{-4} (1.4×10^{-4})	2.4×10^{-5} (1.1×10^{-4})	1.0×10^{-6} (2.8×10^{-6})
90	4.0×10^{-6} (3.4×10^{-6})	1.3×10^{-6} (6.7×10^{-6})	6.3×10^{-8} (2.3×10^{-7})
	1.0×10^{-4} (8.8×10^{-5})	3.2×10^{-5} (1.7×10^{-4})	1.6×10^{-6} (6.0×10^{-6})
WP3000			
70	4.9×10^{-6} (1.5×10^{-5})	2.8×10^{-7} (1.3×10^{-6})	6.9×10^{-10} (1.9×10^{-9})
	1.3×10^{-4} (3.8×10^{-4})	7.1×10^{-6} (3.2×10^{-5})	2.6×10^{-7} (4.9×10^{-8})
80	4.1×10^{-6} (1.6×10^{-5})	5.4×10^{-7} (1.9×10^{-6})	1.8×10^{-9} (5.6×10^{-9})
	1.1×10^{-4} (4.2×10^{-4})	1.4×10^{-5} (4.9×10^{-5})	4.5×10^{-8} (1.4×10^{-7})
90	3.9×10^{-6} (1.6×10^{-5})	6.5×10^{-7} (2.4×10^{-6})	2.1×10^{-9} (7.8×10^{-9})
	1.0×10^{-4} (4.0×10^{-4})	1.7×10^{-5} (6.0×10^{-5})	5.4×10^{-8} (2.0×10^{-7})
WP5000			
70	5.5×10^{-6} (1.4×10^{-5})	1.2×10^{-7} (1.6×10^{-7})	2.3×10^{-10} (1.1×10^{-10})
	1.4×10^{-4} (3.7×10^{-4})	3.2×10^{-6} (4.1×10^{-6})	5.8×10^{-9} (2.7×10^{-9})
80	4.9×10^{-6} (1.1×10^{-8})	2.3×10^{-7} (2.5×10^{-7})	8.2×10^{-10} (2.1×10^{-9})
	1.3×10^{-4} (2.7×10^{-4})	6.0×10^{-6} (6.5×10^{-6})	1.2×10^{-8} (5.3×10^{-8})
90	4.0×10^{-6} (7.6×10^{-6})	4.1×10^{-7} (1.8×10^{-7})	1.7×10^{-9} (6.1×10^{-9})
	1.0×10^{-4} (2.0×10^{-4})	1.1×10^{-5} (4.7×10^{-6})	4.4×10^{-6} (1.6×10^{-7})

Point probability is in first row, target probability is in second row. Fixed wind direction probabilities are in parenthesis

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specific distances from the turbine. Authorities having jurisdiction can use the results from this work to develop, evaluate, and revise wind turbine setbacks. The results show that if the setback is based on a multiple of overall turbine height, the probability of impact decreases as the wind turbine rating increases (larger turbines).

Although there may be benefit to using fixed distances for setbacks depending on turbine rating and tip speed, it would be simpler to continue to use setbacks as a function of overall turbine height. It would be logical to change this approach if the decrease in risk with turbine rating was more dramatic. For an allowable 1×10^{-6}/year impact probability, a setback of two overall heights to a property line and three overall heights to a dwelling may be reasonable. This is similar to ordinances reported in Larwood and van Dam (2006). Setbacks approaching one turbine height would have an order of magnitude increase in impact probability.

The trajectory model showed good agreement with Sørensen (1984). Individual trajectories were sensitive to the input parameters. However, setbacks determined from multiple throws are not sensitive to inputs except for blade mass. The effect of spanwise drag was negligible and could be removed from modeling. Parked turbines/extreme winds do not need to be included. The setbacks are sensitive to the wind direction probability; however, a realistic distribution was shown to be very close to a uniform distribution.

Data from actual failures and experimental studies can be used to validate the modeling approach taken here. Validation with an actual failure can be made with information regarding the operating conditions (Table 2), the range/direction of impact, and the geometric/mass properties of the fragment. Experimental studies should include realistic translational and rotational velocity at release. One approach would be to deliberately cause a rotor failure on a turbine at the end of its useful life in a clear field. Explosive bolts or a ring charge could be used to separate the blade or fragment from the turbine. The azimuth at break must be carefully determined. Another approach would be to launch fragments from a catapult.

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RESEARCH ARTICLE

Analysis of blade fragment risk at a wind energy facility

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Abstract
An analysis was performed to determine the risk posed by wind turbine fragments on roads and buildings at the National Wind Technology Center at the National Renewable Energy Laboratory. The authors used a previously developed model of fragment trajectory and took into account the wind speed/direction distribution at the site and the probability of rotor failure. The site-specific risk was assessed by determining the likelihood of impact and related consequences. For both the roads and buildings, the risk varied from low to routine, which was considered acceptable.

KEYWORDS
hazards, safety, wind energy

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1 | INTRODUCTION

At the time of this writing, wind energy is the fastest growing source of new energy production. At the end of 2017 (most current year reported[1]), global installed capacity was 539GW with 89 GW in the United States. US wind energy penetration was at 6.3%; a remarkable achievement considering the amount of total energy production. Although praised for its environmental benefits, wind energy must still be sited with appropriate appreciation for the impact of installations on local land usage. Examples are discussed in Abbasi and Abbasi[2] and in Price et al.[3] This article reports on the potential safety risk posed by wind energy production, which is the possibility of impact of wind turbine blade fragments in the event of structural failure.

Larwood and van Dam[4] reported on the history of this risk and the modeling of rotor fragments in the context of safety setbacks for wind turbines. Since their report, there has been a renewed interest in modeling, with several authors reporting on fragment analysis.[5-8] The state-of-the-art modeling approach is six degrees-of-freedom (6DOF) motion of the blade fragments with aerodynamic loading. Simplified models do not match the results of the 6DOF models; Sørensen[9] showed that drag ballistics do not capture the downwind distance, and the range for vacuum ballistics is too far. All of these models have not been validated with experimental data.

This article presents an analysis of a wind energy facility with several research wind turbines of different sizes. The research site is the National Wind Technology Center (NWTC) which is part of the US Department of Energy's National Renewable Energy Laboratory (NREL). Located south of Boulder, Colorado, the NWTC is nestled at the base of the Rocky Mountain foothills. Researchers have been studying wind energy at the NWTC since the 1970s, originally focusing on small-scale utility turbines. Larger turbines were installed in the 1990s and with the maturity of the industry, multimegawatt turbines, based on production models, have been installed in the past decade. All of the turbines are utilized to support the NWTC's research mission and may be operated outside of conventional parameters. The site is therefore not representative of a typical wind energy plant. The wind season is primarily in the winter with predominant western winds. The site regularly experiences high-velocity foehn winds in the winter (up to 100 miles per hour), making it an ideal location for investigating the reliability and performance of wind turbines.

Eggers et al[10] reported on a fragment analysis of the NWTC in 2001. Although they made several parametric studies that may pave a path towards generalizing the problem, their overall model assumed a constant drag coefficient (C_D) of 0.5, which would be considered high compared with findings from Sørensen[9] and Larwood and van Dam.[7] The model was also for a full blade and half-blade thrown from a turbine with a 15.2 m radius on two tower heights (30.4 and 91.4 m), limited to two wind speeds (11.2 and 22.4 m/s), with a Gaussian distribution of rotor speeds from 1.25 to 1.75 times the rated speed. It is difficult to determine if their results can be scaled to turbines with a higher rating.

The purpose of the study was to analyze the risk posed by rotor fragments from the wind turbines to roads and buildings at the NWTC based on methods developed by Larwood and van Dam.[7] The analysis showed that the likelihood of impact with catastrophic consequences to be extremely unlikely, therefore the risk was determined to be low.

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2 | METHODS

Figure 1 shows a three-dimensional image of the NWTC. The turbines and data sheds of interest are labeled. The roads of interest are the east-west road in green ("main access road") and the northeast-southwest road ("row 4 road") in yellow. CART2 and CART3 are the two-bladed (CART2) and three-bladed (CART3) Controls Advanced Research Turbines.

The purpose of the analysis was to determine the risk of rotor fragments posed by the turbines installed on row 4 on the main entrance road, the row 4 road, and the 4.1, 4.2, and 4.4 data sheds. Table 1 lists details of the turbines that were analyzed.

The analysis requires blade mass properties as inputs. With the exception of the CART turbines, all blade properties were proprietary. Properties were estimated using properties from the WindPACT study[11] and from the modeling described in Larwood et al.[12] The WindPACT models were 1.5 and 3 MW, matching the ratings of the GE and Alstom turbines. The blade properties were matched at values of percentage radius. The Siemens turbine was scaled from the 1.5 model using scaling laws described in Sarlak and Sørensen[8] for mass, mass center, and mass moment of inertia scaling. The adjustment to the mass was:

$$m = m_{ref}(r/r_{ref})^{2.3}, \tag{1}$$

where m_{ref} is the reference (known) mass, and r_{ref} is the reference radius. The adjustment to the mass center was:

$$d = d_{ref}(P/P_{ref})^{1/2}, \tag{2}$$

where d_{ref} is the reference (known) distance, and P_{ref} is the reference rated power. The adjustment to the mass moment of inertia was:

$$I = I_{ref}(r/r_{ref})^{4.3}, \tag{3}$$

where I_{ref} is the reference (known) mass moment of inertia. The mass and inertia exponents come from data of actual blade mass versus radius. The diameter is related to the square root of the power. The CART turbine properties were provided by NREL; however, mass center and mass moment of inertia were not available and were therefore scaled from the WindPACT 1.5 model highlighted earlier.

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FIGURE 1 National Wind Technology Center (NWTC) row 4 wind turbines [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 NWTC turbines

Turbine	Rating (MW)	Diameter (m)	Hub Height (m)	Rated rpm
Alstom ECO 110	3	110	90	13.6
CART2	0.6	42.672	36.85	41.7
CART3	0.6	40	36.594	38
Gamesa G97	2	97	90	16
GE 1.5 SLE	1.5	77	80	18.3
Siemens SWT 2.3	2.3	106	80	16

The method used to determine frequency of impact is described in Larwood and van Dam.[7] The method models the fragment as a rigid body with translation and rotation. The translation is modeled with Newton's second law, and the rotation is determined with Euler's rotation equations. The method also uses equations to determine the changes in the orientation matrix. The fragment is divided into elements to compute the aerodynamic forces using airfoil tables. This method was based on Sørensen.[9] The analysis generates 10 000 throws, with release conditions and probability listed in Table 2. The blade fragment parameters are independent of the wind parameters. The amount of throws was determined

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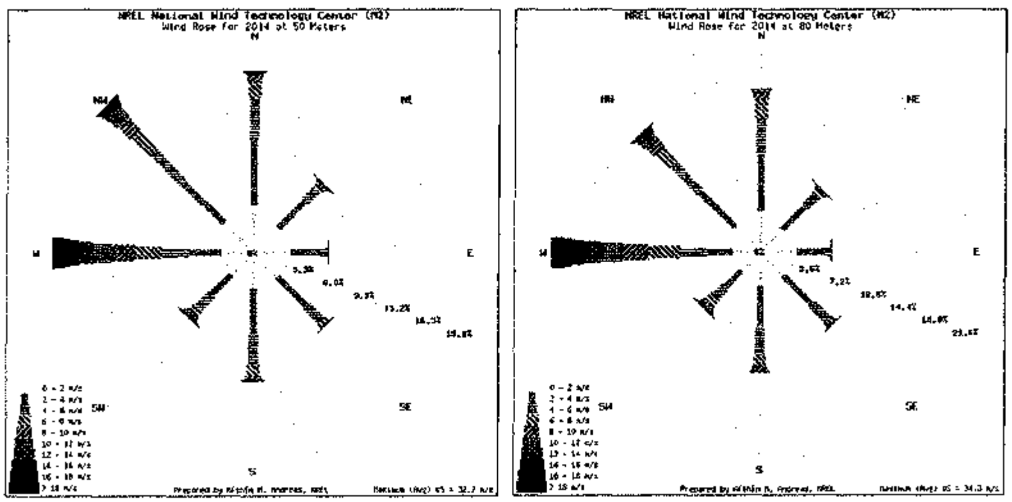
TABLE 2 Release condition probability

Input Variable	Probability Distribution
Blade pitch	Based on wind speed
Rotor rotational speed	Based on wind speed
Rotor azimuth at break	Uniform between 0° and 360°
Blade break position	Uniform between hub radius and blade tip
Yaw error	Uniform between −10° and 10°



50 m height

80 m height

FIGURE 2 National Wind Technology Center (NWTC) M2 2014 annual wind roses, with circles representing percent of time

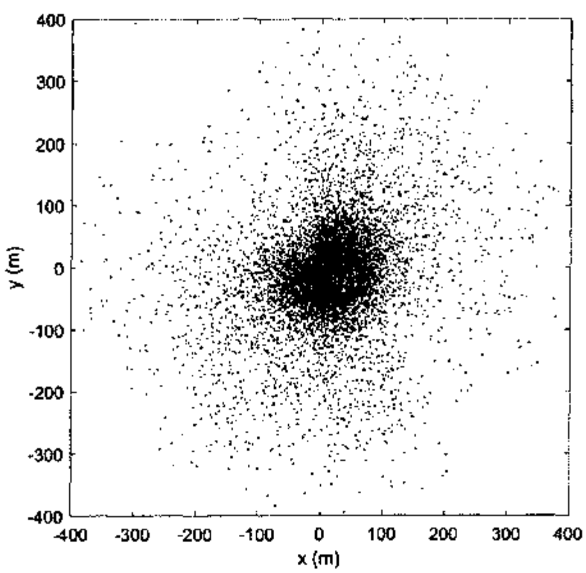


FIGURE 3 Impacts for CART2 at nominal rpm. East is positive x and north is positive y in this and following plots [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 3 Rotor failure probabilities from[14]

Operating Condition	Probability Per Turbine Per Year
Nominal operating rpm	4.2×10^{-4}
Braking (1.25 times nominal rpm)	4.2×10^{-4}
Emergency (2.0 times nominal rpm)	5×10^{-6}

by a sensitivity analysis in Larwood and van Dam,[7] which showed convergence at 5000 throws. The wind magnitude and direction are considered random with the probability distribution based on the wind rose, which describes the frequency of occurrence for wind speed and wind direction. The wind rose was from the NWTC M2 meteorological tower (https://www.nrel.gov/midc/nwtc_m2/). Annual wind roses from 2014 and at heights 50 and 80 m were used (Figure 2). Each rose has eight wind speed distributions for a 30° wind direction sector. The roses show the predominant western wind direction. The CART wind velocities and turbines with 90 m hub height were sheared to hub height with the standard power law as in:

$$V = V_{ref}(h/h_{ref})^{\alpha}, \tag{4}$$

where V_{ref} is the reference (known) wind speed, h_{ref} is the reference height, and α is 1/7. Note that atmospheric turbulence has not been included in the model (was recommended for further study Larwood and van Dam[4]).

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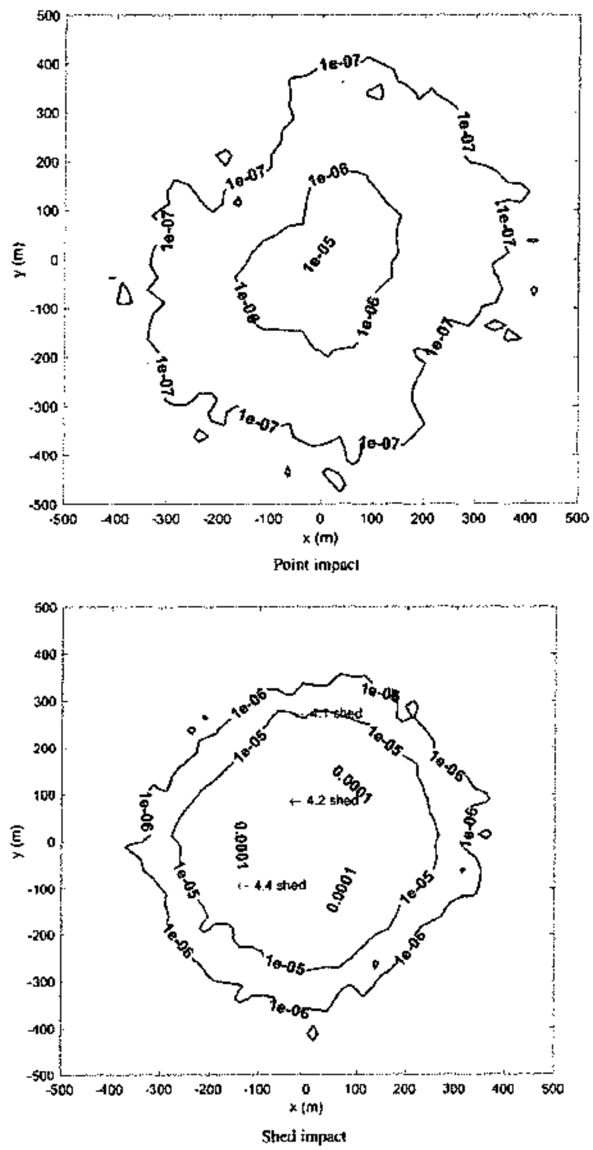

FIGURE 4 Probability of impact for CART2 [Colour figure can be viewed at wileyonlinelibrary.com]

As an example for a single turbine, Figure 3 shows the impacts for the CART2 at nominal rpm. The impacts are clustered to the south and east of the turbine, which indicates alignment of the turbine with the wind rose.

The probability of impact at a particular ground location is determined by using methods described in Larwood and van Dam[7] and were based on work by Turner.[13] The probability of impact from a blade fragment is for a point (used for the roads- impact with vehicle/personnel) and for a target of 25 × 25 × 3.67-m height (for data sheds). Three separate 10 000 throw runs were conducted at rated rpm, braking rpm (1.25 times rated), and emergency rpm (2 times rated). The probability from these runs was multiplied by the failure probability as reported in Braam[14] and listed in Table 3. Note that these failure data were compiled in 2005. Current failure rates may have decreased with maturity in the technology. However, due to the outcome of this study, no further analysis of failure rates was deemed necessary.

As an example, Figure 4 shows contours (using the MATLAB `contour` function) of constant probability of impact from the CART2 fragments with a point on the ground and for a data shed. For example, the probability of a blade fragment from the CART2 impacting data shed 4.2 is approximately 1 in 10 000, or (0.0001) per year. Again, the alignment of the contours is with the wind rose, with the majority of the impacts occurring perpendicular and downwind from the prevailing wind direction. The uneven contour of the lower probabilities (eg, 1e-07) is because of a low number of impacts; these contours would be smoother with more throws added to the analysis.

The overall risk was assessed by determining the likelihood and consequence of the impacts. NREL values for likelihood (Table 4) and consequence (Table 5) were adapted from methods specified in the US Department of Defense Standard Practice for System Safety.[15] In the case of the CART2 fragments impacting the 4.2 data shed, the likelihood is considered extremely remote. Note that this example is only for impacts from CART2. The consequence of the impact can vary from negligible to catastrophic, depending on several factors including the kinetic energy of the impact and if the shed is occupied at the time of impact. Kinetic energy of the impact can be determined; however, the analysis does not currently include a measure of damage.

The likelihood and consequence are combined into the NREL risk matrix (Figure 5) that NREL researchers adapted from methods specified in the U.S. Department of Defense Standard Practice for System Safety.[15] NREL considers levels "low" and "routine" risk to be acceptable. Fragment impacts with personnel may result in death and therefore are considered catastrophic consequences; however, if the likelihood is extremely remote, the risk is considered low.

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TABLE 4 National Renewable Energy Laboratory (NREL) likelihood values

Level	Frequency
Frequent	$F \geq 1.0/y$
Reasonably Probable	$1.0 > F \geq 0.1/y$
Occasional	$0.1 > F \geq 0.01/y$
Remote	$0.01 > F \geq 10^{-4}/y$
Extremely Remote	$10^{-4} > F \geq 10^{-6}/y$
Improbable	$F < 10^{-6}/y$

TABLE 5 National Renewable Energy Laboratory (NREL) consequence values

Level	Consequence
Catastrophic	Death; permanent total disability; loss > $10 million
Critical	Partial disability; loss > $1 million
Marginal	Injury; loss > $100 000
Negligible	Minor injury; loss < $100 000

Likelihood

Consequence	Frequent	Reasonably Probable	Occasional	Remote	Extremely Remote	Improbable
Catastrophic				Moderate	Low	Routine
Critical			Moderate	Low	Low	Routine
Marginal	Moderate	Moderate	Low	Low	Routine	Routine
Negligible	Routine	Routine	Routine	Routine	Routine	Routine

FIGURE 5 National Renewable Energy Laboratory (NREL) risk matrix [Colour figure can be viewed at wileyonlinelibrary.com]

3 | RESULTS AND DISCUSSION

3.1 | Risk assessment

All throws for the six turbines were combined to determine the overall risk for the site. Figure 6 shows the probability of impact for the roads. The probability is between 1×10^{-5} and 1×10^{-6}, which indicates an "extremely remote" likelihood in Table 4 and a "low" to "routine" risk in Figure 5. The risk as a result of impact from blade fragments on the roads is therefore considered acceptable.

Figure 7 shows the probability of impact for the sheds. The sheds are very close to the 1×10^{-4} probability line, which places the likelihood between "remote" and "extremely remote" in Table 4. The sheds will, at most, be occupied one-third of a year, which would make the likelihood of injury from blade fragments less than 1×10^{-4} ($1/3 \times 1 \times 10^{-4}$) and therefore "extremely remote." Depending on the severity of the injury

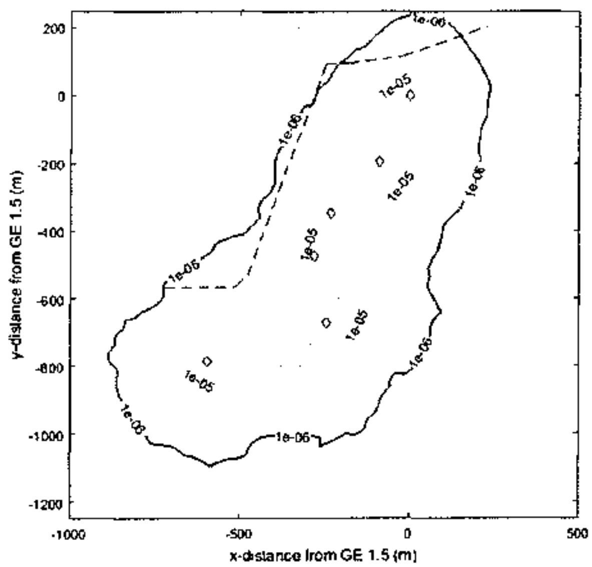

FIGURE 6 Probability of impact for roads (- - -). Turbines are indicated by open diamonds (◊) [Colour figure can be viewed at wileyonlinelibrary.com]

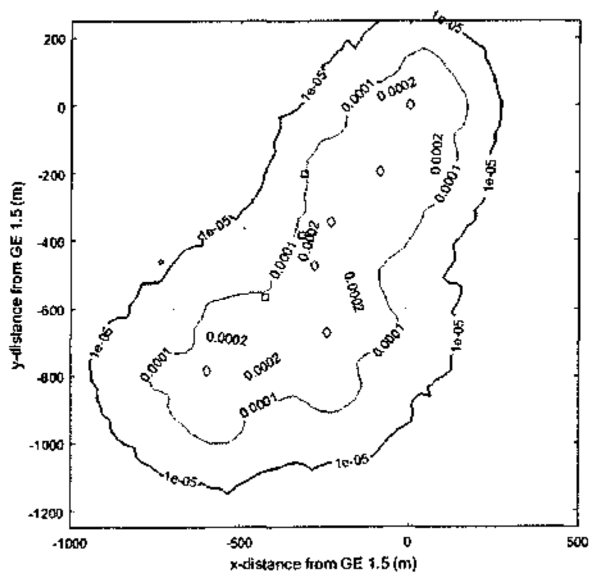

FIGURE 7 Probability of impact for sheds (□). Turbines are indicated by open diamonds (◊) [Colour figure can be viewed at wileyonlinelibrary.com]

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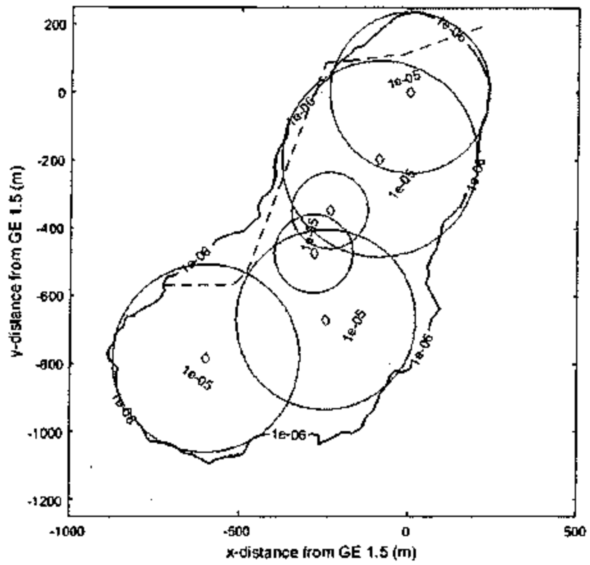

FIGURE 8 Probability of point impact; turbines are indicated by open diamonds (◇) with circles of radius two times the overall height [Colour figure can be viewed at wileyonlinelibrary.com]

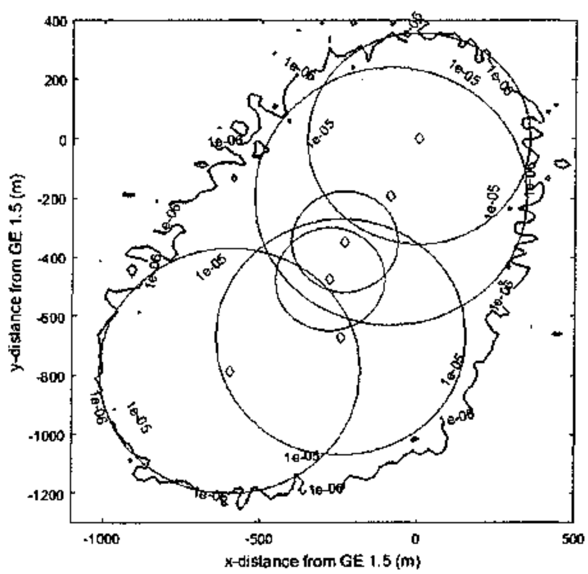

FIGURE 9 Probability of building impact; turbines are indicated by open diamonds (◇) with circles of radius three times the overall height [Colour figure can be viewed at wileyonlinelibrary.com]

(consequence), the risk is "low" to "routine" in Figure 5. Impact from fragments may cause damage to the sheds; however, it would not likely exceed $1 million. Therefore, the damage (consequence) at most will be considered "negligible" to "marginal" in Table 5. With a "remote" likelihood, the risk for damage to the sheds from blade fragments is "low" to "routine." The risk as a result of impact from blade fragments on the sheds is therefore considered acceptable.

3.2 | Comparison with commercial plant analysis

As an extension of this work, the results were compared with setbacks recommended in Larwood and van Dam.[7] Row 4 of the NWTC approximates the spacing of a typical wind plant, with 3-rotor-diameter spacing along the row. The exception is the positioning of the two smaller turbines: CART2 and CART3. Row-to-row spacing in wind plants can vary from 5 to 10 diameters; therefore, the probability of impact from other upwind/downwind rows would be negligible at a particular row. Figure 8 shows the probability of point impact (same as Figure 6 for the roads), with circles of radius that are two times the overall height of the turbine. The overall height is defined as the hub height plus the rotor radius.

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This was a setback proposed by Larwood and van Dam[7] for property line setbacks. For the most part, the probability of impact at this setback is 1×10^{-6} and therefore considered "improbable" with a "routine" risk level. The exception to this is the area surrounding the CARTs, which increase the probability of impact upwind of the Siemens turbine (second most southerly turbine).

Figure 9 shows the probability of building impact (same as Figure 7 for the shed), with circles of radius that are three times the overall height of the turbine. This was a setback proposed by Larwood and van Dam[7] for distances to dwellings. The probability of impact is at or above 1×10^{-6} and therefore would not result in a "routine" risk level for all consequences. However, moving to 3.5 times the overall height would lower the risk to a "routine" level for all consequences.

4 | CONCLUSIONS

An analysis was performed on the risk associated with wind turbine blade fragments from research wind turbines at the National Wind Technology Center at the National Renewable Energy Laboratory. The objective was to demonstrate application of the risk analysis methodology, and does not represent risks associated with commercial wind turbines or plants. The analysis used a previously developed model for the blade fragment trajectory and the associated probability of impact around the turbines. The likelihood and consequences of the impacts were assessed and an overall risk was determined for various roads and structures located in the vicinity of the turbines. The risk was determined to range from "low" to "routine" and was considered acceptable.

As mentioned in previous work, the trajectory model used in this work and other models in the literature could benefit from experimental validation. The study of this hazard would also benefit from an updated investigation of rotor failure probability.

4.1 | Note on retracted version

This article was previous retracted[16] by agreement between the authors, the journal Editor in Chief, Prof. Simon Watson and John Wiley and Sons Ltd. The retraction was agreed because of an error in the conclusion, which used the analysis of NREL's wind site for evaluation of wind turbine setbacks in general. The assumptions and results do not apply to commercial wind energy sites, as the previous conclusion suggested, and was therefore not suitable for setback recommendations in other locations. P21-36 cont.

ACKNOWLEDGEMENTS

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P21-36 cont.

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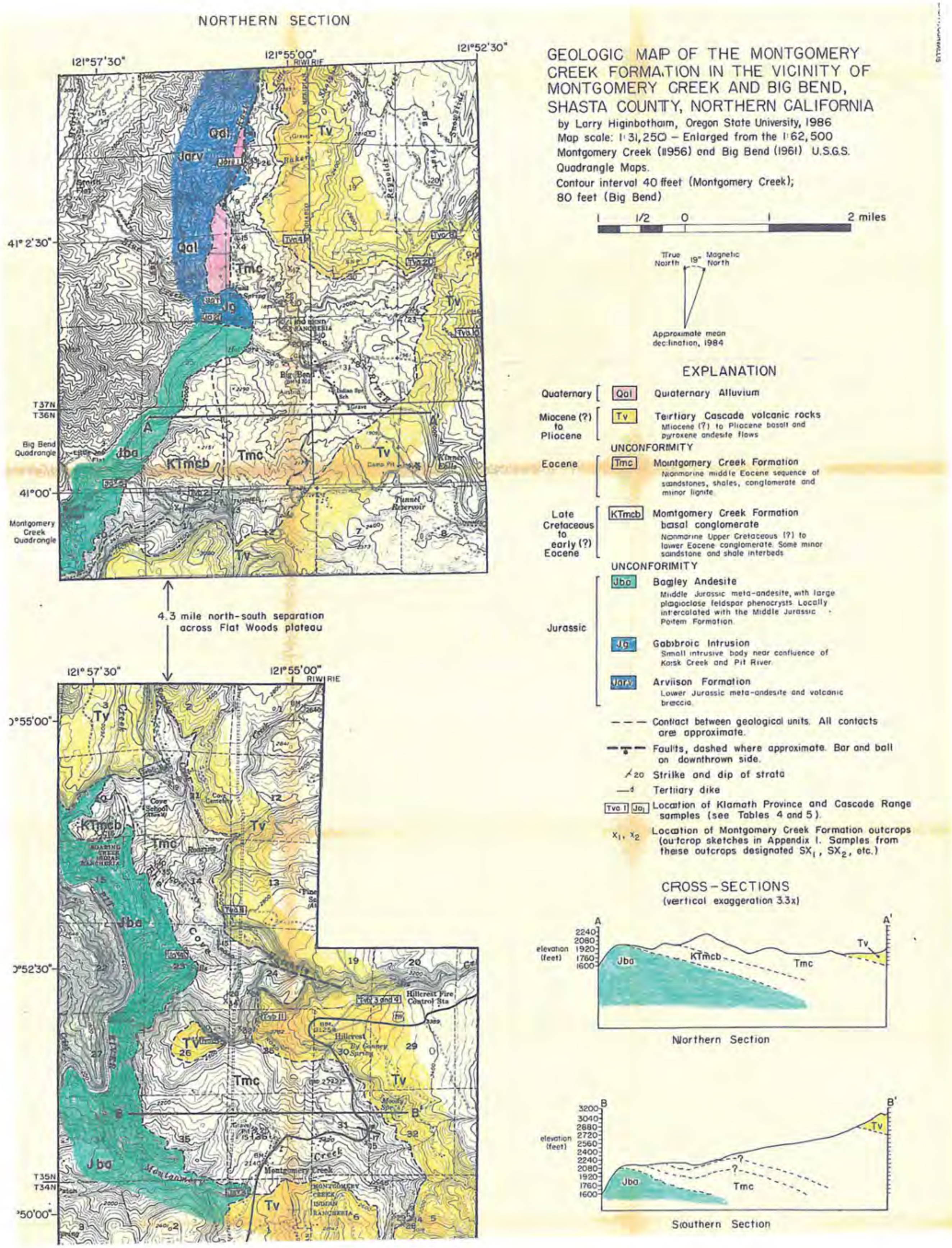


NORTHERN SECTION
GEOLOGIC MAP OF THE MONTGOMERY CREEK FORMATION IN THE VICINITY OF MONTGOMERY CREEK AND BIG BEND, SHASTA COUNTY, NORTHERN CALIFORNIA
by Larry Higinbotham, Oregon State University, 1986
Map scale: 1:31,250 – Enlarged from the 1:62,500 Montgomery Creek (1956) and Big Bend (1961) U.S.G.S. Quadrangle Maps.
Contour interval 40 feet (Montgomery Creek); 80 feet (Big Bend)
1 1/2 0 1 2 miles
True North 19° Magnetic North
Approximate mean declination, 1984
EXPLANATION
Quaternary — Qal — Quaternary Alluvium
Miocene (?) to Pliocene — Tv — Tertiary Cascade volcanic rocks. Miocene (?) to Pliocene basalt and pyroxene andesite flows
UNCONFORMITY
Eocene — Tmc — Montgomery Creek Formation. Nonmarine middle Eocene sequence of sandstones, shales, conglomerate and minor lignite.
Late Cretaceous to early (?) Eocene — KTmcb — Montgomery Creek Formation basal conglomerate. Nonmarine Upper Cretaceous (?) to lower Eocene conglomerate. Some minor sandstone and shale interbeds.
UNCONFORMITY
Jurassic — Jba — Bagley Andesite. Middle Jurassic meta-andesite, with large plagioclase feldspar phenocrysts. Locally intercalated with the Middle Jurassic Potem Formation.
Jg — Gabbroic Intrusion. Small intrusive body near confluence of Kosk Creek and Pit River.
Jarv — Arvison Formation. Lower Jurassic meta-andesite and volcanic breccia.
Contact between geological units. All contacts are approximate.
Faults, dashed where approximate. Bar and ball on downthrown side.
Strike and dip of strata
Tertiary dike
Tva 1 Ja1 Location of Klamath Province and Cascade Range samples (see Tables 4 and 5).
x1, x2 Location of Montgomery Creek Formation outcrops (outcrop sketches in Appendix I. Samples from these outcrops designated SX1, SX2, etc.)
CROSS-SECTIONS
(vertical exaggeration 3.3x)
Northern Section
Southern Section
4.3 mile north-south separation across Flat Woods plateau
121°57'30"
121°55'00"
121°52'30"
41°2'30"
41°00'
T37N
T36N
T35N
T34N
Big Bend Quadrangle
Montgomery Creek Quadrangle
Big Bend
Hillcrest
Montgomery Creek
Tunnel Reservoir

P21-36 cont.

Maintenance & Repair (continued)

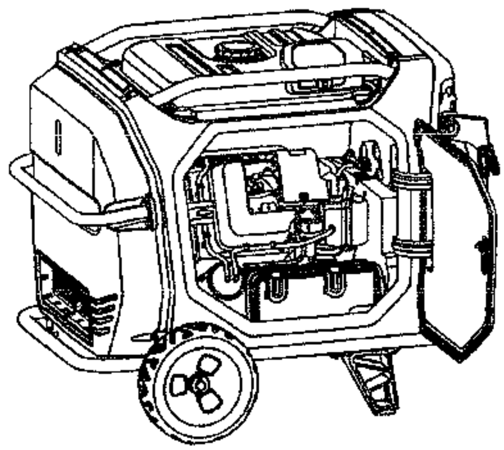
e) Wash the foam element in a solution of household detergent and warm water, rinse thoroughly, and let air dry.
f) Soak the foam element in oil and squeeze out excess oil. The foam element should be wet but not dripping.

NOTICE: DO NOT twist or wring out the foam element when squeezing; this could cause it to tear.

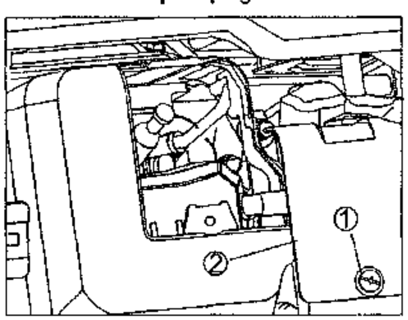
g) Install the foam element and paper filter.
h) Install the air filter case cover in its original position and latch clamps.
i) Close side left side cover and turn screw ¼ turn.

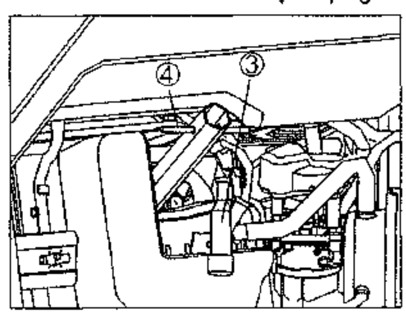
Spark Plug Cleaning and Replacement

a) Open left side cover by turning screw ¼ turn.



b) Remove spark plug cap③. Insert the spark plug wrench onto the spark plug and turn it counter clockwise to remove the spark plug.





c) Check for discoloration and remove any carbon build-up. The porcelain insulator around the center electrode of the spark plug should be a medium-to-light tan color.

d) Check the spark plug type and gap ⓐ. The gap should be measured with a wire thickness gauge.

P21-36 cont.

Review of Soil Corrosivity Testing for General Building Materials

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P21-36 cont.

Abstract

This presentation will explain what corrosion engineers need to know to develop their corrosion control recommendations for common construction materials used in underground infrastructure to avoid costly future failures. The goal of a corrosion study is to know the corrosivity of the soil at the depth where infrastructure will be installed. Soil corrosivity can change dramatically per depth and location. Typically, builders rely on geotechnical engineers to provide soil reports which can consist of 100 pages of paragraphs describing the loads that the soils can support, the site's likelihood for landslides, the potential for seismic damage, and any potential pollution dangers or underground gas dangers. Of those 100 pages, there, may be a quarter page paragraph about soil corrosivity based upon one sample that was collected at the surface for a site as large as 20 acres. In the United States, geotechnical engineers rely on corrosion control recommendations described in American Association of State Highway and Transportation Officials (AAHSTO), State Transportation Departments such as Cal Trans, and American Concrete Institute (ACI). Very often by recommendation of these publications, no chemical analysis is performed if soil minimum resistivity is less than 1,100 ohm-cm. Every material has its weakness. Aluminum alloys, galvanized/zinc coatings, and copper alloys do not survive well in very alkaline or very acidic pH environments. Copper and brasses do not survive well in high nitrate or ammonia environments. Steels and iron do not survive well in low soil resistivity and high chloride environments. High chloride environments can even overcome and attack steel encased in normally protective concrete. Concrete does not survive well in high sulfate environments. And nothing survives well in high sulfide and low redox potential environments with corrosive bacteria. This is why Project X Corrosion Engineering tests for these eight factors to determine a soil's corrosivity towards various construction materials and wish geotechnical engineers would do so too. As general construction materials include concrete, steel, iron, stainless steel, copper, brass, aluminum, zinc coatings, and other materials, it is this author's opinion that geotechnical engineers should always have a corrosion engineer, familiar with soil corrosivity and material science, write their corrosion control recommendation paragraphs.

Keywords: General construction materials; bacteria, MIC, soil resistivity, water soluble ions

Introduction

The goal of a corrosion study is to know the corrosivity of the soil at the depth where infrastructure will be installed. Soil corrosivity can change dramatically per depth and location. Typically, builders rely on geotechnical engineers to provide soil reports which can consist of 100 pages of paragraphs describing the loads that the soils can support, the site's likelihood for landslides, the potential for seismic damage, and any potential pollution dangers or underground gas dangers. Of those 100 pages, there, may be a quarter page paragraph about soil corrosivity based upon one sample that was collected at the surface for a site as large as 20 acres. The sample is typically tested for minimum resistivity, water soluble salts such as sulfates, water soluble chlorides, and pH by geotechnical engineers to evaluate corrosivity but sulfate testing is the only one required to be tested per the international building code. In the United States, geotechnical engineers rely on corrosion control recommendations described in American Association of State Highway and Transportation Officials (AAHSTO), State Transportation Departments such as Cal Trans, and American Concrete Institute (ACI). Very often by recommendation of these publications, no chemical analysis is performed if soil minimum resistivity is less than 1,100 ohm-cm [1] [2] [3] [4], thus the soil is categorized as non-corrosive. Water soluble sulfate is the only required test for general construction for the sake of choosing the proper concrete type. [5] These recommendations focus on evaluating soil so that the correct concrete mix is chosen and to determine if a corrosion engineer should be contacted. Unfortunately, the materials mostly protected by these recommendations are concrete and steel. General construction materials will consist of a variety of materials each with a different corrosion weakness. [6] [7] [8] [9] [10] [11] [12] [13] [14] [15] [16] [17] As general construction materials include concrete, steel, iron, stainless steel, copper, brass, aluminum, zinc coatings, and other materials, it is this author's opinion that geotechnical engineers should always have a corrosion engineer, familiar with soil corrosivity and material science, write their corrosion control recommendation paragraphs.

P21-36 cont.

As of 2018 Cal Trans Corrosion Guidelines, for structural elements, a site is considered corrosive if one or more of the following conditions exist for the representative soil/water sample taken from the site [1]:

- Soil/Water with less than 1,100 ohm-cm resistivity must be tested for chloride and sulfates
- Chloride concentration is 500 ppm or greater
- Sulfate concentration is 1,500 ppm or greater
- pH is 5.5 or less

Deciding on the correct amount of due diligence in evaluating a site can be a mystery to investors and developers who are not themselves experts in corrosion or familiar with the cost of future corrosion failures and construction defect lawsuits.

I recommend collection of soil samples at every acre of a site plan. Collecting in this grid pattern will allow identifying corrosion hotspots at a site enabling the corrosion engineer to isolate expensive corrosion control recommendations to the hotspots. Our clients have told us that this protocol often saves them US$5,000 per residential lot. The savings are significantly greater than the cost of the corrosion study itself. Pricing for a corrosion study is often US$150 per soil sample plus US$1,200 for the corrosion control recommendations report plus other indirect costs if client requires extra paperwork, insurance, or meetings.

Eight different factors in soil which affect the corrosion rates of general construction materials such as steel, copper, brass, galvanized steel, concrete, iron, stainless steels, and aluminum are recommended to be tested. These are minimum resistivity, pH, water soluble sulfates, chlorides, ammonia, nitrate, sulfide, and REDOX potential [13]. With this information, the situation for each material buried will be known and corrosion control recommendations for each material can be provided.

Every material has its weakness. Aluminum alloys, galvanized/zinc coatings, and copper alloys do not survive well in very alkaline or very acidic pH environments. Copper and brasses do not survive well in high nitrate or ammonia environments. Steels and iron do not survive well in low soil resistivity and high chloride environments. High chloride environments can even overcome and attack steel encased in normally protective concrete. Concrete does not survive well in high sulfate environments. And nothing survives well in high sulfide and low redox potential environments with corrosive bacteria. This is why Project X tests for these 8 factors to determine a soil's corrosivity towards various construction materials and wish geotechnical engineers would do so too.

It should not be forgotten that import soil should also be tested for all factors to avoid making your site more corrosive than it was to begin with. Composite samples, those samples that combine samples from different depths and locations, should not be used in corrosion studies. Composite samples are typically used in agriculture to determine a field's fertilizer mix design. The field will eventually be thoroughly plowed and mixed. P21-36 cont.

Experimental

To study the correlation of corrosive elements and soil minimum resistivity as assumed in Caltrans 2018 Corrosion Guidelines, we compared data of hundreds of soil tests performed at Project X Corrosion Engineering. The soil samples were tested for the following:

1. Minimum electrical resistivity per ASTM G187
2. Water Soluble Sulfates per ASTM D516
3. Water Soluble Chlorides per ASTM D512B
4. Water Soluble Nitrates per SM 4500-NO3-E
5. Water Soluble Ammonia per SM 4500-NH3-C
6. Water Soluble Sulfide per SM 4500-S2-D
7. Oxidation Reduction Potential per ASTM G200
8. pH per ASTM G51

Soil samples were prepared per CalTrans methods described in CTM 643, 417, & 422 in which soil is dried below 140F (60C), sieved thru a #8 (2.36 mm) sieve, with 1:3 extract of 100 grams of sieved soil to 300 mL water.

Seven graphs were created to search for correlation of elements versus minimum resistivity such as (1) Min-Resistivity vs Sulfates PPM, (2) Min-Resistivity vs Chlorides PPM, (3) Min-Resistivity vs Ammonia PPM, (4) Min-Resistivity vs Nitrates PPM, (5) Min-Resistivity vs Sulfides PPM, (6) Min-Resistivity vs Oxidation Reduction Potential, (7) Min-Resistivity vs pH.

Per generally accepted recommendations, the following graph would be expected.

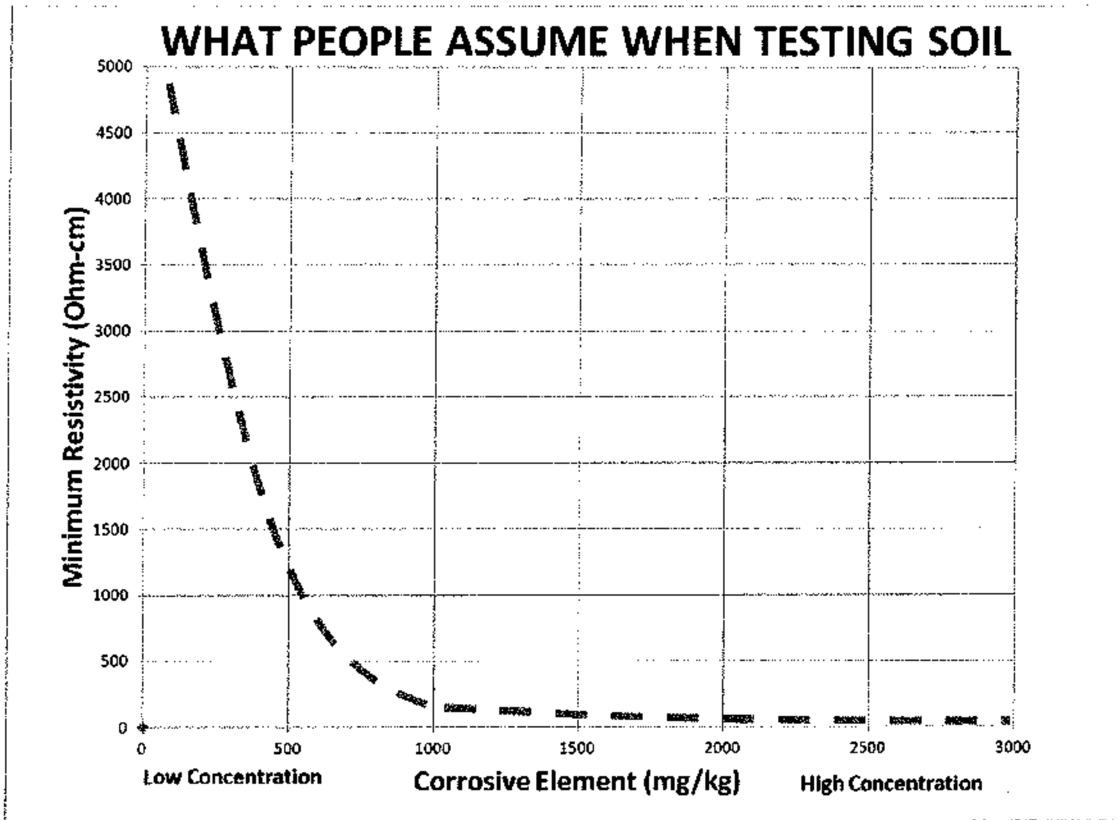

Figure 1 – Assumed trend of Min-Resistivity versus Corrosive element concentration

Results

The following graphs were created from 482 soil tests from various locations across the United States. The red vertical dash lines represent concentration limits generally accepted by corrosion engineers per various publications. The green dash line represents the assumed corrosive element concentration if soil minimum resistivity is the determining factor as is generally explained in most agency corrosion guidelines and accepted by most cathodic protection engineers.

P21-36 cont.

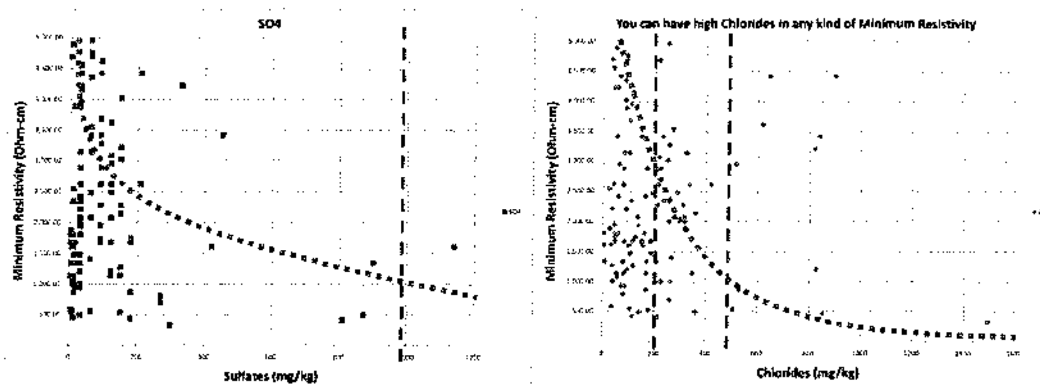

Figure 2 - Min-Resistivities versus Sulfate (left) versus Chloride (right). Overlaid generally assumed trendline from Figure 1.

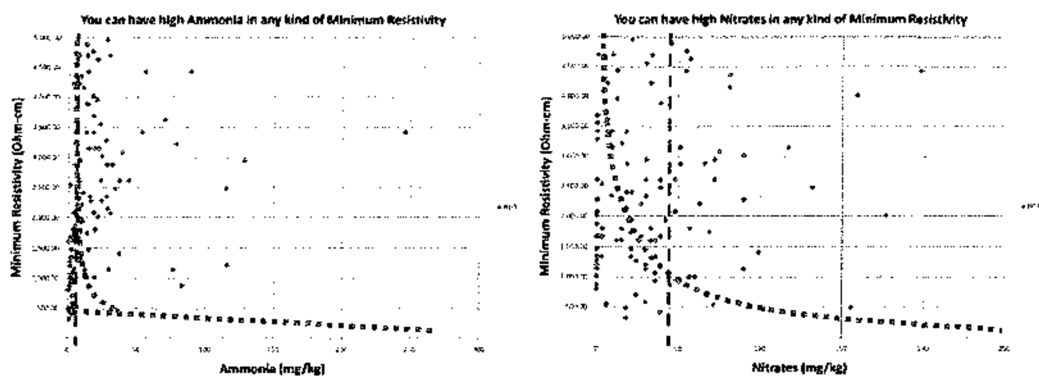

Figure 3 - Min-Resistivities versus Sulfate (left) versus Chloride (right). Overlaid generally assumed trendline from Figure 1.

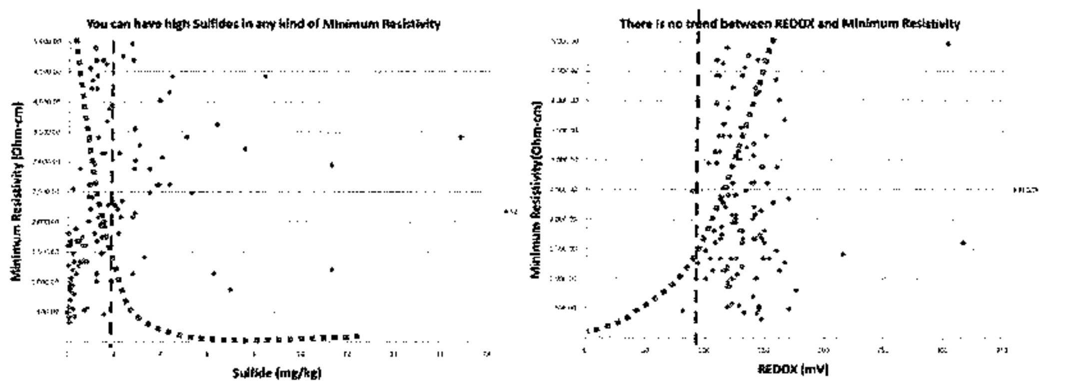

Figure 4 - Min-Resistivities versus Sulfate (left) versus Chloride (right). Overlaid generally assumed trendline from Figure 1.

P21-36 cont.

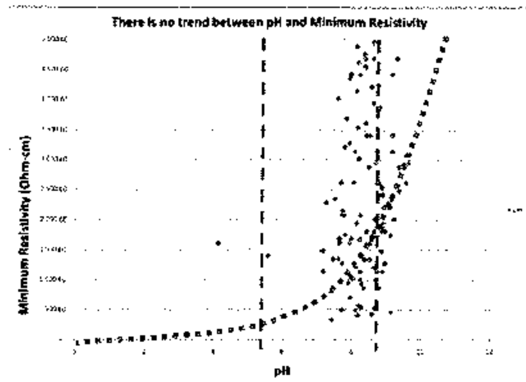

Figure 5 - Min-Resistivities versus Sulfate. Green dashed line represents general expectations per current agency corrosion guidelines.

Discussion

As can be seen in the graphs presented, there is no significant correlation between the assumed corrosive element concentrations versus the soil minimum resistivity in any of the graphs.

The lack of awareness of these facts places geotechnical engineers who provide preliminary corrosion results into dangerous liability. The industry's desire to keep material selection and corrosion control recommendations as simple as possible has led to oversimplification of material selection leading to cycles of construction defect lawsuits due to corrosion that could have been avoided had proper corrosion studies been carried out.

P21-36 cont.

All corrosion engineers will agree that in order for the soil side corrosion to occur, there must be moisture present to allow ion exchange in the oxidation reduction reactions. Thus many people assume that if there is no recent rain, the soil must be dry. People who camp outdoors or wake up early in the morning remember that there is dew falling to the ground every night. Most people remember that pipes carrying cold fluids such as water, form condensate on pipe exterior surfaces but they forget that condensate can also form underground.

As corrosion is a surface phenomenon, even a thin layer of moist corrosive soil on a material is enough to cause corrosion. This is why measurement of minimum resistivity is important as opposed to simply reading as-received soil resistivity or in-situ Wenner 4 pin soil resistivity per ASTM G57. In-situ Wenner 4 pin resistivity can change seasonally depending on the weather and moisture in the ground. This reading alone can be misleading for a corrosivity study because condensation or minor water leaks will occur underground along pipe surfaces creating a saturated soil environment in the trench along infrastructure surfaces. This is why minimum or saturated soil resistivity measurements of soil from depth of infrastructure are more important than as-received resistivities. Wenner 4 pin testing is more important and properly applied for the design of electrical grounding systems and cathodic protection system anode beds.

All corrosion engineers also agree that corrosion reactions occur most when oxygen is plentiful. Thus expansive soils which can form cracks as deep as five feet deep will allow oxygen to penetrate deeper into soils.

Shallow underground water tables can lead to underground splash zones as well as high humidity under large structures. These factors should also be taken into consideration when selecting materials and making corrosion control recommendations.

Conclusions

The limited testing required by today's building code focuses too much on steel or concrete ignoring other general construction materials such as copper, brass, aluminium, and stainless steels. These other materials are affected by other corrosive elements commonly not required to be tested by governing building codes. To aid builders and geotechnical engineers in deciding what soil factors should be tested at a construction site, the following table was created.

Table 1

What Makes an Environment Unsafe/Corrosive to a Material?								
PROJECT X ENGINEERS	Full Corrosion Series Soil Test							
	Typical Geotech Test Order						Bacteria	
Material	Low Resistivity (Ω-cm)	pH	SULFATE	CHLORIDE	NITRATE	AMMONIA	Redox (mV)	SULFIDE
Copper & Brass	X	X		X	X	X		
Steel & Iron	X	X		X	X		X	X
Stainless Steel	X			X	X		X	X
Aluminum Alloys	X	X	X	X	X	X	X	X
Concrete (no rebar)		X	X				X	X
Galvanized Steel	X	X	X	X	X		X	X

P21-36 cont.

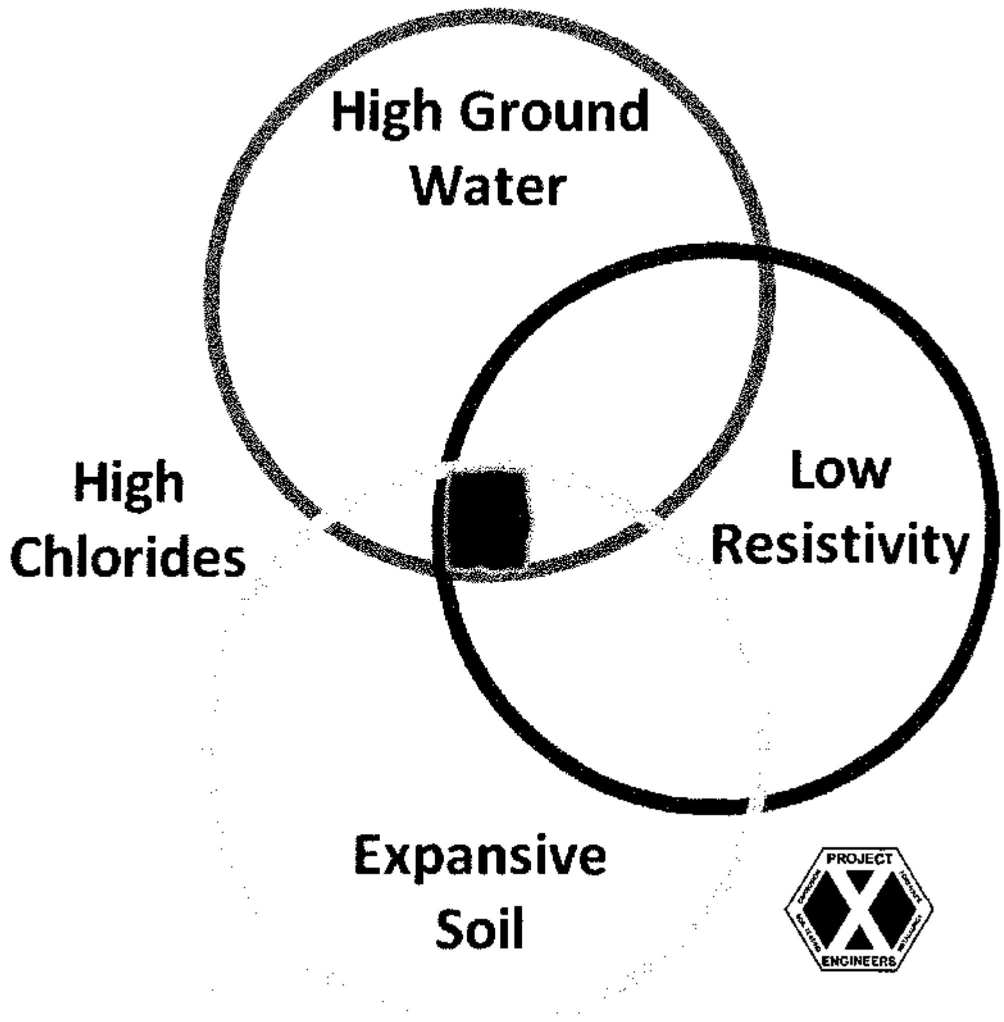

Figure 6 – Most undesirable combinations

P21-36 cont.

Acknowledgements

All corrosion researchers and publishers are to be thanks for adding to the science of corrosion control as well as the California Ridgecrest earthquake that occurred July 5th, 2019 helping me stay awake to write this paper.

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P21-36 cont.

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P21-36 cont.

Dangers of Toxic Fumes from Blasting

By Richard J. Mainiero, Marcia L. Harris, and James H. Rowland III

Abstract

This paper reviews the potential hazards posed by the toxic fumes produced by detonating explosives in surface mining and construction operations. Blasting operations produce both toxic and nontoxic gaseous products; the toxic being mainly carbon monoxide (CO) and the oxides of nitrogen (NO_x). The quantity of toxic gases produced by an explosive is affected by formulation, confinement, age of the explosive, and contamination of the explosive with water or drill cuttings, among others. Techniques to protect workers and the public from the potential hazards of explosive-related toxic fumes are discussed. These include:

- Minimizing the quantity of toxic fumes produced.
- Determining where the fumes may go so workers and neighbors can be moved out of harm's way.
- Preventing the fumes from moving towards workers and neighbors.
- Monitoring the air near workers and neighbors so they can be relocated if fumes appear.
- Ventilating structures or confined spaces until CO falls below a hazardous concentration.

P21-36 cont.

Background

Ideally, the gaseous detonation products of explosives would consist of water (H_2O), carbon dioxide (CO_2), and nitrogen (N_2). Due to the kinetics of the chemical reaction, the detonation of explosives in a blasting operation also produces toxic nitrogen dioxide (NO_2), nitric oxide (NO), and carbon monoxide (CO) (ISEE, 1998). The concentrations Immediately Dangerous to Life or Health (IDLH) for NO_2, NO, and CO are 20, 100, and 1,200 ppm, respectively (NIOSH, 1994). Blasters working in underground or confined environments have long been aware of the hazards of these gases and must ensure adequate ventilation to quickly dilute them below harmful levels. In an effort to protect workers, extensive research has been done on the toxic fumes generated by the detonation of high explosives and many countries have test procedures and formal or informal requirements in place for the maximum permitted fumes production by a given amount of explosives (Streng, 1971, Karmakar and Banerjee, 1984, and International Society of Explosives Engineers, 1998).

Blasters at surface mines and construction operations have not been as concerned about blasting fumes as their counterparts in underground mines, believing that fumes would disperse in the open air (ISEE, 1998). Surface blasters, however, must be aware that toxic fumes have the potential to create hazards in their operations. Large surface mines may detonate up to two million pounds of blasting agent in a single shot. Some of the shots produce a product cloud colored red or orange by the presence of NO_2 (Barnhart, 2004), (Barnhart, 2003), and (Lawrence, 1995). At present it is not known whether the orange cloud contains toxic levels of NO_2 since there have been no published reports of direct measurements. However, in the interest of safety every blaster should assume that any blasting product cloud is unsafe to breathe. P21-36 cont.

For surface blasting operations, the CO in the gaseous products released immediately after a blast is not of great concern since CO is much less toxic than NO_2; the IDLH for CO is 1,200 ppm compared to 20 ppm for NO_2. For CO, the danger lies with the gas that remains in the ground after the blast. This CO will be released during loading operations or may migrate hundreds of feet through the ground and collect in confined spaces. Since 1988, there have been eighteen documented incidents of CO migration in the United States and Canada; the confined space typically being a home and in one case a sewer manhole vault (NIOSH, 1998), (Eltschlager, Schuss, Kovalchuk, 2001), (NIOSH, 2001), and (Santis, 2001). There have been thirty-nine suspected or medically verified carbon monoxide poisonings, with one fatality. In one incident in Kittanning, Pennsylvania, blasting fumes traveled 450 feet from a coal strip mine into a home, poisoning a couple and their baby. Fortunately, all three recovered following treatment in a hyperbaric chamber (Eltschlager et al. 2001) and (NIOSH, 2001).

Protecting Personnel

There are a number of ways to protect workers and neighbors from toxic fumes produced by blasting operations. Several of these are:

1. Minimize the quantity of toxic fumes produced,
2. Determine where the fumes may go so workers and neighbors may be moved out of the way,
3. Prevent the fumes from moving towards workers and neighbors,
4. Monitor the air near workers and neighbors so they can be relocated if fumes appear, and
5. Ventilating structures or confined spaces until CO falls below a hazardous concentration.

Each of these items will be discussed.

1. Minimize the quantity of toxic fumes produced.

Due to expansion and subsequent cooling of detonation product gasses, the combustion reactions are quenched before they can go to completion. The quenching freezes out CO and NO_x at concentrations higher than those expected for equilibrium. It is not possible to entirely prevent the release of CO and nitrogen oxides (NO_x) in blasting, but the quantities can be minimized. Some factors that lead to excessive CO and NO_x production are incorrectly formulated explosives, use of deteriorated explosives, reaction in diameters below the critical diameter, loading wet boreholes with explosives that are not water resistant, mixing of explosive with drill cuttings at the top and bottom of the hole, and poor confinement (ISEE, 1998), (Rowland III and Mainiero, 2000), (Roberts, Katsabanis, and deSouza, 1992), and (Engsbraten, 1980).

An explosive containing a stoichiometric mix of fuel and oxidizer minimizes the production of CO and NO_x. If there is an excess of fuel, detonation of the explosive or blasting agent will generate increased quantities of CO. If there is not enough fuel, detonation of the explosive or blasting agent will generate increased quantities of NO_x. Figures 1 and 2 illustrate the effect of ANFO fuel oil content on CO and NO_x production.

Explosive manufacturers are careful to balance the oxidizer and fuel in their explosive formulations to minimize fumes production. Blasters must insure the proper compositions for explosives and blasting agents mixed in the field. The performance of modern explosives is controlled by both the composition and the physical structure of the chemical mix. Explosives that are beyond the manufacturer-recommended shelf life or visibly deteriorated should not be used. As some explosives age, ingredients may leak out of the packaging, changing their compositions or their physical structure may break down. Either of these will result in an explosive that may not function as intended by the manufacturer and may produce excessive fumes. P21-36 cont.

Proper use of explosives and blasting agents is also very important in minimizing toxic fume production. For every explosive or blasting agent there is a minimum charge diameter, commonly referred to as critical diameter, below which it will not detonate properly. Below this critical diameter, the surroundings absorb sufficient energy from the explosion front to quench the detonation. Bulk-loaded blasting agents used in large-scale surface mine blasting do not detonate properly in boreholes of 1-inch diameter or less (ISEE, 1998). If the blasting agent is diluted by mixing with drill cuttings at the top or bottom of the borehole it may not detonate properly and excessive quantities of toxic fumes may be produced (Sapko, 2002). Similarly, the blasting agent may flow into cracks and crevices around the borehole where it may not detonate properly because the width of the cracks and crevices may be below the critical diameter. Incomplete detonation of the blasting agent leads to excessive toxic fumes (ISEE, 1998). Stemming plugs may be placed in the top and bottom of the blasthole to prevent mixture of the blasting agent with drill cuttings or rocks. Flow of the blasting agent into cracks and crevices may be prevented through the use of packaged product or borehole liners.

Production of excessive NO_x during blasting may also be caused by incomplete detonation as a result of loading wet boreholes with an explosive that is not water resistant. When wet boreholes are encountered, the water must be removed or they must be loaded with explosives or blasting agents that are packaged to keep out the water or with a product that is designed to be water resistant. ANFO is not water resistant and will not shoot properly in wet holes unless it is packaged to resist the water. Emulsion blasting agents are water resistant and may be loaded in bulk in wet boreholes. ANFO/emulsion blends exhibit water resistance to varying degrees depending on the ratio of ANFO to emulsion. The explosive supplier can recommend a mix ratio that is appropriate for a given application.

2. Determine where the blasting fumes are likely to go.

For surface blasting, much of the detonation products can be seen as a cloud of gas and dust coming off the blast. When a surface blast is initiated all workers should be positioned at locations outside of the likely path of the product cloud. Monitoring the wind direction immediately prior to the blast can be useful in accomplishing this. Some mines also have blasting plans that specify a blast should not be initiated if the wind will carry the cloud in the direction of neighbors off mine property. In addition, detonation product gases may be present in the muck pile and may also move into cracks and fissures in the ground. The gases move through the ground and may collect in a nearby confined space such as underground sewers, pipeline trenches, or basements of homes and businesses. As the gases move, CO will be the toxic gas of main interest since NO_2 and indirectly NO are absorbed by the soil. (NO oxidizes to NO_2 which is readily absorbed by the soil.)

In most cases the fumes will spread slowly through the ground in all directions. However, in some cases, pathways exist that allow the gases to move preferentially in one direction. Such pathways may be created by broken rock from an earlier blast (ISEE, 1998), a hill seam (a pathway caused by the movement of rock layers on a hillside) (Eltschlager et. al. 2001) and (NIOSH, 2001), underground utility lines, a French drain, or fractures in the ground (Harris, Sapko, and Mainiero, 2005). A review of available maps and examination of nearby structures should reveal utility lines or French drains that may serve as pathways. Identifying naturally occurring pathways would be much more difficult and it would be impractical to do this for every blast. However, once CO migration has been identified as a problem at a blast site, the blaster may want to consult a geologist for aid in identifying the pathway. Knowledge of the probable pathway will be useful in deciding how to minimize the likelihood of CO migration problems in future blasts. P21-36 cont.

3. Prevent the fumes from moving towards workers and neighbors.

For surface blasts there is no practical way to change the direction in which the product cloud will move; all a blaster can do is try to ensure that no one will be in the cloud's path. This is not the case for blasting fumes moving through the ground.

Techniques for mitigating the migration of CO were evaluated during blasting research conducted at the NIOSH Pittsburgh Research Laboratory (PRL) (Harris et al. 2005). When no actions were taken to prevent or mitigate CO in the ground, CO was measured for several days in monitoring boreholes after a blast. This has been demonstrated at the PRL site and also during reported incidents in the field. However, when the muck pile is immediately excavated after the shot, the levels of CO measured in monitoring holes are orders of magnitude lower and do not last for a long duration. When negative pressure was applied to a monitoring hole close to the blast location after a blast that was not excavated, the levels of CO measured were comparable with immediate excavation and were of a short duration as well. A reasonable and immediate source of negative pressure is the vacuum from the dust collection system of a drill rig. If a hole is drilled in the near proximity of the blast, the end of the drill boom can be located on top of the drilled hole and the dust collection system turned on for a period of time. A more extensive system may be constructed using several holes connected to a fan. These techniques need not be applied to every shot but rather only when a problem with CO migration is encountered.

Mucking will remove some gas that is trapped in the muck pile (Harris et al. 2005). Over time CO may migrate beyond the rubble zone and mucking will not remove any CO that has migrated beyond the rubble area. To be effective, mucking should be carried out as soon after the blast as possible.

Blasters' awareness is important in preventing future CO poisonings. Monitoring nearby enclosed spaces for toxic gases before and after blasting still remains the best recommendation for a first approach to intervention and triggering other actions.

4. Monitor the air near workers and neighbors so they can be relocated if fumes appear.

Studies at blasting sites in Amherst, New York (Harris and Mainiero, 2004) and Bristow, Virginia (Harris, Rowland III, and Mainiero, 2004) identified ways to protect people from the CO that may migrate from a blast into nearby homes or other confined spaces. Based on these studies, it was recommended that the blaster place CO monitors in occupied parts of nearby homes and businesses. CO monitors of the type sold in department and hardware stores for home use should be adequate if the instructions on the packaging are followed. These detectors are designed and tested to protect people in their homes from CO poisoning, whatever the source. Each CO migration occurrence is unique and depends on the route of entry, distance of site from CO generation source, and geology. Therefore, possible monitoring of nearby homes or businesses may continue for an extended period of time, from several hours to a few days. Monitoring should continue until CO from the blasting operation no longer enters the home or business. In recent years CO poisonings were most likely prevented by the early warning of a homeowner-installed CO detector. Because of early warning, the source of CO was determined and affected homes were evacuated and closely monitored before anyone could become ill. To the best of our knowledge, no one has had to be treated for blasting-related CO poisoning since the western Pennsylvania incident in April, 2000 (Eltschlager et al. 2001) and (NIOSH, 2001).

P21-36 cont.

It is important that workers follow the confined space requirements of the Occupational Safety and Health Administration when entering a manhole vault, trench, or other confined space near a blasting site (OSHA, 2005). In 1998 a worker was killed and two injured when they entered a manhole vault 45 minutes after a nearby blast. No one had checked the vault for toxic gases prior to entry. The vault contained toxic levels of CO (NIOSH, 1998).

5. Ventilate structures or confined spaces until CO falls below a hazardous concentration.

Once CO is detected in a confined space near a blast site, no one should reenter until safety personnel have stated that it is safe to do so. Local firefighters and other emergency response personnel may be called to assist. These people have been trained and are equipped to deal with toxic atmospheres in homes, businesses, and other confined spaces, and will take appropriate action.

Conclusion

The major toxic gases produced by detonation of commercial explosives and blasting agents are CO and NO_x. These gases may migrate through the ground into the basements of nearby homes and businesses, trenches, manhole vaults, and other confined spaces. NO_x does not migrate through the ground because it is absorbed by the soil as the gases travel. However, NO_x is a concern in surface blasting because it is very toxic; much more toxic that CO. Excessive NO_x production at a blasting site may be evidenced by the presence of an orange or red cloud produced by the blast. The boreholes must be properly loaded to minimize the production of NO_x. To the best of the authors' knowledge, no one knows the concentrations of NO_x in a blasting product cloud but it is best to err on the side of safety and assume the cloud is toxic. People should be kept out of contact with the product cloud. Carbon monoxide is a serious concern because it is not absorbed on passage through the ground. Carbon monoxide may travel up to several hundred feet and collect at toxic levels in a confined space. Carbon monoxide is odorless so there is no obvious indication that a hazard exists. This hazard may be dealt with at several levels. A blaster should use explosives and blasting agents in the manner specified by the manufacturer to minimize the quantity of CO produced. The blaster should attempt to identify any pathways by which gases produced by the detonation may travel from the blast site into homes, businesses, or other confined spaces. If a blaster is aware that there is a likelihood of CO migrating into occupied spaces he/she may minimize the hazard by excavating the blasted rock soon after the blast or may connect a fan to a borehole near the blast to pull the CO out of the ground. The blaster may place home-type CO monitors in homes or businesses near the blast site so occupants will be alerted if CO concentrations rise to unsafe levels. OHSA's confined space regulations must be followed when a worker enters a trench, manhole vault, or other confined space. Firefighters or other emergency personnel may be called in to ventilate any homes or businesses where CO has been detected and determine when a CO hazard no longer exists.

It is very difficult to predict when CO produced by a blast will migrate into homes, businesses, and other confined spaces. It would be impractical to do this for every blast. At present the best defense is to ensure that people are alerted if the air they are breathing contains toxic levels of CO.

P21-36 cont.

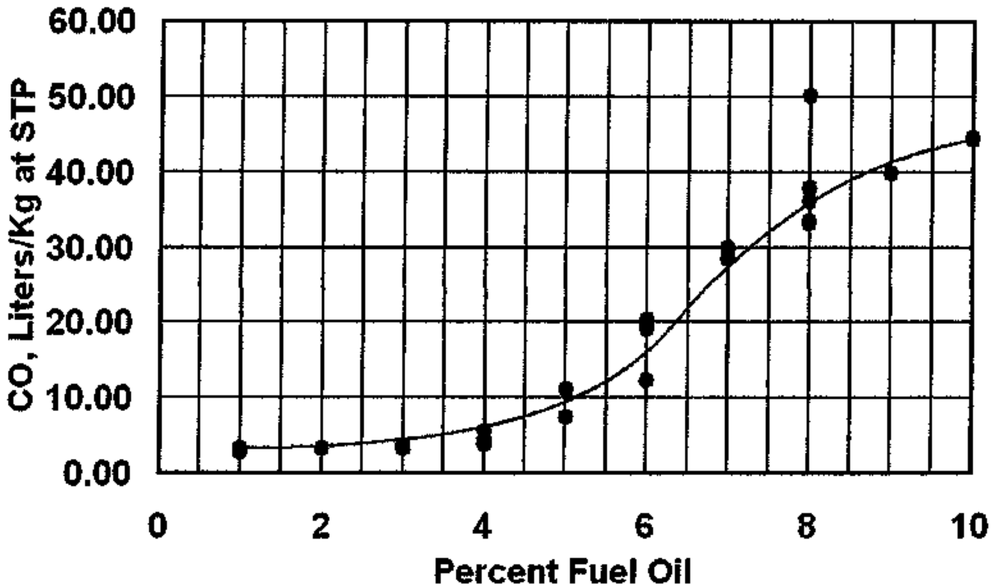

Figure 1. The effect of fuel oil content on the quantity of carbon monoxide produced by detonating ANFO. (Rowland III and Mainiero, 2000)

P21-36 cont.

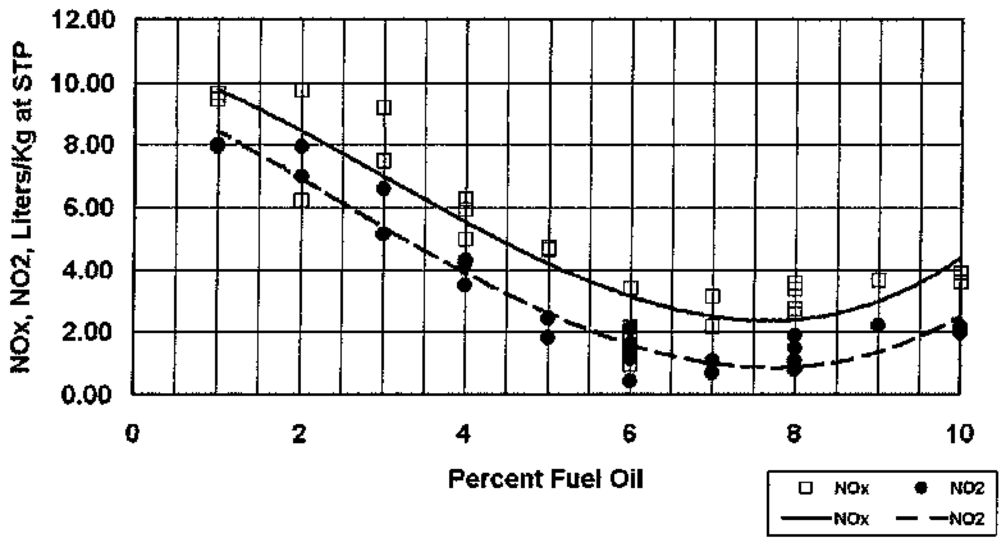

Figure 2. The effect of fuel oil content on the quantity of nitrogen oxides produced by detonating ANFO. (Rowland III and Mainiero, 2000)

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Decline of the North American Avifauna

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Abstract: Species extinctions have defined the global biodiversity crisis, but extinction begins with loss in abundance of individuals that can result in compositional and functional changes of ecosystems. Using multiple and independent monitoring networks, we report population losses across much of the North American avifauna over 48 years, including once common species and from most biomes. Integration of range-wide population trajectories and size estimates indicates a net loss approaching 3 billion birds, or 29% of 1970 abundance. A continent-wide weather radar network also reveals a similarly steep decline in biomass passage of migrating birds over a recent 10-year period. This loss of bird abundance signals an urgent need to address threats to avert future avifaunal collapse and associated loss of ecosystem integrity, function and services.

One Sentence Summary: Cumulative loss of nearly three billion birds since 1970, across most North American biomes, signals a pervasive and ongoing avifaunal crisis.

P21-36 cont.

Main Text:

Slowing the loss of biodiversity is one of the defining environmental challenges of the 21st century (*1–5*). Habitat loss, climate change, unregulated harvest, and other forms of human-caused mortality (*6, 7*) have contributed to a thousand-fold increase in global extinctions in the Anthropocene compared to the presumed prehuman background rate, with profound effects on ecosystem functioning and services (*8*). The overwhelming focus on species extinctions, however, has underestimated the extent and consequences of biotic change, by ignoring the loss of abundance within still-common species and in aggregate across large species assemblages (*2, 9*). Declines in abundance can degrade ecosystem integrity, reducing vital ecological, evolutionary, economic, and social services that organisms provide to their environment (*8, 10–15*). Given the current pace of global environmental change, quantifying change in species abundances is essential to assess ecosystem impacts. Evaluating the magnitude of declines requires effective long-term monitoring of population sizes and trends, data which are rarely available for most taxa.

Birds are excellent indicators of environmental health and ecosystem integrity (*16, 17*), and our ability to monitor many species over vast spatial scales far exceeds that of any other animal group. We evaluated population change for 529 species of birds in the continental United States and Canada (76% of breeding species), drawing from multiple standardized bird-monitoring datasets, some of which provide close to fifty years of population data. We integrated range-wide estimates of population size and 48-year population trajectories, along with their associated uncertainty, to quantify net change in numbers of birds across the avifauna over recent decades (*18*). We xalso used a network 143 weather radars (NEXRAD) across the contiguous U.S. to estimate long-term changes in nocturnal migratory passage of avian biomass through the airspace in spring from 2007 to 2017. The continuous operation and broad coverage of NEXRAD provide an automated and standardised monitoring tool with unrivaled temporal and spatial extent (*19*). Radar measures cumulative passage across all nocturnally migrating species, many of which breed in areas north of the contiguous U.S. that are poorly monitored by avian surveys. Radar thus expands the area and the proportion of the migratory avifauna that is sampled relative to ground surveys.

Results from long-term surveys, accounting for both increasing and declining species, reveal a net loss in total abundance of 2.9 billion (95% CI = 2.7-3.1 billion) birds across almost all biomes, a reduction of 29% (95% CI = 27-30%) since 1970 (Figure 1; Table 1). Analysis of NEXRAD data indicate a similarly steep decline in nocturnal passage of migratory biomass, a reduction of 13.6 ± 9.1% since 2007 (Figure 2A). Reduction in biomass passage occurred across the eastern U.S. (Figure 2 C,D), where migration is dominated by large numbers of temperate- and boreal-breeding songbirds; we observed no consistent trend in the Central or Pacific flyway regions (Figure 2B,C,D, Table S5). Two completely different and independent monitoring techniques thus signal major population loss across the continental avifauna.

Species exhibiting declines (57%, 303/529) based on long-term survey data span diverse ecological and taxonomic groups. Across breeding biomes, grassland birds showed the largest magnitude of total population loss since 1970—more than 700 million breeding individuals across 31 species— and the largest proportional loss (53%); 74% of grassland species are declining. (Figure 1; Table 1). All forest biomes experienced large avian loss, with a cumulative reduction of more than 1 billion birds. Wetland birds represent the only biome to show an overall

P21-36 cont.

net gain in numbers (13%), led by a 56% increase in waterfowl populations (Figure 3, Table 1). Surprisingly, we also found a large net loss (63%) across 10 introduced species (Figure 3D,E, Table 1).

A total of 419 native migratory species experienced a net loss of 2.5 billion individuals, whereas 100 native resident species showed a small net increase (26 million). Species overwintering in temperate regions experienced the largest net reduction in abundance (1.4 billion), but proportional loss was greatest among species overwintering in coastal regions (42%), southwestern aridlands (42%), and South America (40%) (Table 1; Figure S1). Shorebirds, most of which migrate long distances to winter along coasts throughout the hemisphere, are experiencing consistent, steep population loss (37%).

More than 90% of the total cumulative loss can be attributed to 12 bird families (Figure 3A), including sparrows, warblers, blackbirds, and finches. Of 67 bird families surveyed, 38 showed a net loss in total abundance, whereas 29 showed gains (Figure 3B), indicating recent changes in avifaunal composition (Table S2). While not optimized for species-level analysis, our model indicates 19 widespread and abundant landbirds (including 2 introduced species) each experienced population reductions of >50 million birds (Data S1). Abundant species also contribute strongly to the migratory passage detected by radar (*19*), and radar-derived trends provide a fully independent estimate of widespread declines of migratory birds.

P21-36 cont.

Our study documents a long-developing but overlooked biodiversity crisis in North America—the cumulative loss of nearly 3 billion birds across the avifauna. Population loss is not restricted to rare and threatened species, but includes many widespread and common species that may be disproportionately influential components of food webs and ecosystem function. Furthermore, losses among habitat generalists and even introduced species indicate that declining species are not replaced by species that fare well in human-altered landscapes. Increases among waterfowl and a few other groups (e.g. raptors recovering after the banning of DDT) are insufficient to offset large losses among abundant species (Figure 3). Importantly, our population loss estimates are conservative since we estimated loss only in breeding populations. The total loss and impact on communities and ecosystems could be even higher outside the breeding season if we consider the amplifying effect of "missing" reproductive output from these lost breeders.

Extinction of the Passenger Pigeon (*Ectopistes migratorius*), once likely the most numerous bird on the planet, provides a poignant reminder that even abundant species can go extinct rapidly. Systematic monitoring and attention paid to population declines could have alerted society to its pending extinction (*20*). Today, monitoring data suggest that avian declines will likely continue without targeted conservation action, triggering additional endangered species listings at tremendous financial and social cost. Moreover, because birds provide numerous benefits to ecosystems (e.g., seed dispersal, pollination, pest control) and economies (47 million people spend 9.3 billion U.S. dollars per year through bird-related activities in the U.S. (*21*)), their population reductions and possible extinctions will have severe direct and indirect consequences (*10*, *22*). Population declines can be reversed, as evidenced by the remarkable recovery of waterfowl populations under adaptive harvest management (*23*) and the associated allocation of billions of dollars devoted to wetland protection and restoration, providing a model for proactive conservation in other widespread native habitats such as grasslands.

Steep declines in North American birds parallel patterns of avian declines emerging globally (*14*, *15*, *22*, *24*). In particular, depletion of native grassland bird populations in North America, driven by habitat loss and more toxic pesticide use in both breeding and wintering areas (*25*), mirrors loss of farmland birds throughout Europe and elsewhere (*15*). Even declines among introduced species match similar declines within these same species' native ranges (*26*). Agricultural intensification and urbanization have been similarly linked to declines in insect diversity and biomass (*27*), with cascading impacts on birds and other consumers (*24*, *28*, *29*). Given that birds are one of the best monitored animal groups, birds may also represent the tip of the iceberg, indicating similar or greater losses in other taxonomic groups (*28*, *30*).

Pervasiveness of avian loss across biomes and bird families suggests multiple and interacting threats. Isolating spatio-temporal limiting factors for individual species and populations will require additional study, however, since migratory species with complex life histories are in contact with many threats throughout their annual cycles. A focus on breeding season biology hampers our ability to understand how seasonal interactions drive population change (*31*), although recent continent-wide analyses affirm the importance of events during the non-breeding season (*19*, *32*). Targeted research to identify limiting factors must be coupled with effective policies and societal change that emphasize reducing threats to breeding and non-breeding habitats and minimizing avoidable anthropogenic mortality year-round. Endangered species legislation and international treaties, such as the 1916 Migratory Bird Treaty between Canada and the United States, have prevented extinctions and promoted recovery of once-depleted bird species. History shows that conservation action and legislation works. Our results signal an urgent need to address the ongoing threats of habitat loss, agricultural intensification, coastal disturbance, and direct anthropogenic mortality, all exacerbated by climate change, to avert continued biodiversity loss and potential collapse of the continental avifauna.

P21-36 cont.

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Table S2.

Net change in abundance across North American bird families, 1970-2017. Taxonomy and common names of families follow (*99*); families listed in order of greatest decline. Net change in abundance expressed in millions of breeding individuals, with upper and lower 90% credible intervals (CI) shown. Percentage of species in each group with negative trend trajectories also noted.

Family	Common Name	N Spp	Net Abundance Change (Millions) & 90% CI			Percent Change & 90% CIs			% Spp in Decline
			Change	UC90	LC90	Change	LC90	UC90	
Passerellidae	New World Sparrows	38	-862.0	-925.7	-798.6	-38.0%	-40.1%	-35.8%	87%
Parulidae	New World Warblers	44	-617.5	-737.8	-509.0	-37.6%	-42.0%	-33.0%	64%
Icteridae	New World Blackbirds	18	-439.8	-467.8	-412.4	-44.2%	-45.9%	-42.4%	83%
Passeridae	Old World Sparrows	2	-331.0	-374.6	-290.2	-81.1%	-82.7%	-79.4%	50%
Alaudidae	Larks	1	-182.0	-207.2	-157.8	-67.4%	-70.9%	-63.7%	100%
Fringillidae	Finches and Allies	13	-144.6	-189.2	-91.9	-36.7%	-45.9%	-23.8%	62%
Tyrannidae	Tyrant Flycatchers	26	-88.2	-107.3	-69.5	-20.1%	-23.7%	-16.2%	50%
Sturnidae	Starlings	1	-83.2	-94.7	-72.6	-49.3%	-52.4%	-46.0%	100%
Turdidae	Thrushes	11	-77.6	-114.2	-38.1	-10.1%	-14.6%	-5.0%	55%
Hirundinidae	Swallows	8	-60.8	-86.7	-31.4	-22.1%	-30.1%	-11.9%	75%
Caprimulgidae	Nightjars	5	-39.3	-44.0	-34.9	-55.0%	-58.0%	-51.5%	60%
Calcariidae	Longspurs	5	-39.3	-79.0	34.3	-31.2%	-60.5%	26.8%	80%
Odontophoridae	New World Quail	5	-21.1	-32.6	-10.0	-51.6%	-61.2%	-35.7%	80%
Laridae	Gulls, Terns	22	-20.1	-27.6	-13.3	-50.5%	-58.4%	-39.9%	73%
Apodidae	Swifts	4	-19.2	-21.4	-17.1	-65.3%	-68.1%	-61.6%	100%
Trochilidae	Hummingbirds	8	-18.9	-36.0	-2.2	-17.0%	-27.7%	-2.6%	63%
Mimidae	Thrashers and Allies	10	-18.3	-22.1	-14.6	-19.4%	-22.9%	-16.0%	80%
Regulidae	Kinglets	2	-17.9	-47.6	12.1	-7.1%	-17.7%	5.0%	50%
Scolopacidae	Sandpipers	32	-15.4	-19.9	-11.1	-38.4%	-46.7%	-28.6%	72%
Cardinalidae	Cardinals and Allies	14	-10.8	-20.6	-1.0	-3.3%	-6.3%	-0.3%	43%
Laniidae	Shrikes	2	-10.3	-11.6	-9.0	-69.0%	-72.2%	-65.7%	100%
Cuculidae	Cuckoos	4	-8.9	-10.5	-7.4	-47.9%	-53.6%	-41.5%	75%
Motacillidae	Pipits, Wagtails	2	-8.1	-12.7	-2.4	-29.0%	-44.0%	-8.6%	100%
Corvidae	Jays, Crows	16	-6.6	-11.8	-1.2	-6.5%	-11.4%	-1.1%	69%
Phylloscopidae	Leaf Warblers	1	-6.4	-16.3	0.7	-50.4%	-76.8%	5.6%	100%
Paridae	Tits, Chickadees	10	-5.3	-11.4	0.8	-4.9%	-10.2%	0.7%	70%
Alcidae	Auks	11	-4.6	-16.8	9.0	-15.9%	-45.8%	33.4%	45%
Icteriidae	Yellow-breasted Chat	1	-3.9	-5.4	-2.5	-21.2%	-28.0%	-13.9%	100%
Ardeidae	Herons	12	-3.4	-4.4	-2.4	-28.0%	-34.1%	-21.2%	58%
Remizidae	Penduline-Tits	1	-2.6	-4.0	-1.4	-42.0%	-53.2%	-28.0%	100%
Charadriidae	Plovers	8	-1.9	-3.1	-0.9	-38.6%	-47.4%	-32.0%	88%

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Shorebird Flyway Population Database	2012	Breeding population	Compilation of best available estimates	Continentwide for each species	0	45	(*69*, *70*)
Birds of North America (BNA) species accounts	1970-2007	Breeding adults	Variable: best for each species	Continentwide for each species	0	33	(*71*)
Avian Conservation Assessment Database (ACAD)	Variable	Breeding adults	Variable: compiled from other sources	North American estimates	0	17	(*46*)

[*] Estimates for 344 landbird species provided by (*35*); identical methods applied to 55 additional non-landbird species in the present study.

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Alcedinidae	Kingfishers	1	-1.6	-1.9	-1.3	-47.8%	-51.5%	-44.0%	100%
Procellariidae	Petrels	1	-1.0	-3.8	3.7	-33.8%	-79.3%	104.4%	100%
Aegithalidae	Long-tailed Tits	1	-0.9	-1.4	-0.3	-28.4%	-42.5%	-10.7%	100%
Podicipedidae	Grebes	6	-0.7	-2.6	1.9	-10.9%	-35.8%	35.7%	50%
Sylviidae	Sylviid Warblers	1	-0.6	-1.1	-0.3	-27.7%	-38.0%	-15.4%	100%
Cinclidae	Dippers	1	-0.03	-0.05	0.00	-15.5%	-27.2%	-2.0%	100%
Aramidae	Limpkin	1	0.00	-0.02	0.02	-15.0%	-62.1%	89.0%	100%
Ciconiidae	Storks	1	0.01	0.00	0.02	77.6%	18.3%	166.9%	0%
Haematopodidae	Oystercatchers	2	0.01	0.01	0.02	123.7%	59.5%	218.0%	0%
Falconidae	Falcons, Caracaras	6	0.03	-0.49	0.63	0.5%	-9.3%	12.6%	33%
Anhingidae	Anhingas	1	0.03	0.02	0.04	109.1%	66.3%	164.5%	0%
Psittacidae	Parrots	1	0.1	0.0	0.3	>1000%	>1000%	>1000%	0%
Tytonidae	Barn Owls	1	0.1	0.1	0.2	211.6%	132.6%	317.8%	0%
Recurvirostridae	Avocets, Stilts	2	0.2	0.0	0.5	57.5%	16.2%	174.6%	0%
Ptiliogonatidae	Silky Flycatchers	1	0.3	0.0	0.7	26.4%	-3.8%	65.2%	0%
Sulidae	Boobies	1	0.4	0.2	0.7	988.6%	497.0%	1891.7%	0%
Gaviidae	Loons	3	0.4	0.1	0.8	32.6%	11.7%	60.7%	33%
Pandionidae	Osprey	1	0.4	0.3	0.5	304.4%	248.4%	370.3%	0%
Rallidae	Rails, Coots	7	0.6	-1.9	4.2	6.2%	-18.1%	40.5%	57%
Gruidae	Cranes	1	0.7	0.5	0.9	914.5%	743.0%	1119.1%	0%
Pelecanidae	Pelicans	2	0.7	0.5	1.2	810.4%	534.6%	1214.2%	0%
Phalacrocoracidae	Cormorants	4	0.8	0.4	1.3	152.3%	73.1%	267.3%	50%
Strigidae	Owls	11	1.7	0.5	3.4	15.9%	4.6%	30.1%	64%
Certhiidae	Treecreepers	1	2.5	1.5	3.7	33.6%	20.8%	47.9%	0%
Threskiornithidae	Ibises, Spoonbills	4	2.9	1.4	6.3	332.8%	167.3%	639.4%	0%
Columbidae	Doves, Pigeons	7	3.6	-17.4	43.3	1.9%	-9.0%	23.1%	57%
Accipitridae	Hawks	16	5.5	5.0	6.0	78.9%	71.8%	86.4%	19%
Bombycillidae	Waxwings	2	8.0	2.1	14.6	13.8%	3.6%	25.0%	50%
Cathartidae	New World Vultures	2	9.4	8.3	10.6	265.3%	238.7%	293.6%	0%
Troglodytidae	Wrens	10	13.3	6.5	20.7	13.8%	6.8%	21.5%	40%
Picidae (including "Woody")	Woodpeckers	21	13.6	10.2	17.2	18.5%	13.9%	23.4%	33%
Sittidae	Nuthatches	4	14.4	11.0	18.4	66.6%	50.5%	85.0%	50%
Phasianidae	Grouse and Allies	12	15.2	2.9	36.6	24.3%	4.5%	56.4%	33%
Polioptilidae	Gnatcatchers	2	31.9	12.7	54.5	15.6%	6.2%	26.3%	0%
Anatidae	Waterfowl	42	34.8	24.5	48.3	56.1%	37.9%	79.5%	43%
Vireonidae	Vireos	12	89.9	78.6	102.1	53.6%	46.7%	60.7%	17%

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Table S3.

GAM spatial trend analysis and model comparison. AIC gives Akaike's An Information Criterion. df gives degrees of freedom. Models significantly different according to a Chi-squared likelihood ratio test are labelled by different letters (a,b). Change in biomass traffic was calculated as a spatial mean of the multiplication of spatial trend and kriging-interpolated biomass passage. Changes in biomass traffic are based on spatial averages of the GAM predictions over the contiguous US, as detailed in the text. From left to right: % / yr = annual rate of decline in seasonal migration traffic, % = decline over the period 2007-2017, loss in seasonal migration traffic, p = significance of the te(lon,lat):year trend term. See Figure S7 for plots of the estimated smoothed spatial trend.

					change in biomass traffic 2007-2017			
Model*	Formula	AIC	df		% / yr	%	10^5 birds/km	p
1	index ~ te(lon,lat) + te(lon,lat):year + dualpol†	337	10	a	-1.2 ± 0.7	-11.6 ± 5.9	-1.4 ± 1.7	<0.0001
2	index ~ te(lon,lat) + te(lon,lat):year + mode‡	338	11	a	-1.6 ± 0.8	-14.8 ± 7.2	-1.8 ± 1.9	<0.0001
3	Index ~ te(lon,lat) + te(lon,lat):year + superres§	342	10	b	-2.9 ± 0.5	-25.6 ± 4.2	-3.2 ± 2.8	<0.0001
4	index ~ te(lon,lat) + te(lon,lat):year	360	9	c	-3.3 ± 0.6	-28.7 ± 4.1	-3.7 ± 3.1	<0.0001
1-4	(model average)				-1.5 ± 1.0	-13.6 ± 9.1	-1.7 ± 1.8	

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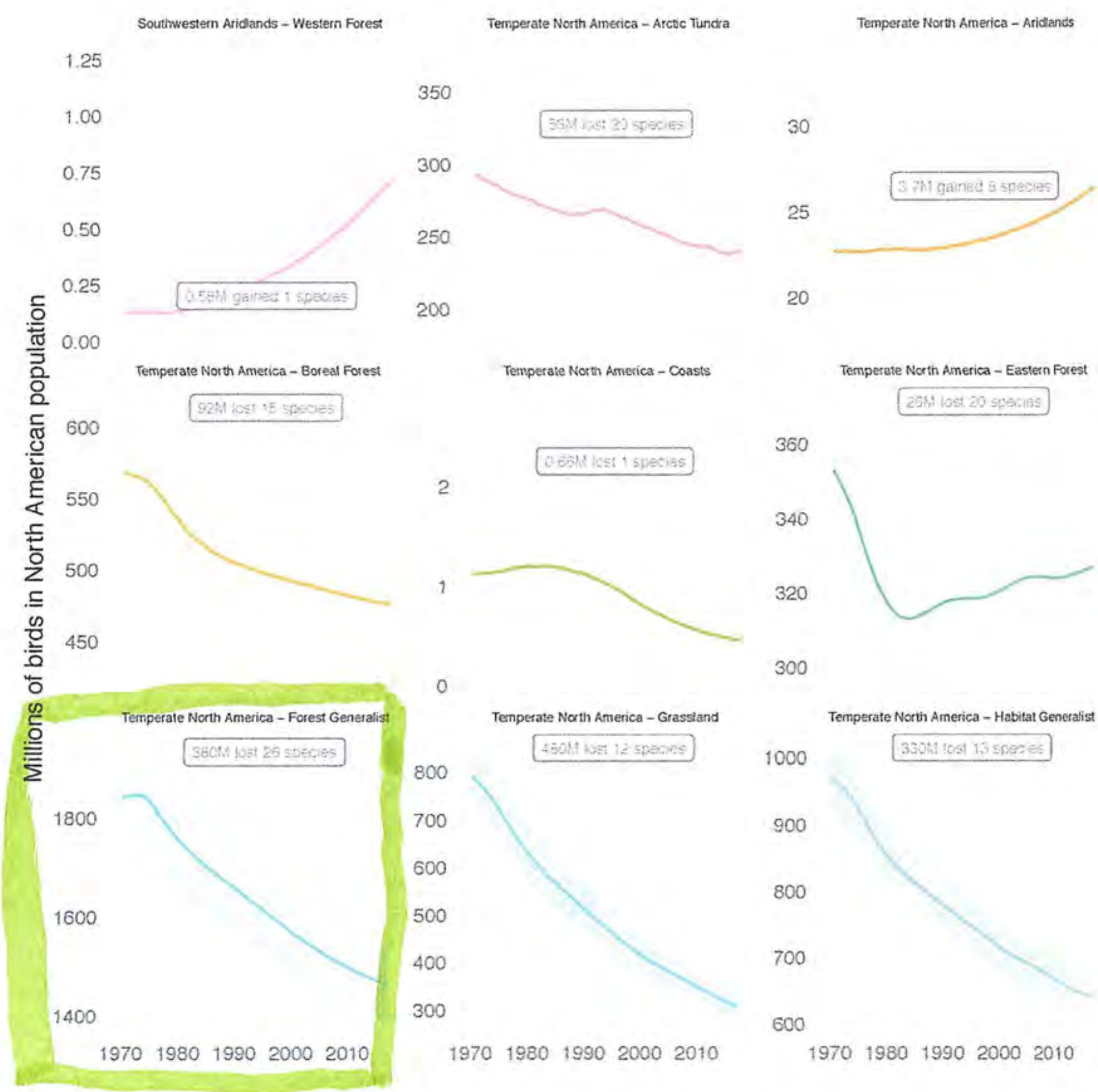
*Family=Gamma(link=log)
‡mode is a factor variable with levels "legacy", "superres" and "dualpol", distinguishing the three time periods in which the radar acquired legacy, super-resolution and dual-polarization data. Note that the dual-polarization upgrade occurred after the super-resolution upgrade, and dual-polarization data includes super-resolution.
†dualpol is a logical variable that is true after the dual-polarization upgrade, and false before
§superres is a logical variable that is true after the superresolution upgrade, and false before



P21-36 cont.

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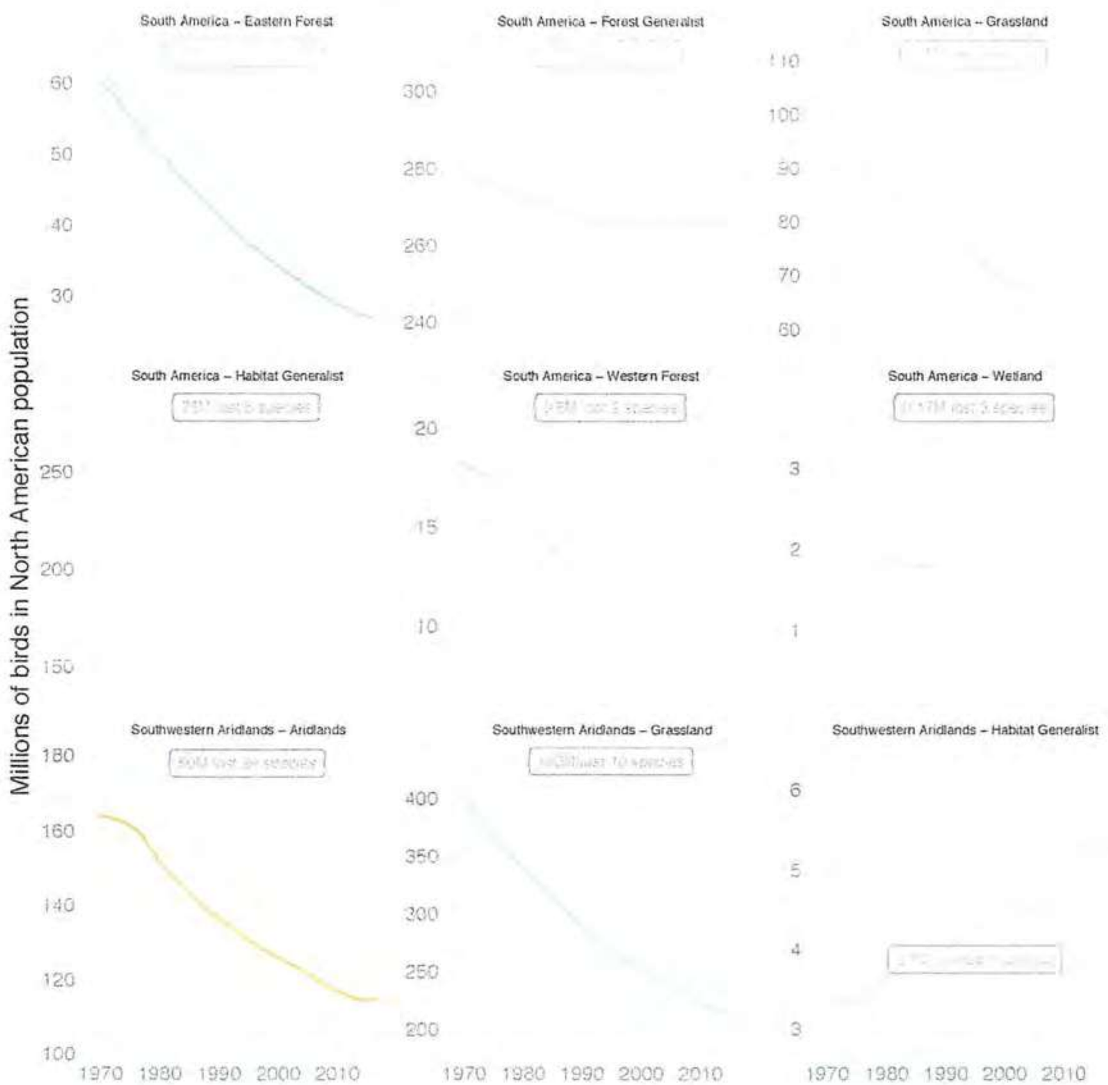

P21-36 cont.

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be published in future versions of the Avian Conservation Assessment Database (http://pif.birdconservancy.org/ACAD/).

Supplementary Materials:

Materials and Methods

Figures S1-S7

Tables S1-S5

External Databases S1-S2

References (*33-100*)

P21-36 cont.

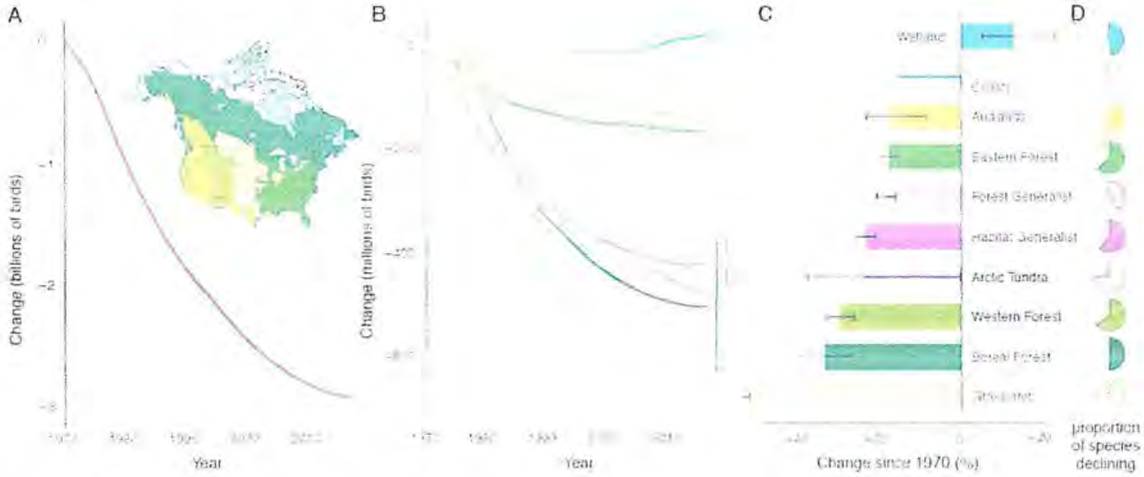
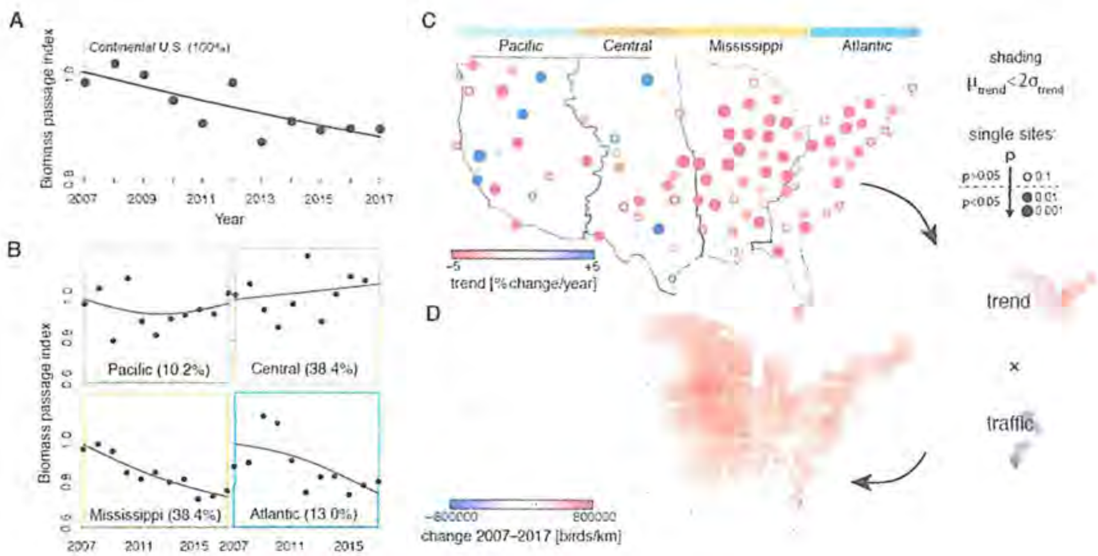


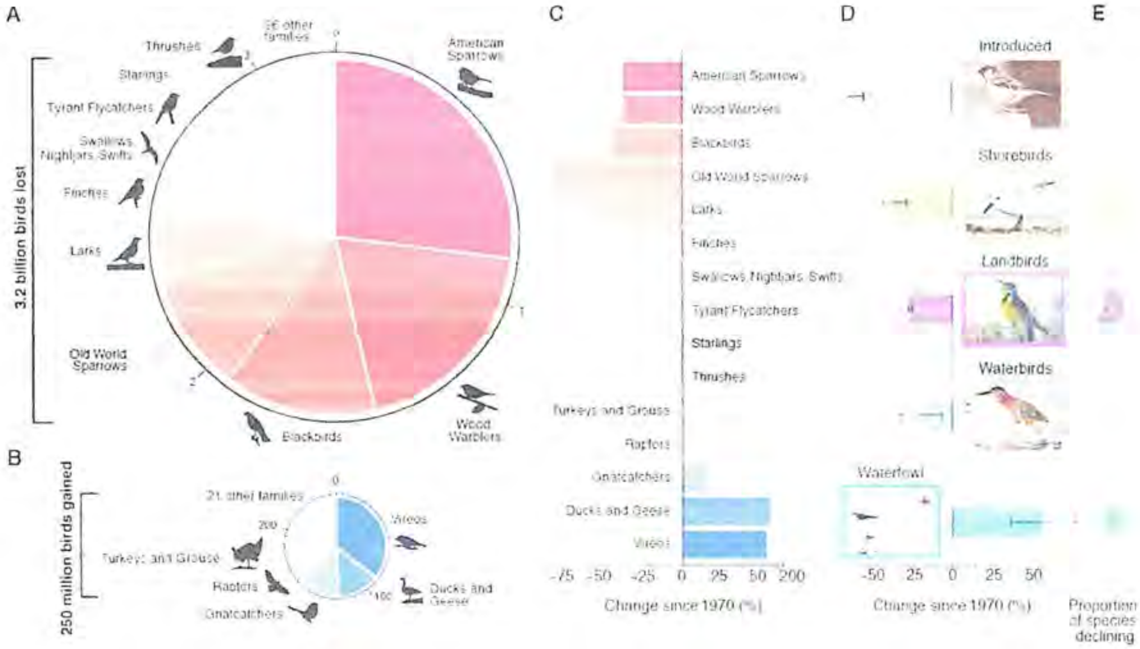
Fig. 1. Net population change in North American birds. (**A**) By integrating population size estimates and trajectories for 529 species (*18*), we show a net loss of 2.9 billion breeding birds across the continental avifauna since 1970. Gray shading represents ± 95% credible intervals around total estimated loss. Map shows color-coded breeding biomes based on Bird Conservation Regions and land cover classification (*18*). (**B**) Net loss of abundance occurred across all major breeding biomes except wetlands (see Table 1). (**C**) Proportional net population change relative to 1970, ±95% C.I. (**D**) Proportion of species declining in each biome.

P21-36 cont.



P21-36 cont.

Fig. 2. NEXRAD radar monitoring of nocturnal bird migration across the contiguous U.S. (A) Annual change in biomass passage for the full continental U.S. (black) and **(B)** the Pacific (green), Central (brown), Mississippi (yellow), and Atlantic (blue) flyways (borders indicated in panel C), with percentage of total biomass passage (migration traffic) for each flyway indicated; Declines are significant only for the full U.S. and the Mississippi and Atlantic flyways (Table S3-5). **(C)** Single-site trends in seasonal biomass passage at 143 NEXRAD stations in spring (1 Mar – 1 Jul), estimated for the period 2007-2017. Darker red colors indicate higher declines and loss of biomass passage, while blue colors indicate biomass increase. Circle size indicates trend significance, with closed circles being significant at a 95% confidence level. Only areas outside gray shading have a spatially consistent trend signal separated from background variability. **(D)** 10-year cumulative loss in biomass passage, estimated as the product of a spatially-explicit (generalized additive model) trend, times the surface of average cumulative spring biomass passage.



P21-36 cont.

Fig. 3. Gains and losses across the North American avifauna over the last half century. **(A)** Bird families were categorized as having a net loss (red) or gain (blue). Total loss of 3.2 billion birds occurred across 38 families; each family with losses greater than 50 million individuals is shown as a proportion of total loss, including two introduced families (gray). Swallows, nightjars, and swifts together show loss within the aerial insectivore guild. (**B**) 29 families show a total gain of 250 million individual birds; the five families with gains greater than 15 million individuals are shown as a proportion of total gain. Four families of raptors are shown as a single group. Note that combining total gain and total loss yields a net loss of 2.9 billion birds across the entire avifauna. (**C**) For each individually represented family in B and C, proportional population change within that family is shown. See Table S2 for statistics on each individual family. (**D**) *Left*, proportion of species with declining trends and, *Right*, percentage population change among introduced and each of four management groups (*18*). A representative species from each group is shown (top to bottom, house sparrow, *Passer domesticus*; sanderling, *Calidris alba*; western meadowlark, *Sturnella neglecta*; green heron, *Butorides virescens*; and snow goose, *Anser caerulescens*).

Species Group	Number of Species	Net Abundance Change (Millions) & 95% CI			Percent Change & 95% CIs			Proportion Species in Decline
		Change	LC95	UC95	Change	LC95	UC95	
Species Summary								
All N. Am. Species	529	-2,911.9	-3,097.5	-2,732.9	-28.8%	-30.2%	-27.3%	57.3%
All Native Species	519	-2,521.0	-2,698.5	-2,347.6	-26.5%	-28.0%	-24.9%	57.4%
Introduced Species	10	-391.6	-442.3	-336.6	-62.9%	-66.5%	-56.4%	50.0%
Native Migratory Species	419	-2,547.7	-2,723.7	-2,374.5	-28.3%	-29.8%	-26.7%	58.2%
Native Resident Species	100	26.3	7.3	46.9	5.3%	1.4%	9.6%	54.0%
Landbirds	357	-2,516.5	-2,692.2	-2,346.0	-27.1%	-28.6%	-25.5%	58.8%
Shorebirds	44	-17.1	-21.8	-12.6	-37.4%	-45.0%	-28.8%	68.2%
Waterbirds	77	-22.5	-37.8	-6.3	-21.5%	-33.1%	-6.2%	51.9%
Waterfowl	41	34.8	24.5	48.3	56.0%	37.9%	79.4%	43.9%
Aerial Insectivores	26	-156.8	-183.8	-127.0	-31.8%	-36.4%	-26.1%	73.1%
Breeding Biome								
Grassland	31	-717.5	-763.9	-673.3	-53.3%	-55.1%	-51.5%	74.2%
Boreal forest	34	-500.7	-627.1	-381.0	-33.1%	-38.9%	-26.9%	50.0%
Forest Generalist	40	-482.2	-552.5	-413.4	-18.1%	-20.4%	-15.8%	40.0%
Habitat Generalist	38	-417.3	-462.1	-371.3	-23.1%	-25.4%	-20.7%	60.5%
Eastern Forest	63	-166.7	-185.8	-147.7	-17.4%	-19.2%	-15.6%	63.5%
Western forest	67	-139.7	-163.8	-116.1	-29.5%	-32.8%	-26.0%	64.2%
Arctic Tundra	51	-79.9	-131.2	-0.7	-23.4%	-37.5%	-0.2%	56.5%
Aridlands	62	-35.6	-49.7	-17.0	-17.0%	-23.0%	-8.1%	56.5%
Coasts	38	-6.1	-18.9	8.5	-15.0%	-39.4%	21.9%	50.0%
Wetlands	95	20.6	8.3	35.3	13.0%	5.1%	23.0%	47.4%
Nonbreeding Biome								
Temperate North America	192	-1,413.0	-1,521.5	-1,292.3	-27.4%	-29.3%	-25.3%	55.2%
South America	41	-537.4	-651.1	-432.6	-40.1%	-45.2%	-34.6%	75.6%
Southwestern Aridlands	50	-238.1	-261.2	-215.6	-41.9%	-44.5%	-39.2%	74.0%
Mexico-Central America	76	-155.3	-187.8	-122.0	-15.5%	-18.3%	-12.6%	52.6%
Widespread Neotdropical	22	-126.0	-171.2	-86.1	-26.8%	-33.4%	-19.3%	45.5%
Widespread	60	-31.6	-63.1	1.6	-3.7%	-7.4%	0.2%	43.3%
Marine	26	-16.3	-29.7	-1.2	-30.8%	-49.1%	-2.5%	61.5%
Coastal	44	-11.0	-14.9	-6.7	-42.0%	-51.8%	-26.7%	68.2%
Caribbean	8	-6.0	1.4	-15.7	12.1%	-2.8%	31.7%	25.0%

Table 1. Net change in abundance across the North American avifauna, 1970-2017. Species are grouped into native and introduced species, management groups (landbirds, shorebirds, waterbirds, waterfowl), major breeding biomes, and nonbreeding biomes (see Data S1 in (*18*) for

P21-36 cont.

assignments and definitions of groups and biomes). Net change in abundance is expressed in millions of breeding individuals, with upper and lower 95% credible intervals (CI) shown. Percentage of species in each group with negative trend trajectories are also noted. Rows colored in red indicate declines and loss; blue rows indicate gains.

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Science
AAAS

Supplementary Materials for

Decline of the North American Avifauna

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This PDF file includes:

Other Supplementary Materials for this manuscript include the following:

Data S1
Data S2

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Materials and Methods

General approach to estimating long-term net population change

We compiled estimates of long-term population change and current population size for 529 species from a variety of sources (Table S1), as described below. For every species, we selected the most appropriate data sources and assessed the quality of population size and change estimates, based on sampling methodology, range coverage, and precision of the estimates. Our primary source of population change estimates was the North American Breeding Bird Survey (BBS) (*33*), which provides conservation assessment information for hundreds of bird species (*34*). For our current analysis we relied on the full trajectory of population change for each species, which we define as the scaled time-series of annual population indices derived from the underlying trend model. Note that using the full trajectory provides much more information on population change than the simple trend value (% change/yr) usually associated with survey data. We used Partners in Flight's (PIF) recently published population size estimates for North American landbirds (*35*), and we supplemented these with data from several other surveys (Table S1). Values for all U.S./Canada population size estimates, along with their sources, are provided in Data S1.

After compiling population size and trajectory estimates for all species (Data S1), we integrated these into a single hierarchical Bayesian model that estimates the full time-series (1970-2017) of population sizes for each species and for the overall avifauna. Because some species are better monitored than others, the precision of estimates varied greatly among species (Data S1). To reduce the effects of imprecise species-level estimates on our overall estimates of population change, our model included a hierarchical structure that allowed for estimation of composite change based on shrinkage estimators, in which imprecise species results are shrunk toward species-group means based on common ecological biomes in which they breed and overwinter (see below). For summaries, estimates of net population change were computed for four general management categorizations (shorebirds, landbirds, waterbirds, waterfowl), taxonomic familes, and breeding and nonbreeding biomes.

Our hierarchical model of composite change is similar in concept to the bird-group indicator models used to summarize the status of major bird groups at a national level in recent State of the Birds reports in Canada and the United States (*36*, *37*). These indicator models estimate an average population trajectory with respect to a base-year, across species in a group. To this basic group-level model, we added 4 major components: (1) we added a non-parametric smooth to each species estimated population trajectory, accounting for the uncertainty of each annual value, to emphasize the medium- and long-term changes in species populations and reduce the effects of annual fluctuations; (2) we added a second layer to the hierarchical structure to account for influences on each species population trajectory from across the full annual cycle (both nonbreeding and breeding biome); (3) we used the species-level predictions, instead of the group-level trajectories summarized for the State of the Birds reports, as improved estimates of a species population trajectory; and (4) we integrated these improved species trajectories with the species-level population size estimates, to sample the full posterior distribution of population change estimates for each species. The model, an R-script to run it, and all of the orginal data are available on GitHub (https://github.com/AdamCSmithCWS/Rosenberg_et_al).

Data included in the modeling were (1) species (s) population indices by year (y) and associated variances ($\hat{\iota}_{s,y}, \hat{\sigma}^2_{s,y}$); (2) species population size estimates and associated variances ($\hat{n}_s, \sigma^2_{\hat{n}_s}$); (3) year(s) in which each species population size was estimated (e.g., most PIF

P21-36 cont.

population estimates represent the species mean population size in the years 2006-2015; ($K_s = 10, k_s = 2006 - 2015$); and (4) information regarding wintering region and breeding biome associations for each species (w = wintering region, b = breeding biome).

<u>Non-parametric smoothing of species' trajectories, centering, and missing data</u>

We used a generalized additive model (GAM) to smooth each species population trajectory ($\hat{\iota}_{s,y}, \hat{\sigma}^2_{s,y}$) before including them in the main model, similar to (*38*). The GAM smooth allowed us to accommodate the wide variation in the underlying population trajectory data and models across the various datasets; for example, some species trajectories have gaps in the time-series when data were not available in a particular year, but were available before and after, and other trajectories are derived from models that allow annual values to fluctuate completely independently, leading to extreme annual fluctuations in relation to other species. Modeling each species trajectory with a flexible smoother retains the most important medium- and long-term patterns in the species' population, and reconciles the level of annual variation among species. We used the R-package mgcv (*39*) to smooth each species trajectory, using a hierarchical Bayesian GAM that accounted for the uncertainty of each annual index in the trajectory to model most species, and for the few species where published estimates of uncertainty were not available (N = 3, Trumpeter Swan, Emperior Goose, and American Woodcock), we used a simpler non-Bayesian GAM function from the same package.

The annual predictions from the GAM smooth ($i_{s,y}, \sigma^2_{s,y}$) for each species and from each data-source were in different units, e.g., BBS estimates are scaled to the number of birds seen on a single route and CBC estimates are scaled to the number observed in an average count-circle. To allow for the hierarchical structure of the model that pools information across groups of species (e.g., grassland birds that winter in Mexico), each species' trajectory was re-scaled to a common base-year (1970) and log-transformed. P21-36 cont.

$$\hat{\theta}_{s,y} = \ln\left(\frac{i_{s,y}}{i_{s,1970}}\right)$$

Where, $\hat{\theta}_{s,y}$ is the log-transformed standardized annual estimate for year y and species s ($i_{s,y}$) and represents the status of the species in year-y, as a proportion of the original estimate in the base-year, 1970 ($i_{s,1970}$). We calculated the variance of $\hat{\theta}_{s,y}$ as the log transformation of the variance of a ratio of two random variables (Cochran 1977, pg. 183), making the simplifying assuming that the annual estimates are independent in time. We acknowledge that this assumption of independent estimates in time is certaintly invalid for adjacent years, but becomes more plausible as length of the time-series increases

$$\sigma^2_{\hat{\theta}_{s,y}} = \ln\left(1 + \frac{\sigma^2_{i_{s,y}}}{i^2_{s,y}} + \frac{\sigma^2_{i_{s,1970}}}{i^2_{s,1970}}\right)$$

For 8% of species (43), population trajectories spanning 1970-2017 were not available. About half have data-sources that started in the early 1970s and most of the remainder have trajectories starting in the 1990s. In these cases, we assumed that the population did not change during the missing years. Years with missing trajectory information at the beginning of the time-series (e.g., no data before 1993 for some boreal species monitored by the BBS) were given values equal to the first year with data (i.e. a conservative assumption of no overall change) but we increased the estimated variance ($\sigma^2_{\hat{\theta}_{s,y}}$) by the square of the number of years since non-missing data, so that these imputed data would have little overall effect on the final results. For these species and years, because of the extremely high variance and the hierarchical structure of the model, the modeled population trajectories and the annual number of birds were almost entirely determined by the group-level mean trajectories for the other species sharing the same wintering region and breeding biome.

The primary model: population trajectories accounting for nonbreeding and breeding biome

Each species' estimated status in a given year ($\hat{\theta}_{s,y}$) was treated as a normal random variable with mean $\theta_{s,y}$ and a variance estimated from the species data ($\sigma^2_{\hat{\theta}_{s,y}}$).

$$\hat{\theta}_{s,y} \sim N\left(\theta_{s,y}, \sigma^2_{\hat{\theta}_{s,y}}\right)$$

The the species status parameter $\theta_{s,y}$ was assumed to be normally distributed, governed by a hyperparameter ($\mu_{w,b,y}$) with year-specific variance ($\sigma^2_{\mu_y}$),

$$\theta_{s,y} \sim N\left(\mu_{w,b,y}, \sigma^2_{\mu_y}\right)$$

representing mean status for all species with the same combination of wintering range and breeding biome (e.g., all species that winter in South American and breed in the boreal forest). This structure has the effect of shrinking each species population trajectory towards the mean trajectory for species in the same nonbreeding-by-breeding group. The mean trajectories for each group ($\mu_{w,b,y}$) were estimated using an additive sub-model that combined the effects of nonbreeding and breeding biomes. The biome-level components of the additive model were estimated using random-walk time-series for the effects of nonbreeding biomes ($\omega_{w,y}$) and breeding biomes ($\beta_{b,y}$).

$$\mu_{w,b,y} = \omega_{w,y} + \beta_{b,y}$$

$$\omega_{w,y} = N(\omega_{w,y-1}, \sigma^2_{\omega_w})$$
$$\omega_{w,1970} = 0$$

$$\beta_{b,y} = N(\beta_{b,y-1}, \sigma^2_{\beta_y})$$
$$\beta_{b,1970} = 0$$

The random-walk structure has the effect of slightly smoothing large annual fluctuations in the wintering-group annual means, while also allowing for non-linear temporal changes across the 48-year time series.

Integrating the population sizes and population trajectories

Each species' population size estimate was incorporated in the model as the mean ($\hat{n}_s$) and variance ($\sigma^2_{n_s}$) of a normal distribution. Random draws from those distributions (n_s) allowed the model to incorporate the uncertainty around each species' population estimate. We used the

P21-36 cont.

estimated population sizes and the population trajectories during the relevant years represented by each species' population estimate to calculate a scaling factor (ψ_s) that allowed us to re-scale the species estimated population trajectory (θ_{s,y_i}) to an estimated number of birds in each year of the time-series ($v_{s,y}$). Each population estimate was related to a specific year or range of years; e.g., all PIF population estimates reflect the species' mean population size between 2006 and 2015 ($K_s = 10, k = 2006 - 2015$). We estimated the scaling factors by averaging the ratio across the relevant span of years, with $K_s = 3$ as a minimum in a few cases where the species' estimated population reportedly related to a single year.

$$\psi_s = \frac{\sum_{y_i}^{y_k} \left(\frac{n_s}{\exp(\theta_{s,y_i})} \right)}{K_s}$$

$$v_{s,y} = \psi_s * \theta_{s,y}$$

All precision parameters were given diffuse gamma prior distributions, with scale and shape parameters set to 0.001. Formal measures of model fit are difficult to implement for complex hierarchical models, and are generally not presented for analyses of complex surveys (*40*). We used graphical comparisons between data and predictions (see additional figures available in the data and code repository) to ensure there was no important lack of fit between the model and the data.

P21-36 cont.

Annual number of birds and overall population change

We calculated the overall population change by species (λ_s) using the posterior distribution of the difference between the estimated number of birds in 1970 and the number in 2017. We calculated the estimated number of birds in the North American avifauna for each year (N_y) using the posterior distribution of the annual sums of all species estimates. We calculated the overall net change in the North American avifauna using the posterior distribution of the sum of the species-level change estimates (Λ). Estimates of the annual number of birds (N_y) and overall change (Λ) by family, nonbreeding biome (Figure S1), breeding biome (Figure 1A), and combinations of nonbreeding and breeding biome (Figure S2) were made from the posterior distribution of group-level summaries across all S-species in a group.

$$\lambda_s = v_{s,1970} - v_{s,2017}$$

$$N_y = \sum_{s_i}^{S} (v_{s,y})$$

$$\Lambda = \sum_{s_i}^{S} (\lambda_s)$$

Sources of Population Trajectories for North American Birds

We compiled long term population trajectories for 529 species, based on the best available survey data for each species (Table S1; see Data S1 for species-specific information). We note that this compilation reflects standard data sources used by North American bird conservation and management (*23, 36, 41–45*). We are fortunate that standardized, long-term survey data exist for a majority of North American bird species, perhaps the best-monitored group of organisms globally. We used trajectory estimates based on surveys of breeding populations whenever possible; however not all species are well-monitored during the breeding season, and for 18% of species we relied on surveys from migration periods or winter (Table S1). In all cases, trajectories and population estimates for each species were calculated from data during the same season (i.e., breeding to breeding, winter to winter). We could not find credible surveys for estimation of continent-scale trajectories for oceanic birds, many coastal-nesting seabirds, and other rare, secretive, range-restricted or nocturnal species. However, our synthesis includes 76% of species that breed regularly in the continental U.S. and Canada (*46*), and these species likely account for 95%-99% of total breeding abundance across the North American avifauna (i.e., most species omitted have very small populations in the U.S. and Canada).

For 434 species (82% of 529 species considered) we used trajectories from BBS data, most of which are updated annually and publicly available at https://www.mbr-pwrc.usgs.gov/. For species surveyed by the BBS, a hierarchical model (*47*) was used to estimate annual indices of abundance. In our hierarchical analysis, annual indices are based on regional fits within states and provinces that are weighted by area and local abundance to accommodate differences in population sizes among strata. For a majority of species (415) we used data from the 'core' BBS area from 1970-2017, based on road-based survey routes in the contiguous U.S. and southern Canada. For 19 species with restricted or northern breeding distributions (See Data S1), we used data from an expanded analysis beginning in 1993, including additional BBS routes in Alaska and northern Canada (*48*). The proportion of each species' breeding range covered by the BBS is provided in (*33*), and all metadata and data are available (https://www.pwrc.usgs.gov/bbs/).

Potential limitations or biases in BBS trends (overall rates of change across the trajectories) have been extensively examined and documented (e.g., (*33*, *49*)). In general, there is no evidence to suggest that estimates of population trends from the BBS are systematically biased across large spatial areas or across many species. Published studies that have examined the potential roadside bias in BBS trends have found that the magnitudes of bias in the sampling of habitat-change are generally small, e.g. (*50–53*), that potential biases vary in space (e.g., contrasting biases in the regions used in (*54*), or in (*55*)), and that they vary among species (i.e., if biases exist, some species' trends may be underestimated and others overestimated, e.g., (*55*, *56*)). Overall, BBS routes survey a reasonably representative sample of the overall habitat in the landscape at the broad spatial and temporal scales, for which the BBS was designed (*50*).

National Audubon Society Christmas Bird Counts (*57*) provided trajectory data for 58 species; these are primarily species that breed in northern regions not surveyed by the BBS, but are encountered in CBCs because they spend the non-breeding season primarily within the U.S. and southern Canada. The CBC protocols are less standardized than BBS, but annual winter-season counts in fixed 15-mile diameter circles cover a large portion of the U.S. and Canada, especially in coastal regions. Trajectories from CBC data were estimated using a hierarchical model that controlled for effort (*57*). Annual indices to compute trajectories from the CBC for the 1970-2017 period were provided to us by Tim Meehan (National Audubon).

Trajectories for 20 species of long-distance migrant shorebirds came from an analysis of migration monitoring surveys carried out across Canada and the United States (*58*, *59*). The shorebird migration surveys used here are part of the International Shorebird Survey, coordinated by Manomet, and the Atlantic Canada and Ontario Shorebird Surveys, coordinated by Environment and Climate Change Canada. Volunteers carry out surveys every 10 days in spring and fall, at sites distributed across Canada and the United States but concentrated primarily in the eastern half of the continent. Analyses of shorebird trajectories from fall count data, 1974-2016,

P21-36 cont.

were carried out using hierarchical Bayesian models similar to those used for the BBS (*47*), with an additional General Additive Model (GAM) component to describe variation in birds' abundance during the period of migratory passage. The model assumes that counts follow an overdispersed Poisson distribution, and includes terms for a long-term, log-linear trend, year-effects and site-level abundance. Sites were grouped into biologically relevant regions, and trend terms within each region were estimated as hierarchical random effects distributed around a mean, continental trend. Methods and survey coverage are described in more detail at wildlife-species.canada.ca/bird-status (https://tinyurl.com/yak95ssn). For one shorebird species, American Woodcock, we made use of Singing-ground Survey estimates from the 2017 American Woodcock Status report (*60*).

For nine species of intensely managed waterfowl we relied on trajectory data from the U.S. Fish and Wildlife Service (USFWS) (*61*), and trajectories for nine additional waterfowl species came from other species-specific sources (see Table S1, Data S1). Trajectories for many waterfowl species were computed using population estimates from Spring Breeding Ground Surveys, which use a combination of aerial and ground-based counts in late spring, covering 2.0 million square miles in Alaska, Canada, and the northern U.S. (Table c3 in (*61*)). For a small subset of species, we employed other sources of trajectory information where this resulted in better coverage of North American populations, and/or more current information. For all goose species we relied on estimated trajectories from the same sources of information on population trends reported for North American goose populations by Fox and Leafloor (*62*); these sources represent the most appropriate survey for each species as determined by experts on goose populations. Finally, for Trumpeter Swans we relied on values in the 2015 North American Trumpeter Swan Survey report (*63*). P21-36 cont.

Sources of Population Size Estimates and Variances

We relied on the best available data sources and published estimates of North American breeding population size and variance for all species with credible data (Table S1; Data S1). The largest source of population estimates for our current analysis (65% of species) was the recently published PIF estimates for 344 landbird species (*35*). The PIF estimates were based on extrapolations from BBS count data from 2006-2015, using previously described methods (*64–67*). Averaged annual BBS counts were converted to a regional (landscape-scale) abundance estimate through the application of detectability adjustment factors for time-of-day, detection distance, and likelihood of both members of a pair being detected on BBS routes, and extrapolation from BBS count area to area of the region. These regional estimates are calculated for each state, province and territory portion of each Bird Conservation Region (BCR), and then summed across regions to derive U.S.-Canada population estimates. Estimates incorporated uncertainty in the estimation components, resulting in confidence bounds around the final estimates (*35*). Population estimates are therefore adjusted for detection, account for variation in relative abundance across the species' range, and are accompanied by a measure of uncertainty. This approach to estimation of total population size has been widely adopted in conservation planning (*35*), and is considered to be conservative, likely underestimating true population size due to sampling concerns associated with BBS data (*67*).

The PIF methods for estimating population size have historically been applied only to landbirds (*41*, *42*). For this analysis, we determined that the BBS also provides adequate survey coverage for 46 waterbirds, and 6 waterfowl that otherwise were lacking useful population estimates (see Data S1 for sources by species), and we applied the PIF approach for calculating population size estimates to data for these species. Adjustment factors used in the estimation of U.S.-Canada population sizes for the current analysis, based on BBS relative abundances, are provided in Table S2. More details on the use of adjustment factors and their ranges of uncertainty for landbirds can be found in (*35*).

Estimates of population size for many shorebirds and waterfowl came from published sources that rely on other surveys. Estimates for 12 waterfowl species were from the 2017 USFWS Waterfowl Status Report (*61*) (7 species from traditional area surveys, 2 from eastern survey area, 2 summed from traditional and eastern surveys, and 1 from western survey area) – for these species, we used an average of published estimates across the last 5 years (2013-2017) to smooth out annual variance in population sizes. Estimates for 14 additional waterfowl species were based on a 2007 Seaduck Joint Venture Report (*68*). All 45 shorebird species estimates were North American population estimates (*69*) from the Shorebird Flyway Population Database (*70*).

Other estimates of population size came from species-specific sources (Table S1; Data S1): We used published estimates from Birds of North America (BNA) accounts (*71*) for 33 species; a Conservation of Arctic Flora and Fauna (CAFF) 2018 report provided current estimates for 7 goose species (*62*); estimates for 17 landbird species without useful BBS-based estimates were taken from the Avian Conservation Assessment Database ACAD (*46*, *72*), which itself relied on a variety of sources; the 2015 North American Trumpeter Swan Survey (*63*) was used for Trumpeter Swan, and the Waterbird Population Estimates database (WPE5) provided estimates for Arctic Tern (*73*).

Most sources of population estimates also provided estimates of variance in population size, which we incorporated into our analysis. For those that did not, we estimated a range of variance based on a description of methods used for population estimation. For example, we applied a range 10% below and above the mean for species if estimates were based on well-designed surveys with good population coverage, versus 75% below and above the mean for species with ballpark estimates and/or low coverage of relevant populations, with an intermediate range of variance if limitations were between those two.

Note that our goal was to compile and use the most current estimates of breeding population size for each species; i.e., the number of breeding adult individuals in the population. We did not attempt to estimate the annual increase in population size due to the influences of reproductive output, as this will likely vary greatly across species and years and be subject to density-dependent effects. Total population size varies throughout the annual cycle, but post-breeding total population could increase as much as four to five times the size of the pre-breeding population size depending on recruitment success of young of the year. Estimating this annual variation for individual species is currently impossible, but it is important to point out that the cumulative impact of population loss on ecosystems throughout the year could be quite significant. Our estimates of population change are therefore conservative.

P21-36 cont.

Assigning species to management and biome categories

For the purpose of summarizing changes in abundance across the North American avifauna, we recognize four broad species categories used for management and conservation planning: *Landbirds* are defined by Partners in Flight (*41*, *42*) as all birds occupying terrestrial habitats and a few species from primarily terrestrial bird families that use wetland habitats (e.g., Marsh Wren, *Cistothorus palustris*). The ACAD lists (448) native landbirds breeding in the U.S. and Canada; in this paper we include 366 landbird species with adequate population size and trajectory data, including 9 introduced species. *Shorebirds* include all sandpipers, plovers, stilts, avocets, and oystercatchers that are considered under the U.S. Shorebird Conservation Partnership

(*43*); we had adequate data for 45 shorebird species for the current analysis. *Waterfowl* include all ducks, geese, and swans, which are managed separately under the North American Waterfowl Management Plan; most species have populations that are adaptively managed for sport hunting (*23*). We had adequate data for 42 species in the current analysis, including 1 introduced species. Other *Waterbird* species that are not specifically covered by the three plans above are included under the Waterbird Conservation for the Americas initiative (*44*); these include colonial-nesting seabirds, herons, beach-nesting species and secretive marshbirds. *Waterbirds* are most poorly represented in our dataset, as many species are poorly monitored. We had adequate data for 77 species in the current analysis.

We assigned each species to a primary breeding biome and a primary nonbreeding biome, using the Avian Conservation Assessment Database. The ACAD provides broad breeding-habitat categories (e.g., forests, grasslands, oceans) derived from similar categories used to develop habitat indicators for State of the Birds reports in the U.S. and Canada (e.g., (*36*, *45*)), as well as more descriptive sub-categories within major habitats (e.g., Temperate Eastern Forest; Desert Scrub, Freshwater Marsh). All category assignments were based on literature review (primarily BNA accounts) or expert knowledge and underwent extensive review as part of the ACAD process (*66*). Species that use three or more broad habitats in similar importance were considered habitat generalists.

For this paper, we used a combination of *Primary Breeding Habitat* and *Breeding Habitat Description* sub-categories defined in the ACAD to derive a single set of unique breeding biome categories across the North American avifauna (shown in Figure 1A), as follows:

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- *Wetlands* = freshwater, inland wetlands; does not include coastal marshes or Arctic tundra.
- *Coasts* = all habitats associated with the Coastal zone, including saltmarsh, beach and tidal estuary, mangroves, and rocky cliffs and islands; includes birds that forage primary in the marine zone
- *Tundra* = Alpine tundra and Arctic tundra, including upland and low, seasonally wet tundra
- *Grasslands* = native grassland, prairie, pasture, and agriculture that supports grassland birds
- *Aridlands* = all arid shrub-dominated communities; primarily in southwestern U.S. and northwestern Mexico; includes ACAD sub-categories of sagebrush, chaparral, desert scrub, barren rocky cliffs, and extensions of tropical dry forest (thornscrub) in southern Texas
- *Boreal forest* = "True" boreal forest of Canada and Alaska; note that some boreal-forest birds also use the boreal zone (primarily spruce-fir) of high mountains in the western and northeastern U.S.
- *Eastern forest* = all temperate forest types of eastern U.S. and southeastern Canada (south of the boreal), including northern hardwoods, oak-hickory, pine-oak, southern pine, and bottomland hardwood associations
- *Western forest* = all temperate forest types of western U.S. and Canada (south of the boreal) and extending in high mountains south into northwestern Mexico; includes Pacific Northwest rainforest, all western conifer, oak-dominated, and riparian forests, pinyon-juniper, juniper-oak woodlands of Edward's Plateau, pine-oak and high-elevation conifer forests of northwestern Mexico
- *Forest generalist* = occurs in similar abundance in two or more forest biomes as described above

- *Habitat Generalist* = occurs in similar abundance in three or more major habitat types, usually including forest and non-forest categories

The ACAD database also lists *Primary Wintering Regions*, in which a majority of the population of each species spends the stationary nonbreeding period during the boreal winter. For this paper we modified and lumped ACAD regions into broader nonbreeding biome categories, using published range maps and eBird distributional data (https://ebird.org/explore), as follows:

- *Temperate North America* = broad region encompassing all of Canada and most of the U.S., excluding arid regions in the Southwest
- *Southwestern Aridlands* = arid regions of southwestern U.S., northwestern Mexico and Mexican Plateau; included species that winter in arid Chihuahuan grassland habitat
- *Mexico-Central America* = combination of ACAD regions within Mexico and Central America, including *Pacific Lowlands, Gulf-Caribbean Lowlands, Mexican Highlands*, and species from *Central and South American Highlands* that winter primarily in Central America
- *South America* = includes *South American Lowlands*, species from *Central and South American Highlands* that winter primarily in South America, and *Southern Cone* ACAD regions
- *Caribbean* = West Indies region, including Cuba, Bahamas, Greater and Lesser Antilles
- *Widespread Neotropical* = occurs in similar numbers in two or more biome regions within the Neotropics
- *Coastal* = coastline habitats throughout the western Hemisphere from Arctic to Atlantic and Pacific Coasts of North, Middle, and South America; eastern Hemisphere coastlines were included to incorporate the main wintering grounds of Pacific Golden-Plover
- *Marine* = littoral zone; area of oceans influenced by continental coastlines; includes bays and deep estuaries (includes a few species that are largely pelagic in the nonbreeding season)
- *Widespread* = occurs in similar abundance in 3 or more nonbreeding biomes, usually encompassing both temperate North American and Neotropical regions
- *Southeast Asia* = overwintering region for Arctic Warbler (and additional Arctic-breeding species not included in the present analysis); note that this nonbreeding biome is not included in summaries presented in Table 1 and Figure S1, but data for Arctic Warbler (Data S1) and included in higher level summaries of population change for all birds, breeding biomes, etc.

P21-36 cont.

<u>Computing vertical profile time series of birds from NEXRAD radar data</u>

While designed to monitor meteorological phenomena (e.g., precipitation, tornados, hail), weather radars routinely detect migrating birds. Weather radar infrastructure represents a biological monitoring tool that achieves an unprecedented spatial and temporal coverage for studying bird migration (*74*). The NEXRAD weather radar network consists of 143 radars in the contiguous US that continuously survey the airspace above the US (*75*). Each of these radars was used to estimate vertical profiles of birds , which summarize a radar's scans completed at a given timestep into the amount, speeds, and directions of birds aloft as a function of altitude. Profile data can be used to accurately estimate migratory biomass abundance and its change throughout the year at comprehensive continental scales (*19, 77*), an approach we extended here to detect long-term change in migratory passage across the full US. We restricted our analysis to spring data only (Mar 1 to Jul 1), which is the migratory period closest in time to the breeding bird surveys by BBS. Also, aerial insects are far less numerous in the airspace in early spring as compared to autumn, therefore the spring period allows us to obtain the cleanest bird signal from NEXRAD (see final paragraph of section "Calculating biomass passage from vertical profile time series" below).

Data were obtained from the NOAA-nexrad-level2 public S3 bucket on Amazon Web Services (*78*). Data were analyzed for the period 2007-2018, the period after the Open RDA deployment in NEXRAD (RDA build 7.0), which was a significant upgrade to the Radar Data Acquisition (RDA) functional area of the WSR-88D. In particular, it implemented Gaussian Model Adaptive Processing (GMAP) (*79*, *80*), replacing and improving over the legacy ground clutter filter (*81*) by Doppler filtering. We did not include older potentially lower quality data in the analysis to limit the possibility of legacy filter settings affecting our results. Trend analyses (see following sections for details) controlled for two important data acquisition updates, the gradual upgrades to superresolution (2008-2009) and dual-polarization (2010-2013). The superresolution upgrade increased the azimuthal resolution from 1 to 0.5 degree and range resolution from 1 km to 250 m. The dual-polarization upgrade added functionality to receive horizontally and vertically polarized electromagnetic waves independently, which provided additional products that greatly simplify the classification of meteorological and biological scatterers (*82*).

Night-time polar volumes (level-II data) were processed for all 143 radars in the contiguous US at half-hour interval from 2007-2018 using the vol2bird algorithm (version 0.4.0) (*76*, *83*, *84*), available in R-package bioRad (version 0.4.0) (*83*, *85*). Using cloud computing with 1000 parallel cores on Amazon Web Services (AWS) we reduced this computational task of ~ 4 years on a single CPU to less than a day. Data were processed using the vol2bird algorithm in single-polarization mode (*76*), which requires radial velocity and reflectivity factor information only and no dual-polarization data. Dual-polarization data became available only after mid-2013, and therefore cannot be used for analyses involving older data. In single-polarization mode, resolution samples with high reflectivity values are masked out (η above 36000 cm^2/km^3, i.e., 31 dBZ at S-band / 20 dBZ at C-band, cf. algorithm parameter ETAMAX and paragraph 3.2 in (*76*)), since such high reflectivities are typically associated with precipitation (*76*). The algorithm also identifies contiguous areas of direct neighbors (in a queen's case sense; i.e., diagonal pixels are included as direct neighbors) of reflectivity above 0 dBZ, denoted as reflectivity cells. Cells with a mean reflectivity above 11500 cm^2/km^3 (i.e., 26 dBZ at S-band / 15 dBZ at C-band, cf. algorithm parameter ETACELL and Z_{cell} in (*76*)) are masked from the data. Following recommendations for S-band data discussed in (*83*), we used sd_vvp_threshold=1 m/s (cf. Eq. A2 in (*76*)) and STDEV_CELL=1 m/s (cf. Eq. A3 in (*76*)) to limit masking based on radial velocity texture at S-band. P21-36 cont.

At S-band, single-polarization mode masks out only the strongest precipitation areas, and weaker precipitation may remain (*83*) (see Figure S3C/E). Precipitation is generally easily identifiable in vertical profiles by experts, based on high reflectivities extending over a relatively large portion of the altitude column (see Figure S3D). Such precipitation cases stand out from bird migration cases, which are characterized by low reflectivities that typically decrease with altitude (see Figure S3A). We used machine learning to develop a full-profile classifier that automatically identifies precipitation-contaminated profiles, as follows.

Years when dual-polarization data were available (2014-2017) were processed a second time in dual-polarization mode (*19*, *83*), which adequately removes precipitation based on high correlation coefficient values (*19*, *82*). These precipitation-free profile data were paired with the single-polarization profile data. By comparing the precipitation-free reflectivity ($\eta_{dualpol}$, cf.

Figure S3A) with the total reflectivity including precipitation (η_{total} derived from reflectivity factor DBZH, cf. Figure S3D), we defined a measure that indicates the range of altitudes H (m) likely containing precipitation, as follows:

$$H = \sum_{i=1}^{n_{layer}} (\text{if } \eta_{total,i} - \eta_{dualpol,i} > \Delta \text{ then } w_{layer} \text{ else } 0)$$

with Δ=50 cm^2 km^{-3} (corresponding to 3 dBZ at S-band), and w_{layer} the width of a single altitude layer (200 m). The value of Δ amounts to a fairly low threshold value for classifying potential precipitation, as meteorologists typically assume weak precipitation to start at 7 dBZ (*86*) (133 cm^2 km^{-3} at a 10 cm S-band wavelength), and therefore the vast majority of rain events will show differences in reflectivity exceeding Δ. We labelled all single-polarization profiles in the 4-year dataset with their corresponding H value.

Next, we used gradient boosted trees to detect rain-contaminated profiles computed in single-polarization mode automatically in an unsupervised learning approach, using the H value as our labeling of profiles, with higher H values indicating a wider altitudinal range containing precipitation. We used the R implementation of XGBoost, a highly efficient and scalable gradient boosting algorithm, which can deal with complex nonlinear interactions and collinearity among predictors (*87*, *88*). We used default hyperparameter settings of the xgboost algorithm (learning rate eta=0.3, tree depth max_depth=6, min_child_weight=1, gamma=1, colsample_bytree=1, and subsample=1). Full-profile classifiers were trained for each radar separately. Response variable was the range of altitudes with precipitation H. Predictors included total reflectivity factor (DBZH), precipitation-filtered reflectivity in single-polarization mode (eta), ground speed components (u,v), all at each of the 20 profiles altitude layers, as well as day of year (1-366) and time of day (UTC time). Profiles of each radar were randomly assigned to training (75%) and testing (25%) datasets. P21-36 cont.

Finally, we determined the parameter H_{max} as the value of H above which profiles are removed in order to discard precipitation contaminations. The value of H_{max} was determined using Figure S4, showing an R-squared measure that quantifies the correspondence between the seasonal migration traffic MT (see next paragraph for definition) of the single-polarization vertical profile time series (with contaminated profiles removed by the full-profile classifier), and the seasonal migration traffic of the reference computed in dual-polarization mode. This R-squared measure amounts to the the coefficient of determination of the scatter points in Figure S5 for a given value of H_{max}. We choose the value of H_{max}=1600 m, producing the best correspondence between the dual-polarization reference and our new single-polarization method. Gaps in a radar's profile time series (after removal of rain-contaminated profiles) of less than 4 hours were filled by linearly interpolating between the neighboring profiles directly before and after the gap.

Applying this value of H_{max} and the full-profile classifier on the testing dataset, we find a precision to correctly classify a profile as rain-contaminated of 99.2%, and a recall of rain-contaminated cases of 97.4%. Precision and recall (*89*) did not depend strongly on the value of the H_{max} threshold, e.g., for H_{max} = 800 m we have a precision of 97.0 % and recall of 99.0%. Our classification performance therefore did not depend critically on the adopted value of the H_{max} parameter.

<u>Calculating biomass passage from vertical profile time series</u>

Nightly reflectivity traffic (RT) (*83*) was calculated for the vertical profile time series of each station for each night with the integrate_profile() function in bioRad (version 0.4.0) (*83*, *85*), which equals the total reflectivity crossing the radar stations per season per one kilometer transect perpendicular to the ground speed direction of movement. Reflectivity traffic is closely related to the amount of biomass that has passed the radar station (*83*). It can be converted to migration traffic (MT), the number of individual birds having passed the radar station per km transect, under assumption of radar cross section (RCS) per individual bird, as in MT = RT/RCS. To express RT in a more intuitive unit, we report MT values in figures using a constant seasonal mean RCS = 11 cm^2 for an individual bird. This value was determined in a calibration experiment spanning a full spring and autumn migration season (*76*), corresponding to passerine-sized birds (10-100 g range) (*90*), which represents the highest-abundance species group dominating our radar signals (*19*). As additional quality control for non-avian signals, we only included altitude layers of profiles for which the ground speed direction was in the northward semicircle surrounding a radar, since migratory bird movements in spring are expected to fall within this semicircle.

Spatial interpolations across the contiguous US of nightly migration traffic were estimated by ordinary kriging with a spherical variogram model, using the R package gstat (*91*). We clipped water areas after interpolating, leaving land areas of the contiguous United States. Missing estimates of nightly migration traffic (e.g., due to temporary radar down time) were imputed from nightly kriging-interpolated maps of MT based on operational stations, imputing the MT value at the location of the inactive radars. Parameters of the spherical variogram model were estimated for each night. In cases where the variogram fit did not converge - typically during nights with very limited migration - we used variogram parameters fit to the average seasonal spring migration traffic (partial sill = 0.577, range = 1093 km). Radar availability was very high, therefore only a small percentage of in total 2.8% of nightly MT values were imputed by this procedure.

P21-36 cont.

Total seasonal migration traffic was calculated as the sum of nightly MT values within a season from Mar 1 to Jul 1. Radar seasons were excluded from trend analysis entirely if data availability dropped below 80% in the period 1 Mar – 1 Jul (4.8% of radar seasons for 143 stations during 11 spring seasons).

While traffic rates suppress any non-migratory stationary signals, like those of non-directed foraging movements of insects or bats (*19*), a small contribution of directed migratory movements of bats or insects could remain in our data. Free-tailed bats in the south are known to show up in radar (*92*) and have a population size estimated up to 100 million individuals (*93*), which amounts to up to a few percent of the total migratory passage of several billion birds along the southern border (*19*). In the North-East - where we observe strongest declines in biomass passage - several migratory tree-dwelling bat species occur, but their population sizes are thought to be smaller than of free-tailed bats. For the period 2013-2017 we have provided earlier a detailed quantitative estimate of the upper limit to the migratory insect contribution to the migratory passage in autumn, when insect abundances are highest. The estimated passage due to insects was 2.1 % (northern US border) – 3.8 % (southern US border) (*19*). Our current study is conducted in spring when aerial insect abundances are far lower (*94*), especially in the North East where we observe most declines, and we estimate the insect contribution to the biomass passage to be on the order of a percent or less.

<u>Calculating trends from seasonal biomass passage values</u>

To correct for potential radar sensitivity changes related to radar processing upgrades, we determined the timing of the upgrade to super-resolution and the upgrade to dual-polarization for each station. Radar seasons for which the upgrade fell within a migration period were excluded from the analysis. The mode of operation was classified as "legacy" (before superresolution upgrade), "superres" (after superresolution upgrade, before dual-polarization upgrade) or "dualpol" (after dual-polarization upgrade), and stored as a factor variable 'mode' having three factor levels to denote each mode of operation. Variable 'mode' was included in models to correct for changes in operational mode. We also tested for the effect of dual-polarization and superresolution upgrade separately. In these cases, factor variable 'mode' was replaced with a logical explanatory variable 'dualpol' (true after dual-polarization upgrade, otherwise false) or 'superres' (true after superresolution upgrade, otherwise false) in the trend models. The total model candidate set thus contained 4 models, encompassing all combinations of possible corrections for mode of operation, including no correction.

We estimated geographically varying trend patterns using a spatial GAM (*95*) using the mgcv package in R (*39*). Seasonal migration traffic was standardized to each radar's 11-year mean, stored as variable 'index'. We then modeled the spatial trend using an offset tensor product smooth te(lon,lat) and a tensor smooth representing a spatially varying linear trend with year te(lon,lat,by=year) on the linear predictor scale (see Table S3). We used a Gamma distribution with log-link, such that our linear trend smooth term on the linear predictor scale represents a spatially varying annual rate of change μ_{trend} (with standard deviation σ_{trend}) on the response scale. The Gamma distribution accommodates a small right-skew in our continuous positive response variable and warrants normality of deviance residuals, as inspected using QQ plots. Plots of the spatial trend surfaces estimated for the models in Table S3 are shown in Figure S7.

Changes in seasonal migration traffic (Table S4, Figure 2D) were calculated as the GAM prediction for year 2007 minus 2017 (the proportional loss over 11 years), times the 11-year average seasonal migratory traffic (MT) of each station. The surface of average migratory traffic was obtained from a kriging interpolation of the 11-year mean seasonal MT value for each station (see Figure S6, 2). Average trends for the entire US (see main text and Table S3) were averaged over all pixels of these spatially-explicit decline and loss surfaces across the contiguous US, using arithmetic mean and harmonic mean for calculating mean and variance values, respectively, effectively weighing the trend by passage of biomass. The trend value reported in the main text refers to this biomass-weighted average trend for a model average of all GAM models in our candidate set (listed in Table S3). Models were averaged using package MuMIn (*96*), which averages models based on AIC (*97*).

P21-36 cont.

We also estimated continental-wide trends in migratory passage and trends for four flyway regions: Atlantic, Mississippi, Central and Western, following the definitions of the US Fish and Wildlife Service, REF (cf. Figure 2B,C). We fitted generalized linear mixed models using R-package lme4 (*98*), including radar station as a random offset, and region and the interaction year:region as fixed effects, see Table S4 for model structures and Table S5 for estimated model parameters. Like in the GAM analysis, the candidate model set equaled for 4 models, containing all combinations of possible corrections for operational mode.

Regional biomass passage indices (Figure 2A,B) were calculated as the yearly sum of seasonal migration traffic values MT for the radars within each region, standardized by the sum of seasonal migration traffic values MT for all radars in the network of the first year (2007). Values of regionalized decline rates (Atlantic, Mississippi, Central and Western) in the main text are based on the model average (*96*) of all GLMs in the candidate set. Reported errors represent standard errors at a 95% confidence level.

Our GAM analysis (Table S3) and GLM analysis (Table S5) both found support for the dual-polarization upgrade affecting the value of MT, but not for the superresolution upgrade: including variable 'mode' did not produce a more informative model relative to a model with variable 'dualpol' that makes no distinction between "legacy" and "superresolution" data. Effect of the dual-polarization upgrade was a reduction in seasonal migration traffic by a factor 0.85 ± 0.03 (regionalized GLM) or 0.88 ± 0.05 (spatial GAM). Accounting for potential changes in detectability effectively reduced the steepness of decline rates and biomass loss. Both the superresolution and dual-polarization upgrades were designed to prevent changes in detectability and minimize bias effects for meteorological echoes as much as possible, and it is not known whether including correction terms for biological echoes is required. We report versions of the models with and without correction terms such that the effects of these corrections can be compared. By including correction terms, potentially part of the declines in seasonal migration traffic are modelled by the detection-related explanatory variables, and our estimates of decline of models with most information-theoretic support (model 1, model 5) are thus potentially too conservative. Importantly, the presence of an average decline in the passage of migratory biomass is robust to inclusion of correction terms for changes in operational mode of the radar, and even our most conservative rates of decline are alarming.

P21-36 cont.

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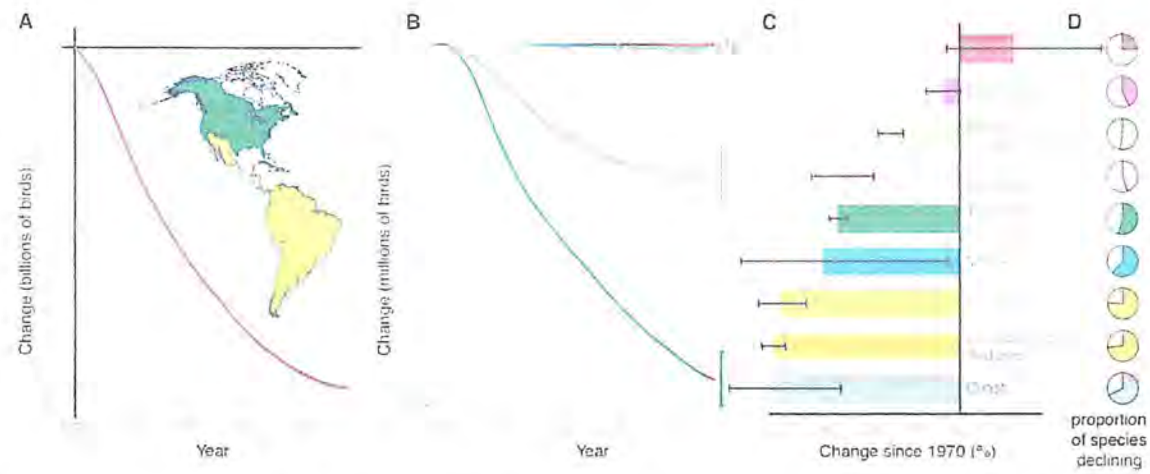
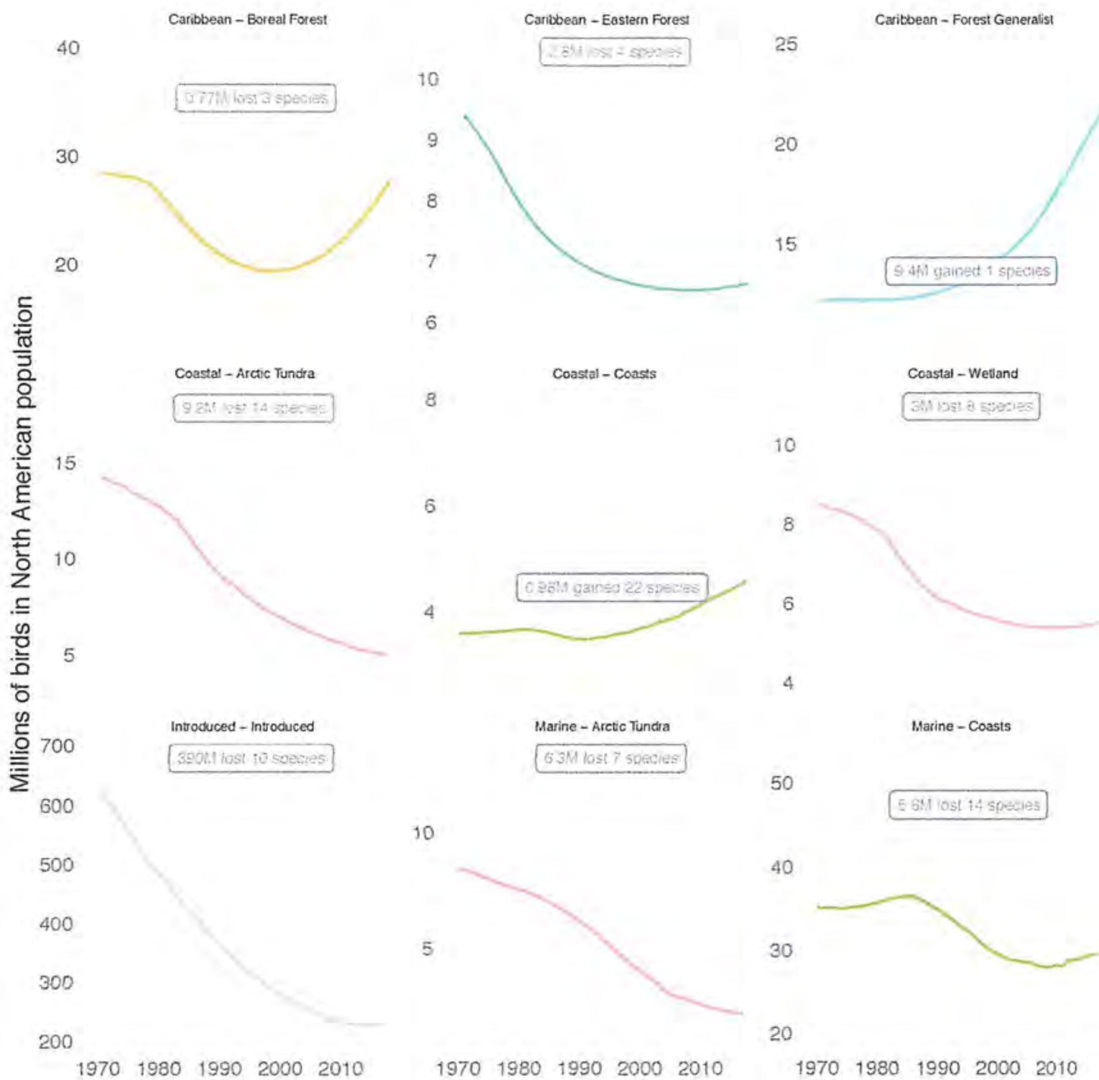
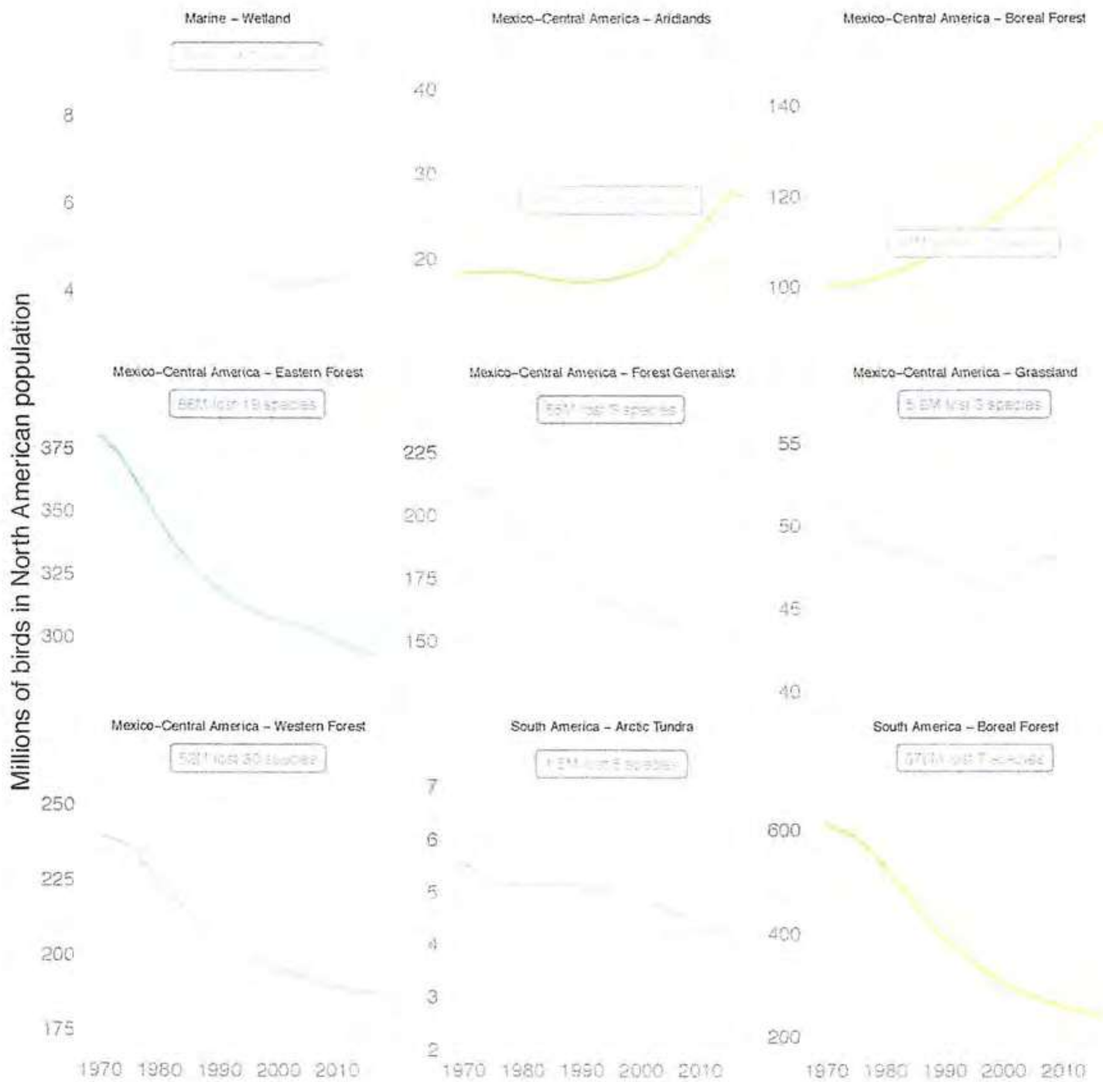


Fig. S1. **Net population change in North American migratory birds grouped by non-breeding biome**. (A) By integrating breeding-season population trajectory and size estimates for 529 species (see Methods), we show tthe continental avifauna lost > 2.9 billion breeding birds since 1970. Gray shaded region represents ± 95% credible intervals around total estimated loss. Map shows color-coded non-breeding biomes based on primary overwinter distributions of each species (See Methods). (**B**) Net loss of abundance occurred across all major non-breeding biomes, except Caribbean (see Table 1). (**C**) Proportional population loss, ±95% C.I. (**D**) Proportion of species declining in each biome.

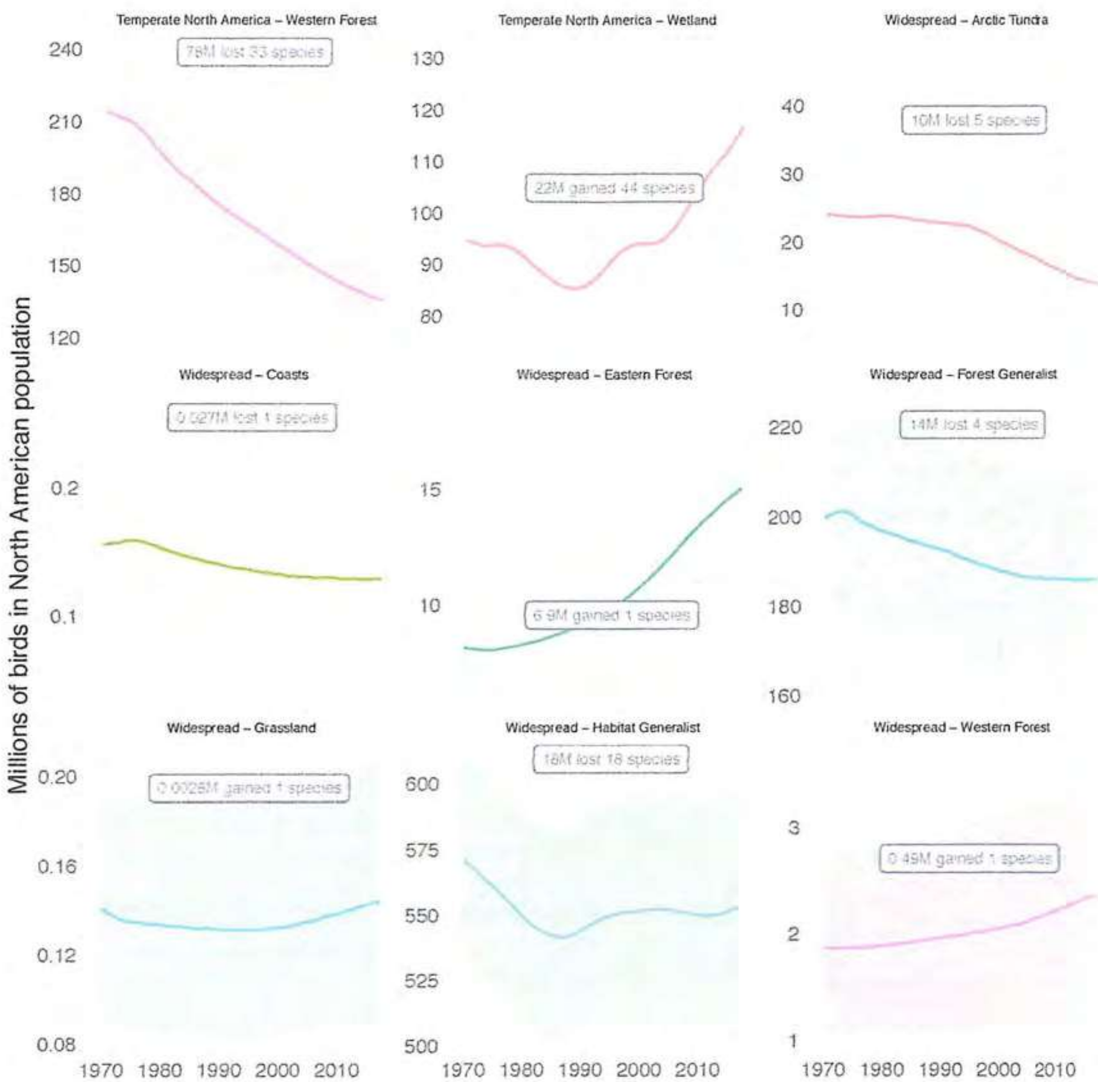
P21-36 cont.


Millions of birds in North American population
Caribbean – Boreal Forest
0.77M lost 3 species
Caribbean – Eastern Forest
Caribbean – Forest Generalist
9.4M gained 1 species
Coastal – Arctic Tundra
9.2M lost 14 species
Coastal – Coasts
0.96M gained 22 species
Coastal – Wetland
3M lost 8 species
Introduced – Introduced
390M lost 10 species
Marine – Arctic Tundra
6.3M lost 7 species
Marine – Coasts
5.6M lost 14 species
1970 1980 1990 2000 2010

P21-36 cont.


Marine – Wetland
Mexico–Central America – Aridlands
Mexico–Central America – Boreal Forest
Mexico–Central America – Eastern Forest
Mexico–Central America – Forest Generalist
Mexico–Central America – Grassland
Mexico–Central America – Western Forest
South America – Arctic Tundra
South America – Boreal Forest
Millions of birds in North American population
1970 1980 1990 2000 2010

P21-36 cont.


Millions of birds in North American population
Temperate North America – Western Forest
78M lost 33 species
Temperate North America – Wetland
22M gained 44 species
Widespread – Arctic Tundra
10M lost 5 species
Widespread – Coasts
0.027M lost 1 species
Widespread – Eastern Forest
6.9M gained 1 species
Widespread – Forest Generalist
14M lost 4 species
Widespread – Grassland
0.0026M gained 1 species
Widespread – Habitat Generalist
18M lost 18 species
Widespread – Western Forest
0.49M gained 1 species
1970 1980 1990 2000 2010

P21-36 cont.

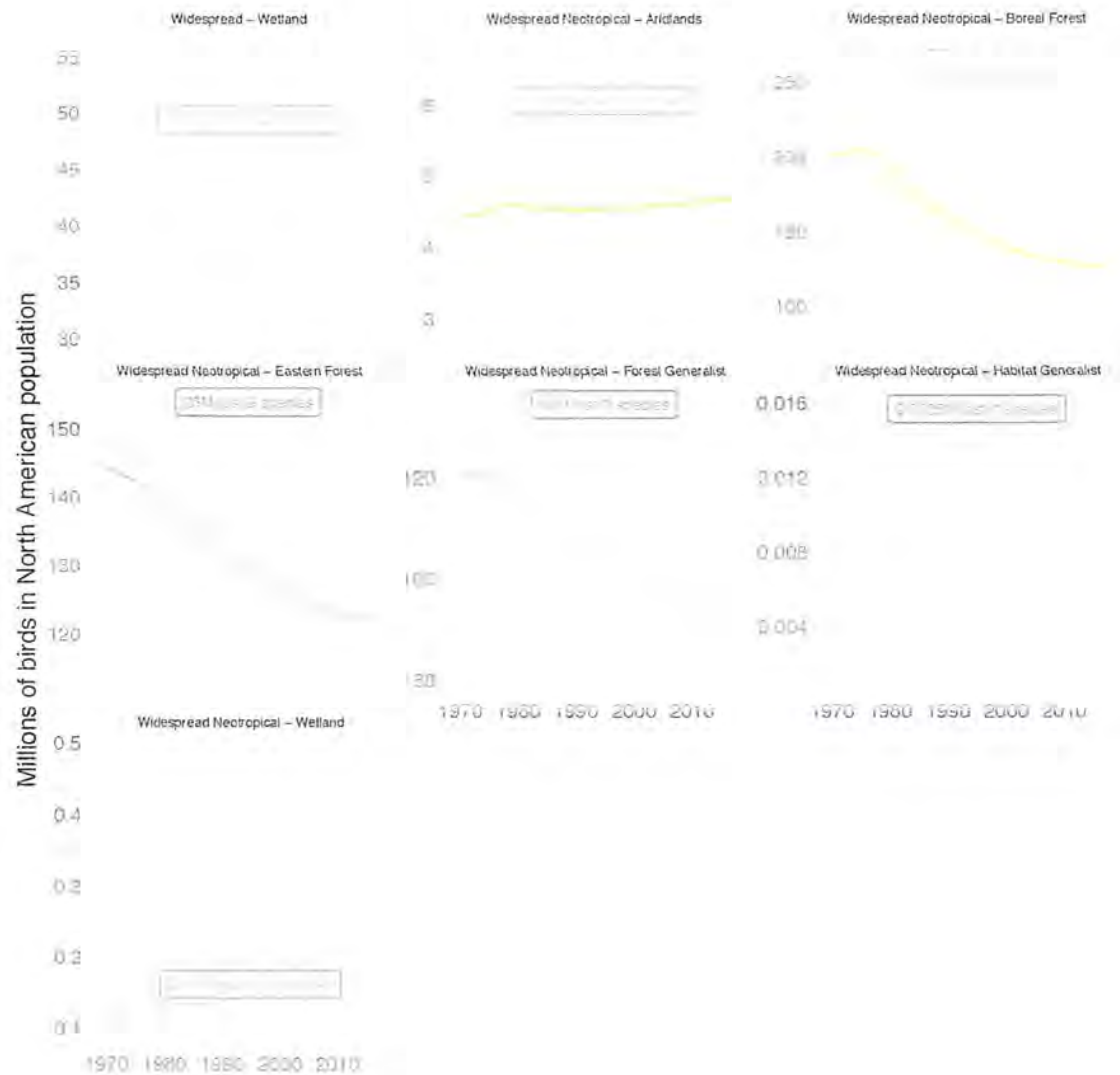


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Fig. S2.

Change in number of birds in North America by combined nonbreeding and breeding biomes from 1970–2017. Each panel of the figure shows the 1970-2017 trajectory of summed abundance across the species that share a given combination of nonbreeding and breeding biomes (e.g., the first panel shows the trajectory in summed abundance across the 3 species that winter in the Caribbean and breed in the boreal forest). The panel title indicates the wintering biome followed by the breeding biome; labels within the plots show the estimated change in total abundance in millions (M) of birds between 1970 and 2017, and the number of species included in the group. Colored lines and the colored uncertainty bounds represent the median and 95% C.I. of the posterior distribution from the hierarchical Bayesian model. The panels are sorted by nonbreeding biome and the lines are coloured based on the breeding biome.

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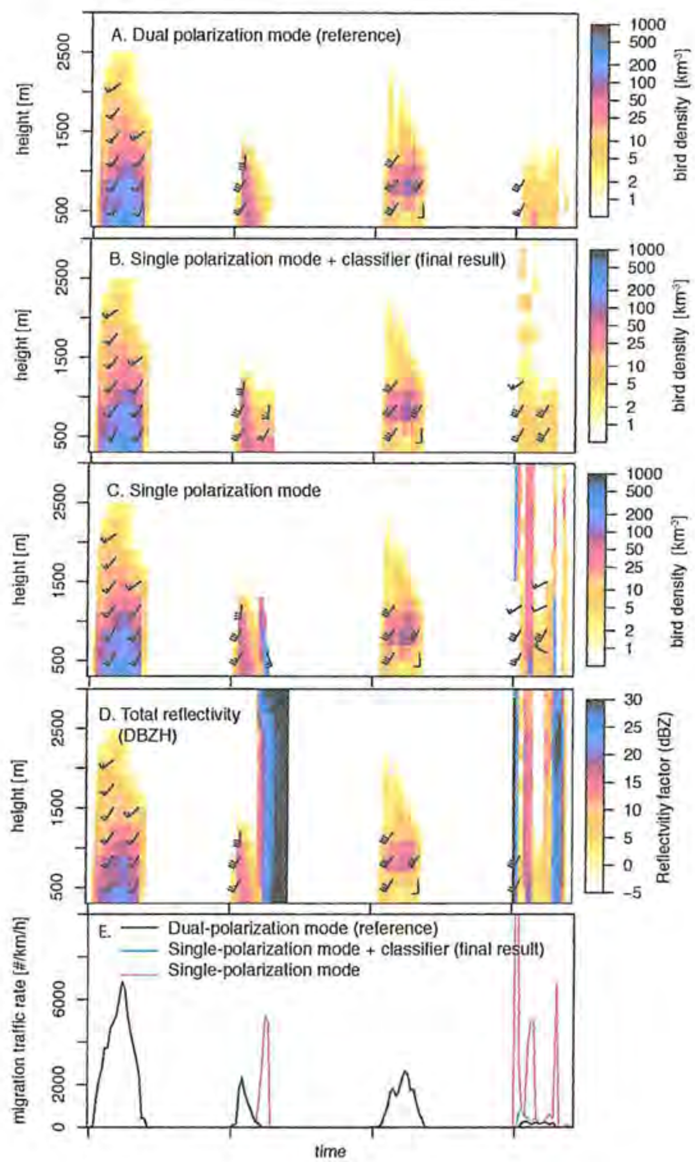

Fig. S3.

Example of vertical profile time series for bird density and speed retrieved in dual polarization mode (A, precipitation-free reference) and the final single-polarization product used in the study (B) for the KBGM radar from 28-31 May 2017. The full-profile classifier that screens precipitation uses the reflectivity product obtained in single-polarization mode (C) and the total reflectivity including precipitation (D). Precipitation is characterized by high reflectivities spanning a large part of the vertical air column (see D), as well by cases in which the single-polarization rain filter removes part (but not necessarily all) of the signal (C versus D). The final single-polarization product (B) closely matches the dual-polarization mode reference (A), see also E, black and blue lines closely overlapping).

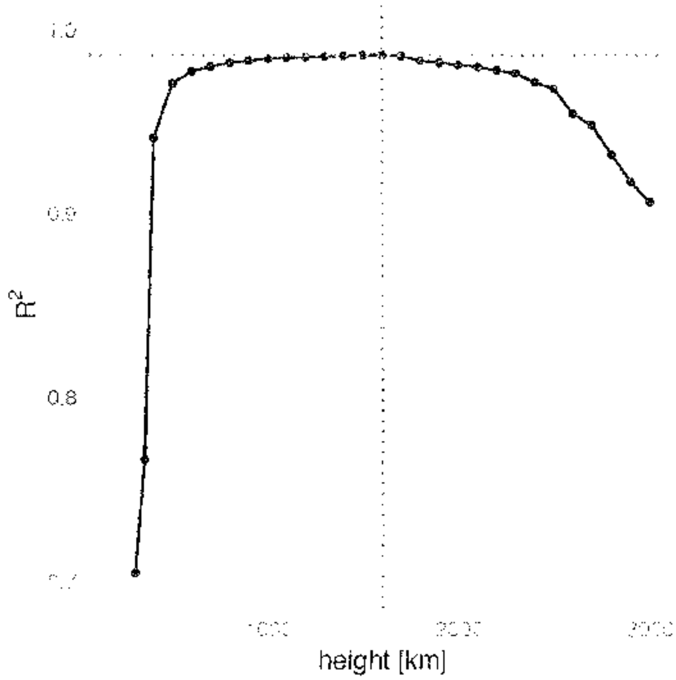

Fig. S4.

Coefficient of determination R^2 between full-spring seasonal migration traffic values calculated in single polarization mode (rain-filtered using full-profile classifier) and dual-polarization mode reference (R^2 based on n=143 stations * 4 years = 572 points), as a function of the classification threshold H_{max}. The value of R^2 peaks at H_{max} = 1600 m .

P21-36 cont.

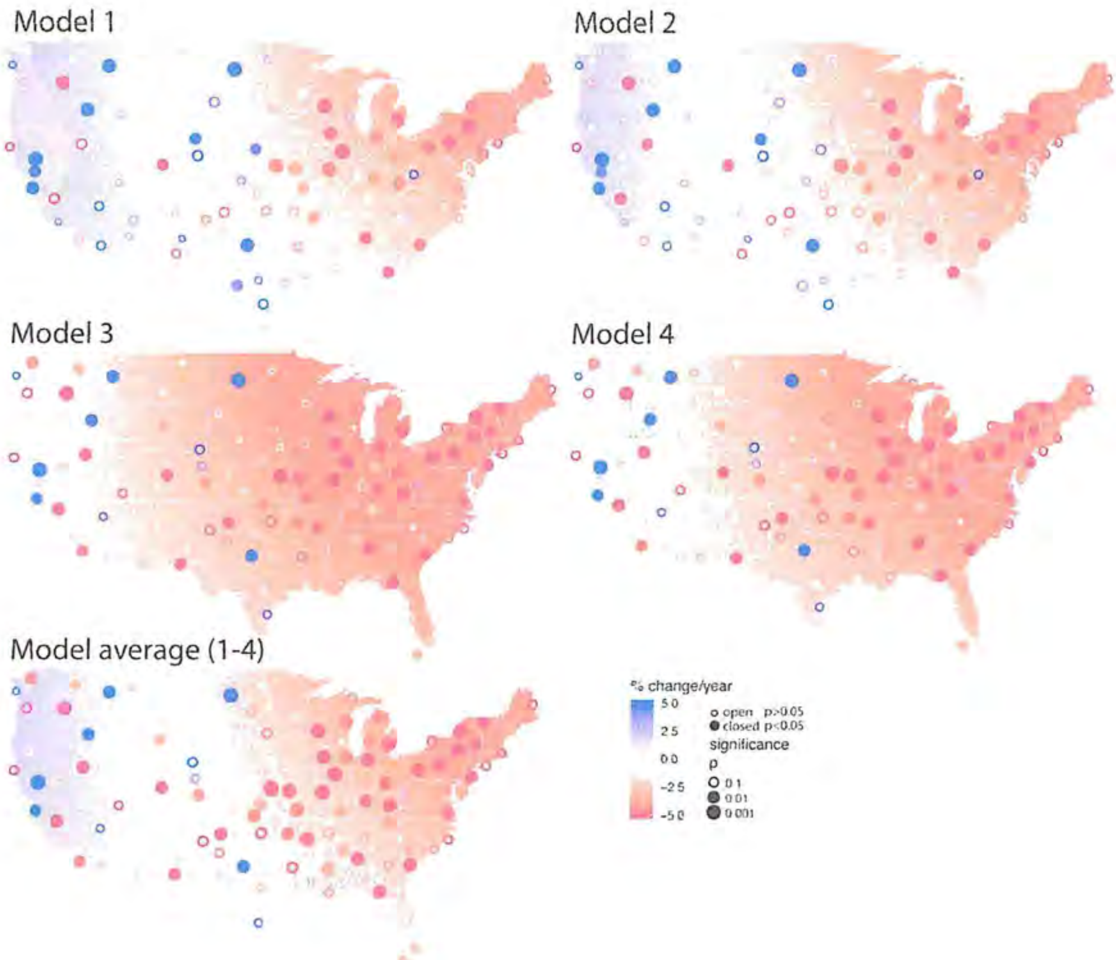

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Fig. S7. GAM spatial trend surfaces estimated for the models in Table S3 for the period 2007-2017. Darker red colors indicate higher declines and loss of migration traffic (biomass passage) MT, while blue colors indicate migration traffic increase. Gray shaded regions have an annual rate of change μ_{trend} that is smaller than twice the standard deviation in the rate of change σ_{trend}, i.e. $\mu_{trend} < 2*\sigma_{trend}$. Overlaid circles indicate single-site trend estimates (circle color) and their significance (circle area ~ log(1/p)), with closed circles being significant at a 95% confidence level. Single site trends are fits to seasonal migration traffic data of each radar site separately, using a Generalized Linear Model (GLM) with a Gamma distributional family and log-link. Detectability effects as estimated by the GAM were accounted for in the single-site data prior to fitting the GLMs.

Table S1.

Data sources for population size estimates and population trajectories for 529 North American bird species included in the net population change analysis for the present study. We used published sources of data wherever possible, and applied published methods to calculate estimates for the remaining species. Brief description of methodology, time-span, seasonal, and geographic coverage of surveys and other data sources provided, along with number of species for which that source was used and key citations.

Data source	Years	Season	Methods	Coverage	N Spp. Trajectory	N Spp. Pop	Refs
North American Breeding Bird Survey (BBS)	1970-2017	Breeding	25-mile roadside surveys with 50 3-minute point counts	>4,100 routes in contiguous U.S., southern Canada	415	0	(*33, 34, 47*)
North American Breeding Bird Survey (BBS)	1993-2017	Breeding	25-mile roadside surveys with 50 3-minute point counts	Same as above, with additional routes in northern Canada and Alaska	19	0	(*48*)
Audubon Christmas Bird Count (CBC)	1970-2017	Winter	Non-standard counts within 15-mile diameter circles	1,500-2,000 circles in U.S. and Canada	58	0	(*57*)
Partners in Flight (PIF) Population Estimates	2006-2015	Breeding adults	Extrapolation from BBS and other survey count data	Same as BBS, above	0	399*	(*35*)
Arctic goose surveys (CAFF 2018)	1975-2014	Variable	Aerial or ground surveys or mark-recapture models, depending on species	Continentwide for each species	7	7	(*62*)
Shorebird Migration Surveys	1974-2016	Fall migration	Volunteer-conducted surveys at pre-determined sites	Canada and U.S., concentrated in eastern portion	20	0	(*58, 59*)
USFWS Breeding Waterfowl Surveys	1970-2017	Breeding	Aerial surveys corrected for detectability with ground surveys	2.0 million square miles in Alaska, Canada, and northern U.S.	9	13	(*61*)
North American Trumpeter Swan Survey	1968-2015	Breeding	Aerial surveys and ground counts	Rangewide	1	1	(*63*)
American Woodcock Singing Ground Survey	1968-2017	Breeding	3.6-mile roadside routes	1,500 routes in eastern North America	1	0	(*60*)
2007 Seaduck Joint Venture Report	1970-2007	Variable	Compilation of best available estimates	Continentwide for each species	0	14	(*68*)

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Table S4.

Model comparison of regionalized generalized mixed models, differentiating in four geographic flyway regions: Atlantic, Mississippi, Central and Western (see Fig. XXX). AIC gives Akaike's An Information Criterion, df degrees of freedom. Models significantly different according to a Chi-squared likelihood ratio test are labelled by different letters (a,b). We found support for an effect of dual-polarization upgrade on detected biomass passage (cf. model 5), but not for additional correction for the superresolution upgrade (model 6 did not improve over model 5). See Table S5 for fixed effect estimates.

Model[*]	Formula	AIC	df	
5	index ~ region + year:flyway + (1 | radar) + dualpol[†]	338	11	a
6	index ~ region + year:flyway + (1 | radar) + mode[‡]	340	12	a
7	Index ~ region + year:flyway + (1 | radar) + superres	343	11	b
8	Index ~ region + year:flyway + (1 | radar)	361	10	c

[*]Family=Gamma(link=log)
[‡]mode is a factor variable with levels "legacy", "superres" and "dualpol", distinguishing the three time periods in which the radar acquired legacy, super-resolution and dual-polarization data. Note that the dual-polarization upgrade occurred after the super-resolution upgrade, and dual-polarization data includes super-resolution.
[†]dualpol is a logical variable that is true after the dual-polarization upgrade, and false before
[§]superres is a logical variable that is true after the superresolution upgrade, and false before

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Table S5.

Parameter estimates of temporal and detection-related fixed effects, based on generalized mixed models differentiating in three geographic regions: west (lon < -105°), central (-105° < lon < -95°) and east (lon> -95°). Estimates of change in migratory biomass traffic are expressed as percentages change per year. Explanatory variable year was scaled to zero at 2007. Significant model terms are highlighted in **bold**. See Table S4 for model comparisons.

Model	Fixed effect	Estimate	Unit	t	p
5	**year:flyway_Atlantic**	**-3.0 ± 0.6**	**%/yr**	**-4.7**	**<0.0001**
5	**year:flyway_Mississippi**	**-2.7 ± 0.6**	**%/yr**	**-4.5**	**<0.0001**
5	year:flyway_Central	0.6 ± 0.6	%/yr	1.0	0.3
5	year:flyway_Pacific	0.2 ± 0.6	%/yr	0.3	0.8
5	**dualpol=TRUE**	**-16 ± 3**	**%**	**-5.0**	**<0.0001**
6	**year:flyway_Atlantic**	**-3.4 ± 0.7**	**%/yr**	**-4.5**	**<0.0001**
6	**year:flyway_Mississippi**	**-3.0 ± 0.7**	**%/yr**	**-4.2**	**<0.0001**
6	year:flyway_Central	0.2 ± 0.7	%/yr	0.3	0.7
6	year:flyway_Pacific	0.1 ± 0.8	%/yr	-0.2	0.9
6	mode="superres"	25 ± 27	%	0.9	0.4
6	**mode="dualpol"**	**-12 ± 5**	**%**	**-2.4**	**0.02**
7	**year:flyway_Atlantic**	**-4.7 ± 0.5**	**%/yr**	**-9.9**	**<0.0001**
7	**year:flyway_Mississippi**	**-4.4 ± 0.4**	**%/yr**	**-10.2**	**<0.0001**
7	**year:flyway_Central**	**-1.2 ± 0.4**	**%/yr**	**-2.7**	**0.007**
7	**year:flyway_Pacific**	**-1.5 ± 0.5**	**%/yr**	**-3.0**	**0.003**
7	**superres=TRUE**	**8 ± 2**	**%**	**4.4**	**<0.0001**
8	**year:flyway_Atlantic**	**-5.2 ± 0.5**	**%/yr**	**-10.9**	**<0.0001**
8	**year:flyway_Mississippi**	**-4.8 ± 0.4**	**%/yr**	**-11.3**	**<0.0001**
8	**year:flyway_Central**	**-1.5 ± 0.4**	**%/yr**	**-3.5**	**0.0004**
8	**year:flyway_Pacific**	**-1.9 ± 0.5**	**%/yr**	**-3.8**	**0.0001**
5-8 (average)†	**year:flyway_Atlantic**	**-3.2 ± 0.8**	**%/yr**	**4.1***	**<0.0001**
5-8 (average)†	**year:flyway_Mississippi**	**-2.9 ± 0.7**	**%/yr**	**3.9***	**0.0001**
5-8 (average)†	year:flyway_Central	0.4 ± 0.8	%/yr	0.5*	0.6
5-8 (average)†	year:flyway_Pacific	0.3 ± 0.8	%/yr	0.0*	1.0

*z value instead of t value

†showing full model-averaged coefficients for temporal fixed effects only

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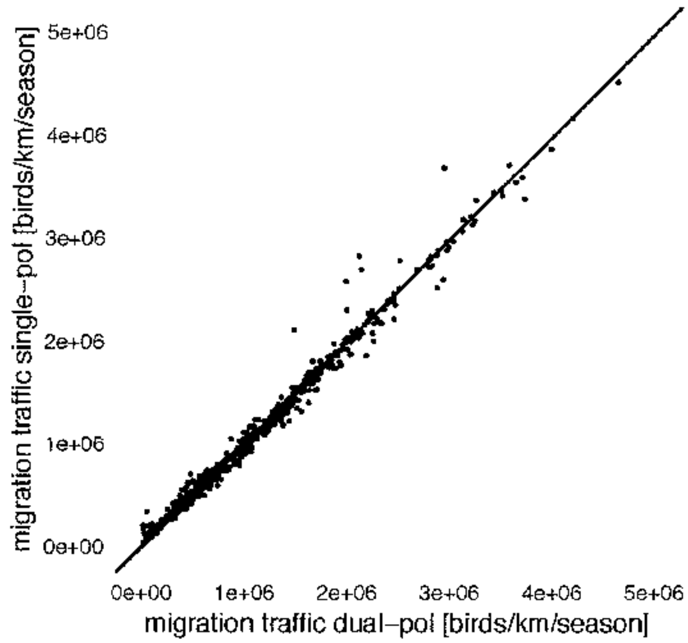

Fig. S5. Seasonal migration traffic (MT) as estimated in dual-polarization mode and in single-polarization mode (rain-filtered using full-profile classifier) for the years 2014-2017 (n=143 stations * 4 year = 572 points). Solid line equals the y=x line of perfect correspondence. This figure shows MT values for H_{max} = 1600 m, which achieves the best correspondence with the dual-polarization reference mode (see Figure S4).

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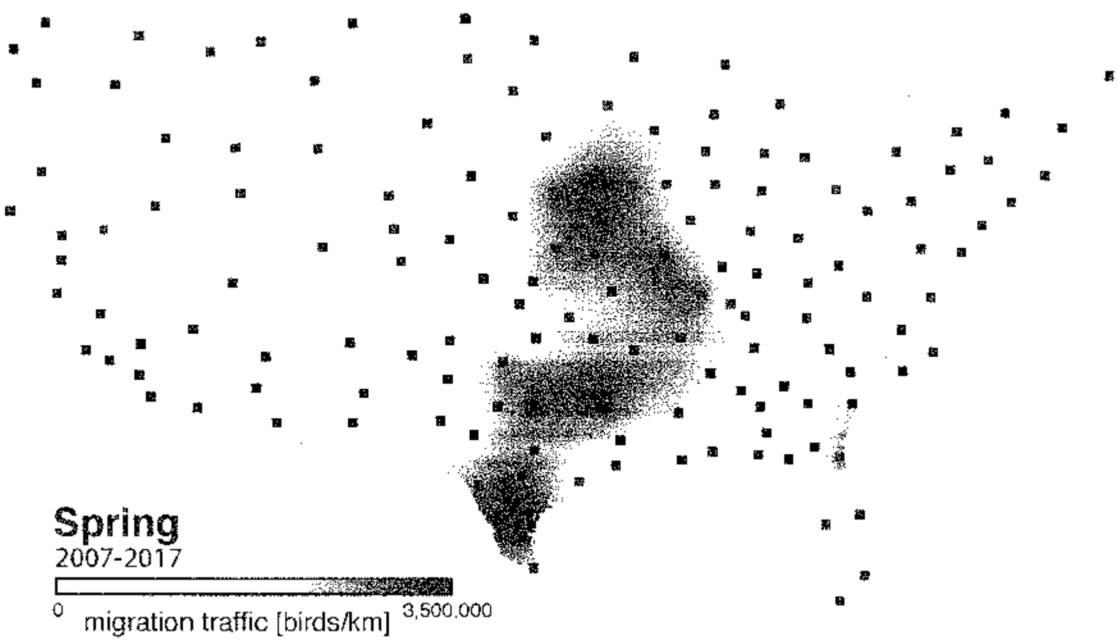

Fig. S6. Cumulated nocturnal migration traffic (biomass passage) MT in spring (1 Mar – 1 Jul) averaged over 11 seasons (2007-2017). Darker colors indicate more migratory biomass passage MT. Values give the numbers of birds passing per 1 km transect perpendicular to the migratory direction per spring season. Radar reflectivity was converted to bird numbers under the assumption of a constant radar cross section of 11 cm^2 per bird. Ordinary kriging was used to interpolate between radar stations. Dots indicate locations of radar station sites.

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U.S. Fish & Wildlife Service

U.S. Fish and Wildlife Service Land-Based Wind Energy Guidelines

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Cover Photo:

Wind Turbine. Photo by Stefanie Stavrakas, USFWS

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March 23, 2012

Acknowledgements

The U.S. Fish and Wildlife Service (Service) would like to recognize and thank the Wind Turbine Guidelines Advisory Committee for its dedication and preparation of its Recommendations. The Recommendations have served as the basis from which the Service's team worked to develop the Service's Land-Based Wind Energy Guidelines. The Service also recognizes the tireless efforts of the Headquarters, Regional and Field Office staff that helped to review and update these Guidelines.

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Paperwork Reduction Act Statement: The Land-Based Wind Energy Guidelines contain reporting and recordkeeping requirements that require Office of Management and Budget approval in accordance with the Paperwork Reduction Act of 1995. Your response is voluntary. We collect this information in order to provide technical assistance related to addressing wildlife conservation concerns at all stages of land-based wind energy development. For each response, we estimate the time necessary to provide the information as follows:

Tier 1 – 83 hours
Tier 2 – 375 hours
Tier 3 – 2,880 hours
Tier 4 – 2,550 hours
Tier 5 – 2,400 hours

The above estimates include time for reviewing instructions, gathering and maintaining data, and preparing and transmitting reports. Send comments regarding these estimates or any other aspect of the requirements to the Service Information Collection Clearance Officer, U.S. Fish and Wildlife Service, 4401 N. Fairfax Drive, MS 2042-PDM, Arlington, VA 22203.

We may not conduct and you are not required to respond to a collection of information unless it displays a currently valid OMB control number.

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List of Figures and Tables

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Executive Summary

As the Nation shifts to renewable energy production to supplant the need for carbon-based fuel, wind energy will be an important source of power. As wind energy production increases, both developers and wildlife agencies have recognized the need for a system to evaluate and address the potential negative impacts of wind energy projects on species of concern. These voluntary Guidelines provide a structured, scientific process for addressing wildlife conservation concerns at all stages of land-based wind energy development. They also promote effective communication among wind energy developers and federal, state, and local conservation agencies and tribes. When used in concert with appropriate regulatory tools, the Guidelines form the best practical approach for conserving species of concern. The Guidelines have been developed by the Interior Department's U.S. Fish and Wildlife Service (Service) working with the Wind Turbine Guidelines Advisory Committee. They replace interim voluntary guidance published by the Service in 2003.

The Guidelines discuss various risks to "species of concern" from wind energy projects, including collisions with wind turbines and associated infrastructure; loss and degradation of habitat from turbines and infrastructure; fragmentation of large habitat blocks into smaller segments that may not support sensitive species; displacement and behavioral changes; and indirect effects such as increased predator populations or introduction of invasive plants. The Guidelines assist developers in identifying species of concern that may potentially be affected by their proposed project, including migratory birds; bats; bald and golden eagles and other birds of prey; prairie and sage grouse; and listed, proposed, or candidate endangered and threatened species. Wind energy development in some areas may be precluded by federal law; other areas may be inappropriate for development because they have been recognized as having high wildlife value based on their ecological rarity and intactness.

The Guidelines use a "tiered approach" for assessing potential adverse effects to species of concern and their habitats. The tiered approach is an iterative decision-making process for collecting information in increasing detail; quantifying the possible risks of proposed wind energy projects to species of concern and their habitats; and evaluating those risks to make siting, construction, and operation decisions. During the pre-construction tiers (Tiers 1, 2, and 3), developers are working to identify, avoid and minimize risks to species of concern. During post-construction tiers (Tiers 4 and 5), developers are assessing whether actions taken in earlier tiers to avoid and minimize impacts are successfully achieving the goals and, when necessary, taking additional steps to compensate for impacts. Subsequent tiers refine and build upon issues raised and efforts undertaken in previous tiers. Each tier offers a set of questions to help the developer evaluate the potential risk associated with developing a project at the given location.

Briefly, the tiers address:

- Tier 1 – Preliminary site evaluation (landscape-scale screening of possible project sites)
- Tier 2 – Site characterization (broad characterization of one or more potential project sites)
- Tier 3 – Field studies to document site wildlife and habitat and predict project impacts
- Tier 4 – Post-construction studies to estimate impacts[1]
- Tier 5 – Other post-construction studies and research

The tiered approach provides the opportunity for evaluation and decision-making at each stage, enabling a developer to abandon or proceed with project development, or to collect additional information if required. This approach does not require that every tier, or every element within each tier, be implemented for every project. The Service anticipates that many distributed or community facilities will not need to follow the Guidelines beyond Tiers 1 and 2. Instead, the tiered approach allows efficient use of developer and wildlife agency resources with increasing levels of effort.

If sufficient data are available at a particular tier, the following outcomes are possible:

1. The project proceeds to the next tier in the development process without additional data collection.
2. The project proceeds to the next tier in the development process with additional data collection.
3. An action or combination of actions, such as project

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[1] The Service anticipates these studies will include fatality monitoring as well as studies to evaluate habitat impacts.

modification, mitigation, or specific post-construction monitoring, is indicated.

4. The project site is abandoned because the risk is considered unacceptable.

If data are deemed insufficient at a tier, more intensive study is conducted in the subsequent tier until sufficient data are available to make a decision to modify the project, proceed with the project, or abandon the project.

The most important thing a developer can do is to consult with the Service as early as possible in the development of a wind energy project. Early consultation offers the greatest opportunity for avoiding areas where development is precluded or where wildlife impacts are likely to be high and difficult or costly to remedy or mitigate at a later stage. By consulting early, project developers can also incorporate appropriate wildlife conservation measures and monitoring into their decisions about project siting, design, and operation.

Adherence to the Guidelines is voluntary and does not relieve any individual, company, or agency of the responsibility to comply with laws and regulations. However, if a violation occurs the Service will consider a developer's documented efforts to communicate with the Service and adhere to the Guidelines. The Guidelines include a Communications Protocol which provides guidance to both developers and Service personnel regarding appropriate communication and documentation.

The Guidelines also provide Best Management Practices for site development, construction, retrofitting, repowering, and decommissioning. For additional reference, a glossary of terms and list of literature cited are included in the appendices.

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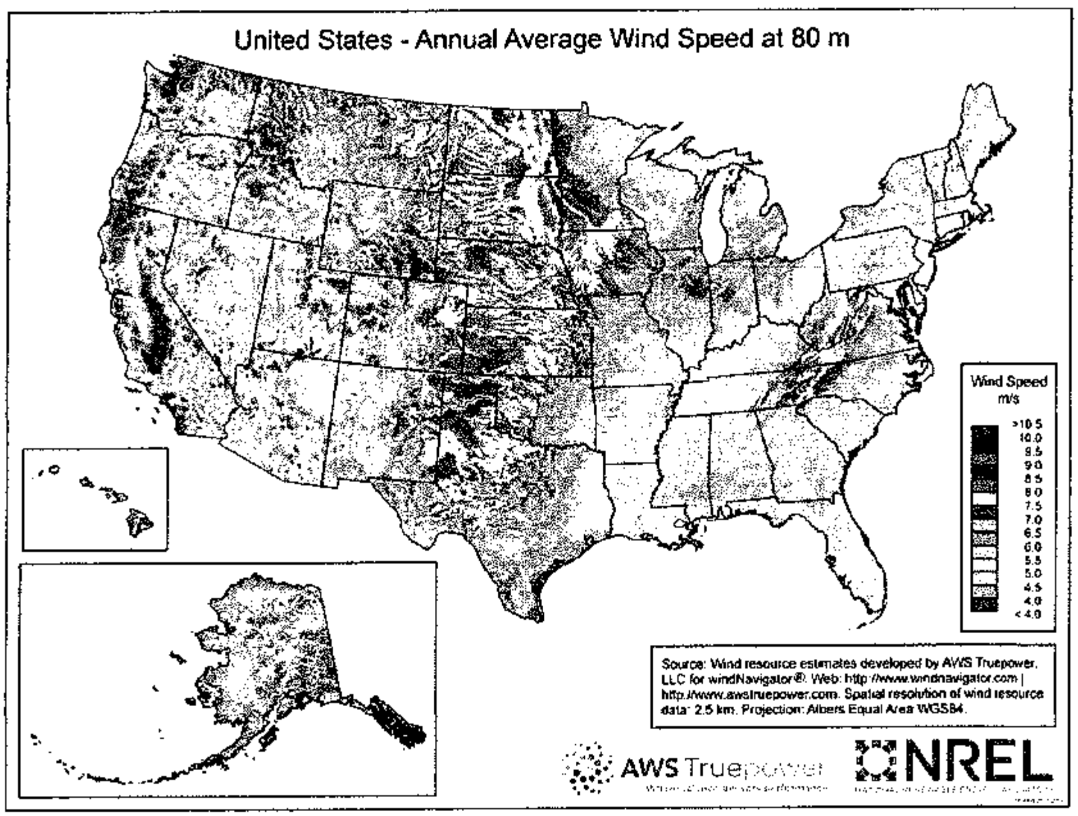
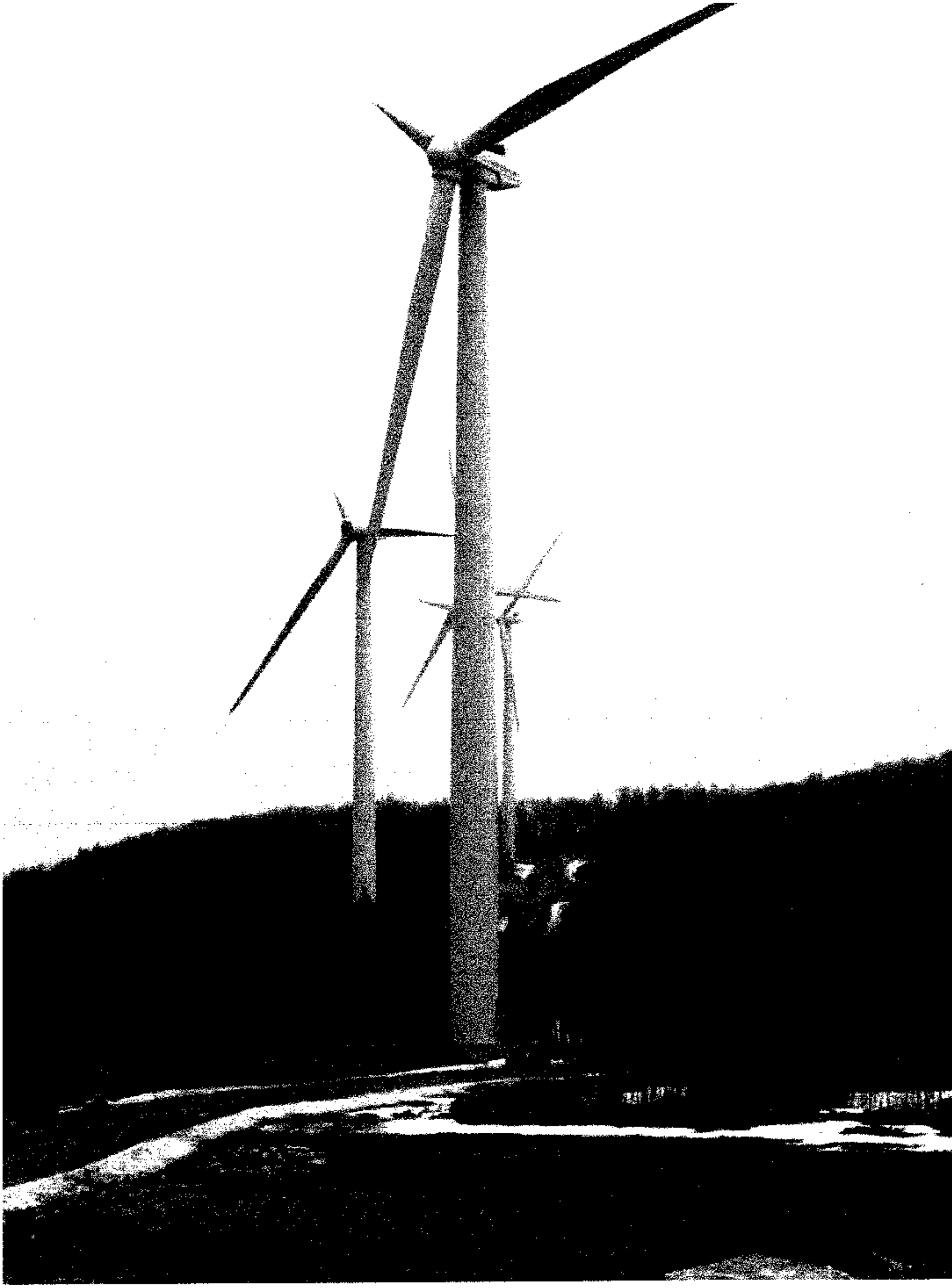


Wind Resource Map. Credit: NREL



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Chapter 1 - General Overview

The mission of the U.S. Fish and Wildlife Service (Service) is working with others to conserve, protect and enhance fish, wildlife, plants and their habitats for the continuing benefit of the American people. As part of this, the Service implements statutes including the Endangered Species Act, Migratory Bird Treaty Act, and Bald and Golden Eagle Protection Act. These statutes prohibit taking of federally listed species, migratory birds, and eagles unless otherwise authorized.

Recent studies have documented that wind energy facilities can kill birds and bats. Mortality rates in fatalities per nameplate MW per year vary among facilities and regions. Studies have indicated that relatively low raptor (e.g., hawks, eagles) fatality rates exist at most modern wind energy developments with the exception of some facilities in California and Wyoming. Turbine-related bat deaths have been reported at each wind facility to date. Generally, studies in the West have reported lower rates of bat fatalities than facilities in the East. There is still much uncertainty regarding geographic distribution and causes of bat fatalities (NWCC 2010).

These Guidelines are intended to:

(1) Promote compliance with relevant wildlife laws and regulations;

(2) Encourage scientifically rigorous survey, monitoring, assessment, and research designs proportionate to the risk to species of concern;

(3) Produce potentially comparable data across the Nation;

(4) Mitigate, including avoid, minimize, and compensate for potential adverse effects on species of concern and their habitats; and,

(5) Improve the ability to predict and resolve effects locally, regionally, and nationally.

As the United States moves to expand wind energy production, it also must maintain and protect the Nation's wildlife and their habitats, which wind energy production can negatively affect. As with all responsible energy development, wind energy projects should adhere to high standards for environmental protection. With proper diligence paid to siting, operations, and management of projects, it is possible to mitigate for adverse effects to wildlife, and their habitats. This is best accomplished when the wind energy project developer communicates as early as possible with the Service and other stakeholders. Such early communication allows for the greatest range of development and mitigation options. The following website contains contact information for the Service Regional and Field offices as well as State wildlife agencies: http://www.fws.gov/offices/statelinks.html.

In response to increasing wind energy development in the United States, the Service released a set of voluntary, interim guidelines for reducing adverse effects to fish and wildlife resources from wind energy projects for public comment in July 2003. After the Service reviewed the public comments, the Secretary of the Interior (Secretary) established a Federal Advisory Committee[2] to provide recommendations to revise the guidelines related to land-based wind energy facilities. In March 2007, the U.S. Department of the Interior established the Wind Turbine Guidelines Advisory Committee (the Committee). The Committee submitted its final Recommended Guidelines (Recommendations) to the Secretary on March 4, 2010. The Service used the Recommendations to develop its Land-Based Wind Energy Guidelines.

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The Service encourages project proponents to use the process described in these voluntary Land-based Wind Energy Guidelines (Guidelines) to address risks to species of concern. The Service intends that these Guidelines, when used in concert with the appropriate regulatory tools, will form the best practical approach for conservation of species of concern.

Statutory Authorities

These Guidelines are not intended nor shall they be construed to limit or preclude the Service from exercising its authority under any law, statute, or regulation, or from conducting enforcement action against any individual, company, or agency. They are not meant to relieve any individual, company, or agency of its obligations to comply with any applicable federal, state,

[2] Committee membership, from 2008 to 2011, has included: Taber Allison, Massachusetts Audubon; Dick Anderson, California Energy Commission; Ed Arnett, Bat Conservation International; Michael Azeka, AES Wind Generation; Thomas Bancroft, National Audubon; Kathy Boydston, Texas Parks and Wildlife Department; René Braud, EDP Renewables; Scott Darling, Vermont Fish and Wildlife Department; Michael Daulton, National Audubon; Aimee Delach, Defenders of Wildlife; Karen Douglas, California Energy Commission; Sam Enfield, MAP Royalty; Greg Hueckel, Washington Department of Fish and Wildlife; Jeri Lawrence, Blackfeet Nation; Steve Lindenberg, U.S. Department of Energy; Andy Linehan, Iberdrola Renewables; Rob Manes, The Nature Conservancy, Kansas; Winifred Perkins, NextEra Energy Resources; Steven Quarles, Crowell & Moring; Rich Rayhill, Ridgeline Energy; Robert Robel, Kansas State University; Keith Sexson, Association of Fish and Wildlife Agencies; Mark Sinclair, Clean Energy States Alliance; David Stout, U.S. Fish and Wildlife Service; Patrick Traylor, Hogan Lovells.

tribal, or local laws, statutes, or regulations. The Guidelines do not prevent the Service from referring violations of law for enforcement when a company has not followed the Guidelines.

Ultimately it is the responsibility of those involved with the planning, design, construction, operation, maintenance, and decommissioning of wind projects to conduct relevant wildlife and habitat evaluation and determine, which, if any, species may be affected. The results of these analyses will inform all efforts to achieve compliance with the appropriate jurisdictional statutes. Project proponents are responsible for complying with applicable state and local laws.

Migratory Bird Treaty Act

The Migratory Bird Treaty Act (MBTA) is the cornerstone of migratory bird conservation and protection in the United States. The MBTA implements four treaties that provide for international protection of migratory birds. It is a strict liability statute, meaning that proof of intent, knowledge, or negligence is not an element of an MBTA violation. The statute's language is clear that actions resulting in a "taking" or possession (permanent or temporary) of a protected species, in the absence of a Service permit or regulatory authorization, are a violation of the MBTA.

The MBTA states, "Unless and except as permitted by regulations ... it shall be unlawful at any time, by any means, or in any manner to pursue, hunt, take, capture, kill ... possess, offer for sale, sell ... purchase ... ship, export, import ... transport or cause to be transported ... any migratory bird, any part, nest, or eggs of any such bird .... [The Act] prohibits the taking, killing, possession, transportation, import and export of migratory birds, their eggs, parts, and nests, except when specifically authorized by the Department of the Interior." 16 U.S.C. 703. The word "take" is defined by regulation as "to pursue, hunt, shoot, wound, kill, trap, capture, or collect, or attempt to pursue, hunt, shoot, wound, kill, trap, capture, or collect." 50 CFR 10.12.

The MBTA provides criminal penalties for persons who commit any of the acts prohibited by the statute in section 703 on any of the species protected by the statute. See 16 U.S.C. 707. The Service maintains a list of all species protected by the MBTA at 50 CFR 10.13. This list includes over one thousand species of migratory birds, including eagles and other raptors, waterfowl, shorebirds, seabirds, wading birds, and passerines. The MBTA does not protect introduced species such as the house (English) sparrow, European starling, rock dove (pigeon), Eurasian collared-dove, and non-migratory upland game birds. The Service maintains a list of introduced species not protected by the Act. See 70 Fed. Reg. 12,710 (Mar. 15, 2005).

Bald and Golden Eagle Protection Act

Under authority of the Bald and Golden Eagle Protection Act (BGEPA), 16 U.S.C. 668–668d, bald eagles and golden eagles are afforded additional legal protection. BGEPA prohibits the take, sale, purchase, barter, offer of sale, purchase, or barter, transport, export or import, at any time or in any manner of any bald or golden eagle, alive or dead, or any part, nest, or egg thereof. 16 U.S.C. 668. BGEPA also defines take to include "pursue, shoot, shoot at, poison, wound, kill, capture, trap, collect, molest, or disturb," 16 U.S.C. 668c, and includes criminal and civil penalties for violating the statute. See 16 U.S.C. 668. The Service further defined the term "disturb" as agitating or bothering an eagle to a degree that causes, or is likely to cause, injury, or either a decrease in productivity or nest abandonment by substantially interfering with normal breeding, feeding, or sheltering behavior. 50 CFR 22.3. BGEPA authorizes the Service to permit the take of eagles for certain purposes and under certain circumstances, including scientific or exhibition purposes, religious purposes of Indian tribes, and the protection of wildlife, agricultural, or other interests, so long as that take is compatible with the preservation of eagles. 16 U.S.C. 668a.

In 2009, the Service promulgated a final rule on two new permit regulations that, for the first time, specifically authorize the incidental take of eagles and eagle nests in certain situations under BGEPA. See 50 CFR 22.26 & 22.27. The permits authorize limited, non-purposeful (incidental) take of bald and golden eagles; authorizing individuals, companies, government agencies (including tribal governments), and other organizations to disturb or otherwise take eagles in the course of conducting lawful activities such as operating utilities and airports.

Bald Eagle, Credit: USFWS

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Removal of active eagle nests would usually be allowed only when it is necessary to protect human safety or the eagles. Removal of inactive nests can be authorized when necessary to ensure public health and safety, when a nest is built on a human-engineered structure rendering it inoperable, and when removal is necessary to protect an interest in a particular locality, but only if the take or mitigation for the take will provide a clear and substantial benefit to eagles.

To facilitate issuance of permits under these new regulations, the Service has drafted Eagle Conservation Plan (ECP) Guidance. The ECP Guidance is compatible with these Land-Based Wind Energy Guidelines. The Guidelines guide developers through the process of project development and operation. If eagles are identified as a potential risk at a project site, developers are strongly encouraged to refer to the ECP Guidance. The ECP Guidance describes specific actions that are recommended to comply with the regulatory requirements in BGEPA for an eagle take permit, as described in 50 CFR 22.26 and 22.27. The ECP Guidance provides a national framework for assessing and mitigating risk specific to eagles through development of ECPs and issuance of programmatic incidental takes of eagles at wind turbine facilities. The Service will make its final ECP Guidance available to the public through its website.

Endangered Species Act

The Endangered Species Act (16 U.S.C. 1531–1544; ESA) was enacted by Congress in 1973 in recognition that many of our Nation's native plants and animals were in danger of becoming extinct. The ESA directs the Service to identify and protect these endangered and threatened species and their critical habitat, and to provide a means to conserve their ecosystems. To this end, federal agencies are directed to utilize their authorities to conserve listed species, and ensure that their actions

Indiana bat. Credit: USFWS

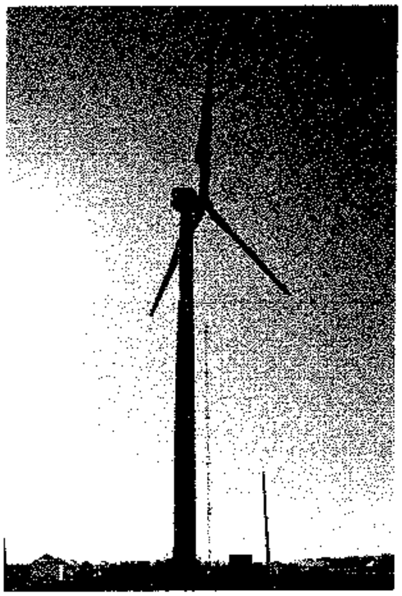
are not likely to jeopardize the continued existence of these species or destroy or adversely modify their critical habitat. Federal agencies are encouraged to do the same with respect to "candidate" species that may be listed in the near future. The law is administered by the Service and the Commerce Department's National Marine Fisheries Service (NMFS). For information regarding species protected under the ESA, see: http://www.fws.gov/endangered/.

The Service has primary responsibility for terrestrial and freshwater species, while NMFS generally has responsibility for marine species. These two agencies work with other agencies to plan or modify federal projects so that they will have minimal impact on listed species and their habitats. Protection of species is also achieved through partnerships with the states, through federal financial assistance and a system of incentives available to encourage state participation. The Service also works with private landowners, providing financial and technical assistance for management actions on their lands to benefit both listed and non-listed species.

Section 9 of the ESA makes it unlawful for a person to "take" a listed species. Take is defined as "... to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect or attempt to engage in any such conduct." 16 U.S.C. 1532(19). The terms harass and harm are further defined in our regulations. See 50 CFR 17.3. However, the Service may authorize "incidental take" (take that occurs as a result of an otherwise legal activity) in two ways.

Take of federally listed species incidental to a lawful activity may be authorized through formal consultation under section 7(a)(2) of the ESA, whenever a federal agency, federal funding, or a federal permit is involved. Otherwise, a person may seek an incidental take permit under section 10(a)(1)(B) of the ESA upon completion of a satisfactory habitat conservation plan (HCP) for listed species. Developers not receiving federal funding or authorization should contact the Service to obtain an incidental take permit if a wind

P21-36 cont.



Utility-Scale Wind turbine with an anemometer tower in the background. Credit: University of Minnesota College of Science and Engineering

energy project is likely to result in take of listed threatened or endangered wildlife species. For more information regarding formal consultation and the requirements of obtaining HCPs, please see the Endangered Species Consultation Handbook at http://www.fws.gov/endangered/esa-library/index.html#consultations and the Service's HCP website, http://www.fws.gov/endangered/what-we-do/hcp-overview.html.

Implementation of the Guidelines

Because these Guidelines are voluntary, the Service encourages developers to use them as soon as possible after publication. To receive the considerations discussed on page 6 regarding enforcement priorities, a wind energy project would fall into one of three general categories relative to timing and implementation:

- For projects initiated after publication, the developer has applied the Guidelines, including the tiered approach, through site selection, design, construction, operation and post-operation phases of the project, and has communicated and shared information with the Service and considered its advice.
- For projects initiated prior to publication, the developer should consider where they are in the planning process relative to the appropriate tier and inform the Service of what actions they will take to apply the Guidelines.
- For projects operating at the time of publication, the developer should confer with the Service regarding the appropriate period of fatality monitoring consistent with Tier 4, communicate and share information with the Service on monitoring results, and consider Tier 5 studies and mitigation options where appropriate.

Projects that are already under development or are in operation are not expected to start over or return to the beginning of a specific tier. Instead, these projects should implement those portions of the Guidelines relevant to the current phases of the project per the bullets above.

The Service is aware that it will take time for Service staff and other personnel, including wind energy developers and their biologists, to develop expertise in the implementation of these Guidelines. Service staff and many staff associated with the wind energy industry have been involved with developing these Guidelines. Therefore, they have a working knowledge of the Guidelines. To further refine their training, the Service will make every effort to offer an in-depth course within 6 months of the final Guidelines being published.

The Communications Protocol on page 5 provides guidance to Service staff and developers in the exchange of information and recommendations at each tier in the process. Although the advice of the Service is not binding, a developer should review such advice, and either accept or reject it. If they reject it, they should contemporaneously document with reasoned justification why they did so. Although the Guidelines leave decisions up to the developer, the Service retains authority to evaluate whether developer efforts to mitigate impacts are sufficient, to determine significance, and to refer for prosecution any unlawful take that it believes to be reasonably related to lack of incorporation of Service recommendations or insufficient adherence with the Guidelines.

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Table 1. Suggested Communications Protocol
This table provides examples of potential communication opportunities between a wind energy project developer and the Service. Not all projects will follow all steps indicated below.

TIER	*Project Developer/Operator Role*	*Service Role*
Tier 1: Preliminary site evaluation	• Landscape level assessment of habitat for species of concern • Request data sources for existing information and literature	• Provide lists of data sources and references, if requested
Tier 2: Site characterization	• Assess potential presence of species of concern, including species of habitat fragmentation concern, likely to be on site • Assess potential presence of plant communities present on site that may provide habitat for species of concern • Assess potential presence of critical congregation areas for species of concern • One or more reconnaissance level site visit by biologist • Communicate results of site visits and other assessments with the Service • Provide general information about the size and location of the project to the Service	• Provide species lists, for species of concern, including species of habitat fragmentation concern, for general area, if available • Provide information regarding plant communities of concern, if available • Respond to information provided about findings of biologist from site visit • Identify initial concerns about site(s) based on available information • Inform lead federal agencies of communications with wind project developers
Tier 3: Field studies and impact prediction	• Discuss extent and design of field studies to conduct with the Service • Conduct biological studies • Communicate results of all studies to Service field office in a timely manner • Evaluate risk to species of concern from project construction and operation • Identify ways to mitigate potential direct and indirect impacts of building and operating the project	• Respond to requests to discuss field studies • Advise project proponent about studies to conduct and methods for conducting them • Communicate with project proponent(s) about results of field studies and risk assessments • Communicate with project proponents(s) ways to mitigate potential impacts of building and operating the project • Inform lead federal agencies of communications with wind project developers
Tier 4: Post construction studies to estimate impacts	• Discuss extent and design of post-construction studies to conduct with the Service • Conduct post-construction studies to assess fatalities and habitat-related impacts • Communicate results of all studies to Service field office in a timely manner • If necessary, discuss potential mitigation strategies with Service • Maintain appropriate records of data collected from studies	• Advise project operator on study design, including duration of studies to collect adequate information • Communicate with project operator about results of studies • Advise project operator of potential mitigation strategies, when appropriate
Tier 5: Other post-construction studies and research	• Communicate with the Service about the need for and design of other studies and research to conduct with the Service, when appropriate, particularly when impacts exceed predicted levels • Communicate with the Service about ways to evaluate cumulative impacts on species of concern, particularly species of habitat fragmentation concern • Conduct appropriate studies as needed • Communicate results of studies with the Service • Identify potential mitigation strategies to reduce impacts and discuss them with the Service	• Advise project proponents as to need for Tier 5 studies to address specific topics, including cumulative impacts, based on information collected in Tiers 3 and 4 • Advise project proponents of methods and metrics to use in Tier 5 studies • Communicate with project operator and consultants about results of Tier 5 studies • Advise project operator of potential mitigation strategies, when appropriate, based on Tier 5 studies

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Consideration of the Guidelines in MBTA and BGEPA Enforcement

The Service urges voluntary adherence to the Guidelines and communication with the Service when planning and operating a facility. While it is not possible to absolve individuals or companies from MBTA or BGEPA liability, the Office of Law Enforcement focuses its resources on investigating and prosecuting those who take migratory birds without identifying and implementing reasonable and effective measures to avoid the take. The Service will regard a developer's or operator's adherence to these Guidelines, including communication with the Service, as appropriate means of identifying and implementing reasonable and effective measures to avoid the take of species protected under the MBTA and BGEPA.[3] The Chief of Law Enforcement or more senior official of the Service will make any decision whether to refer for prosecution any alleged take of such species, and will take such adherence and communication fully into account when exercising discretion with respect to such potential referral. Each developer or operator will be responsible for maintaining internal records sufficient to demonstrate adherence to the Guidelines and response to communications from the Service. Examples of these records could include: studies performed in the implementation of the tiered approach; an internal or external review or audit process; a bird and bat conservation strategy; or a wildlife management plan.

If a developer and operator are not the same entity, the Service expects the operator to maintain sufficient records to demonstrate adherence to the Guidelines.

Scope and Project Scale of the Guidelines

The Guidelines are designed for "utility-scale" land-based wind energy projects to reduce potential impacts to species of concern, regardless of whether they are proposed for private or public lands. A developer of a distributed or community scale wind project may find it useful to consider the general principles of the tiered approach to assess and reduce potential impacts to species of concern, including answering Tier 1 questions using publicly available information. In the vast majority of situations, appropriately sited small wind projects are not likely to pose significant risks to species of concern. Answering Tier 1 questions will assist a developer of distributed or community wind projects, as well as landowners, in assessing the need to further communicate with the Service, and precluding, in many cases, the need for full detailed pre-construction assessments or monitoring surveys typically called for in Tiers 2 and 3. If landowners or community/distributed wind developers encounter problems locating information about specific sites they can contact the Service and/or state wildlife agencies to determine potential risks to species of concern for their particular project.

Communication with Christy Johnson-Hughes. Credit: Rachel London, USFWS

The tiered approach is designed to lead to the appropriate amount of evaluation in proportion to the anticipated level of risk that a project may pose to species of concern and their habitats. Study plans and the duration and intensity of study efforts should be tailored specifically to the unique characteristics of each site and the corresponding potential for significant adverse impacts on species of concern and their habitats as determined through the tiered approach. This is why the tiered approach begins with an examination of the potential location of the project, not the size of the project. In all cases, study plans and selection of appropriate study methods and techniques may be tailored to the relative scale, location, and potential for significant adverse impacts of the proposed site.

The Service considers a "project" to include all phases of wind energy development, including, but not limited to, prospecting, site assessment, construction, operation, and decommissioning, as well as all associated infrastructure and interconnecting electrical lines. A "project site" is the land and airspace where development occurs

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[3] With regard to eagles, this paragraph will only apply when a project is not likely to result in take. If Tiers 1, 2, and/or 3 identify a potential to take eagles, developers should consider developing an ECP and, if necessary, apply for a take permit

or is proposed to occur, including the turbine pads, roads, power distribution and transmission lines on or immediately adjacent to the site; buildings and related infrastructure, ditches, grades, culverts; and any changes or modifications made to the original site before development occurs. Project evaluations should consider all potential effects to species of concern, which includes species 1) protected by the MBTA, BGEPA, or ESA (including candidate species), designated by law, regulation or other formal process for protection and/or management by the relevant agency or other authority, or that have been shown to be significantly adversely affected by wind energy development; and 2) determined to be possibly affected by the project.

These Guidelines are not designed to address power transmission beyond the point of interconnection to the transmission system.

Service Review Period

The Service is committed to providing timely responses. Service Field Offices should typically respond to requests by a wind energy developer for information and consultation on proposed site locations (Tiers 1 and 2), pre- and post-construction study designs (Tiers 3 and 4), and proposed mitigation (Tier 3) within 60 calendar days. The request should be in writing to the Field Office and copied to the Regional Office with information about the proposed project, location(s) under consideration, and point of contact. The request should contain a description of the information needed from the Service. The Service will provide a response, even if it is to notify a developer of additional review time, within the 60 calendar day review period. If the Service does not respond within 60 calendar days of receipt of the document, then the developer can proceed through Tier 3 without waiting for Service input. If the Service provides comments at a later time, the developer should incorporate the comments if feasible. It is particularly important that if data from Tier 1-3 studies predict that the project is likely to produce significant adverse impacts on species of concern, the developer inform the Service of the actions it intends to implement to mitigate those impacts. If the Service cannot respond within 60 calendar days, this does not relieve developers from their MBTA, BGEPA, and ESA responsibilities.

The tiered approach allows a developer in certain limited circumstances to move directly from Tier 2 to construction (e.g., adequate survey data for the site exists). The developer should notify the Service of this decision and give the Service 60 calendar days to comment on the proposed project prior to initiating construction activities.

Introduction to the Decision Framework Using a Tiered Approach

The tiered approach provides a decision framework for collecting information in increasing detail to evaluate risk and make siting and operational decisions. It provides the opportunity for evaluation and decision-making at each tier, enabling a developer to proceed with or abandon project development, or to collect additional information if necessary. This approach does not require that every tier, or every element within each tier, be implemented for every project. Instead, it allows efficient use of developer and wildlife agency resources with increasing levels of effort until sufficient information and the desired precision is acquired for the risk assessment.

Figure 1 ("General Framework of Tiered Approach") illustrates the tiered approach, which consists of up to five iterative stages, or tiers:

- Tier 1 – Preliminary site evaluation (landscape-scale screening of possible project sites)
- Tier 2 – Site characterization (broad characterization of one or more potential project sites)
- Tier 3 – Field studies to document site wildlife and habitat and predict project impacts
- Tier 4 – Post-construction studies to estimate impacts[4]
- Tier 5 – Other post-construction studies and research

At each tier, potential issues associated with developing or operating a project are identified and questions formulated to guide the decision process. Chapters Two through Six outline the questions to be posed at each tier, and describe recommended methods and metrics for gathering the data needed to answer those questions.

The first three tiers correspond to the pre-construction evaluation phase of wind energy development. At each of the three tiers, the Guidelines provide questions that developers should answer, followed by recommended methods and metrics to use in answering the questions. Some questions are repeated at each tier, with successive tiers requiring a greater investment in data collection to answer certain questions. For example, while Tier 2 investigations may discover some existing information on federal or state-listed species and their use of the proposed development site, it may be necessary to collect empirical data in Tier 3 studies to determine the presence of federal or state-listed species.

Developers decide whether to proceed to the next tier. Timely communication and sharing of information will allow opportunities for the Service to provide, and developers to consider, technical advice. A developer should base the decision on the information obtained from adequately answering the questions in this tier, whether the methods used were appropriate for the site selected, and the resulting

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[4] The Service anticipates these studies will include fatality monitoring as well as studies to evaluate habitat impacts.

Wind turbines in California. Credit: Rachel London, USFWS

assessment of risk posed to species of concern and their habitats.

If sufficient data are available at a particular tier, the following outcomes are possible:

1. The project proceeds to the next tier in the development process without additional data collection.

2. The project proceeds to the next tier in the development process with additional data collection.

3. An action or combination of actions, such as project modification, mitigation, or specific post-construction monitoring, is indicated.

4. The project site is abandoned because the risk is considered unacceptable.

If data are deemed insufficient at a tier, more intensive study is conducted in the subsequent tier until sufficient data are available to make a decision to modify the project, proceed with the project, or abandon the project.

The tiered approach used in these Guidelines embodies adaptive management by collecting increasingly detailed information that is used to make decisions about project design, construction, and operation as the developer progresses through the tiers. Adaptive management is an iterative learning process producing improved understanding and improved management over time (Williams et al 2007). DOI has determined that its resource agencies, and the natural resources they oversee, could benefit from adaptive management. Use of adaptive management in DOI is guided by the DOI Policy on Adaptive Management. DOI has adopted the National Research Council's 2004 definition of adaptive management, which states:

"Adaptive management promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process. Adaptive management also recognizes the importance of natural variability in contributing to ecological resilience and productivity. It is not a 'trial and error' process, but rather emphasizes learning while doing. Adaptive management does not represent an end in itself, but rather a means to more effective decisions and enhanced benefits. Its true measure is in how well it helps meet environmental, social, and economic goals, increases scientific knowledge, and reduces tensions among stakeholders."

This definition gives special emphasis to uncertainty about management effects, iterative learning to reduce uncertainty, and improved management as a result of learning. The DOI Adaptive Management Technical Guide is located on the web at: www.doi.gov/initiatives/AdaptiveManagement/index.html.

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Figure 1. General Framework of Tiered Approach

TIER 1

A. Species of concern known to be present?
1. No ....proceed to Tier 2
2. Unknown - Insufficient or inconclusive data ....proceed to Tier 2
3. Yes....................abandon site or proceed to Tier 2

TIER 2

A. Probability of significant adverse impacts?
1. Unknown - Insufficient or inconclusive data ....proceed to Tier 3
2. Low..............proceed to obtain state and local permit (if required), design, and construction following BMPs
3. Moderate ....proceed to Tier 3 and mitigate
4. High, and:
   a. can be adequately mitigated...modify project and proceed to Tier 3
   b. cannot be adequately mitigated....................abandon project

TIER 3

A. Probability of significant adverse impacts?
1. Low ....proceed to Tier 4
2. Moderate to high, and:
   a. certainty regarding mitigation .... proceed to Tier 4
   b. uncertainty regarding mitigation ....proceed to Tier 4
3. High, and:
   a. can be adequately mitigated....................proceed to Tier 4
   b. cannot be adequately mitigated ....modify or abandon project

TIER 4a (See Table 2, pg 39)

A. Tier 3 studies indicate low probability of significant adverse impacts
1. Documented fatalities are equal to or lower than predicted....................no further studies or mitigation needed
2. Documented fatalities are higher than predicted, but not significant, and:
   a. comparable data are available that support findings of not significant....................no further studies needed
   b. comparable data not available to support findings of not significant................additional year(s) of monitoring recommended
3. Documented fatalities are higher than predicted and are significant....................communicate with Service

B. Tier 3 studies indicate moderate probability of significant adverse impacts
1. Documented fatalities are lower than or no different predicted, and:
   a. are not significant and no ESA or BGEPA species are affected ....no further monitoring or mitigation needed
   b. are significant *OR* ESA or BGEPA species are affected ....communicate with Service
2. Documented fatalities are greater than predicted and are likely to be significant *OR* ESA or BGEPA species are affected....................communicate with Service

C. Tier 3 studies indicate high probability of significant adverse impacts
1. Documented fatalities are less than predicted and are not significant, and no ESA or BGEPA species are affected....................no further monitoring or mitigation needed
2. Documented fatalities are less than predicted but are still significant, and no ESA or BGEPA species are affected....................further monitoring or mitigation needed
3. Fatalities are equal to or greater than predicted and are significant OR ESA or BGEPA species are affected....................communicate with Service regarding additional mitigation

TIER 4b (See Table 3, pg. 42)

A. Species of habitat fragmentation concern potentially present?
1. No....................no further studies needed
2. Yes, and:
   a. Tier 3 studies do not confirm presence...no further studies needed
   b. Tier 3 studies confirm presence, but no significant adverse impacts predicted, and:
      i. Tier 4b studies confirm Tier 3 predictions....................no further studies or mitigation needed
      ii. Tier 4b studies indicate potentially significant adverse impacts ....Tier 5 studies and mitigation may be needed
   c. Tier 3 studies confirm presence, and significant adverse impacts predicted and mitigation plan is developed and implemented, and:
      i. Tier 4b studies determine mitigation is effective ....no further studies or mitigation needed
      ii. Tier 4b studies determine mitigation not effective...........further mitigation and, where appropriate, Tier 5 studies needed

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Considering Risk in the Tiered Approach

In the context of these Guidelines, risk refers to the likelihood that adverse impacts will occur to individuals or populations of species of concern as a result of wind energy development and operation. Estimates of fatality risk can be used in a relative sense, allowing comparisons among projects, alternative development designs, and in the evaluation of potential risk to populations. Because there are relatively few methods available for direct estimation of risk, a weight-of-evidence approach is often used (Anderson et al. 1999). Until such time that reliable risk predictive models are developed regarding avian and bat fatality and wind energy projects, estimates of risk would typically be qualitative, but should be based upon quantitative site information.

For the purposes of these Guidelines, risk can also be defined in the context of populations, but that calculation is more complicated as it could involve estimating the reduction in population viability as indicated by demographic metrics such as growth rate, size of the population, or survivorship, either for local populations, metapopulations, or entire species. For most populations, risk cannot easily be reduced to a strict metric, especially in the absence of population viability models for most species. Consequently, estimating the quantitative risk to populations is usually beyond the scope of project studies due to the difficulties in evaluating these metrics, and therefore risk assessment will be qualitative.

Risk to habitat is a component of the evaluation of population risk. In this context, the estimated loss of habitat is evaluated in terms of the potential for population level effects (e.g., reduced survival or reproduction).

The assessment of risk should synthesize sufficient data collected at a project to estimate exposure and predict impact for individuals and their habitats for the species of concern, with what is known about the population status of these species, and in communication with the relevant wildlife agency and industry wildlife experts. Predicted risk of these impacts could provide useful information for determining appropriate mitigation measures if determined to be necessary. In practice in the tiered approach, risk assessments conducted in Tiers 1 and 2 require less information to reach a risk-based decision than those conducted at higher tiers.

Cumulative Impacts of Project Development

Cumulative impacts are the comprehensive effect on the environment that results from the incremental impact of a project when added to other past, present, and reasonably foreseeable future actions. Developers are encouraged to work closely with federal and state agencies early in the project planning process to access any existing information on the cumulative impacts of individual projects on species and habitats at risk, and to incorporate it into project development and any necessary wildlife studies. To achieve that goal, it is important that agencies and organizations take the following actions to improve cumulative impacts analysis:

- review the range of development-related significant adverse impacts;
- determine which species of concern or their habitats within the landscape are most at risk of significant adverse impacts from wind development in conjunction with other reasonably foreseeable significant adverse impacts; and
- make that data available for regional or landscape level analysis.

The magnitude and extent of the impact on a resource depend on whether the cumulative impacts exceed the capacity for resource sustainability and productivity.

For projects that require a federal permit, funding, or other federal nexus, the lead federal agency is required to include a cumulative impacts analysis in their National Environmental Policy Act (NEPA) review. The federal action agency coordinates with the developer to obtain the necessary information for the NEPA review and cumulative impacts analysis. To avoid project delays, federal and state agencies are encouraged to use existing wildlife data for the cumulative impacts analysis until improved data are available.

Where there is no federal nexus, individual developers are not expected to conduct their own cumulative impacts analysis. However, a cumulative impacts analysis would help developers and other stakeholders better understand the significance of potential impacts on species of concern and their habitats.

Other Federal Agencies

Other federal agencies, such as the Bureau of Land Management, National Park Service, U.S. Department of Agriculture Forest Service and Rural Utility Service, Federal Energy Regulatory Commission and Department of Energy are often interested in and involved with wind project developments. These agencies have a variety of expertise and authorities they implement. Wind project developers on public lands will have to comply with applicable regulations and policies of those agencies. State and local agencies and Tribes also have additional interests and knowledge. The Service recommends that, where appropriate, wind project developers contact these agencies early in the tiered process and work closely with them throughout project planning and development to assure that projects address issues of concern to those agencies. The definition of "species of concern" in these Guidelines includes species which are trust resources of States and of federal agencies (See Glossary). In those instances where a project may significantly affect State trust

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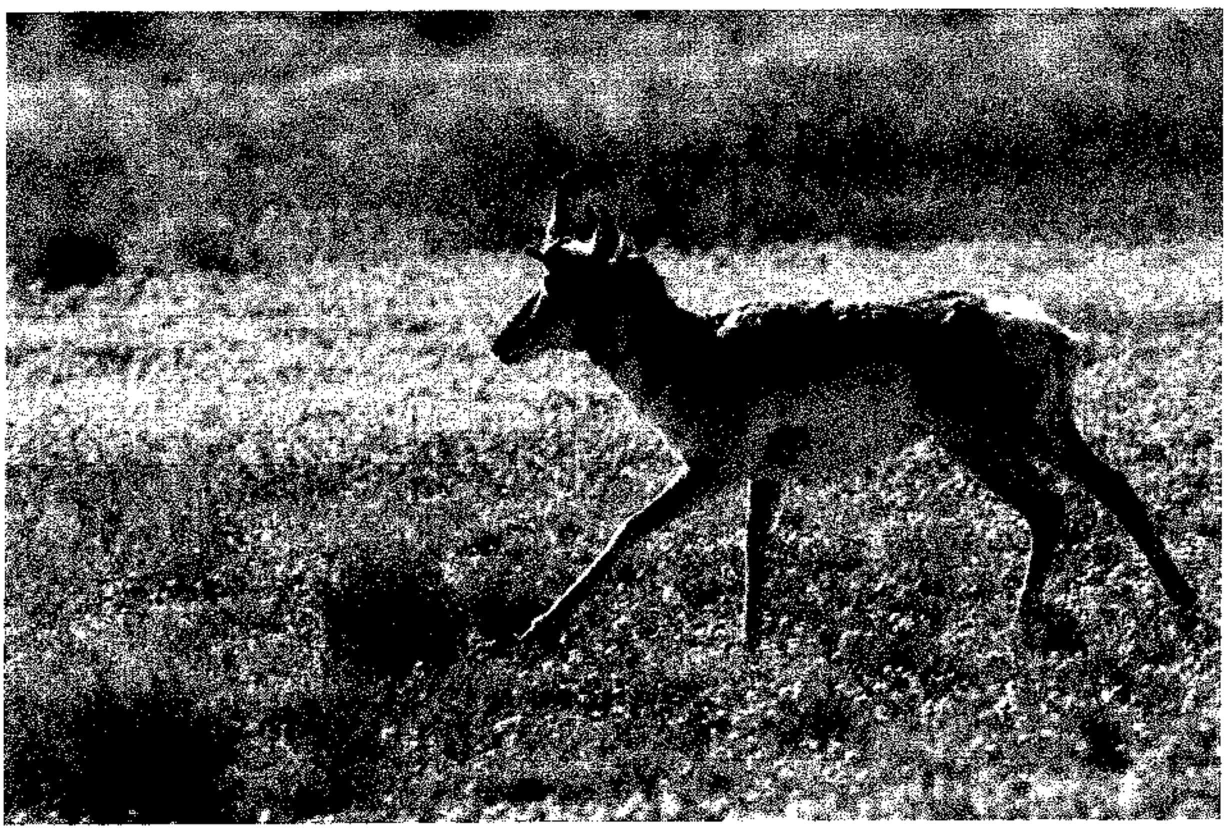
resources, wind energy developers should work closely with appropriate State agencies.

Relationship to Other Guidelines

These Guidelines replace the Service's 2003 interim voluntary guidelines. The Service intends that these Guidelines, when used in concert with the appropriate regulatory tools, will form the best practical approach for conservation of species of concern. For instance, when developers find that a project may affect an endangered or threatened species, they should comply with Section 7 or 10 of the ESA to obtain incidental take authorization. Other federal, state, tribal and local governments may use these Guidelines to complement their efforts to address wind energy development/wildlife interactions. They are not intended to supplant existing regional or local guidance, or landscape-scale tools for conservation planning, but were developed to provide a means of improving consistency with the goals of the wildlife statutes that the Service is responsible for implementing. The Service will continue to work with states, tribes, and other local stakeholders on map-based tools, decision-support systems, and other products to help guide future development and conservation. Additionally, project proponents should utilize any relevant guidance of the appropriate jurisdictional entity, which will depend on the species and resources potentially affected by proposed development.



Pronghorn Antelope. Credit: Steve Hillebrand, USFWS

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Chapter 2: Tier 1 – Preliminary Site Evaluation

For developers taking a first look at a broad geographic area, a preliminary evaluation of the general ecological context of a potential site or sites can serve as useful preparation for working with the federal, state, tribal, and/or local agencies. The Service is available to assist wind energy project developers to identify potential wildlife and habitat issues and should be contacted as early as possible in the company's planning process. With this internal screening process, the developer can begin to identify broad geographic areas of high sensitivity due to the presence of: 1) large blocks of intact native landscapes; 2) intact ecological communities; 3) fragmentation-sensitive species' habitats; or 4) other important landscape-scale wildlife values.

Tier 1 may be used in any of the following three ways:

1. To identify regions where wind energy development poses significant risks to species of concern or their habitats, including the fragmentation of large-scale habitats and threats to regional populations of federal- or state-listed species.

2. To "screen" a landscape or set of multiple potential sites to avoid those with the highest habitat values.

3. To begin to determine if a single identified potential site poses serious risk to species of concern or their habitats.

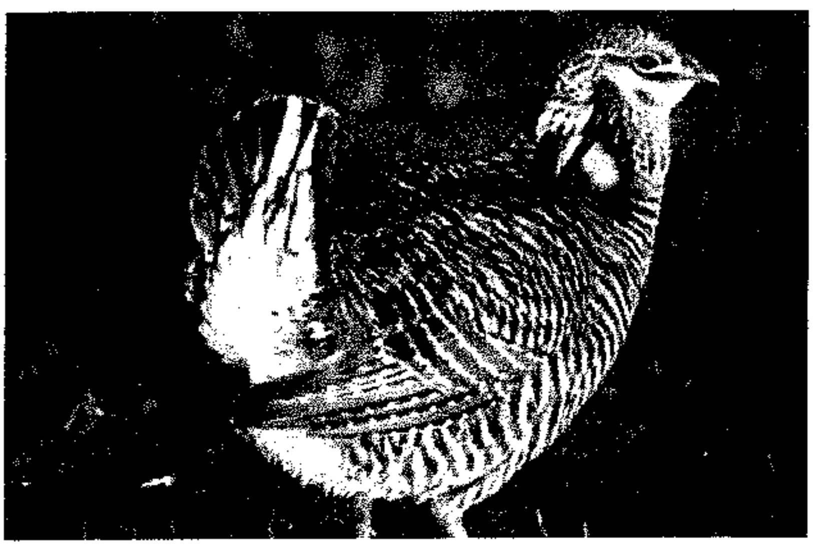
Tier 1 can offer early guidance about the sensitivity of the site within a larger landscape context; it can help direct development away from sites that will be associated with additional study need, greater mitigation requirements, and uncertainty; or it can identify those sensitive resources that will need to be studied further to determine if the site can be developed without significant adverse impacts to the species of concern or local population(s). This may facilitate discussions with the federal, state, tribal, and/or local agencies in a region being considered for development. In some cases, Tier 1 studies could reveal serious concerns indicating that a site should not be developed.

Developers of distributed or community scale wind projects are typically considering limited geographic areas to install turbines. Therefore, they would not likely consider broad geographic areas. Nevertheless, they should consider the presence of habitats or species of concern before siting projects.

Development in some areas may be precluded by federal law. This designation is separate from a determination through the tiered approach that an area is not appropriate for development due to feasibility, ecological reasons, or other issues. Developers are encouraged to visit Service and other publicly available databases or other available information during Tier 1 or Tier 2 to see if a potential wind energy area is precluded from development by federal law. Some areas may be protected from development through state or local laws or ordinances, and the appropriate agency should be contacted accordingly. Service field offices are available to answer questions where they are knowledgeable, guide developers to databases, and refer developers to other agency contacts.

Some areas may be inappropriate for large scale development because they have been recognized according to scientifically credible information as having high wildlife value, based solely on their ecological rarity and intactness (e.g., Audubon Important Bird Areas, The Nature Conservancy portfolio sites, state wildlife action plan priority habitats). It is important to identify such areas through the tiered approach, as reflected in Tier 1, Question 2 below. Many of North America's native landscapes are greatly diminished, with some existing at less than 10 percent of their pre-settlement occurrence.

P21-36 cont.



Attwater's prairie chicken. Credit: Gary Halvorsen, USFWS

Herbaceous scrub-shrub steppe in the Pacific Northwest and old growth forest in the Northeast represent such diminished native resources. Important remnants of these landscapes are identified and documented in various databases held by private conservation organizations, state wildlife agencies, and, in some cases, by the Service. Developers should collaborate with such entities specifically about such areas in the vicinity of a prospective project site.

Tier 1 Questions

Questions at each tier help determine potential environmental risks at the landscape scale for Tier 1 and project scale for Tiers 2 and 3. Suggested questions to be considered for Tier 1 include:

1. **Are there species of concern present on the potential site(s), or is habitat (including designated critical habitat) present for these species?**

2. **Does the landscape contain areas where development is precluded by law or areas designated as sensitive according to scientifically credible information? Examples of designated areas include, but are not limited to: federally-designated critical habitat; high-priority conservation areas for non-government organizations (NGOs); or other local, state, regional, federal, tribal, or international categorizations.**

3. **Are there known critical areas of wildlife congregation, including, but not limited to: maternity roosts, hibernacula, staging areas, winter ranges, nesting sites, migration stopovers or corridors, leks, or other areas of seasonal importance?**

4. **Are there large areas of intact habitat with the potential for fragmentation, with respect to species of habitat fragmentation concern needing large contiguous blocks of habitat?**

Tier 1 Methods and Metrics

Developers who choose to conduct Tier 1 investigations would generally be able to utilize existing public or other readily available landscape-level maps and databases from sources such as federal, state, or tribal wildlife or natural heritage programs, the academic community, conservation organizations, or the developers' or consultants' own information. The Service recommends that developers conduct a review of the publicly available data. The analysis of available sites in the region of interest will be based on a blend of the information available in published and unpublished reports, wildlife range distribution maps, and other such sources. The developer should check with the Service Field Office for data specific to wind energy development and wildlife at the landscape scale in Tier 1.

Tier 1 Decision Points

The objective of the Tier 1 process is to help the developer identify a site or sites to consider further for wind energy development. Possible outcomes of this internal screening process include the following:

1. One or more sites are found within the area of investigation where the answer to each of the above Tier 1 questions is "no," indicating a low probability of significant adverse impact to wildlife. The developer proceeds to Tier 2 investigations and characterization of the site or sites, answering the Tier 2 questions with site-specific data to confirm the validity of the preliminary indications of low potential for significant adverse impact.

2. If a developer answers "yes" to one or more of the Tier 1 questions, they should proceed to Tier 2 to further assess the probability of significant adverse impacts to wildlife. A developer may consider abandoning the area or identifying possible means by which the project can be modified to avoid or minimize potential significant adverse impacts.

3. The data available in the sources described above are insufficient to answer one or more of the Tier 1 questions. The developer proceeds to Tier 2, with a specific emphasis on collecting the data necessary to answer the Tier 2 questions, which are inclusive of those asked at Tier 1.

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Chapter 3: Tier 2 – Site Characterization

At this stage, the developer has narrowed consideration down to specific sites, and additional data may be necessary to systematically and comprehensively characterize a potential site in terms of the risk wind energy development would pose to species of concern and their habitats. In the case where a site or sites have been selected without the Tier 1 preliminary evaluation of the general ecological context, Tier 2 becomes the first stage in the site selection process. The developer will address the questions asked in Tier 1; if addressing the Tier 1 questions here, the developer will evaluate the site within a landscape context. However, a distinguishing feature of Tier 2 studies is that they focus on site-specific information and should include at least one visit by a knowledgeable biologist to the prospective site(s). Because Tier 2 studies are preliminary, normally one reconnaissance level site visit will be adequate as a "ground-truth" of available information. Notwithstanding, if key issues are identified that relate to varying conditions and/or seasons, Tier 2 studies should include enough site visits during the appropriate times of the year to adequately assess these issues for the prospective site(s).

If the results of the site assessment indicate that one or more species of concern are present, a developer should consider applicable regulatory or other agency processes for addressing them. For instance, if migratory birds and bats are likely to experience significant adverse impacts by a wind project at the proposed site, a developer should identify and document possible actions that will avoid or compensate for those impacts. Such actions might include, but not be limited to, altering locations of turbines or turbine arrays, operational changes, or compensatory mitigation. As soon as a developer anticipates that a wind energy project is likely to result in a take of bald or golden eagles, a developer should prepare an ECP and, if necessary, apply for a programmatic take permit. As soon as a developer realizes endangered or threatened species are present and likely to be affected by a wind project located there, a federal agency should consult with the Service under Section 7(a)(2) of the ESA if the project has a federal nexus or the developer should apply for a section 10(a)(1)(B) incidental take permit if there is not a federal nexus, and incidental take of listed wildlife is anticipated. State, tribal, and local jurisdictions may have additional permitting requirements.

Developers of distributed or community scale wind projects are typically considering limited geographic areas to install turbines. Therefore, they would likely be familiar with conditions at the site where they are considering installing a turbine. Nevertheless, they should do preliminary site evaluations to determine the presence of habitats or species of concern before siting projects.

Tier 2 Questions

Questions suggested for Tier 2 can be answered using credible, publicly available information that includes published studies, technical reports, databases, and information from agencies, local conservation organizations, and/or local experts. Developers or consultants working on their behalf should contact the federal, state, tribal, and local agencies that have jurisdiction or management authority and responsibility over the potential project.

1. **Are known species of concern present on the proposed site, or is habitat (including designated critical habitat) present for these species?**
2. **Does the landscape contain areas where development is precluded by law or designated as sensitive according to scientifically credible information? Examples of designated areas include, but are not limited to: federally-designated critical habitat;**

Open landscape with wind turbines. Credit: NREL

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high-priority conservation areas for NGOs; or other local, state, regional, federal, tribal, or international categorizations.

3. **Are there plant communities of concern present or likely to be present at the site(s)?**

4. **Are there known critical areas of congregation of species of concern, including, but not limited to: maternity roosts, hibernacula, staging areas, winter ranges, nesting sites, migration stopovers or corridors, leks, or other areas of seasonal importance?**

5. **Using best available scientific information has the developer or relevant federal, state, tribal, and/or local agency identified the potential presence of a population of a species of habitat fragmentation concern?**

6. **Which species of birds and bats, especially those known to be at risk by wind energy facilities, are likely to use the proposed site based on an assessment of site attributes?**

7. **Is there a potential for significant adverse impacts to species of concern based on the answers to the questions above, and considering the design of the proposed project?**

Tier 2 Methods and Metrics

Obtaining answers to Tier 2 questions will involve a more thorough review of the existing site-specific information than in Tier 1. Tier 2 site characterizations studies will generally contain three elements:

1. A review of existing information, including existing published or available literature and databases and maps of topography, land use and land cover, potential wetlands, wildlife, habitat, and sensitive plant distribution. If agencies have documented potential habitat for species of habitat fragmentation concern, this information can help with the analysis.

2. Contact with agencies and organizations that have relevant scientific information to further help identify if there are bird, bat or other wildlife issues. The Service recommends that the developer make contact with federal, state, tribal, and local agencies that have jurisdiction or management authority over the project or information about the potentially affected resources. In addition, because key NGOs and relevant local groups are often valuable sources of relevant local environmental information, the Service recommends that developers contact key NGOs, even if confidentiality concerns preclude the developer from identifying specific project location information at this stage. These contacts also provide an opportunity to identify other potential issues and data not already identified by the developer.

3. One or more reconnaissance level site visits by a wildlife biologist to evaluate current vegetation/habitat coverage and land management/use. Current habitat and land use practices will be noted to help in determining the baseline against which potential impacts from the project would be evaluated. The vegetation/habitat will be used for identifying potential bird and bat resources occurring at the site and the potential presence of, or suitable habitat for, species of concern. Vegetation types or habitats will be noted and evaluated against available information such as land use/land cover mapping. Any sensitive resources located during the site visit will be noted and mapped or digital location data recorded for future reference. Any individuals or signs of species of concern observed during the site visit will be noted. If land access agreements are not in place, access to the site will be limited to public roads.

Specific resources that can help answer each Tier 2 question include:

1. **Are known species of concern present on the proposed site, or is habitat (including designated critical habitat) present for these species?**

   Information review and agency contact: locations of state and federally listed, proposed and candidate species and species of concern are frequently documented in state and federal wildlife databases. Examples include published literature such as: Natural Heritage Databases, State Wildlife Action Plans, NGOs publications, and developer and consultant information, or can be obtained by contacting these entities.

   Site Visit: To the extent practicable, the site visit(s) should evaluate the suitability of habitat at the site for species identified and the likelihood of the project to adversely affect the species of concern that may be present.

2. **Does the landscape contain areas where development is precluded by law or designated as sensitive according to scientifically credible information?** Examples of designated areas include, but are not limited to: federally-designated critical habitat; high-priority conservation areas for NGOs; or other local, state, regional, federal, tribal, or international categorizations.

   Information review and agency contact such as: maps of political and administrative boundaries; National Wetland Inventory data files; USGS National Land Cover data maps; state, federal and tribal agency data on areas that have been designated to preclude development, including wind energy development; State Wildlife Action Plans; State Land and Water Resource Plans; Natural Heritage databases; scientifically credible information provided by NGO and local

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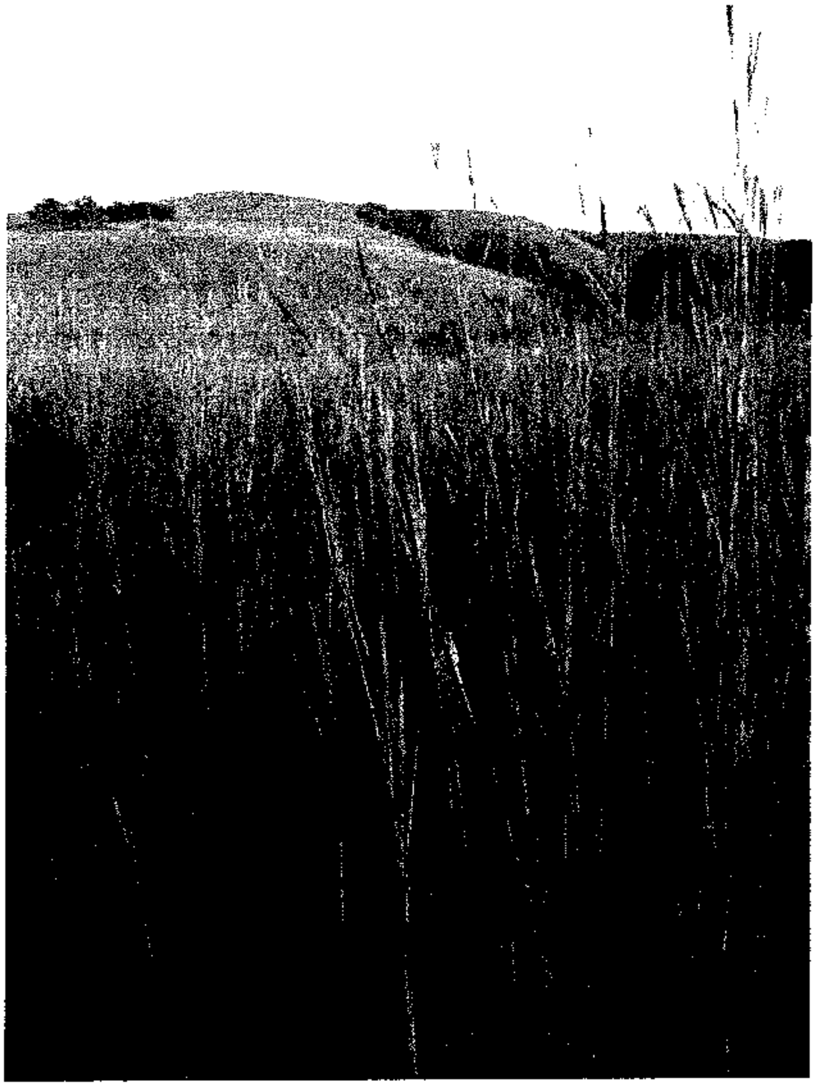

Tall grass prairie. Credit: Amy Thornburg, USFWS

resources; and the additional resources listed in Appendix C: Sources of Information Pertaining to Methods to Assess Impacts to Wildlife of this document, or through contact of agencies and NGOs, to determine the presence of high priority habitats for species of concern or conservation areas.

Site Visit: To the extent practicable, the site visit(s) should characterize and evaluate the uniqueness of the site vegetation relative to surrounding areas.

3. **Are plant communities of concern present or likely to be present at the site(s)?**

Information review and agency contact such as: Natural Heritage Data of state rankings (S1, S2, S3) or globally (G1, G2, G3) ranked rare plant communities.

Site Visit: To the extent practicable, the site visit should evaluate the topography, physiographic features and uniqueness of the site vegetation in relation to the surrounding region. If plant communities of concern are present, developers should also assess in Tier 3 whether the proposed project poses risk of significant adverse impacts and opportunities for mitigation.

4. **Are there known critical areas of wildlife congregation, including, but not limited to, maternity roosts, hibernacula, staging areas, winter ranges, nesting sites, migration stopovers or corridors, leks, or other areas of seasonal importance?**

Information review and agency contact such as: existing databases, State Wildlife Action Plan, Natural Heritage Data, and NGO and agency information regarding the presence of Important Bird Areas, migration corridors or stopovers, leks, bat hibernacula or maternity roosts, or game winter ranges at the site and in the surrounding area.

Site Visit: To the extent practicable, the site visit should, during appropriate times to adequately assess these issues for prospective site(s), evaluate the topography, physiographic features and uniqueness of the site in relation to the surrounding region to assess the potential for the project area to concentrate resident or migratory birds and bats.

5. **Using best available scientific information, has the relevant federal, state, tribal, and/or local agency determined the potential presence of a population of a species of habitat fragmentation concern?**

If not, the developer need not assess impacts of the proposed project on habitat fragmentation.

Habitat fragmentation is defined as the separation of a block of habitat for a species into segments, such that the genetic or demographic viability of the populations surviving in the remaining habitat segments is reduced; and risk, in this case, is defined as the probability that this fragmentation will occur as a result of the project. Site clearing, access roads, transmission lines and turbine tower arrays remove habitat and displace some species

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of wildlife, and may fragment continuous habitat areas into smaller, isolated tracts. Habitat fragmentation is of particular concern when species require large expanses of habitat for activities such as breeding and foraging.

Consequences of isolating local populations of some species include decreased reproductive success, reduced genetic diversity, and increased susceptibility to chance events (e.g. disease and natural disasters), which may lead to extirpation or local extinctions. In addition to displacement, development of wind energy infrastructure may result in additional loss of habitat for some species due to "edge effects" resulting from the break-up of continuous stands of similar vegetation resulting in an interface (edge) between two or more types of vegetation. The extent of edge effects will vary by species and may result in adverse impacts from such effects as a greater susceptibility to colonization by invasive species, increased risk of predation, and competing species favoring landscapes with a mosaic of vegetation.

Site Visit: If the answer to Tier 2 Question 5 is yes, developers should use the general framework for evaluating habitat fragmentation at a project site in Tier 2 outlined below. Developers and the Service may use this method to analyze the impacts of habitat fragmentation at wind development project sites on species of habitat fragmentation concern. Service field offices may be able to provide the available information on habitat types, quality and intactness. Developers may use this information in combination with site-specific information on the potential habitats to be impacted by a potential development and how they will be impacted.

General Framework for Evaluating Habitat Fragmentation at a Project Site (Tier 2)

A. The developer should define the study area. The study area should not only include the project site for the proposed project, but be based on the distribution of habitat for the local population of the species of habitat fragmentation concern.

B. The developer should analyze the current habitat quality and spatial configuration of the study area for the species of habitat fragmentation concern.

   i. Use recent aerial and remote imagery to determine distinct habitat patches, or boundaries, within the study area, and the extent of existing habitat fragmenting features (e.g., highways).

   ii. Assess the level of fragmentation of the existing habitat for the species of habitat fragmentation concern and categorize into three classes:

      - High quality: little or no apparent fragmentation of intact habitat
      - Medium quality: intact habitat exhibiting some recent disturbance activity
      - Low quality: Extensive fragmentation of habitat (e.g., row-cropped agricultural lands, active surface mining areas)

C. The developer should determine potential changes in quality and spatial configuration of the habitat in the study area if development were to proceed as proposed using existing site information.

D. The developer should provide the collective information from steps A-C for all potential developments to the Service for use in assessing whether the habitat impacts, including habitat fragmentation, are likely to affect population viability of the potentially affected species of habitat fragmentation concern.

6. Which species of birds and bats, especially those known to be at risk by wind energy facilities, are likely to use the proposed site based on an assessment of site attributes?

Information review and agency contact: existing published information and databases from NGOs and federal and state resource agencies regarding the potential presence of:

- Raptors: species potentially present by season
- Prairie grouse and sage grouse: species potentially present by season and location of known leks
- Other birds: species potentially present by season that may be at risk of collision or adverse impacts to habitat, including loss, displacement and fragmentation
- Bats: species likely to be impacted by wind energy facilities and likely to occur on or migrate through the site

   Site Visit: To the extent practicable, the site visit(s) should identify landscape features or habitats that could be important to raptors, prairie grouse, and other birds that may be at risk of adverse impacts, and bats, including nesting and brood-rearing habitats, areas of high prey density, movement corridors and features such as ridges that may concentrate raptors. Raptors, prairie grouse, and other presence or sign of species of concern seen during the site visit should be noted, with species identification if possible.

7. Is there a potential for significant adverse impacts to species of concern based on the answers to the questions above, and considering the design of the proposed project?

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The developer has assembled answers to the questions above and should make an initial evaluation of the probability of significant adverse impacts to species of concern and their habitats. The developer should make this evaluation based on assessments of the potential presence of species of concern and their habitats, potential presence of critical congregation areas for species of concern, and any site visits. The developer is encouraged to communicate the results of these assessments with the Service.

Tier 2 Decision Points

Possible outcomes of Tier 2 include the following:

1. The most likely outcome of Tier 2 is that the answer to one or more Tier 2 questions is inconclusive to address wildlife risk, either due to insufficient data to answer the question or because of uncertainty about what the answers indicate. The developer proceeds to Tier 3, formulating questions, methods, and assessment of potential mitigation measures based on issues raised in Tier 2 results.

2. Sufficient information is available to answer all Tier 2 questions, and the answer to each Tier 2 question indicates a low probability of significant adverse impact to wildlife (for example, infill or expansion of an existing facility where impacts have been low and Tier 2 results indicate that conditions are similar, therefore wildlife risk is low). The developer may then decide to proceed to obtain state and local permit (if required), design, and construction following best management practices (see Chapter 7: Best Management Practices).

3. Sufficient information is available to answer all Tier 2 questions, and the answer to each Tier 2 question indicates a moderate probability of significant adverse impacts to species of concern or their habitats. The developer should proceed to Tier 3 and identify measures to mitigate potential significant adverse impacts to species of concern.

4. The answers to one or more Tier 2 questions indicate a high probability of significant adverse impacts to species of concern or their habitats that:

   a) Cannot be adequately mitigated. The proposed site should be abandoned.

   b) Can be adequately mitigated. The developer should proceed to Tier 3 and identify measures to mitigate potential significant adverse impacts to species of concern or their habitats.

Greater sage grouse, Credit: Stephen Ting, USFWS

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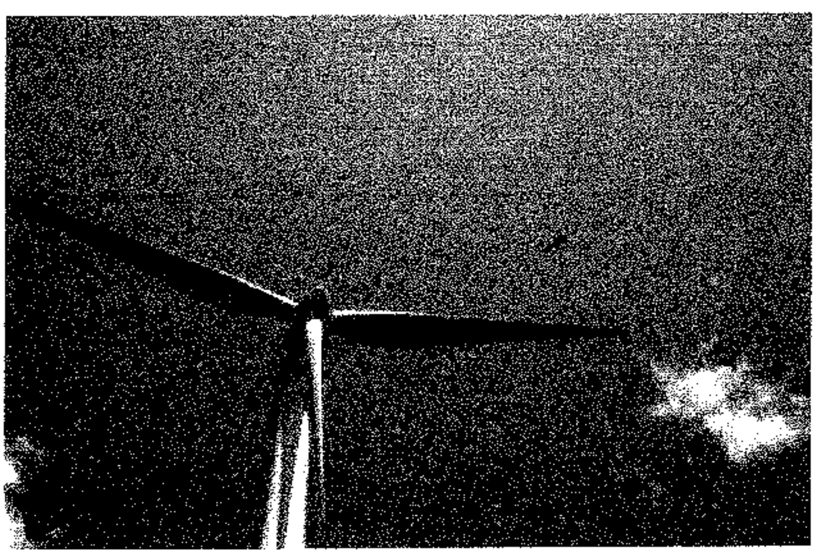
Chapter 4: Tier 3 – Field Studies to Document Site Wildlife and Habitat and Predict Project Impacts

Tier 3 is the first tier in which a developer would conduct quantitative and scientifically rigorous studies to assess the potential risk of the proposed project. Specifically, these studies provide pre-construction information to:

- Further evaluate a site for determining whether the wind energy project should be developed or abandoned
- Design and operate a site to avoid or minimize significant adverse impacts if a decision is made to develop
- Design compensatory mitigation measures if significant adverse habitat impacts cannot acceptably be avoided or minimized
- Determine duration and level of effort of post-construction monitoring. If warranted, provide the pre-construction component of post-construction studies necessary to estimate and evaluate impacts

At the beginning of Tier 3, a developer should communicate with the Service on the pre-construction studies. At the end of Tier 3, developers should communicate with the Service regarding the results of the Tier 3 studies and consider the Service's comments and recommendations prior to completing the Tier 3 decision process. The Service will provide written comments to a developer that identify concerns and recommendations to resolve the concerns based on study results and project development plans.

Not all Tier 3 studies will continue into Tiers 4 or 5. For example, surveys conducted in Tier 3 for species of concern may indicate one or more species are not present at the proposed project site, or siting decisions could be made in Tier 3 that remove identified concerns, thus removing the need for continued efforts in later tiers. Additional detail on the design issues for post-construction studies that begin in Tier 3 is provided in the discussion of methods and metrics in Tier 3.



Turkey vulture and wind turbine. Credit: Rachel London, USFWS

Tier 3 Questions

Tier 3 begins as the other tiers, with problem formulation: what additional studies are necessary to enable a decision as to whether the proposed project can proceed to construction or operation or should be abandoned? This step includes an evaluation of data gaps identified by Tier 2 studies as well as the gathering of data necessary to:

- Design a project to avoid or minimize predicted risk
- Evaluate predictions of impact and risk through post-construction comparisons of estimated impacts
- Identify compensatory mitigation measures, if appropriate, to offset significant adverse impacts that cannot be avoided or minimized

The problem formulation stage for Tier 3 also will include an assessment of which species identified in Tier 1 and/or Tier 2 will be studied further in the site risk assessment. This determination is based on analysis of existing data from Tier 1 and existing site-specific data and Project Site (see Glossary in Appendix A) visit(s) in Tier 2, and on the likelihood of presence and the degree of adverse impact to species or their habitat. If the habitat is suitable for a species needing further study and the site occurs within the historical range of the species, or is near the existing range of the species but presence has not been documented, additional field studies may be appropriate. Additional analyses should not be necessary if a species is unlikely to be present or is present but adverse impact is unlikely or of minor significance.

Tier 3 studies address many of the questions identified for Tiers 1 and 2, but Tier 3 studies differ because they attempt to quantify

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the distribution, relative abundance, behavior, and site use of species of concern. Tier 3 data also attempt to estimate the extent that these factors expose these species to risk from the proposed wind energy facility. Therefore, in answering Tier 3 questions 1-3, developers should collect data sufficient to analyze and answer Tier 3 questions 4-6. High risk sites may warrant additional years of pre-construction studies. The duration and intensity of studies needed should be determined through communication with the Service.

If Tier 3 studies identify species of concern or important habitats, e.g., wetlands, which have specific regulatory processes and requirements, developers should work with appropriate state, tribal, or federal agencies to obtain required authorizations or permits.

Tier 3 studies should be designed to answer the following questions:

1. **Do field studies indicate that species of concern are present on or likely to use the proposed site?**

2. **Do field studies indicate the potential for significant adverse impacts on affected population of species of habitat fragmentation concern?**

3. **What is the distribution, relative abundance, behavior, and site use of species of concern identified in Tiers 1 or 2, and to what extent do these factors expose these species to risk from the proposed wind energy project?**

4. **What are the potential risks of adverse impacts of the proposed wind energy project to individuals and local populations of species of concern and their habitats? (In the case of rare or endangered species, what are the possible impacts to such species and their habitats?)**

5. **How can developers mitigate identified significant adverse impacts?**

6. **Are there studies that should be initiated at this stage that would be continued in post-construction?**

The Service encourages the use of common methods and metrics in Tier 3 assessments for measuring wildlife activity and habitat features. Common methods and metrics provide great benefit over the long-term, allowing for comparisons among projects and for greater certainty regarding what will be asked of the developer for a specific project. Deviation from commonly used methods should be carefully considered, scientifically justifiable and discussed with federal, tribal, or state natural resource agencies, or other credible experts, as appropriate. It may be useful to consult other scientifically credible information sources.

Tier 3 studies will be designed to accommodate local and regional characteristics. The specific protocols by which common methods and metrics are implemented in Tier 3 studies depend on the question being addressed, the species or ecological communities being studied and the characteristics of the study sites. Federally-listed threatened and endangered species, eagles, and some other species of concern and their habitats, may have specific protocols required by local, state or federal agencies. The need for special surveys and mapping that address these species and situations should be discussed with the appropriate stakeholders.

In some instances, a single method will not adequately assess potential collision risk or habitat impact. For example, when there is concern about moderate or high risk to nocturnally active species, such as migrating passerines and local and migrating bats, a combination of remote sensing tools such as radar, and acoustic monitoring for bats and indirect inference from diurnal bird surveys during the migration period may be necessary. Answering questions about habitat use by songbirds may be accomplished by relatively small-scale observational studies, while answering the same question related to wide-ranging species such as prairie grouse and sage grouse may require more time-consuming surveys, perhaps including telemetry.

Because of the points raised above and the need for flexibility in application, the Guidelines do not make specific recommendations on protocol elements for Tier 3 studies. The peer-reviewed scientific literature (such as the articles cited throughout this section) contains numerous recently published reviews of methods for assessing bird and bat activity, and tools for assessing habitat and landscape level risk. Details on specific methods and protocols for recommended studies are or will be widely available and should be consulted by industry and agency professionals.

Many methods for assessing risk are components of active research involving collaborative efforts of public-private research partnerships with federal, state and tribal agencies, wind energy developers and NGOs interested in wind energy-wildlife interactions (e.g., Bats and Wind Energy Cooperative and the Grassland Shrub Steppe Species Cooperative). It is important to recognize the need to integrate the results of research that improves existing methods or describes new methodological developments, while acknowledging the value of utilizing common methods that are currently available.

The methods and metrics that may be appropriate for gathering data to answer Tier 3 questions are compiled and outlined in the Technical Resources section, page 26. These are not meant to be all inclusive and other methods and metrics are available, such as the NWCC Methods & Metrics document (Strickland et al. 2011) and others listed in Appendix C:

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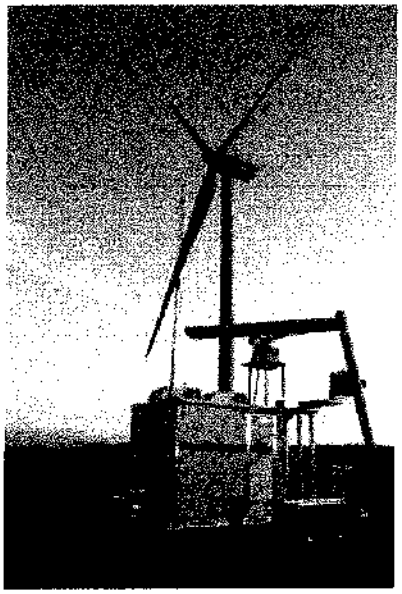

Avian Radar

Sources of Information Pertaining to Methods to Assess Impacts to Wildlife.

Each question should be considered in turn, followed by a discussion of the methods and their applicability.

1. **Do field studies indicate that species of concern are present on or likely to use the proposed site?**

In many situations, this question can be answered based on information accumulated in Tier 2. Specific presence/absence studies may not be necessary, and protocol development should focus on answering the remaining Tier 3 questions. Nevertheless, it may be necessary to conduct field studies to determine the presence, or likelihood of presence, when little information is available for a particular site. The level of effort normally contemplated for Tier 3 studies should detect common species and species that are relatively rare, but which visit a site regularly (e.g., every year). In the event a species of concern is very rare and only occasionally visits a site, a determination of "likely to occur" would be inferred from the habitat at the site and historical records of occurrence on or near the site.

State, federal and tribal agencies often require specific protocols be followed when species of concern are potentially present on a site. The methods and protocols for determining presence of species of concern at a site are normally established for each species and required by federal, state and tribal resource agencies. Surveys should sample the wind turbine sites and applicable disturbance area during seasons when species are most likely present. Normally, the methods and protocols by which they are applied also will include an estimate of relative abundance. Most presence/absence surveys should be done following a probabilistic sampling protocol to allow statistical extrapolation to the area and time of interest.

Determining the presence of diurnally or nocturnally active mammals, reptiles, amphibians, and other species of concern will typically be accomplished by following agency-required protocols. Most listed species have required protocols for detection (e.g., the black-footed ferret). State, tribal and federal agencies should be contacted regarding survey protocols for those species of concern. See Corn and Bury 1990, Olson et al. 1997, Bailey et al. 2004, Graeter et al. 2008 for examples of reptile and amphibian protocols, survey and analytical methods. See Tier 3 Study Design Considerations on page 24 for further details.

2. **Do field studies indicate the potential for significant adverse impacts on affected populations of species of habitat fragmentation concern?**

If Tier 2 studies indicate the presence of species of habitat fragmentation concern, but existing information did not allow for a complete analysis of potential impacts and decision-making, then additional studies and analyses should take place in Tier 3.

As in Tier 2, the particulars of the analysis will depend on the species of habitat fragmentation concern and how habitat block size and fragmentation are defined for the life cycles of that species, the likelihood that the project will adversely affect a local population of the species and the significance of these impacts to the viability of that population.

To assess habitat fragmentation in the project vicinity, developers should evaluate landscape characteristics of the proposed site prior to construction and determine the degree to which habitat for species of habitat fragmentation concern will be significantly altered by the presence of a wind energy facility.

A general framework for evaluating habitat fragmentation at a project site, following that described in Tier 2, is outlined on page 27. This framework should be used in those circumstances when the developer, or a relevant federal, state, tribal and/or other local agency determines the potential presence of a population of a species of habitat fragmentation concern that may be adversely affected by the project. Otherwise, the developer need not assess the impacts of the proposed project on habitat fragmentation. This method for analysis of habitat fragmentation at project sites must be adapted to the local population of the species of habitat fragmentation concern potentially affected by the proposed development. P21-36 cont.

3. **What is the distribution, relative abundance, behavior, and site use of species of concern identified in Tiers 1 or 2, and to what extent do these factors expose these species to risk from the proposed wind energy project?**

For those species of concern that are considered at risk of collisions or habitat impacts, the questions to be answered in Tier 3 include: where are they likely to occur (i.e., where is their habitat) within a project site or vicinity, when might they occur, and in what abundance. The spatial distribution of species at risk of collision can influence how a site is developed. This distribution should include the airspace for flying species with respect to the rotor-swept zone. The abundance of a species and the spatial distribution of its habitat can be used to determine the relative risk of impact to species using the sites, and the absolute risk when compared to existing projects where similar information exists. Species abundance and habitat distribution can also be used in modeling risk factors.

Surveys for spatial distribution and relative abundance require coverage of the wind turbine sites and applicable site disturbance area, or a sample of the area using observational methods for the species of concern during the seasons of interest. As with presence/absence (see Tier 3, question 1, above) the methods used to determine distribution, abundance, and behavior may vary with the species and its ecology. Spatial distribution is determined by applying presence/absence or using surveys in a probabilistic manner over the entire area of interest. Suggested survey protocols for birds, bats, and other wildlife are found in the Technical Resources section on page 26.

Whooping crane. Credit: Ryan Hagerty, USFWS

4. What are the potential risks of adverse impacts of the proposed wind energy project to individuals and local populations of species of concern and their habitats? (In the case of rare or endangered species, what are the possible impacts to such species and their habitats?)

Methods used for estimating risk will vary with the species of concern. For example, estimating potential bird fatalities in Tier 3 may be accomplished by comparing exposure estimates (described earlier in estimates of bird use) at the proposed site with exposure estimates and fatalities at existing projects with similar characteristics (e.g., similar technology, landscape, and weather conditions). If models are used, they may provide an additional tool for estimating fatalities, and have been used in Australia (Organ and Meredith 2004), Europe (Chamberlin et al. 2006), and the United States (Madders and Whitfield 2006). As with other prediction tools, model predictions should be evaluated and compared with post-construction fatality data to validate the models. Models should be used as a subcomponent of a risk assessment based on the best available empirical data. A statistical model based on the relationship of pre-construction estimates of raptor abundance and post-construction raptor fatalities is described in Strickland et al. (2011) and promises to be a useful tool for risk assessment.

Collision risk to individual birds and bats at a particular wind energy facility may be the result of complex interactions among species distribution, relative abundance, behavior, weather conditions (e.g., wind, temperature) and site characteristics. Collision risk for an individual may be low regardless of abundance if its behavior does not place it within the rotor-swept zone. If individuals frequently occupy the rotor-swept zone but effectively avoid collisions, they are also at low risk of collision with a turbine (e.g., ravens). Alternatively, if the behavior of individuals frequently places them in the rotor-swept zone, and they do not actively avoid turbine blade strikes, they are at higher risk of collisions with turbines regardless of abundance. For a given species (e.g., red-tailed hawk), increased abundance increases the likelihood that individuals will be killed by turbine strikes, although the risk to individuals will remain about the same. The risk to a population increases as the proportion of individuals in the population at risk to collision increases.

At some projects, bat fatalities are higher than bird fatalities, but the exposure risk of bats at these facilities is not fully understood (National Research Council (NRC) 2007). Horn et al. (2008) and Cryan (2008) hypothesize that bats are attracted to turbines, which, if true, would further complicate estimation

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of exposure. Further research is required to determine if bats are attracted to turbines and if so, to evaluate 1) the influence on Tier 2 methods and predictions, and 2) if this increased individual risk translates into higher population-level impacts for bats.

The estimation of indirect impact risk requires an understanding of animal behavior in response to a project and its infrastructure, and a pre-construction estimate of presence/absence of species whose behavior would cause them to avoid areas in proximity to turbines, roads and other components of the project. The amount of habitat that is lost to indirect impacts will be a function of the sensitivity of individuals to the project and to the activity levels associated with the project's operations. The population-level significance of this indirect impact will depend on the amount of habitat available to the affected population. If the indirect impacts include habitat fragmentation, then the risk to the demographic and genetic viability of the isolated animals is increased. Quantifying cause and effect may be very difficult, however.

5. How can developers mitigate identified significant adverse impacts?

Results of Tier 3 studies should provide a basis for identifying measures to mitigate significant adverse impacts predicted for species of concern. Information on wildlife use of the proposed area is most useful when designing a project to avoid or minimize significant adverse impacts. In cases of uncertainty with regard to impacts to species of concern, additional studies may be necessary to quantify significant adverse impacts and determine the need for mitigation of those impacts.

Chapter 7, Best Management Practices, and Chapter 8, Mitigation, outline measures that can be taken to mitigate impacts throughout all phases of a project.

The following discussion of prairie grouse and sage grouse as species of concern illustrates the uncertainty mentioned above by describing the present state of scientific knowledge relative to these species, which should be considered when designing mitigation measures. The extent of the impact of wind energy development on prairie grouse and sage grouse lekking activity (e.g., social structure, mating success, persistence) and the associated impacts on productivity (e.g., nesting, nest success, chick survival) is poorly understood (Arnett et al. 2007, NRC 2007, Manville 2004). However, recent published research documents that anthropogenic features (e.g., tall structures, buildings, roads, transmission lines) can adversely impact vital rates (e.g., nesting, nest success, lekking behavior) of lesser prairie-chickens (Pruett et al. 2009, Pitman et al. 2005, Hagen et al. 2009, Hagen et al. 2011) and greater prairie-chickens over long distances. Pitman et al. (2005) found that transmission lines reduced nesting of lesser prairie chicken by 90 percent out to a distance of 0.25 miles, improved roads at a distance of 0.25 miles, a house at 0.3 miles, and a power plant at >0.6 miles. Reduced nesting activity of lesser prairie chickens may extend farther, but Pitman et al. (2005) did not analyze their data for lower impacts (less than 90 percent reduction in nesting) of those anthropogenic features on lesser prairie chicken nesting activities at greater distances. Hagen et al. (2011) suggested that development within 1 to 1 ½ miles of active leks of prairie grouse may have significant adverse impacts on the affected grouse population. It is not unreasonable to infer that impacts from wind energy facilities may be similar to those from these other anthropogenic structures. Kansas State University, as part of the National Wind Coordinating Collaborative's Grassland and Shrub Steppe Species Subgroup, is undertaking a multi-year telemetry study to evaluate the effects of a proposed wind-energy facility on displacement and demographic parameters (e.g., survival, nest success, brood success, fecundity) of greater prairie-chickens in Kansas.[5]

The distances over which anthropogenic activities impact sage grouse are greater than for prairie grouse. Based primarily on data documenting reduced fecundity (a combination of nesting, clutch size, nest success, juvenile survival, and other factors) in sage grouse populations near roads, transmissions lines, and areas of oil and gas development/production (Holloran 2005, Connelly et al. 2000), development within three to five miles (or more) of active sage grouse leks may have significant adverse impacts on the affected grouse population. Lyon and Anderson (2003) found that in habitats fragmented by natural gas development, only 26 percent of hens captured on disturbed leks nested within 1.8 miles of the lek of capture, whereas 91 percent of hens from undisturbed areas nested within the same area. Holloran (2005) found that active drilling within 3.1 miles of sage grouse lek reduced the number of breeding males by displacing adult males and reducing recruitment of juvenile males. The magnitudes and proximal causes (e.g., noise, height of structures, movement, human activity, etc.) of those impacts on vital rates in grouse populations are areas of much needed research (Becker et al. 2009). Data accumulated through such research may improve our understanding of the buffer distances necessary to avoid or minimize significant adverse impacts to prairie grouse and sage grouse populations.

When significant adverse impacts cannot be fully avoided or adequately minimized, some form of compensatory mitigation may be

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[5] www.nationalwind.org

appropriate to address the loss of habitat value. For example, it may be possible to mitigate habitat loss or degradation for a species of concern by enhancing or restoring nearby habitat value comparable to that potentially influenced by the project.

6. **Are there studies that should be initiated at this stage that would be continued in post-construction?**

During Tier 3 problem formulation, it is necessary to identify the studies needed to address the Tier 3 questions. Consideration of how the resulting data may be used in conjunction with post-construction Tier 4 and 5 studies is also recommended. The design of post-construction impact or mitigation assessment studies will depend on the specific impact questions being addressed. Tier 3 predictions will be evaluated using data from Tier 4 studies designed to estimate fatalities for species of concern and impacts to their habitat, including species of habitat fragmentation concern. Tier 3 studies may demonstrate the need for mitigation of significant adverse impacts. Where Tier 3 studies indicate the potential for significant adverse direct and indirect impacts to habitat, Tier 4 studies will provide data that evaluate predictions of those impacts, and Tier 5 studies, if necessary, will provide data to evaluate the effect of those impacts on populations and the effectiveness of mitigation measures. Evaluations of the impacts of a project on demographic parameters of local populations, habitat use, or some other parameter(s) are considered Tier 5 studies, and typically will require data on these parameters prior to as well as after construction of the project.

Tier 3 Study Design Considerations

Specific study designs will vary from site to site and should be adjusted to the circumstances of individual projects. Study designs will depend on the types of questions, the specific project, and practical considerations. The most common considerations

Rows of wind turbines. Credit: Joshua Winchell, USFWS

include the area being studied, the species of concern and potential risk to those species, potentially confounding variables, time available to conduct studies, project budget, and the magnitude of the anticipated impacts. Studies will be necessary in part to assess a) which species of concern are present within the project area; b) how these species are using the area (behavior); and c) what risks are posed to them by the proposed wind energy project.

Assessing Presence

A developer should assess whether species of concern are likely to be present in the project area during the life of the project. Assessing species use from databases and site characteristics is a potential first step. However, it can be difficult to assess potential use by certain species from site characteristics alone. Various species in different locations may require developers to use specific survey protocols or make certain assumptions regarding presence. Project developers should seek local wildlife expertise, such as Service Field Office staff, in using the proper procedures and making assumptions.

Some species will present particular challenges when trying to determine potential presence. For instance, species that a) are rare or cryptic; b) migrate, conduct other daily movements, or use areas for short periods; c) are small or nocturnal; or d) have become extirpated in parts of their historical range can be difficult to observe. One of these challenges is migration, broadly defined as the act of moving from one spatial unit to another (Baker 1978), or as a periodic movement of animals from one location to another. Migration is species-specific, and for birds and bats occurs throughout the year.

Assessing Site Use/Behavior

Developers should monitor potential sites to determine the types of migratory species present, what type of spatial and temporal use these species make of the site (e.g., chronology of migration or other use), and the ecological function the site may provide in terms of the migration cycle of these species. Wind developers should determine not only what species may migrate through a proposed development site and when, but also whether a site may function as a staging area or stopover habitat for wildlife on their migration pathway.

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For some species, movements between foraging and breeding habitat, or between sheltering and feeding habitats, occur on a daily basis. Consideration of daily movements (morning and evening; coming and going) is a critical factor when considering project development.

Duration/Intensity of Studies

Where pre-construction assessments are warranted to help assess risk to wildlife, the studies should be of sufficient duration and intensity to ensure adequate data are collected to accurately characterize wildlife presence and use of the area. In ecological systems, resource quality and quantity can fluctuate rapidly. These fluctuations occur naturally, but human actions can significantly affect (i.e., increase or decrease) natural oscillations. Pre-construction monitoring and assessment of proposed wind energy sites are "snapshots in time," showing occurrence or no occurrence of a species or habitat at the specific time surveyed. Often due to prohibitive costs, assessments and surveys are conducted for very low percentages (e.g., less than 5 percent) of the available sample time in a given year, however, these data are used to support risk analyses over the projected life of a project (e.g., 30 years of operations).

To establish a trend in site use and conditions that incorporates annual and seasonal variation in meteorological conditions, biological factors, and other variables, pre-construction studies may need to occur over multiple years. However, the level of risk and the question of data requirements will be based on site sensitivity, affected species, and the availability of data from other sources. Accordingly, decisions regarding studies should consider information gathered during the previous tiers, variability within and between seasons, and years where variability is likely to substantially affect answers to the Tier 3 questions. These studies should also be designed to collect data during relevant breeding, feeding, sheltering, staging, or migration periods for each species being studied. Additionally, consideration for the frequency and intensity of pre-construction monitoring should be site-specific and determined through consultation with an expert authority based on their knowledge of the specific species, level of risk and other variables present at each individual site.

Assessing Risk to Species of Concern

Once likely presence and factors such as abundance, frequency of use, habitat use patterns, and behavior have been determined or assumed, the developer should consider and/or determine the consequences to the "populations" and species.

Below is a brief discussion of several types of risk factors that can be considered. This does not include all potential risk factors for all species, but addresses the most common ones.

Collision

Collision likelihood for individual birds and bats at a particular wind energy facility may be the result of complex interactions among species distribution, "relative abundance," behavior, visibility, weather conditions, and site characteristics. Collision likelihood for an individual may be low regardless of abundance if its behavior does not place it within the "rotor-swept zone." Individuals that frequently occupy the rotor-swept zone but effectively avoid collisions are also at low likelihood of collision with a turbine.

Alternatively, if the behavior of individuals frequently places them in the rotor-swept zone, and they do not actively avoid turbine blade strikes, they are at higher likelihood of collisions with turbines regardless of abundance. Some species, even at lower abundance, may have a higher collision rate than similar species due to subtle differences in their ecology and behavior.

At many projects, the numbers of bat fatalities are higher than the numbers of bird fatalities, but the exposure risk of bats at these facilities is not fully understood. Researchers (Horn et al. 2008 and Cryan 2008) hypothesize that some bats may be attracted to turbines, which, if true, would further complicate estimation of exposure. Further research is required to determine whether bats are attracted to turbines and if so, whether this increased individual risk translates into higher population-scale effects.

Habitat Loss and Degradation

Wind project development results in direct habitat loss and habitat modification, especially at sites previously undeveloped. Many of North America's native landscapes are greatly diminished or degraded from multiple causes unrelated to wind energy. Important remnants of these landscapes are identified and documented in various databases held by private conservation organizations, state wildlife agencies, and, in some cases, by the Service. Species that depend on these landscapes are susceptible to further loss of habitat, which will affect their ability to reproduce and survive. While habitat lost due to footprints of turbines, roads, and other infrastructure is obvious, less obvious is the potential reduction of habitat quality.

Habitat Fragmentation

Habitat fragmentation separates blocks of habitat for some species into segments, such that the individuals in the remaining habitat segments may suffer from effects such as decreased survival, reproduction, distribution, or use of the area. Site clearing, access roads, transmission lines, and arrays of turbine towers may displace some species or fragment continuous habitat areas into smaller, isolated tracts. Habitat fragmentation is of particular concern when species require large expanses of habitat for activities such as breeding, foraging, and sheltering.

Habitat fragmentation can result in increases in "edge" resulting in direct effects of barriers

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and displacement as well as indirect effects of nest parasitism and predation. Sensitivity to fragmentation effects varies among species. Habitat fragmentation and site modification are important issues that should be assessed at the landscape scale early in the siting process. Identify areas of high sensitivity due to the presence of blocks of native habitats, paying particular attention to known or suspected "species sensitive to habitat fragmentation."

Displacement and Behavioral Changes

Estimating displacement risk requires an understanding of animal behavior in response to a project and its infrastructure and activities, and a pre-construction estimate of presence/absence of species whose behavior would cause them to avoid or seek areas in proximity to turbines, roads, and other components of the project. Displacement is a function of the sensitivity of individuals to the project and activity levels associated with operations.

Indirect Effects

Wind development can also have indirect effects to wildlife and habitats. Indirect effects include reduced nesting and breeding densities and the social ramifications of those reductions; loss or modification of foraging habitat; loss of population vigor and overall population density; increased isolation between habitat patches, loss of habitat refugia; attraction to modified habitats; effects on behavior, physiological disturbance, and habitat unsuitability. Indirect effects can result from introduction of invasive plants; increased predator populations or facilitated predation; alterations in the natural fire regime; or other effects, and can manifest themselves later in time than the causing action.

When collection of both pre- and post-construction data in the areas of interest and reference areas is possible, then the Before-After-Control-Impact (BACI) is the most statistically robust design. The BACI design is most like the classic manipulative experiment.[6] In the absence of a suitable reference area, the design is reduced to a Before-After (BA) analysis of effect where the differences between pre- and post-construction parameters of interest are assumed to be the result of the project, independent of other potential factors affecting the assessment area. With respect to BA studies, the key question is whether the observations taken immediately after the incident can reasonably be expected within the expected range for the system (Manly 2009). Reliable quantification of impact usually will include additional study

Virginia big-eared bat. Credit: USFWS

components to limit variation and the confounding effects of natural factors that may change with time.

The developer's timeline for the development of a wind energy facility often does not allow for the collection of sufficient pre-construction data and/or identification of suitable reference areas to complete a BACI or BA study. Furthermore, alterations in land use or disturbance over the course of a multi-year BACI or BA study may complicate the analysis of study results. Additional discussion of these issues can be found in Tier 5 Study Design Considerations.

Tier 3 Technical Resources

The following methods and metrics are provided as suggested sources for developers to use in answering the Tier 3 questions.

Tier 3, Question 1

Acoustic monitoring can be a practical method for determining the presence of threatened, endangered or otherwise rare species of bats throughout a proposed project (Kunz et al. 2007). There are two general types of acoustic detectors used for collection of information on bat activity and species identification: the full-spectrum, time-expansion and the zero-crossing techniques for ultrasound bat detection (see Kunz et al. 2007 for detailed discussion). Full-spectrum time expansion detectors provide nearly complete species discrimination, while zero-crossing detectors provide reliable and cost-effective estimates of total bat use at a site and some species discrimination. Myotis species can be especially difficult to discriminate with zero-crossing detectors (Kunz et al. 2007). Kunz et al. (2007) describe the strengths and weaknesses of each technique for ultrasonic bat detection, and either type of detector may be useful in most situations except where species identification is especially important and zero-crossing methods are inadequate to provide the necessary data. Bat acoustics technology is evolving rapidly and study objectives are an important consideration when selecting detectors. When rare or endangered species of bats are suspected, sampling should occur during different seasons and at

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[6] In this context, such designs are not true experiments in that the treatments (project development and control) are not randomly assigned to an experimental unit, and there is often no true replication. Such constraints are not fatal flaws, but do limit statistical inferences of the results.

multiple sampling stations to account for temporal and spatial variability.

Mist-netting for bats is required in some situations by state agencies, Tribes, and the Service to determine the presence of threatened, endangered or otherwise rare species. Mist-netting is best used in combination with acoustic monitoring to inventory the species of bats present at a site, especially to detect the presence of threatened or endangered species. Efforts should concentrate on potential commuting, foraging, drinking, and roosting sites (Kuenzi and Morrison 1998, O'Farrell et al. 1999). Mist-netting and other activities that involve capturing and handling threatened or endangered species of bats will require permits from state and/or federal agencies.

Tier 3, Question 2

The following protocol should be used to answer Tier 3, Question 2. This protocol for analysis of habitat fragmentation at project sites should be adapted to the species of habitat fragmentation concern as identified in response to Question 5 in Tier 2 and to the landscape in which development is contemplated. The developer should:

1. Define the study area. The study area for the site should include the "footprint" for the proposed facility plus an appropriate surrounding area. The extent of the study area should be based on the area where there is potential for significant adverse habitat impacts, including indirect impacts, within the distribution of habitat for the species of habitat fragmentation concern.

2. Determine the potential for occupancy of the study area based on the guidance provided for the species of habitat fragmentation concern described above in Question 1.

3. Analyze current habitat quality and spatial configuration of the study area for the species of habitat fragmentation concern.

   a. Use recent aerial or remote imagery to determine distinct habitat patches or boundaries within the study area, and the extent of existing habitat fragmenting features.

      i. Assess the level of fragmentation of the existing habitat for the species of habitat fragmentation concern and categorize into three classes:

         - High quality: little or no apparent fragmentation of intact habitat
         - Medium quality: intact habitat exhibiting some recent disturbance activity
         - Low quality: extensive fragmentation of habitat (e.g., row-cropped agricultural lands, active surface mining areas)

      ii. Determine edge and interior habitat metrics of the study area:

         - Identify habitat, non-habitat landscape features and existing fragmenting features relative to the species of habitat fragmentation concern, to estimate existing edge
         - Calculate area and acres of edge
         - Calculate area of intact patches of habitat and compare to needs of species of habitat fragmentation concern

   b. Determine potential changes in quality and spatial configuration of the habitat in the study area if development proceeds as proposed using existing site information and the best available spatial data regarding placement of wind turbines and ancillary infrastructure:

      i. Identify, delineate and classify all additional features added by the development that potentially fragment habitat for the species of habitat fragmentation concern (e.g., roads, transmission lines, maintenance structures, etc.)

      ii. Assess the expected future size and quality of habitat patches for the species of habitat fragmentation concern and the additional fragmenting features, and categorize into three classes as described above

      iii. Determine expected future acreages of edge and interior habitats

      iv. Calculate the area of the remaining patches of intact habitat

   c. Compare pre-construction and expected post-construction fragmentation metrics:

      i. Determine the area of intact habitat lost (to the displacement footprint or by alteration due to the edge effect)

      ii. Identify habitat patches that are expected to be moved to a lower habitat quality classification as a result of the development

4. Assess the likelihood of a significant reduction in the demographic and genetic viability of the local population of the species of habitat fragmentation concern using the habitat fragmentation information collected under item 3 above and any currently available demographic and genetic data. Based on this assessment, the developer makes the finding whether or not there is significant reduction. The developer should share the finding with the relevant agencies. If the developer finds the likelihood of a significant reduction, the developer should

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consider items a, b or c below:

a. Consider alternative locations and development configurations to minimize fragmentation of habitat in communication with species experts, for all species of habitat fragmentation concern in the area of interest.

b. Identify high quality habitat parcels that may be protected as part of a plan to limit future loss of habitat for the impacted population of the species of habitat fragmentation concern in the area.

c. Identify areas of medium or low quality habitat within the range of the impacted population that may be restored or improved to compensate for losses of habitat that result from the project (e.g., management of unpaved roads and ORV trails).

Tier 3, Question 3

The following protocols are suggested for use in answering Tier 3, Question 3.

Bird distribution, abundance, behavior and site use

Diurnal Avian Activity Surveys

The commonly used data collection methods for estimating the spatial distribution and relative abundance of diurnal birds includes counts of birds seen or heard at specific survey points (point count), along transects (transect surveys), and observational studies. Both methods result in estimates of bird use, which are assumed to be indices of abundance in the area surveyed. Absolute abundance is difficult to determine for most species and is not necessary to evaluate species risk. Depending on the characteristics of the area of interest and the bird species potentially affected by the project, additional pre-construction study methods may be necessary. Point counts or line transects should collect vertical as well as horizontal data to identify levels of activity within the rotor-swept zone.

Avian point counts should follow the general methodology described by Reynolds et al. (1980) for point counts within a fixed area, or the line transect survey similar to Schaffer and Johnson (2008), where all birds seen within a fixed distance of a line are counted. These methods are most useful for pre- and post-construction studies to quantify avian use of the project site by habitat, determine the presence of species of concern, and to provide a baseline for assessing displacement effects and habitat loss. Point counts for large birds (e.g., raptors) follow the same point count method described by Reynolds et al. (1980), Ralph et al. (1993) and Ralph et al. 1995).

Point count plots, transects, and observational studies should allow for statistical extrapolation of data and be distributed throughout the area of interest using a probability sampling approach (e.g., systematic sample with a random start). For most projects, the area of interest is the area where wind turbines and permanent meteorological (met) towers are proposed or expected to be sited. Alternatively, the centers of the larger plots can be located at vantage points throughout the potential area being considered with the objective of covering most of the area of interest. Flight height should also be collected to focus estimates of use on activity occurring in the rotor-swept zone.

Sampling duration and frequency will be determined on a project-by-project basis and by the questions being addressed. The most important consideration for sampling frequency when estimating abundance is the amount of variation

Hoary bat. Credit: Paul Cryan, USGS

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expected among survey dates and locations and the species of concern.

The use of comparable methods and metrics should allow data comparison from plot to plot within the area of interest and from site to site where similar data exist. The data should be collected so that avian activity can be estimated within the rotor-swept zone. Relating use to site characteristics requires that samples of use also measure site characteristics thought to influence use (i.e., covariates such as vegetation and topography) in relation to the location of use. The statistical relationship of use to these covariates can be used to predict occurrence in unsurveyed areas during the survey period and for the same areas in the future.

Surveys should be conducted at different intervals during the year to account for variation in expected bird activity with lower frequency during winter months if avian activity is low. Sampling frequency should also consider the episodic nature of activity during fall and spring migration. Standardized protocols for estimating avian abundance are well-established and should be consulted (e.g., Dettmers et al. 1999). If a more precise estimate of density is required for a particular species (e.g., when the goal is to determine densities of a special-status breeding bird species), the researcher will need more sophisticated sampling procedures, including estimates of detection probability.

Raptor Nest Searches

An estimate of raptor use of the project site is obtained through appropriate surveys, but if potential impacts to breeding raptors are a concern on a project, raptor nest searches are also recommended. These surveys provide information to predict risk to the local breeding population of raptors, for micro-siting decisions, and for developing an appropriate-sized non-disturbance buffer around nests. Surveys also provide baseline data for estimating impacts and determining mitigation

Red-tailed hawk. Credit: Dave Menke, USFWS

requirements. A good source of information for raptor surveys and monitoring is Bird and Bildstein (2007).

Searches for raptor nests or raptor breeding territories on projects with potential for impacts to raptors should be conducted in suitable habitat during the breeding season. While there is no consensus on the recommended buffer zones around nest sites to avoid disturbance of most species (Sutter and Jones 1981), a nest search within at least one mile of the wind turbines and transmission lines, and other infrastructure should be conducted. However, larger nest search areas are needed for eagles, as explained in the Service's ECP Guidance, when bald or golden eagles are likely to be present.

Methods for these surveys are fairly common and will vary with the species, terrain, and vegetation within the survey area. The Service recommends that protocols be discussed with biologists from the lead agency, Service, state wildlife agency, and Tribes where they have jurisdiction. It may be useful to consult other scientifically credible information sources. At minimum, the protocols should contain the list of target raptor species for nest surveys and the appropriate search protocol for each site, including timing and number of surveys needed, search area, and search techniques.

Prairie Grouse and Sage Grouse Population Assessments

Sage grouse and prairie grouse merit special attention in this context for three reasons:

1. The scale and biotic nature of their habitat requirements uniquely position them as reliable indicators of impacts on, and needs of, a suite of species that depend on sage and grassland habitats, which are among the nation's most diminished ecological communities (Vodehnal and Haufler 2007).
2. Their ranges and habitats are highly congruent with the nation's richest inland wind resources.
3. They are species for which some known impacts of anthropogenic features (e.g., tall structures, buildings, roads, transmission lines, wind energy facilities, etc.) have been documented.

Populations of prairie grouse and sage grouse generally are assessed by either lek counts (a count of the maximum number of males attending a lek) or lek surveys (classification of known leks as active or inactive) during the breeding season (e.g., Connelly et al. 2000). Methods for lek counts vary slightly by species but in general require repeated visits to known sites and a systematic search of all suitable habitat for leks, followed by repeated visits to active leks to estimate the number of grouse using them.

Recent research indicates that viable prairie grouse and sage grouse populations are dependent on suitable nesting and brood-rearing habitat (Connelly et al. 2000, Hagen et al. 2009). These habitats generally are associated with leks. Leks are the approximate centers of nesting and brood-rearing habitats (Connelly et al. 2000, but see Connelly et al. 1988 and Becker et al. 2009). High quality nesting and

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brood rearing habitats surrounding leks are critical to sustaining viable prairie grouse and sage grouse populations (Giesen and Connelly 1993, Hagen et al. 2004, Connelly et al. 2000). A population assessment study area should include nesting and brood rearing habitats that may extend several miles from leks. For example, greater and lesser prairie-chickens generally nest in suitable habitats within one to two miles of active leks (Hagen et al. 2004), whereas the average distances from nests to active leks of non-migratory sage grouse range from 0.7 to four miles (Connelly et al. 2000), and potentially much more for migratory populations (Connelly et al. 1988).

While surveying leks during the spring breeding season is the most common and convenient tool for monitoring population trends of prairie grouse and sage grouse, documenting available nesting and brood rearing habitat within and adjacent to the potentially affected area is recommended. Suitable nesting and brood rearing habitats can be mapped based on habitat requirements of individual species. The distribution and abundance of nesting and brood rearing habitats can be used to help in the assessment of adverse impacts of the proposed project to prairie grouse and sage grouse.

Mist-Netting for Birds

Mist-netting is not recommended as a method for assessing risk of wind development for birds. Mist-netting cannot generally be used to develop indices of relative bird abundance, nor does it provide an estimate of collision risk as mist-netting is not feasible at the heights of the rotor-swept zone and captures below that zone may not adequately reflect risk. Operating mist-nets requires considerable experience, as well as state and federal permits.

Occasionally mist-netting can help confirm the presence of rare species at documented fallout or migrant stopover sites near a proposed project. If mist-netting is to be used, the Service recommends that procedures for operating nets and collecting data be followed in accordance with Ralph et al. (1993).

Nocturnal and Crepuscular Bird Survey Methods

Additional studies using different methods should be conducted if characteristics of the project site and surrounding areas potentially pose a high risk of collision to night migrating songbirds and other nocturnal or crepuscular species. For most of their flight, songbirds and other nocturnal migrants are above the reach of wind turbines, but they pass through the altitudinal range of wind turbines during ascents and descents and may also fly closer to the ground during inclement weather (Able, 1970; Richardson, 2000). Factors affecting flight path, behavior, and "fall-out" locations of nocturnal migrants are reviewed elsewhere (e.g., Williams et al., 2001; Gauthreaux and Belser, 2003; Richardson, 2000; Mabee et al., 2006).

In general, pre-construction nocturnal studies are not recommended unless the site has features that might strongly concentrate nocturnal birds, such as along coastlines that are known to be migratory songbird corridors. Biologists knowledgeable about nocturnal bird migration and familiar with patterns of migratory stopovers in the region should assess the potential risks to nocturnal migrants at a proposed project site. No single method can adequately assess the spatial and temporal variation in nocturnal bird populations or the potential collision risk. Following nocturnal study methods in Kunz et al. (2007) is recommended to determine relative abundance, flight direction and flight altitude for assessing risk to migrating birds, if warranted. If areas of interest are within the range of nocturnal species of concern (e.g., marbled murrelet, northern spotted owl, Hawaiian petrel, Newell's shearwater), surveyors should use species-specific protocols recommended by state wildlife agencies, Tribes or Service to assess the species' potential presence in the area of interest.

In contrast to the diurnal avian survey techniques previously described, considerable variation and uncertainty exist on the optimal protocols for using acoustic monitoring devices, radar, and other techniques to evaluate species composition, relative abundance, flight height, and trajectory of nocturnal migrating birds. While an active area of research, the use of radar for determining passage rates, flight heights and flight directions of nocturnal migrating animals has yet to be shown as a good indicator of collision risk. Pre- and post-construction studies comparing radar monitoring results to estimates of bird and bat fatalities will be necessary to evaluate radar as a tool for predicting collision risk. Additional studies are also needed before making recommendations on the number of nights per season or the number of hours per night that are appropriate for radar studies of nocturnal bird migration (Mabee et al., 2006).

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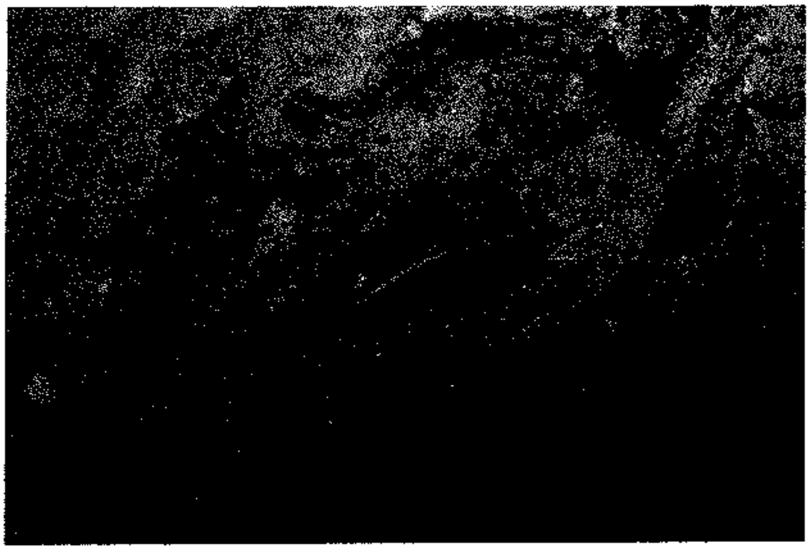
<u>Bat survey methods</u>

The Service recommends that all techniques discussed below be conducted by biologists trained in bat identification, equipment use, and the analysis and interpretation of data resulting from the design and conduct of the studies. Activities that involve capturing and handling bats may require permits from state and/or federal agencies.

Acoustic Monitoring

Acoustic monitoring provides information about bat presence and activity, as well as seasonal changes in species occurrence and use, but does not measure the number of individual bats or population density. The goal of acoustic monitoring is to provide a prediction of the potential risk of bat fatalities resulting from the construction and operation of a project. Our current state of knowledge about bat-wind turbine interactions, however, does not allow a quantitative link between pre-construction acoustic assessments of bat activity and operations fatalities. Discussions with experts, state wildlife trustee agencies, Tribes, and



Tri-colored bat. Credit: USFWS

Service will be needed to determine whether acoustic monitoring is warranted at a proposed project site.

The predominance of bat fatalities detected to date are migratory species and acoustic monitoring should adequately cover periods of migration and periods of known high activity for other (i.e., non-migratory) species. Monitoring for a full year is recommended in areas where there is year round bat activity. Data on environmental variables such as temperature and wind speed should be collected concurrently with acoustic monitoring so these weather data can be used in the analysis of bat activity levels.

The number and distribution of sampling stations necessary to adequately estimate bat activity have not been well established but will depend, at least in part, on the size of the project area, variability within the project area, and a Tier 2 assessment of potential bat occurrence.

The number of detectors needed to achieve the desired level of precision will vary depending on the within-site variation (e.g., Arnett et al. 2006, Weller 2007, See also, Bat Conservation International website for up-to-date survey methodologies). One frequently used method is to place acoustic detectors on existing met towers, approximately every two kilometers across the site where turbines are expected to be sited. Acoustic detectors should be placed at high positions (as high as practicable, based on tower height) on each met tower included in the sample to record bat activity at or near the rotor swept zone, the area of presumed greatest risk for bats. Developers should evaluate whether it would be cost effective to install detectors when met towers are first established on a site. Doing so might reduce the cost of installation later and might alleviate time delays to conduct such studies.

If sampling at met towers does not adequately cover the study area or provide sufficient replication, additional sampling stations can be established at low positions (~1.5-2 meters) at a sample of existing met towers and one or more mobile units (i.e., units that are moved to different locations throughout the study period) to increase coverage of the proposed project area. When practical and based on information from Tier 2, it may be appropriate to conduct some acoustic monitoring of features identified as potentially high bat use areas within the study area (e.g., bat roosts and caves) to determine use of such features.

There is growing interest in determining whether "low" position samples (~1.5-2 meters) can provide equal or greater correlation with bat fatalities than "high" position samples (described above) because this would substantially lower cost of this work. Developers could then install a greater number of detectors at lower cost resulting in improved estimates of bat activity and, potentially, improved qualitative estimates of risk to bats. This is a research question that is not expected to be addressed at a project.

Other bat survey techniques

Occasionally, other techniques may be needed to answer Tier 3 questions and complement the information from acoustic surveys. Kunz et al. (2007), NAS (2007), Kunz and Parsons (2009) provide comprehensive descriptions of bat survey techniques, including those identified below that are relevant for Tier 3 studies at wind energy facilities. P21-36 cont.

Roost Searches and Exit Counts

Pre-construction survey efforts may be recommended to determine whether known or likely bat roosts in mines, caves, bridges, buildings, or other potential roost sites occur within the project vicinity, and to confirm whether known or likely bat roosts are present and occupied by bats. If active roosts are detected, it may be appropriate to address questions about colony size and species composition of roosts. Exit counts and roost searches are two approaches to answering these questions, and Rainey (1995), Kunz and Parsons (2009), and Sherwin et al. (2009) are resources that describe options and approaches for these techniques. Roost searches should be performed cautiously because roosting bats are sensitive to human disturbance (Kunz et al. 1996). Known maternity and hibernation roosts should not be entered or otherwise disturbed unless authorized by state and/or federal wildlife agencies. Internal searches of abandoned mines or caves can be dangerous and should only be conducted by trained researchers. For mine survey protocol and guidelines for protection of bat roosts, see the appendices in Pierson et al. (1999). Exit surveys at known roosts generally should be limited to non-invasive observation using low-light binoculars and infrared video cameras.

Multiple surveys should be conducted to determine the presence or absence of bats in caves and mines, and the number of surveys needed will vary by species of bats, sex (maternity or bachelor colony) of bats, seasonality of use, and type of roost structure (e.g., caves or mines). For example, Sherwin et al. (2003) demonstrated that a minimum of three surveys are needed to determine the absence of large hibernating colonies of Townsend's big-eared bats in mines (90 percent probability), while a minimum of nine surveys (during a single warm season) are necessary before a mine could be eliminated as a bachelor roost for this species (90 percent probability). An average of three surveys was needed before surveyed caves could be eliminated as bachelor roosts (90 percent probability). The Service recommends that decisions on level of effort follow discussion with relevant agencies and bat experts.

Activity Patterns

If active roosts are detected, it may be necessary to answer questions about behavior, movement patterns, and patterns of roost use for bat species of concern, or to further investigate habitat features that might attract bats and pose fatality risk. For some bat species, typically threatened, endangered, or state-listed species, radio telemetry or radar may be recommended to assess both the direction of movement as bats leave roosts, and the bats' use of the area being considered for development. Kunz et al. (2007) describe the use of telemetry, radar and other tools to evaluate use of roosts, activity patterns, and flight direction from roosts.

Mist-Netting for Bats

While mist-netting for bats is required in some situations by state agencies, Tribes, and the Service to determine the presence of threatened, endangered or other bat species of concern, mist-netting is not generally recommended for determining levels of activity or assessing risk of wind energy development to bats for the following reasons: 1) not all proposed or operational wind energy facilities offer conditions conducive to capturing bats, and often the number of suitable sampling points is minimal or not closely associated with the project location; 2) capture efforts often occur at water sources offsite or at nearby roosts and the results may not reflect species presence or use on the site where turbines are to be erected; and 3) mist-netting isn't feasible at the height of the rotor-swept zone, and captures below that zone may not adequately reflect risk of fatality. If mist-netting is employed, it is best used in combination with acoustic monitoring to inventory the species of bats present at a site.

White-Nose Syndrome

White-nose syndrome is a disease affecting hibernating bats. Named for the white fungus that appears on the muzzle and other body parts of hibernating bats, WNS is associated with extensive mortality of bats in eastern North America. All contractors and consultants hired by developers should employ the most current version of survey and handling protocols to avoid transmitting white-nose syndrome between bats.

<u>Other wildlife</u>

While the above guidance emphasizes the evaluation of potential impacts to birds and bats, Tier 1 and 2 evaluations may identify other species of concern. Developers are encouraged to assess adverse impacts potentially caused by development for those species most likely to be negatively affected by such development. Impacts to other species are primarily derived from potential habitat loss or displacement. The general guidance on the study design and methods for estimation of the distribution, relative abundance, and habitat use for birds is applicable to the study of other wildlife. References regarding monitoring for other wildlife are available in Appendix C:

Mule deer. Credit: Tupper Ansel Blake, USFWS

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Sources of Information Pertaining to Methods to Assess Impacts to Wildlife. Nevertheless, most methods and metrics will be species-specific and developers are advised to work with the state, tribal, or federal agencies, or other credible experts, as appropriate, during problem formulation for Tier 3.

Tier 3 Decision Points

Developers and the Service should communicate prior to completing the Tier 3 decision process. A developer should inform the Service of the results of its studies and plans. The Service will provide written comments to a developer on study and project development plans that identify concerns and recommendations to resolve the concerns. The developer and, when applicable, the permitting authority will make a decision regarding whether and how to develop the project. The decision point at the end of Tier 3 involves three potential outcomes:

Little brown bat with white nose syndrome. Credit: Marvin Moriarty, USFWS

1. Development of the site has a low probability of significant adverse impact based on existing and new information.

   There is little uncertainty regarding when and how development should proceed, and adequate information exists to satisfy any required permitting. The decision process proceeds to permitting, when required, and/or development, and Tier 4.

2. Development of the site has a moderate to high probability of significant adverse impacts without proper measures being taken to mitigate those impacts. This outcome may be subdivided into two possible scenarios:

   a. There is certainty regarding how to develop the site to adequately mitigate significant adverse impacts. The developer bases their decision to develop the site adopting proper mitigation measures and appropriate post-construction fatality and habitat studies (Tier 4).

   b. There is uncertainty regarding how to develop the site to adequately mitigate significant adverse impacts, or a permitting process requires additional information on potential significant adverse wildlife impacts before permitting future phases of the project. The developer bases their decision to develop the site adopting proper mitigation measures and appropriate post-construction fatality and habitat studies (Tier 4).

3. Development of the site has a high probability of significant impact that:

   a. Cannot be adequately mitigated.

   Site development should be delayed until plans can be developed that satisfactorily mitigate for the significant adverse impacts. Alternatively, the site should be abandoned in favor of known sites with less potential for environmental impact, or the developer begins an evaluation of other sites or landscapes for more acceptable sites to develop.

   b. Can be adequately mitigated.

   Developer should implement mitigation measures and proceed to Tier 4.

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Chapter 5: Tier 4 – Post-construction Studies to Estimate Impacts

The outcome of studies in Tiers 1, 2, and 3 will determine the duration and level of effort of post-construction studies.

Tier 4 post-construction studies are designed to assess whether predictions of fatality risk and direct and indirect impacts to habitat of species of concern were correct. Fatality studies involve searching for bird and bat carcasses beneath turbines to estimate the number and species composition of fatalities (Tier 4a). Habitat studies involve application of GIS and use data collected in Tier 3 and Tier 4b and/or published information. Post-construction studies on direct and indirect impacts to habitat of species of concern, including species of habitat fragmentation concern need only be conducted if Tier 3 studies indicate the potential for significant adverse impacts.

A male Eastern red bat perches among green foliage. Credit: ©MerlinD.Tuttle,BatConservationInternational,www.batcon.org

Tier 4a – Fatality Studies

At this time, community- and utility-scale projects should conduct at least one year of fatality monitoring. The intensity of the studies should be related to risks of significant adverse impacts identified in pre-construction assessments. As data collected with consistent methods and metrics increases (see discussion below), it is possible that some future projects will not warrant fatality monitoring, but such a situation is rare with the present state of knowledge.

Fatality monitoring should occur over all seasons of occupancy for the species being monitored, based on information produced in previous tiers. The number of seasons and total length of the monitoring may be determined separately for bats and birds, depending on the pre-construction risk assessment, results of Tier 3 studies and Tier 4 monitoring from comparable sites (see Glossary in Appendix A) and the results of first year fatality monitoring. Guidance on the relationship between these variables and monitoring for fatalities is provided in Table 2.

It may be appropriate to conduct monitoring using different durations and intervals depending on the species of concern. For example, if raptors occupy an area year-round, it may be appropriate to monitor for raptors throughout the year (12 months). It may be warranted to monitor for bats when they are active (spring, summer and fall or

P21-36 cont.

approximately eight months). It may be appropriate to increase the search frequency during the months bats are active and decrease the frequency during periods of inactivity. All fatality monitoring should include estimates of carcass removal and carcass detection bias likely to influence those rates.

Tier 4a Questions

Post-construction fatality monitoring should be designed to answer the following questions as appropriate for the individual project:

1. **What are the bird and bat fatality rates for the project?**
2. **What are the fatality rates of species of concern?**
3. **How do the estimated fatality rates compare to the predicted fatality rates?**
4. **Do bird and bat fatalities vary within the project site in relation to site characteristics?**
5. **How do the fatality rates compare to the fatality rates from existing projects in similar landscapes with similar species composition and use?**
6. **What is the composition of fatalities in relation to migrating and resident birds and bats at the site?**
7. **Do fatality data suggest the need for measures to reduce impacts?**

Tier 4a studies should be of sufficient statistical validity to address Tier 4a questions and enable determination of whether Tier 3 fatality predictions were correct. Fatality monitoring results also should allow comparisons with other sites, and provide a basis for determining if operational changes or other mitigation measures at the site are appropriate. The Service encourages project operators to discuss Tier 4 studies with local, state, federal, and tribal wildlife agencies. The number of years of monitoring is based on outcomes of Tier 3 and Tier 4 studies and analysis of comparable Tier 4 data from other projects as indicated in Table 2. The Service may recommend multiple years of monitoring for projects located near a listed species or bald or golden eagle, or other situations, as appropriate.

Tier 4a Protocol Design Considerations

The basic method of measuring fatality rates is the carcass search. Search protocols should be standardized to the greatest extent possible, especially for common objectives and species of concern, and they should include methods for adequately accounting for sampling biases (searcher efficiency and scavenger removal). However, some situations warrant exceptions to standardized protocol. The responsibility of demonstrating that an exception is appropriate and applicable should be on the project operator to justify increasing or decreasing the duration or intensity of operations monitoring.

Some general guidance is given below with regard to the following fatality monitoring protocol design issues:

- Duration and frequency of monitoring
- Number of turbines to monitor
- Delineation of carcass search plots, transects, and habitat mapping
- General search protocol
- Field bias and error assessment
- Estimators of fatality

More detailed descriptions and methods of fatality search protocols can be found in the California (California Energy Commission 2007) and Pennsylvania (Pennsylvania Game Commission 2007) state guidelines and in Kunz et al. (2007), Smallwood (2007), and Strickland et al. (2011).

<u>Duration and frequency of monitoring</u>

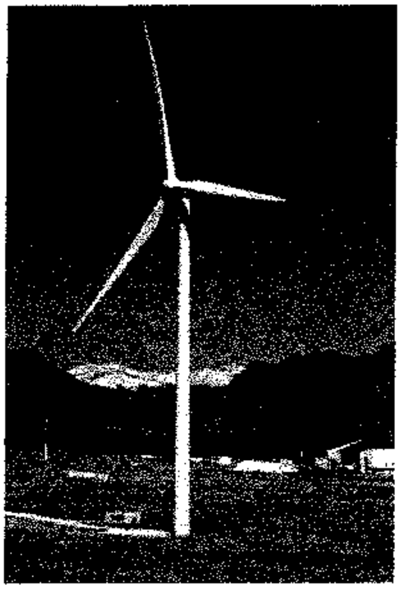
Frequency of carcass searches (search interval) may vary for birds and bats, and will vary depending on the questions to be answered, the species of concern, and their seasonal abundance at the project site. The carcass searching protocol should be adequate to answer applicable Tier 4 questions at an appropriate level of precision to make general conclusions about the project, and is not intended to provide highly precise measurements of fatalities. Except during low use times (e.g. winter months in northern states), the Service recommends that protocols be designed such that carcass searches occur at some turbines within the project area most days each week of the study.

The search interval is the interval between carcass searches at individual turbines, and this interval may be lengthened or shortened depending on the carcass removal rates. If the primary focus is on fatalities of large raptors, where carcass removal is typically low, then a longer interval between searches (e.g., 14-28 days) is sufficient. However, if the focus is on fatalities of bats and small birds and carcass removal is high, then a shorter search interval will be necessary. P21-36 cont.

There are situations in which studies of higher intensity (e.g., daily searches at individual turbines within the sample) may be appropriate. These would be considered only in Tier 5 studies or in research programs because the greater complexity and level of effort goes beyond that recommended for typical Tier 4 post construction monitoring. Tier 5 and research studies could include evaluation of specific measures that have been implemented to mitigate potential significant adverse impacts to species of concern identified during pre-construction studies.

Number of turbines to monitor

If available, data on variability among turbines from existing



Wind turbine. Credit: NREL

projects in similar conditions within the same region are recommended as a basis for determining needed sample size (see Morrison et al., 2008). If data are not available, the Service recommends that an operator select a sufficient number of turbines via a systematic sample with a random start point. Sampling plans can be varied (e.g., rotating panels [McDonald 2003, Fuller 1999, Breidt and Fuller 1999, and Urquhart et al. 1998]) to increase efficiency as long as a probability sampling approach is used. If the project contains fewer than 10 turbines, the Service recommends that all turbines in the area of interest be searched unless otherwise agreed to by the permitting or wildlife resource agencies. When selecting turbines, the Service recommends that a systematic sample with a random start be used when selecting search plots to ensure interspersion among turbines. Stratification among different habitat types also is recommended to account for differences in fatality rates among different habitats (e.g., grass versus cropland or forest); a sufficient number of turbines should be sampled in each strata.

Delineation of carcass search plots, transects, and habitat mapping

Evidence suggests that greater than 80 percent of bat fatalities fall within half the maximum distance of turbine height to ground (Erickson 2003 a, b), and a minimum plot width of 120 meters from the turbine should be established at sample turbines. Plots will need to be larger for birds, with a width twice the turbine height to ground. Decisions regarding search plot size should be made in discussions with the Service, state wildlife agency, permitting agency and Tribes. It may be useful to consult other scientifically credible information sources.

The Service recommends that each search plot should be divided into oblong subplots or belt transects and that each subplot be searched. The objective is to find as many carcasses as possible so the width of the belt will vary depending on the ground cover and its influence on carcass visibility. In most situations, a search width of 6 meters should be adequate, but this may vary from 3-10 meters depending on ground cover.

Searchable area within the theoretical maximum plot size varies, and heavily vegetated areas (e.g., eastern mountains) often do not allow surveys to consistently extend to the maximum plot width. In other cases it may be preferable to search a portion of the maximum plot instead of the entire plot. For example, in some landscapes it may be impractical to search the entire plot because of the time required to do an effective search, even if it is accessible (e.g., croplands), and data from a probability sample of subplots within the maximum plot size can provide a reasonable estimate of fatalities. It is important to accurately delineate and map the area searched for each turbine to adjust fatality estimates based on the actual area searched. It may be advisable to establish habitat visibility classes in each plot to account for differential detectability, and to develop visibility classes for different landscapes (e.g., rocks, vegetation) within each search plot. For example, the Pennsylvania Game Commission (2007) identified four classes based on the percentage of bare ground.

The use of visibility classes requires that detection and removal biases be estimated for each class. Fatality estimates should be made for each class and summed for the total area sampled. Global positioning systems (GPS) are useful for accurately mapping the actual total area searched and area searched in each habitat visibility class, which can be used to adjust fatality estimates. The width of the belt or subplot searched may vary depending on the habitat and species of concern; the key is to determine actual searched area and area searched in each visibility class regardless of transect width. An adjustment may also be needed to take into account the density of fatalities as a function of the width of the search plot.

General search protocol

Personnel trained in proper search techniques should look for bird and bat carcasses along transects or subplots within each plot and record and collect all carcasses located in the searchable areas. The Service will work with developers and operators to provide necessary permits for carcass possession. A complete search of the area should be accomplished and subplot size (e.g., transect width) should be adjusted to compensate for detectability differences in the search area. Subplots should be smaller when vegetation makes it difficult to detect carcasses; subplots can be wider in open terrain. Subplot width also can vary depending on the size of the species being looked for. For example, small species such as bats may require smaller subplots than larger species such as raptors.

Data to be recorded include date, start time, end time, observer, which turbine area was searched (including GPS coordinates) and weather data for each search. When a dead bat or bird is found, the searcher should place a flag near the carcass and continue the search. After searching the entire plot, the searcher returns to each carcass and records information

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on a fatality data sheet, including date, species, sex and age (when possible), observer name, turbine number, distance from turbine, azimuth from turbine (including GPS coordinates), habitat surrounding carcass, condition of carcass (entire, partial, scavenged), and estimated time of death (e.g., <1 day, 2 days). The recorded data will ultimately be housed in the FWS Office of Law Enforcement Bird Mortality Reporting System. A digital photograph of the carcass should be taken. Rubber gloves should be used to handle all carcasses to eliminate possible transmission of rabies or other diseases and to reduce possible human scent bias for carcasses later used in scavenger removal trials. Carcasses should be placed in a plastic bag and labeled. Unless otherwise conditioned by the carcass possession permit, fresh carcasses (those determined to have been killed the night immediately before a search) should be redistributed at random points on the same day for scavenging trials.

Field bias and error assessment

During searches conducted at wind turbines, actual fatalities are likely incompletely observed. Therefore carcass counts must be adjusted by some factor that accounts for imperfect detectability (Huso 2011). Important sources of bias and error include: 1) fatalities that occur on a highly periodic basis; 2) carcass removal by scavengers; 3) differences in searcher efficiency; 4) failure to account for the influence of site (e.g. vegetation) conditions in relation to carcass removal and searcher efficiency; and 5) fatalities or injured birds and bats that may land or move outside search plots.

Some fatalities may occur on a highly periodic basis creating a potential sampling error (number 1 above). The Service recommends that sampling be scheduled so that some turbines are searched most days and episodic events are more likely detected, regardless of the search interval. To address bias sources 2-4 above, it is strongly recommended that all fatality studies conduct carcass removal and searcher efficiency trials using accepted methods (Anderson 1999, Kunz et al. 2007, Arnett et al. 2007, NRC 2007, Strickland et al. 2011). Bias trials should be conducted throughout the entire study period and searchers should be unaware of which turbines are to be used or the number of carcasses placed beneath those turbines during trials. Carcasses or injured individuals may land or move outside the search plots (number 5 above). With respect to Tier 4a fatality estimates, this potential sampling error is considered to be small and can be assumed insignificant (Strickland et al. 2011).

Prior to a study's inception, a list of random turbine numbers and random azimuths and distances (in meters) from turbines should be generated for placement of each bat or bird used in bias trials. Data recorded for each trial carcass prior to placement should include date of placement, species, turbine number, distance and direction from turbine, and visibility class surrounding the carcass. Trial carcasses should be distributed as equally as possible among the different visibility classes throughout the study period and study area. Studies should attempt to avoid "over-seeding" any one turbine with carcasses by placing no more than one or two carcasses at any one time at a given turbine. Before placement, each carcass must be uniquely marked in a manner that does not cause additional attraction, and its location should be recorded. There is no agreed upon sample size for bias trials, though some state guidelines recommend from 50 - 200 carcasses (e.g., PGC 2007).

Estimators of fatality

If there were a direct relationship between the number of carcasses observed and the number killed, there would be no need to develop a complex estimator that adjusts observed counts for detectability, and observed counts could be used as a simple index of fatality (Huso 2011). But the relationship is not direct and raw carcass counts recorded using different search intervals and under different carcass removal rates and searcher efficiency rates are not directly comparable. It is strongly recommended that only the most contemporary equations for estimating fatality be used, as some original versions are now known to be extremely biased under many commonly encountered field conditions (Erickson et al. 2000b, Erickson et al. 2004, Johnson et al. 2003, Kerns and Kerlinger 2004, Fiedler et al. 2007, Kronner et al. 2007, Smallwood 2007, Huso 2011, Strickland et al. 2011).

Tier 4a Study Objectives

In addition to the monitoring protocol design considerations described above, the metrics used to estimate fatality rates must be selected with the Tier 4a questions and objectives in mind. Metrics considerations for each of the Tier 4a questions are discussed briefly below. Not all questions will be relevant for each project, and which questions apply would depend on Tier 3 outcomes. P21-36 cont.

1. What are the bird and bat fatality rates for the project?

The primary objective of fatality searches is to determine the overall estimated fatality rates for birds and bats for the project. These rates serve as the fundamental basis for all comparisons of fatalities, and if studies are designed appropriately they allow researchers to relate fatalities to site characteristics and environmental variables, and to evaluate mitigation measures. Several metrics are available for expressing fatality rates. Early studies reported fatality rates per turbine. However, this metric is somewhat misleading as turbine sizes and their risks to birds vary significantly (NRC 2007). Fatalities are frequently reported per nameplate capacity (i.e. MW), a metric that is easily calculated and better for comparing fatality rates among different sized turbines. Even with turbines of the same name plate capacity, the size of the rotor swept area may vary among manufacturers, and turbines at various sites may operate for different lengths of time and during different times of the day and seasons. With these considerations in mind, the Service recommends that fatality rates be expressed on a per-turbine and per-nameplate MW basis until a better metric becomes available.

2. What are the fatality rates of species of concern?

This analysis simply involves calculating fatalities per turbine of all species of concern at a site when sample sizes are sufficient to do so. These fatalities should be expressed on a per nameplate MW basis if comparing species fatality rates among projects.

3. How do the estimated fatality rates compare to the predicted fatality rates?

There are several ways that predictions can be evaluated with actual fatality data. During the planning stages in Tier 2, predicted fatalities may be based on existing data at similar facilities in similar landscapes used by similar species. In this case, the assumption is that use is similar, and therefore that fatalities may be similar at the proposed facility. Alternatively, metrics derived from pre-construction assessments for an individual species or group of species – usually an index of activity or abundance at a proposed project – could be used in conjunction with use and fatality estimates from existing projects to develop a model for predicting fatalities at the proposed project site. Finally, physical models can be used to predict the probability of a bird of a particular size striking a turbine, and this probability, in conjunction with estimates of use and avoidance behavior, can be used to predict fatalities.

The most current equations for estimating fatality should be used to evaluate fatality predictions. Several statistical methods can be found in the revised Strickland et al. 2011 and used to evaluate fatality predictions. Metrics derived from Tier 3 pre-construction assessments may be correlated with fatality rates, and (using the project as the experimental unit), in Tier 5 studies it should be possible to determine if different preconstruction metrics can in fact accurately predict fatalities and, thus, risk.

4. Do bird and bat fatalities vary within the project site in relation to site characteristics?

Data from pre-construction studies can demonstrate patterns of activity that may depend upon the site characteristics. Turbines placed near escarpments or cliffs may intrude upon airspace used by raptors soaring on thermals. Pre-construction and post construction studies and assessments can be used to avoid siting individual, specific turbines within an area used by species of concern. Turbine-specific fatality rates may be related to site characteristics such as proximity to water, forest edge, staging and roosting sites, known stop-over sites, or other key resources, and this relationship may be estimated using regression analysis. This information is particularly useful for evaluating micro-siting options when planning a future facility or, on a broader scale, in determining the location of the entire project.

5. How do the fatality rates compare to the fatality rates from existing facilities in similar landscapes with similar species composition and use?

Comparing fatality rates among facilities with similar characteristics can be useful to determine patterns and broader landscape relationships. Developers should communicate with the Service to ensure that such comparisons are appropriate to avoid false conclusions. Fatality rates should be expressed on a per nameplate MW or some other standardized metric basis for comparison with other projects,

Big brown bat. Credit: USFWS

and may be correlated with site characteristics – such as proximity to wetlands, riparian corridors, mountain-foothill interface, wind patterns, or other broader landscape features – using regression analysis. Comparing fatality rates from one project to fatality rates of other projects provides insight into whether a project has relatively high, moderate or low fatalities.

6. What is the composition of fatalities in relation to migrating and resident birds and bats at the site?

The simplest way to address this question is to separate fatalities per turbine of known resident species (e.g., big brown bat, prairie horned lark) and those known to migrate long distances (e.g. hoary bat, red-eyed vireo). These data are useful in determining patterns of species composition of fatalities and possible mitigation measures directed at residents, migrants, or perhaps both, and can be used in assessing potential population effects.

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[7] In situations where a project operator was not the developer, the Service expects that obligations of the developer for adhering to the Guidelines transfer with the project.

Table 2. Decision Framework for Tier 4a Fatality Monitoring of Species of Concern.[8]

Probability of Significant Adverse Impacts in Tier 3	*Recommended Fatality Monitoring Duration and Effort*	*Possible Outcomes of Monitoring Results*
Tier 3 Studies indicate LOW probability of significant adverse impacts	Duration: At least one year of fatality monitoring to estimate fatalities of birds and bats. Field assessments should be sufficient to confirm that risk to birds and/or bats is indeed "low."	1. Documented fatalities are approximately equal to or lower than predicted risk. No further fatality monitoring or mitigation is needed. 2. Fatalities are greater than predicted, but are not likely to be significant (i.e., unlikely to affect the long-term status of the population). If comparable fatality data at similar sites also supports that impacts are not likely to be high enough to affect population status, no further monitoring or mitigation is needed. If no comparable fatality data are available or such data indicates high risk, one additional year of fatality monitoring is recommended. If two years of fatality monitoring indicate levels of impacts that are not significant, no further fatality monitoring or mitigation is recommended. 3. Fatalities are greater than predicted and are likely to be significant OR federally endangered or threatened species or BGEPA species are affected. Communication with the Service is recommended. Further efforts to address impacts to BGEPA or ESA species may be warranted, unless otherwise addressed in an ESA or BGEPA take permit.
Tier 3 studies indicate MODERATE probability of significant adverse impacts	Duration: Two or more years of fatality monitoring may be necessary. Field assessments should be sufficient to confirm that risk to birds and/or bats is indeed "moderate." Closely compare estimated effects to species to those determined from the risk assessment protocol(s).	1. Documented fatalities after the first two years are lower or not different than predicted and are not significant and no federally endangered species or BGEPA species are affected - no further fatality monitoring or mitigation is needed. 2. Fatalities are greater than predicted and are likely to be significant OR federally endangered or threatened species or BGEPA species are affected, communication with the Service is recommended. Further efforts to address impacts to BGEPA or ESA species may be warranted, unless otherwise addressed in an ESA or BGEPA take permit.
Tier 3 studies indicate HIGH probability of significant adverse impacts	Duration: Two or more years of fatality monitoring may be necessary to document fatality patterns. If fatality is high, developers should shift emphasis to exploring opportunities for mitigation rather than continuing to monitor fatalities. If fatalities are variable, additional years are likely warranted.	1. Documented fatalities during each year of fatality monitoring are less than predicted and are not likely to be significant, and no federally endangered or threatened species or BGEPA species are affected – no further fatality monitoring or mitigation is needed. 2. Fatalities are equal to or greater than predicted and are likely to be significant - further efforts to reduce impacts are necessary; communication with the Service are recommended. Further efforts, such as Tier 5 studies, to address impacts to BGEPA or ESA species may be warranted, unless otherwise addressed in an ESA or BGEPA take permit.

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[8] Ensure that survey protocols, and searcher efficiency and scavenger removal bias correction factors are the most reliable, robust, and up to date (after Huso 2009).

7. **Do fatality data suggest the need for measures to reduce impacts?**

The Service recommends that the wind project operator[7] and the relevant agencies discuss the results from Tier 4 studies to determine whether these impacts are significant. If fatalities are considered significant, the wind project operator and the relevant agencies should develop a plan to mitigate the impacts.

Tier 4b – Assessing direct and indirect impacts of habitat loss, degradation, and fragmentation

The objective of Tier 4b studies is to evaluate Tier 3 predictions of direct and indirect impacts to habitat and the potential for significant adverse impacts on species of concern as a result of these impacts. Tier 4b studies should be conducted if Tier 3 studies indicate the presence of species of habitat fragmentation concern, or if Tier 3 studies indicate significant direct and indirect adverse impacts to species of concern (see discussion below). Tier 4b studies should also inform project operators and the Service as to whether additional mitigation is necessary.

Tier 4b studies should evaluate the following questions:

1. **How do post-construction habitat quality and spatial configuration of the study area compare to predictions for species of concern identified in Tier 3 studies?**

2. **Were any behavioral modifications or indirect impacts noted in regard to species of concern?**

3. **If significant adverse impacts were predicted for species of concern, and the project was altered to mitigate for adverse impacts, were those efforts successful?**

4. **If significant adverse impacts were predicted for species of concern, and the project was altered to mitigate for adverse impacts, were those efforts successful?**

The answers to these questions will be based on information estimating habitat loss, degradation, and fragmentation information collected in Tier 3, currently available demographic and genetic data, and studies initiated in Tier 3. As in the case of Tier 4a, the answers to these questions will determine the need to conduct Tier 5 studies. For example, in the case that significant adverse impacts to species of concern were predicted, but mitigation was not successful, then additional mitigation and Tier 5 studies may be necessary. See Table 3 for further guidance.

1. **How do post-construction habitat quality and spatial configuration of the study area compare to predictions for species of concern identified in Tier 3 studies?**

GIS and demographic data collected in Tier 3 and/or published information can be used to determine predictions of impacts to species of concern from habitat loss, degradation, and fragmentation. The developer can provide development assumptions based on Tier 3 information that can be compared to post-construction information. Additional post-construction studies on impacts to species of concern due to direct and indirect impacts to habitat should only be conducted if Tier 3 studies indicate the potential for significant adverse impacts.

2. **Were any behavioral modifications or indirect impacts noted in regard to affected species?**

Evaluation of this question is based on the analysis of observed use of the area by species of concern prior to construction in comparison with observed use during operation. Observations and demographic data collected during Tier 3, and assessment of published information about the potential for displacement and demographic responses to habit impacts could be the basis for this analysis. If this analysis suggests that direct and/or indirect loss of habitat for a species of concern leads to behavioral modifications or displacement that are significant, further studies of these impacts in Tier 5 may be appropriate.

3. **If significant adverse impacts were not predicted in Tier 3 because of loss, degradation, or fragmentation of habitat, but Tier 4b studies indicate such impacts have the potential to occur, can these impacts be mitigated?**

When Tier 4b studies indicate significant impacts may be occurring, the developer may need to conduct an assessment of these impacts and what opportunities exist for additional mitigation.

4. **If significant adverse impacts were predicted for species of concern, and the project was altered to mitigate for adverse impacts, were those efforts successful?**

When Tier 4b studies indicate significant impacts may be occurring, the developer may need to conduct an assessment of these impacts and what opportunities exist for additional mitigation. Evaluation of the effectiveness of mitigation is a Tier 4 study and should follow design considerations discussed in Tier 5 and from guidance in the scientific literature (e.g. Strickland et al. 2011).

When Tier 3 studies identified potential moderate or high risks to species of concern that caused a developer to incorporate mitigation measures into the project, Tier 4b studies should evaluate the effectiveness of those mitigation measures. Determining such effectiveness is important for the project being evaluated to ascertain whether additional mitigation measures are appropriate as well as informing future decisions about how to improve mitigation at wind

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energy facilities being developed.

Tier 4b Protocol Design Considerations

Impacts to a species of concern resulting from the direct and indirect loss of habitat are important and must be considered when a wind project is being considered for development. Some species of concern are likely to occur at every proposed wind energy facility. This occurrence may range from a breeding population, to seasonal occupancy, such as a brief occurrence while migrating through the area. Consequently the level of concern regarding impacts due to direct and indirect loss of habitat will vary depending on the species and the impacts that occur.

If a breeding population of a species of habitat fragmentation concern occurs in the project area and Tier 3 studies indicate that fragmentation of their habitat is possible, these predictions should be evaluated following the guidance indicated in Table 3 using the protocols described in Tier 3. If the analysis of post-construction GIS data on direct and indirect habitat loss suggests that fragmentation is likely, then additional displacement studies and mitigation may be necessary. These studies would typically begin immediately and would be considered Tier 5 studies using design considerations illustrated by examples in Tier 5 below and from guidance in the scientific literature (e.g. Strickland et al. 2011).

Significant direct or indirect loss of habitat for a species of concern may occur without habitat fragmentation if project impacts result in the reduction of a habitat resource that potentially is limiting to the affected population. Impacts of this type include loss of use of breeding habitat or loss of a significant portion of the habitat of a federally or state protected species. This would be evaluated by determining the amount of the resource that is lost and determining if this loss would potentially result in significant impacts to the affected population. Evaluation of potential significant

Black-capped Vireo. Credit: Greg W. Lasley

impacts would occur in Tier 5 studies that measure the demographic response of the affected population.

The intention of the Guidelines is to focus industry and agency resources on the direct and indirect loss of habitat and limiting resources that potentially reduce the viability of a species of concern. Not all direct and indirect loss of a species' habitat will affect limiting resources for that species, and when habitat losses are minor or non-existent no further study is necessary.

Tier 4b Decision Points

The developer should use the results of the Tier 4b studies to evaluate whether further studies and/or mitigation are needed. The developer should communicate the results of these studies, and decisions about further studies and mitigation, with the Service. Table 3 provides a framework for evaluating the need for further studies and mitigation. Level of effort for studies should be sufficient to answer all questions of interest. Refer to the relevant methods sections for Tier 2 Question 5 and Tier 3 Question 2 in the text for specific guidance on study protocols.

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Table 3. Decision Framework to Guide Studies for Minimizing Impacts to Habitat and Species of Habitat Fragmentation (HF) Concern.

Outcomes of Tier 2	*Outcomes of Tier 3*	*Outcomes of Tier 4b*	*Suggested Study/Mitigation*
• No species of HF concern potentially present	• No further studies needed	• n/a	• n/a
• Species of HF concern potentially present	• No species of HF concern confirmed to be present	• No further studies needed	• n/a
	• Species of HF concern demonstrated to be present, but no significant adverse impacts predicted	• Tier 4b studies confirm Tier 3 predictions	• No further studies or mitigation needed
		• Tier 4b studies indicate potentially significant adverse impacts	• Tier 5 studies and mitigation may be needed
• Species of HF concern potentially present	• Species of HF concern demonstrated to be present; significant adverse impacts predicted	• Tier 4b studies determine mitigation plan is effective; no significant adverse impacts demonstrated	• No further studies or mitigation needed
	• Mitigation plan developed and implemented	• Tier 4b studies determine mitigation plan is NOT effective; potentially significant adverse impacts	• Further mitigation and, where appropriate, Tier 5 studies

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Chapter 6: Tier 5 – Other Post-construction Studies

Tier 5 studies will not be necessary for most wind energy projects. Tier 5 studies can be complex and time consuming. The Service anticipates that the tiered approach will steer projects away from sites where Tier 5 studies would be necessary.

When Tier 5 studies are conducted, they should be site-specific and intended to: 1) analyze factors associated with impacts in those cases in which Tier 4 analyses indicate they are potentially significant; 2) identify why mitigation measures implemented for a project were not adequate; and 3) assess demographic effects on local populations of species of concern when demographic information is important, including species of habitat fragmentation concern.

Tier 5 Questions

Tier 5 studies are intended to answer questions that fall in three major categories; answering yes to any of these questions might indicate a Tier 5 study is needed:

1. **To the extent that the observed fatalities exceed anticipated fatalities, are those fatalities potentially having a significant adverse impact on local populations? Are observed direct and indirect impacts to habitat having a significant adverse impact on local populations?**

For example, in the Tier 3 risk assessment, predictions of collision fatalities and habitat impacts (direct and indirect) are developed. Post-construction studies in Tier 4 evaluate the accuracy of those predictions by estimating impacts. If post-construction studies demonstrate potentially significant adverse impacts, Tier 5 studies may also be warranted and should be designed to understand observed versus predicted impacts.

2. **Were mitigation measures implemented (other than fee in lieu) not effective? This includes habitat mitigation measures as well as measures undertaken to reduce collision fatalities.**

Tier 4a and b studies can assess the effectiveness of measures taken to reduce direct and indirect impacts as part of the project and to identify such alternative or additional measures as are necessary. If alternative or additional measures were unsuccessful, the reasons why would be evaluated using Tier 5 studies.

3. **Are the estimated impacts of the proposed project likely to lead to population declines in the species of concern (other than federally-listed species)?**

Impacts of a project will have population level effects if the project causes a population decline in the species of concern. For non-listed species, this assessment will apply only to the local population.

Wind turbines and habitat. Credit: NREL

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Tier 5 studies may need to be conducted when:

- Realized fatality levels for individual species of concern reach a level at which they are considered significant adverse impacts by the relevant agencies.

  For example, if Tier 4a fatality studies document that a particular turbine or set of turbines exhibits bird or bat collision fatality higher than predicted, Tier 5 studies may be useful in evaluating alternative mitigation measures at that turbine/turbine string.

- There is the potential for significant fatality impacts or significant adverse impacts to habitat for species of concern, there is a need to assess the impacts more closely, and there is uncertainty over how these impacts will be mitigated.

- Fatality and/or significant adverse habitat impacts suggest the potential for a reduction in the viability of an affected population, in which case studies on the potential for population impacts may be warranted.

- A developer evaluates the effectiveness of a risk reduction measure before deciding to continue the measure permanently or whether to use the measure when implementing future phases of a project.

  In the event additional turbines are proposed as an expansion of an existing project, results from Tier 4 and Tier 5 studies and the decision-making framework contained in the tiered approach can be used to determine whether the project should be expanded and whether additional information should be collected. It may also be necessary to evaluate whether additional measures are warranted to reduce significant adverse impacts to species.

Tier 5 Study Design Considerations

As discussed in Chapter 4 Tier 3, Tier 5 studies will be highly variable and unique to the circumstances of the individual project, and therefore these Guidelines do not provide specific guidance on all potential approaches, but make some general statements about study design. Specific Tier 5 study designs will depend on the types of questions, the specific project, and practical considerations. The most common practical considerations include the area being studied, the time period of interest, the species of concern, potentially confounding variables, time available to conduct studies, project budget, and the magnitude of the anticipated impacts. When possible it is usually desirable to collect data before construction to address Tier 5 questions. Design considerations for these studies are including in Tier 3.

One study design is based on an experimental approach to evaluating mitigation measures, where the project proponent will generally select several alternative management approaches to design, implement, and test. The alternatives are generally incorporated into sound experimental designs. Monitoring and evaluation of each alternative helps the developer to decide which alternative is more effective in meeting objectives, and informs adjustments to the next round of management decisions. The need for this type of study design can be best determined by communication between the project operator, the Service field office, and the state wildlife agency, on a project-by-project basis. This study design requires developers and operators to identify strategies to adjust management and/or mitigation measures if monitoring indicates that anticipated impacts are being exceeded. Such strategies should include a timeline for periodic reviews and adjustments as well as a mechanism to consider and implement additional mitigation measures as necessary after the project is developed.

When pre-construction data are unavailable and/or a suitable reference area is lacking, the reference Control Impact Design (Morrison et al. 2008) is the recommended design. The lack of a suitable reference area also can be addressed using the Impact Gradient Design, when habitat and species use are homogenous in the assessment area prior to development. When applied both pre- and post-construction, the Impact Gradient Design is a suitable replacement for the classic BACI (Morrison et al. 2008).

In the study of habitat impacts, the resource selection function (RSF) study design (see Anderson et al 1999; Morrison et al. 2008; Manly et al. 2002) is a statistically robust design, either with or without pre-construction and reference data. Habitat selection is modeled as a function of characteristics measured on resource units and the use of those units by the animals of interest. The RSF allows the estimation of the probability of use as a function of the distance to various environmental features, including wind energy facilities, and thus provides a direct quantification of the magnitude of the displacement effect. RSF could be improved with pre-construction and reference area data. Nevertheless, it is a relatively powerful approach to documenting displacement or the effect of mitigation measures designed to reduce displacement even without those additional data.

Tier 5 Examples

As described earlier, Tier 5 studies will not be conducted at most projects, and the specific Tier 5 questions and methods for addressing these questions will depend on the individual project and the concerns raised during pre-construction studies and during operational phases. Rather than provide specific guidance on all potential approaches, these Guidelines offer the following case studies as examples of studies that have attempted to answer Tier 5 questions.

<u>Habitat impacts - displacement and demographic impact studies</u>

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Rows of wind turbines. Credit: Joshua Winchell, USFWS

Studies to assess impacts may include quantifying species' habitat loss (e.g., acres of lost grassland habitat for grassland songbirds) and habitat modification. For example, an increase in edge may result in greater nest parasitism and nest predation. Assessing indirect impacts may include two important components: 1) indirect effects on wildlife resulting from displacement, due to disturbance, habitat fragmentation, loss, and alteration; and 2) demographic effects that may occur at the local, regional or population-wide levels due to reduced nesting and breeding densities, increased isolation between habitat patches, and effects on behavior (e.g., stress, interruption, and modification). These factors can individually or cumulatively affect wildlife, although some species may be able to habituate to some or perhaps all habitat changes. Indirect impacts may be difficult to quantify but their effects may be significant (e.g., Stewart et al. 2007, Pearce-Higgins et al. 2008, Bright et al. 2008, Drewitt and Langston 2006, Robel et al. 2004, Pruett et al. 2009).

Example: in southwestern Pennsylvania, development of a project is proceeding at a site located within the range of a state-listed terrestrial species. Surveys were performed at habitat locations appropriate for use by the animal, including at control sites. Post-construction studies are planned at all locations to demonstrate any displacement effects resulting from the construction and operation of the project.

The Service recognizes that indirect impact studies may not be appropriate for most individual projects. Consideration should be given to developing collaborative research efforts with industry, government agencies, and NGOs to conduct studies to address indirect impacts.

Indirect impacts are considered potentially significant adverse threats to species such as prairie grouse (prairie chickens, sharp-tailed grouse), and sage grouse, and demographic studies may be necessary to determine the extent of these impacts and the need for mitigation.

Displacement studies may use any of the study designs describe earlier. The most scientifically robust study designs to estimate displacement effects are BACI, RSF, and impact gradient. RSF and impact gradient designs may not require specialized data gathering during Tier 3.

Telemetry studies that measure impacts of the project development on displacement, nesting, nest success, and survival of prairie grouse and sage grouse in different environments (e.g., tall grass, mixed grass, sandsage, sagebrush) will require spatial and temporal replication, undisturbed reference sites, and large sample sizes covering large areas. Examples of study designs and analyses used in the studies of other forms of energy development are presented in Holloran et al. (2005), Pitman et al. (2005), Robel et al. (2004), and Hagen et al. (2011). Anderson et al. (1999) provides a thorough discussion of the design, implementation, and analysis of these kinds of field studies and should be consulted when designing the BACI study. P21-36 cont.

Studies are being initiated to evaluate effects of wind energy development on greater sage grouse in Wyoming. In addition to measuring demographic patterns, these studies will use the RSF study design (see Sawyer et al. 2006) to estimate the probability of sage grouse use as a function of the distance to environmental features, including an existing and a proposed project.

In certain situations, such as for a proposed project site that is relatively small and in a more or less homogeneous landscape, an impact gradient design may be an appropriate means to assess avoidance of the wind energy facility by resident populations (Strickland et al., 2002). For example, Leddy et al. 1999 used the impact gradient design to evaluate grassland bird density as a function of the distance from wind turbines. Data were collected at various distances from turbines along transects.

This approach provides information on whether there is an effect, and may allow quantification of the gradient of the effect and the distance at which the displacement effect no longer exists – the assumption being that the data collected at distances beyond the influence of turbines are the reference data (Erickson et al., 2007). An impact gradient analysis could also involve measuring the number of breeding grassland birds counted at point count plots as a function of distance from the wind turbines (Johnson et al. 2000).

Sound and Wildlife

Turbine blades at normal operating speeds can generate levels of sound beyond ambient background levels. Construction and maintenance activities can also contribute to sound levels by affecting communication distance, an animal's ability to detect calls or danger, or to forage. Sound associated with developments can also cause behavioral and/or physiological effects, damage to hearing from acoustic over-exposure, and masking of communication signals and other biologically relevant sounds (Dooling and Popper 2007). Some birds are able to shift their vocalizations to reduce the masking effects of noise. However, when shifts don't occur or are insignificant, masking may prove detrimental to the health and survival of wildlife (Barber et al. 2010). Data suggest noise increases of 3 dB to 10 dB correspond to 30 percent to 90 percent reductions in alerting distances for wildlife, respectively (Barber et al. 2010).

The National Park Service has been investigating potential impacts to wildlife due to alterations in sound level and type. However, further research is needed to better understand this potential impact. Research may include: how wind facilities affect background sound levels; whether masking, disturbance, and acoustical fragmentation occur; and how turbine, construction, and maintenance sound levels can vary by topographic area.

Levels of fatality beyond those predicted

More intensive post-construction fatality studies may be used to determine relationships between fatalities and weather, wind speed or other covariates, which usually require daily carcass searches. Fatalities determined to have occurred the previous night can be correlated with that night's weather or turbine characteristics to establish important relationships that can then be used to evaluate the most effective times and conditions to implement measures to reduce collision fatality at the project.

Measures to address fatalities

The efficacy of operational changes (e.g. changing turbine cut-in speed) of a project to reduce collision fatalities has only recently been evaluated (Arnett et al. 2009, Baerwald et al 2009). Operational changes to address fatalities should be applied only at sites where collision fatalities are predicted or demonstrated to have significant adverse impacts.

Tier 5 Studies and Research

The Service makes a distinction between Tier 5 studies focused on project-specific impacts and research (which is discussed earlier in the Guidelines). For example, developers may be encouraged to participate in collaborative studies (see earlier discussion of Research) or asked to conduct a study on an experimental mitigation technique, such as differences in turbine cut-in speed to reduce bat fatalities. Such techniques may show promise in mitigating the impacts of wind energy development to wildlife, but their broad applicability for mitigation purposes has not been demonstrated. Such techniques should not be routinely applied to projects, but application at appropriate sites will contribute to the breadth of knowledge regarding the efficacy of such measures in addressing collision fatalities. In addition, studies involving multiple sites and academic researchers can provide more robust research results, and such studies take more time and resources than are appropriately carried out by one developer at a single site. Examples below demonstrate collaborative research efforts to address displacement, operational changes, and population level impacts.

Studies of Indirect Effects

The Service provides two examples below of ongoing studies to assess the effects of indirect impacts related to wind energy facilities.

Kansas State University, as part of the NWCC Grassland Shrub-steppe Species Collaborative, is undertaking a multi-year research project to assess the effects of wind energy facilities on populations of greater prairie-chickens (GPCH) in Kansas. Initially the research was based on a Before/After Control/Impact (BACI) experimental design involving three replicated study sites in the Flint Hills and Smoky Hills of eastern Kansas. Each study site consisted of an impact area where a wind energy facility was proposed to be developed and a nearby reference area with similar rangeland characteristics where no development was planned. The research project is a coordinated field/laboratory effort, i.e., collecting telemetry and observational data from adult and juvenile GPCH in the field, and determining population genetic attributes of GPCH in the laboratory from blood samples of birds and the impact and reference areas. Detailed data on GPCH movements, demography, and population genetics were gathered from all three sites from 2007 to 2010. By late 2008, only one of the proposed wind energy facilities was developed (the Meridian Way Wind Farm in the Smoky Hills of Cloud County), and on-going research efforts are focused on that site. The revised BACI study design now will produce two years of pre-construction data (2007 and 2008), and three years of post-construction data (2009, 2010, and 2011) from a single wind energy facility site (impact area) and its reference area. Several hypotheses were formulated for testing to determine if wind energy facilities impacted GPCH populations, including but not limited to addressing issues relating to: lek attendance, avoidance of turbines and associated features,

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nest success and chick survival, habitat usage, adult mortality and survival, breeding behavior, and natal dispersal. A myriad of additional significant avenues are being pursued as a result of the rich database that has been developed for the GPCH during this research effort. GPCH reproductive data will be collected through the summer of 2011 whereas collection of data from transmitter-equipped GPCH will extend through the lekking season of 2012 to allow estimates of survival of GPCH over the 2011-2012 winter. At the conclusion of the study, the two years of pre-construction data and three years of post-construction data will be analyzed and submitted to peer-reviewed journals for publication.

Erickson et al. (2004) evaluated the displacement effect of a large wind energy facility in the Pacific Northwest. The study was conducted in a relatively homogeneous grassland landscape. Erickson et al. (2004) conducted surveys of breeding grassland birds along 300 meter transects perpendicular to strings of wind turbines. Surveys were conducted prior to construction and after commercial operation. The basic study design follows the Impact Gradient Design (Morrison et al. 2008) and in this application, conformed to a special case of BACI where areas at the distal end of each transect were considered controls (i.e., beyond the influence of the turbines). In this study, there is no attempt to census birds in the area, and observations per survey are used as an index of abundance. Additionally, the impact-gradient study design resulted in less effort than a BACI design with offsite control areas. Erickson et al. (2004) found that grassland passerines as a group, as well as grasshopper sparrows and western meadowlarks, showed reduced use in the first 50 meter segment nearest the turbine string. About half of the area within that segment, however, had disturbed vegetation and separation of behavior avoidance from physical loss of habitat in this portion of the area was impossible. Horned larks and savannah sparrows appeared unaffected. The impact gradient design is best used when the study area is relatively small and homogeneous.

Operational Changes to Reduce Collision Fatality

Arnett et al. (2009) conducted studies on the effectiveness of changing turbine cut-in speed on reducing bat fatality at wind turbines at the Casselman Wind Project in Somerset County, Pennsylvania. Their objectives were to: 1) determine the difference in bat fatalities at turbines with different cut-in-speeds relative to fully operational turbines; and 2) determine the economic costs of the experiment and estimated costs for the entire area of interest under different curtailment prescriptions and timeframes. Arnett et al. (2009) reported substantial reductions in bat fatalities with relatively modest power losses.

In Kenedy County, Texas, investigators are refining and testing a real-time curtailment protocol. The projects use an avian profiling radar system to detect approaching "flying vertebrates" (birds and bats), primarily during spring and fall bird and bat migrations. The blades automatically idle when risk reaches a certain level and weather conditions are particularly risky. Based on estimates of the number and timing of migrating raptors, feathering (real-time curtailment) experiments are underway in Tehuantepec, Mexico, where raptor migration through a mountain pass is extensive.

Other tools, such as thermal imaging (Horn et al. 2008) or acoustic detectors (Kunz et al. 2007), have been used to quantify post-construction bat activity in relation to weather and turbine characteristics for improving operational change efforts. For example, at the Mountaineer project in 2003, Tier 4 studies (weekly searches at every turbine) demonstrated unanticipated and high levels of bat fatalities (Kerns and Kerlinger 2004). Daily searches were instituted in 2004 and revealed that fatalities were strongly associated with low-average-wind-speed nights, thus providing a basis for testing operational changes (Arnett 2005, Arnett et al. 2008). The program also included behavioral observations using thermal imaging that demonstrated higher bat activity at lower wind speeds (Horn et al. 2008).

Studies are currently underway to design and test the efficacy of an acoustic deterrent device to reduce bat fatalities at wind facilities (E.B. Arnett, Bat Conservation International, under the auspices of BWEC). Prototypes of the device have been tested in the laboratory and in the field with some success. Spanjer (2006) tested the response of big brown bats to a prototype eight speaker deterrent emitting broadband white noise at frequencies from 12.5–112.5 kHz and found that during non-feeding trials, bats landed in the quadrant containing the device significantly less when it was broadcasting broadband noise. Spanjer (2006) also reported that during feeding trials, bats never successfully took a tethered mealworm when the device broadcast sound, but captured mealworms near the device in about 1/3 of trials when it was silent. Szewczak and Arnett (2006, 2007) tested the same acoustic deterrent in the field and found that when placed by the edge of a small pond where nightly bat activity was consistent, activity dropped significantly on nights when the deterrent was activated. Horn et al. (2007) tested the effectiveness of a larger, more powerful version of this deterrent device on reducing nightly bat activity and found mixed results. In 2009, a new prototype device was developed and tested at a project in Pennsylvania. Ten turbines were fitted with deterrent devices, daily fatality searches were conducted, and fatality estimates were compared with those from 15 turbines without deterrents (i.e., controls) to determine if bat fatalities were reduced. This experiment found that estimated bat fatalities per turbine were 20 to 53 percent lower at treatment turbines compared to controls.

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More experimentation is required. At the present time, there is not an operational deterrent available that has demonstrated effective reductions in bat kills (E. B. Arnett, Bat Conservation International, unpublished data).

Assessment of Population-level Impacts

The Altamont Pass Wind Resource Area (APWRA) has been the subject of intensive scrutiny because of avian fatalities, especially for raptors, in an area encompassing more than 5,000 wind turbines (e.g., Orloff and Flannery 1992; Smallwood and Thelander 2004, 2005). Field studies on golden eagles, a long-lived raptor species, have been completed using radio telemetry at APWRA to understand population demographics, assess impacts from wind turbines, and explore measures to effectively reduce the incidence of golden eagle mortality for this area. (Hunt et al. 1999, and Hunt 2002). Results from nesting surveys (Hunt 2002) indicated that there was no decline in eagle territory occupancy. However Hunt (2002) also found that subadult and floater components of golden eagle populations at APWRA are highly vulnerable to wind turbine mortality and results from this study indicate that turbine mortality prevented the maintenance of substantial reserves of nonbreeding adults characteristic of healthy populations elsewhere, suggesting the possibility of an eventual decline in the breeding population (Hunt and Hunt 2006). Hunt conducted follow-up surveys in 2005 (Hunt and Hunt 2006) and determined that all 58 territories occupied by eagle pairs in 2000 were occupied in 2005. It should be noted however that golden eagle studies at APWRA (Hunt et al. 1999, Hunt 2002, and Hunt and Hunt 2006) were all conducted after the APWRA was constructed and the species does not nest within the footprint of the APWRA itself (Figure 4; Hunt and Hunt 2006). The APWRA is an area of about 160 sq. km (Hunt 2002) and presumably golden eagles formerly nested within this area. The loss of breeding eagle pairs from the APWRA suggests these birds have all been displaced by the project, or lost due to various types of mortality including collisions with turbine blades.

Golden eagle. Credit: George Gentry, USFWS

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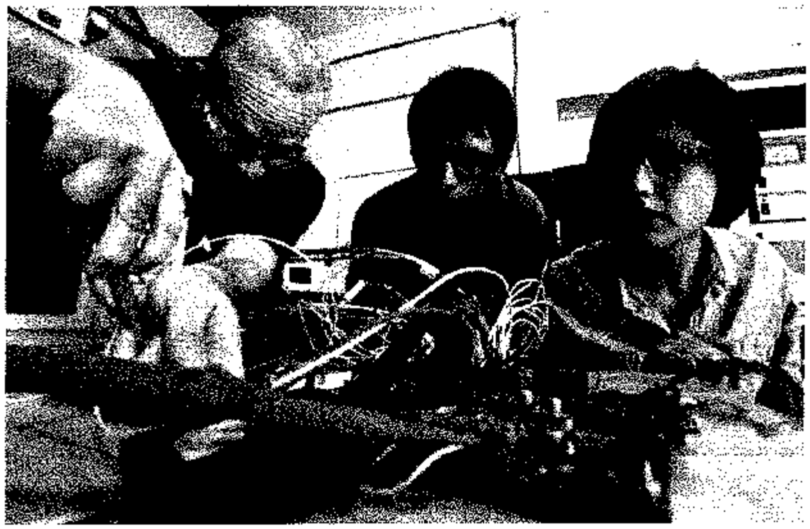
Chapter 7: Best Management Practices

Site Construction and Operation

During site planning and development, careful attention to reducing risk of adverse impacts to species of concern from wind energy projects, through careful site selection and facility design, is recommended. The following BMPs can assist a developer in the planning process to reduce potential impacts to species of concern. Use of these BMPs should ensure that the potentially adverse impacts to most species of concern and their habitats present at many project sites would be reduced, although compensatory mitigation may be appropriate at a project level to address significant site-specific concerns and pre-construction study results.



Wind electronic developers. Credit: NREL

These BMPs will evolve over time as additional experience, learning, monitoring and research becomes available on how to best minimize wildlife and habitat impacts from wind energy projects. Service should work with the industry, stakeholders and states to evaluate, revise and update these BMPs on a periodic basis, and the Service should maintain a readily available publication of recommended, generally accepted best practices.

1. Minimize, to the extent practicable, the area disturbed by pre-construction site monitoring and testing activities and installations.

2. Avoid locating wind energy facilities in areas identified as having a demonstrated and unmitigatable high risk to birds and bats.

3. Use available data from state and federal agencies, and other sources (which could include maps or databases), that show the location of sensitive resources and the results of Tier 2 and/or 3 studies to establish the layout of roads, power lines, fences, and other infrastructure.

4. Minimize, to the maximum extent practicable, roads, power lines, fences, and other infrastructure associated with a wind development project. When fencing is necessary, construction should use wildlife compatible design standards.

5. Use native species when seeding or planting during restoration. Consult with appropriate state and federal agencies regarding native species to use for restoration.

6. To reduce avian collisions, place low and medium voltage connecting power lines associated with the wind energy development underground to the extent possible, unless burial of the lines is prohibitively expensive (e.g., where shallow bedrock exists) or where greater adverse impacts to biological resources would result:

   a. Overhead lines may be acceptable if sited away from high bird crossing locations, to the extent practicable, such as between roosting and feeding areas or between lakes, rivers, prairie grouse and sage grouse leks, and nesting habitats. To the extent practicable, the lines should be marked in accordance with Avian Power Line Interaction Committee (APLIC) collision guidelines.

   b. Overhead lines may be used when the lines parallel tree lines, employ bird flight diverters, or are otherwise screened so that collision risk is reduced.

   c. Above-ground low and medium voltage lines, transformers and conductors should follow the 2006 or most recent APLIC "Suggested Practices for Avian Protection on Power Lines."

7. Avoid guyed communication towers and permanent met towers at wind energy project sites. If guy wires are necessary,

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bird flight diverters or high visibility marking devices should be used.

8. Where permanent meteorological towers must be maintained on a project site, use the minimum number necessary.

9. Use construction and management practices to minimize activities that may attract prey and predators to the wind energy facility.

10. Employ only red, or dual red and white strobe, strobe-like, or flashing lights, not steady burning lights, to meet Federal Aviation Administration (FAA) requirements for visibility lighting of wind turbines, permanent met towers, and communication towers. Only a portion of the turbines within the wind project should be lighted, and all pilot warning lights should fire synchronously.

11. Keep lighting at both operation and maintenance facilities and substations located within half a mile of the turbines to the minimum required:

    a. Use lights with motion or heat sensors and switches to keep lights off when not required.

    b. Lights should be hooded downward and directed to minimize horizontal and skyward illumination.

    c. Minimize use of high-intensity lighting, steady-burning, or bright lights such as sodium vapor, quartz, halogen, or other bright spotlights.

    d. All internal turbine nacelle and tower lighting should be extinguished when unoccupied.

12. Establish non-disturbance buffer zones to protect sensitive habitats or areas of high risk for species of concern identified in pre-construction studies. Determine the extent of the buffer zone in consultation with the Service and state, local and tribal wildlife biologists, and land management agencies (e.g., U.S. Bureau of Land Management (BLM) and U.S. Forest Service (USFS)), or other credible experts as appropriate.

13. Locate turbines to avoid separating bird and bat species of concern from their daily roosting, feeding, or nesting sites if documented that the turbines' presence poses a risk to species.

14. Avoid impacts to hydrology and stream morphology, especially where federal or state-listed aquatic or riparian species may be involved. Use appropriate erosion control measures in construction and operation to eliminate or minimize runoff into water bodies.

15. When practical use tubular towers or best available technology to reduce ability of birds to perch and to reduce risk of collision.

16. After project construction, close roads not needed for site operations and restore these roadbeds to native vegetation, consistent with landowner agreements.

17. Minimize the number and length of access roads; use existing roads when feasible.

18. Minimize impacts to wetlands and water resources by following all applicable provisions of the Clean Water Act (33 USC 1251-1387) and the Rivers and Harbors Act (33 USC 301 et seq.); for instance, by developing and implementing a storm water management plan and taking measures to reduce erosion and avoid delivery of road-generated sediment into streams and waters.

19. Reduce vehicle collision risk to wildlife by instructing project personnel to drive at appropriate speeds, be alert for wildlife, and use additional caution in low visibility conditions.

20. Instruct employees, contractors, and site visitors to avoid harassing or disturbing wildlife, particularly during reproductive seasons.

21. Reduce fire hazard from vehicles and human activities (instruct employees to use spark arrestors on power equipment, ensure that no metal parts are dragging from vehicles, use caution with open flame, cigarettes, etc.). Site development and operation plans should specifically address the risk of wildfire and provide appropriate cautions and measures to be taken in the event of a wildfire.

22. Follow federal and state measures for handling toxic substances to minimize danger to water and wildlife resources from spills. Facility operators should maintain Hazardous Materials Spill Kits on site and train personnel in the use of these.

23. Reduce the introduction and spread of invasive species by following applicable local policies for invasive species prevention, containment, and control, such as cleaning vehicles and equipment arriving from areas with known invasive species issues, using locally sourced topsoil, and monitoring for and rapidly removing invasive species at least annually.

24. Use invasive species prevention and control measures as specified by county or state requirements, or by applicable federal agency requirements (such as Integrated Pest Management) when federal policies apply.

25. Properly manage garbage and waste disposal on project sites to avoid creating attractive nuisances for wildlife by providing them with supplemental food.

26. Promptly remove large animal carcasses (e.g., big game,

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domestic livestock, or feral animal).

27. Wildlife habitat enhancements or improvements such as ponds, guzzlers, rock or brush piles for small mammals, bird nest boxes, nesting platforms, wildlife food plots, etc. should not be created or added to wind energy facilities. These wildlife habitat enhancements are often desirable but when added to a wind energy facility result in increased wildlife use of the facility which may result in increased levels of injury or mortality to them.

Retrofitting, Repowering, and Decommissioning

As with project construction, these Guidelines offer BMPs for the retrofitting, repowering, and decommissioning phases of wind energy projects.

Retrofitting

Retrofitting is defined as replacing portions of existing wind turbines or project facilities so that at least part of the original turbine, tower, electrical infrastructure or foundation is being utilized. Retrofitting BMPs include:

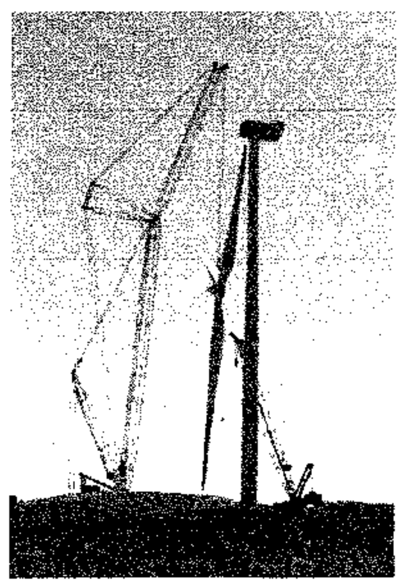
1. Retrofitting of turbines should use installation techniques that minimize new site disturbance, soil erosion, and removal of vegetation of habitat value.
2. Retrofits should employ shielded, separated or insulated electrical conductors that minimize electrocution risk to avian wildlife per APLIC (2006).
3. Retrofit designs should prevent nests or bird perches from being established in or on the wind turbine or tower.
4. FAA visibility lighting of wind turbines should employ only red, or dual red and white strobe, strobe-like, or flashing lights, not steady burning lights.
5. Lighting at both operation and maintenance facilities and substations located within half a mile of the turbines should be kept to the minimum required:
   a. Use lights with motion or heat sensors and switches to keep lights off when not required.
   b. Lights should be hooded downward and directed to minimize horizontal and skyward illumination.
   c. Minimize use of high intensity lighting, steady-burning, or bright lights such as sodium vapor, quartz, halogen, or other bright spotlights.
6. Remove wind turbines when they are no longer cost effective to retrofit.

Repowering

Repowering may include removal and replacement of turbines and associated infrastructure. BMPs include:

1. To the greatest extent practicable, existing roads, disturbed areas and turbine strings should be re-used in repower layouts.
2. Roads and facilities that are no longer needed should be demolished, removed, and their footprint stabilized and re-seeded with native plants appropriate for the soil conditions and adjacent habitat and of local seed sources where feasible, per landowner requirements and commitments.
3. Existing substations and ancillary facilities should be re-used in repowering projects to the extent practicable.
4. Existing overhead lines may be acceptable if located away from high bird crossing locations, such as between roosting and feeding areas, or between lakes, rivers and nesting areas. Overhead lines may be used when they parallel tree lines, employ bird flight diverters, or are otherwise screened so that collision risk is reduced.
5. Above-ground low and medium voltage lines, transformers and conductors should follow the 2006 or most recent APLIC "Suggested Practices for Avian Protection on Power Lines."
6. Guyed structures should be avoided. If use of guy wires is absolutely necessary, they should be treated with bird flight diverters or high visibility marking devices, or are located where known low bird use will occur.
7. FAA visibility lighting of wind turbines should employ only red, or dual red and white strobe, strobe-like, or flashing lights, not steady burning lights.
8. Lighting at both operation and maintenance facilities and substations located within ½ mile of the turbines should be kept to the minimum required.
   a. Use lights with motion or heat sensors and switches to keep lights off when not required.
   b. Lights should be hooded downward and directed to minimize horizontal and skyward illumination.

P21-36 cont.



Towers are being lifted as work continues on the 2 MW Gamesa wind turbine that is being installed at the NWTC. Credit: NREL

c. Minimize use of high intensity lighting, steady-burning, or bright lights such as sodium vapor, quartz, halogen, or other bright spotlights.

Decommissioning

Decommissioning is the cessation of wind energy operations and removal of all associated equipment, roads, and other infrastructure. The land is then used for another activity. During decommissioning, contractors and facility operators should apply BMPs for road grading and native plant re-establishment to ensure that erosion and overland flows are managed to restore pre-construction landscape conditions. The facility operator, in conjunction with the landowner and state and federal wildlife agencies, should restore the natural hydrology and plant community to the greatest extent practical.

1. Decommissioning methods should minimize new site disturbance and removal of native vegetation, to the greatest extent practicable.

2. Foundations should be removed to a minimum of three feet below surrounding grade, and covered with soil to allow adequate root penetration for native plants, and so that subsurface structures do not substantially disrupt ground water movements. Three feet is typically adequate for agricultural lands.

3. If topsoils are removed during decommissioning, they should be stockpiled and used as topsoil when restoring plant communities. Once decommissioning activity is complete, topsoils should be restored to assist in establishing and maintaining pre-construction native plant communities to the extent possible, consistent with landowner objectives.

4. Soil should be stabilized and re-vegetated with native plants appropriate for the soil conditions and adjacent habitat, and of local seed sources where feasible, consistent with landowner objectives.

5. Surface water flows should be restored to pre-disturbance conditions, including removal of stream crossings, roads, and pads, consistent with storm water management objectives and requirements.

6. Surveys should be conducted by qualified experts to detect populations of invasive species, and comprehensive approaches to preventing and controlling invasive species should be implemented and maintained as long as necessary.

7. Overhead pole lines that are no longer needed should be removed.

8. After decommissioning, erosion control measures should be installed in all disturbance areas where potential for erosion exists, consistent with storm water management objectives and requirements.

9. Fencing should be removed unless the landowner will be utilizing the fence.

10. Petroleum product leaks and chemical releases should be remediated prior to completion of decommissioning.

P21-36 cont.

Chapter 8: Mitigation

Mitigation is defined in this document as avoiding or minimizing significant adverse impacts, and when appropriate, compensating for unavoidable significant adverse impacts, as determined through the tiered approach described in the recommended Guidelines. The Service places emphasis in project planning on first avoiding, then minimizing, potential adverse impacts to wildlife and their habitats. Several tools are available to determine appropriate mitigation, including the Service Mitigation Policy (USFWS Mitigation Policy, 46 FR 7656 (1981)). The Service policy provides a common basis for determining how and when to use different mitigation strategies, and facilitates earlier consideration of wildlife values in wind energy project planning.

Under the Service Mitigation Policy, the highest priority is for mitigation to occur on-site within the project planning area. The secondary priority is for the mitigation to occur off-site. Off-site mitigation should first occur in proximity to the planning area within the same ecological region and secondarily elsewhere within the same ecological region. Generally, the Service prefers on-site mitigation over off-site mitigation because this approach most directly addresses project impacts at the location where they actually occur. However, there may be individual cases where off-site mitigation could result in greater net benefits to affected species and habitats. Developers should work with the Service in comparing benefits among multiple alternatives.

In some cases, a project's effects cannot be forecast with precision. The developer and the agencies may be unable to make some mitigation decisions until post-construction data have been collected. If significant adverse effects have not been adequately addressed, additional mitigation for those adverse effects from operations may need to be implemented.

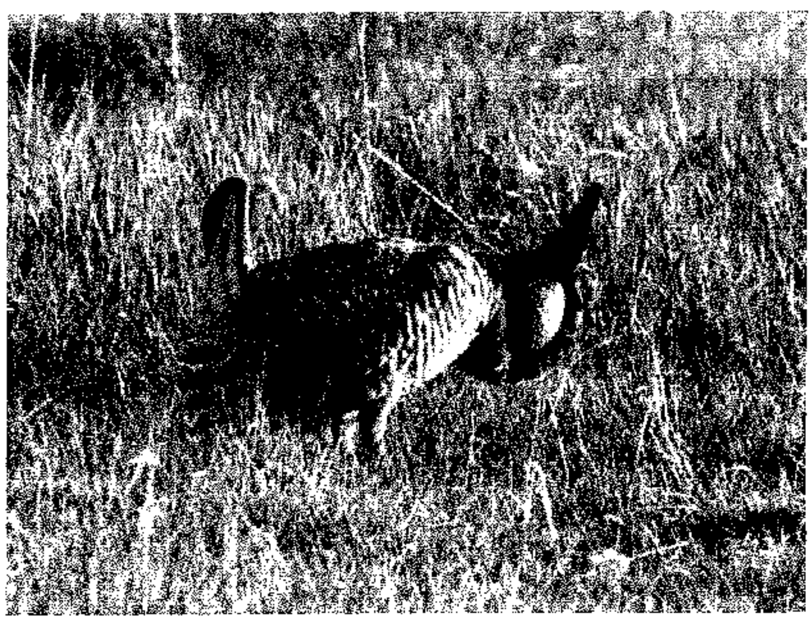
Mitigation measures implemented post-construction, whether in addition to those implemented pre-construction or whether they are new, are appropriate elements of the tiered approach. The general terms and funding commitments for future mitigation and the triggers or thresholds for implementing such compensation should be developed at the earliest possible stage in project development. Any mitigation implemented after a project is operational should be well defined, bounded, technically feasible, and commensurate with the project effects.

NEPA Guidance on Mitigation

CEQ issued guidance in February 2011 on compliance with the National Environmental Policy Act (NEPA) entitled, "Appropriate Use of Mitigation and Monitoring and Clarifying the Appropriate Use of Mitigated Findings of No Significant Impact." This new guidance clarifies that when agencies premise their Finding of No Significant Impact on a commitment to mitigate the environmental impacts of a proposed action, they should adhere to those commitments, publicly report on those efforts, monitor how they are implemented, and monitor the effectiveness of the mitigation.

To the extent that a federal nexus with a wind project exists, for example, developing a project on federal lands or obtaining a federal permit, the lead federal action agency should make its decision based in part on a developer's commitment to mitigate adverse environmental impacts. The federal action agency should ensure that the developer adheres to those commitments, monitors how they are implemented, and monitors the effectiveness of the mitigation. Additionally, the lead federal action agency should make information on mitigation monitoring available to the public through its web site;

P21-36 cont.



Greater prairie chicken. Credit: Amy Thornburg, USFWS and should ensure that mitigation successfully achieves its goals.

Compensatory Mitigation

Compensatory mitigation as defined in this document refers to replacement of project-induced losses to fish and wildlife resources. Substitution or offsetting of fish and wildlife resource losses with resources considered to be of equivalent biological value.

- **In-kind** – Providing or managing substitute resources to replace the value of the resources lost, where such substitute resources are physically and biologically the same or closely approximate to those lost.

- **Out-of-kind** – Providing or managing substitute resources to replace the value of the resources lost, where such substitute resources are physically or biologically different from those lost. This may include conservation or mitigation banking, research or other options.

The amount of compensation, if necessary, will depend on the effectiveness of any avoidance and minimization measures undertaken. If a proposed wind development is poorly sited with regard to wildlife effects, the most important mitigation opportunity is largely lost and the remaining options can be expensive, with substantially greater environmental effects.

Compensation is most often appropriate for habitat loss under limited circumstances or for direct take of wildlife (e.g., Habitat Conservation Plans). Compensatory mitigation may involve contributing to a fund to protect habitat or otherwise support efforts to reduce existing impacts to species affected by a wind project. Developers should communicate with the Service and state agency prior to initiating such an approach.

Ideally, project impact assessment is a cooperative effort involving the developer, the Service, tribes, local authorities, and state resource agencies. The Service does not expect developers to provide compensation for the same habitat loss more than once. But the Service, state resource agencies, tribes, local authorities, state and federal land management agencies may have different species or habitats of concern, according to their responsibilities and statutory authorities. Hence, one entity may seek mitigation for a different group of species or habitat than does another.

Migratory Birds and Eagles

Some industries, such as the electric utilities, have developed operational and deterrent measures that when properly used can avoid or minimize "take" of migratory birds. Many of these measures to avoid collision and electrocution have been scientifically tested with publication in peer-reviewed, scientific journals. The Service encourages the wind industry to use these measures in siting, placing, and operating all power lines, including their distribution and grid-connecting transmission lines.

E.O. 13186, which addresses responsibilities of federal agencies to protect migratory birds, includes a directive to federal agencies to restore and enhance the habitat of migratory birds as practicable. E.O. 13186 provides a basis and a rationale for compensating for the loss of migratory bird habitat that results from developing wind energy projects that have a federal nexus.

Regulations concerning eagle take permits in 50 CFR 22.26 and 50 CFR 22.27 may allow for compensation as part of permit issuance. Compensation may be a condition of permit issuance in cases of nest removal, disturbance or take resulting in mortality that will likely occur over several seasons, result in permanent abandonment of one or more breeding territories, have large scale impacts, occur at multiple locations, or otherwise contribute to cumulative negative effects. The draft ECP Guidance has additional information on the use of compensation for programmatic permits.

Endangered Species

The ESA has provisions that allow for compensation through the issuance of an Incidental Take Permit (ITP). Under the ESA, mitigation measures are determined on a case by case basis, and are based on the needs of the species and the types of effects anticipated. If a federal nexus exists, or if a developer chooses to seek an ITP under the ESA, then effects to listed species need to be evaluated through the Section 7 and/or Section 10 processes. If an ITP is requested, it and the associated HCP must provide for minimization and mitigation to the maximum extent practicable, in addition to meeting other necessary criteria for permit issuance. For further information about compensation under federal laws administered by the Service, see the Service's Habitat and Resource Conservation website http://www.fws.gov/habitatconservation.

P21-36 cont.

Bald eagle. Credit: USFWS

Chapter 9: Advancing Use, Cooperation and Effective Implementation

This chapter discusses a variety of policies and procedures that may affect the way wind project developers and the Service work with each other as well as with state and tribal governments and non-governmental organizations. The Service recommends that wind project developers work closely with field office staff for further elaboration of these policies and procedures.

Conflict Resolution

The Service and developers should attempt to resolve any issues arising from use of the Guidelines at the Field Office level. Deliberations should be in the context of the intent of the Guidelines and be based on the site-specific conditions and the best available data. However, if there is an issue that cannot be resolved within a timely manner at the field level, the developer and Service staff will coordinate to bring the matter up the chain of command in a stepwise manner.

Bird and Bat Conservation Strategies (BBCS)

The Service has recommended that developers prepare written records of their actions to avoid, minimize and compensate for potential adverse impacts. In the past, the Service has referred to these as Avian and Bat Protection Plans (ABPP). However, ABPPs have more recently been used for transmission projects and less for other types of development. For this reason the Service is introducing a distinct concept for wind energy projects and calling them Bird and Bat Conservation Strategies (BBCS).

Electricity towers and wind turbines. Credit: NREL

Typically, a project-specific BBCS will explain the analyses, studies, and reasoning that support progressing from one tier to the next in the tiered approach. A wind energy project-specific BBCS is an example of a document or compilation of documents that describes the steps a developer could or has taken to apply these Guidelines to mitigate for adverse impacts and address the post-construction monitoring efforts the developer intends to undertake. A developer may prepare a BBCS in stages, over time, as analysis and studies are undertaken for each tier. It will also address the post-construction monitoring efforts for mortality and habitat effects, and may use many of the components suggested in the Suggested Practices for Avian Protection on Power Lines (APLIC 2006). Any Service review of, or discussion with a developer, concerning its BBCS is advisory only, does not result in approval or disapproval of the BBCS by the Service, and does not constitute a federal agency action subject to the National Environmental Policy Act or other federal law applicable to such an action. P21-36 cont.

Project Interconnection Lines

The Guidelines are designed to address all elements of a wind energy facility, including the turbine string or array, access roads, ancillary buildings, and the above- and below-ground electrical lines which connect a project to the transmission system. The Service recommends that the project evaluation include consideration of the wildlife- and habitat-related impacts of these electrical lines, and that the developer include measures to reduce impacts of these lines, such as those outlined in the Suggested Practices for Avian Protection on Power Lines (APLIC 2006). The Guidelines are not designed to address transmission beyond the point of interconnection to the transmission system. The national grid and proposed smart grid system are beyond the scope of these Guidelines.

Confidentiality of Site Evaluation Process as Appropriate

Some aspects of the initial pre-construction risk assessment, including preliminary screening and site characterization, occur early in the development process, when land or other competitive issues limit developers' willingness to share information on projects with the public and competitors. Any consultation or coordination with agencies at this stage may include confidentiality agreements.

Collaborative Research

Much uncertainty remains about predicting risk and estimating impacts of wind energy development on wildlife. Thus there is a need for additional research to improve scientifically based decision-making when siting wind energy facilities, evaluating impacts on wildlife and habitats, and testing the efficacy of mitigation measures. More extensive studies are needed to further elucidate patterns and test hypotheses regarding possible solutions to wildlife and wind energy impacts.

It is in the interests of wind developers and wildlife agencies to improve these assessments to better mitigate the impacts of wind energy development on wildlife and their habitats. Research can provide data on operational factors (e.g. wind speed, weather conditions) that are likely to result in fatalities. It could also include studies of cumulative impacts of multiple wind energy projects, or comparisons of different methods for assessing avian and bat activity relevant to predicting risk. Monitoring and research should be designed and conducted to ensure unbiased data collection that meets technical standards such as those used in peer review. Research projects may occur at the same time as project-specific Tier 4 and Tier 5 studies.

Research would usually result from collaborative efforts involving appropriate stakeholders, and is not the sole or primary responsibility of any developer. Research partnerships (e.g., Bats and Wind Energy Cooperative (BWEC[9], Grassland and Shrub Steppe Species Collaborative (GS3C)[10]) involving diverse players will be helpful for generating common goals and objectives and adequate funding to conduct studies (Arnett and Haufler 2003). The National Wind Coordinating Collaborative (NWCC)[11], the American Wind Wildlife Institute (AWWI)[12], and the California Energy Commission (CEC)'s Public Interest Energy Research Program[13] all support research in this area.

Study sites and access will be necessary to design and implement research, and developers are encouraged to participate in these research efforts when possible. Subject to appropriations, the Service also should fund priority research and promote collaboration and information sharing among research efforts to advance science on wind energy-wildlife interactions, and to improve these Guidelines.

Service - State Coordination and Cooperation

The Service encourages states to increase compatibility between state guidelines and these voluntary Guidelines, protocols, data collection methods, and recommendations relating to wildlife and wind energy. States that desire to adopt, or those that have formally adopted, wind energy siting, permitting, or environmental review regulations or guidelines are encouraged to cooperate with the Service to develop consistent state level guidelines. The Service may be available to confer, coordinate and share its expertise with interested states when a state lacks its own guidance or program to address wind energy-wildlife interactions. The Service will also use states' technical resources as much as possible and as appropriate.

The Service will explore establishing a voluntary state/federal program to advance cooperation and compatibility between the Service and interested state and local governments for coordinated review of projects under both federal and state wildlife laws. The Service, and interested states, will consider using the following tools to reach agreements to foster consistency in review of projects:

- Cooperation agreements with interested state governments.
- Joint agency reviews to reduce duplication and increase coordination in project review.
- A communication mechanism:
  - To share information about prospective projects
  - To coordinate project review
  - To ensure that state and federal regulatory processes, and/or mitigation requirements are being adequately addressed

P21-36 cont.

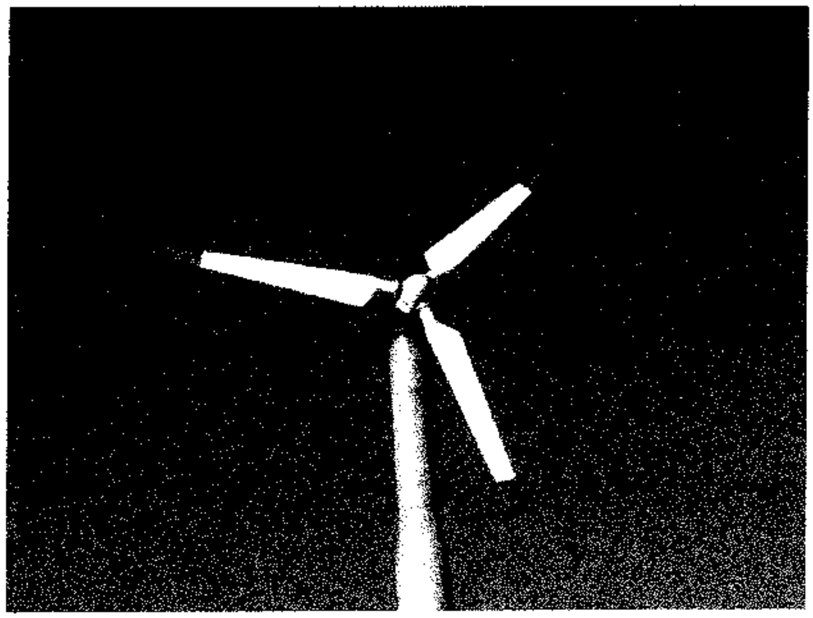
[9] www.batsandwind.org
[10] www.nationalwind.org
[11] www.nationalwind.org
[12] http://www.awwi.org
[13] http://www.energy.ca.gov/research

- To ensure that species of concern and their habitats are fully addressed

- Establishing consistent and predictable joint protocols, data collection methodologies, and study requirements to satisfy project review and permitting.

- Designating a Service management contact within each Regional Office to assist Field Offices working with states and local agencies to resolve significant wildlife-related issues that cannot be resolved at the field level.

- Cooperative state/federal/ industry research agreements relating to wind energy -wildlife interactions.



Wind turbine in California. Credit: NREL

The Service will explore opportunities to:

- Provide training to states.

- Foster development of a national geographic data base that identifies development-sensitive ecosystems and habitats.

- Support a national database for reporting of mortality data on a consistent basis.

- Establish national BMPs for wind energy development projects.

- Develop recommended guidance on study protocols, study techniques, and measures and metrics for use by all jurisdictions.

- Assist in identifying and obtaining funding for national research priorities.

Service - Tribal Consultation and Coordination

Federally-recognized Indian Tribes enjoy a unique government-to-government relationship with the United States. The United States Fish and Wildlife Service (Service) recognizes Indian tribal governments as the authoritative voice regarding the management of tribal lands and resources within the framework of applicable laws. It is important to recall that many tribal traditional lands and tribal rights extend beyond reservation lands.

The Service consults with Indian tribal governments under the authorities of Executive Order 13175 "Consultation and Coordination with Indian Tribal Governments" and supporting DOI and Service policies. To this end, when it is determined that federal actions and activities may affect a Tribe's resources (including cultural resources), lands, rights, or ability to provide services to its members, the Service must, to the extent practicable, seek to engage the affected Tribe(s) in consultation and coordination.

Tribal Wind Energy Development on Reservation Lands

Indian tribal governments have the authority to develop wind energy projects, permit their development, and establish relevant regulatory guidance within the framework of applicable laws.

The Service will provide technical assistance upon the request of Tribes that aim to establish regulatory guidance for wind energy development for lands under the Tribe's jurisdiction. Tribal governments are encouraged to strive for compatibility between their guidelines and these Guidelines.

Tribal Wind Energy Development on Lands that are not held in Trust

Indian tribal governments may wish to develop wind energy projects on lands that are not held in trust status. In such cases, the Tribes should coordinate with agencies other than the Service. At the request of a Tribe, the Service may facilitate discussions with other regulatory organizations. The Service may also lend its expertise in these collaborative efforts to help determine the extent to which tribal resource management plans and priorities can be incorporated into established regulatory protocols.

Non-Tribal Wind Energy Development – Consultation with Indian Tribal Governments

When a non-Tribal wind energy project is proposed that may affect a Tribe's resources (including cultural resources), lands, rights, or ability to govern or provide services to its members, the Service should seek to engage the affected Tribe(s) in consultation and coordination as

P21-36 cont.

early as possible in the process. In siting a proposed project that has a federal nexus, it is incumbent upon the regulatory agency to notify potentially affected Tribes of the proposed activity. If the Service or other federal agency determines that a project may affect a Tribe(s), they should notify the Tribe(s) of the action at the earliest opportunity. At the request of a Tribe, the Service may facilitate and lend its expertise in collaborating with other organizations to help determine the extent to which tribal resource management plans and priorities can be incorporated into established regulatory protocols or project implementation. This process ideally should be agreed to by all involved parties.

In the consultative process, Tribes should be engaged as soon as possible when a decision may affect a Tribe(s). Decisions made that affect Indian Tribal governments without adequate federal effort to engage Tribe(s) in consultation have been overturned by the courts. See, e.g., Quechan Tribe v. U.S. Dep't of the Interior, No. 10cv2241 LAB (CAB), 2010 WL 5113197 (S.D. Cal. Dec. 15, 2010). When a tribal government is consulted, it is neither required, nor expected that all of the Tribe's issues can be resolved in its favor. However, the Service must listen and may not arbitrarily dismiss concerns of the tribal government. Rather, the Service must seriously consider and respond to all tribal concerns. Regional Native American Liaisons are able to provide in-house guidance as to government-to-government consultation processes. (See Service - State Coordination and Cooperation, above).

Non-Governmental Organization Actions

If a specific project involves actions at the local, state, or federal level that provide opportunities for public participation, non-governmental organizations (NGOs) can provide meaningful contributions to the discussion of biological issues associated with that project, through the normal processes such as scoping, testimony at public meetings, and comment processes. In the absence of formal public process, there are many NGOs that have substantial scientific capabilities and may have resources that could contribute productively to the siting of wind energy projects. Several NGOs have made significant contributions to the understanding of the importance of particular geographic areas to wildlife in the United States. This work has benefited and continues to benefit from extensive research efforts and from associations with highly qualified biologists. NGO expertise can – as can scientific expertise in the academic or private consulting sectors – serve highly constructive purposes. These can include:

- Providing information to help identify environmentally sensitive areas, during the screening phases of site selection (Tiers 1 and 2, as described in this document)
- Providing feedback to developers and agencies with respect to specific sites and site and impact assessment efforts
- Helping developers and agencies design and implement mitigation or offset strategies
- Participating in the defining, assessing, funding, and implementation of research efforts in support of improved predictors of risk, impact assessments and effective responses
- Articulating challenges, concerns, and successes to diverse audiences

Non-Governmental Organization Conservation Lands

Implementation of these Guidelines by Service and other state agencies will recognize that lands owned and managed by non-government conservation organizations represent a significant investment that generally supports the mission of state and federal wildlife agencies. Many of these lands represent an investment of federal conservation funds, through partnerships between agencies and NGOs. These considerations merit extra care in the avoidance of wind energy development impacts to these lands. In order to exercise this care, the Service and allied agencies can coordinate and consult with NGOs that own lands or easements which might reasonably be impacted by a project under review.

P21-36 cont.

Appendix A: Glossary

Accuracy – The agreement between a measurement and the true or correct value.

Adaptive management – An iterative decision process that promotes flexible decision-making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Comprehensively applying the tiered approach embodies the adaptive management process.

Anthropogenic – Resulting from the influence of human beings on nature.

Area of interest – For most projects, the area where wind turbines and meteorological (met) towers are proposed or expected to be sited, and the area of potential impact.

Avian – Pertaining to or characteristic of birds.

Avoid – To not take an action or parts of an action to avert the potential effects of the action or parts thereof. First of three components of "mitigation," as defined in Service Mitigation Policy. (See mitigation.)

Before-after/control-impact (BACI) – A study design that involves comparisons of observational data, such as bird counts, before and after an environmental disturbance in a disturbed and undisturbed site. This study design allows a researcher to assess the effects of constructing and operating a wind turbine by comparing data from the "control" sites (before and undisturbed) with the "treatment" sites (after and disturbed). P21-36 cont.

Best management practices (BMPs) – Methods that have been determined by the stakeholders to be the most effective, practicable means of avoiding or minimizing significant adverse impacts to individual species, their habitats or an ecosystem, based on the best available information.

Buffer zone – A zone surrounding a resource designed to protect the resource from adverse impact, and/or a zone surrounding an existing or proposed wind energy project for the purposes of data collection and/or impact estimation.

Community-scale – Wind energy projects greater than 1 MW, but generally less than 20 MW, in name-plate capacity, that produce electricity for off-site use, often partially or totally owned by members of a local community or that have other demonstrated local benefits in terms of retail power costs, economic development, or grid issues.

Comparable site – A site similar to the project site with respect to topography, vegetation, and the species under consideration.

Compensatory mitigation – Replacement of project-induced losses to fish and wildlife resources. Substitution or offsetting of fish and wildlife resource losses with resources considered to be of equivalent biological value.

- **In-kind** – Providing or managing substitute resources to replace the value of the resources lost, where such substitute resources are physically and biologically the same or closely approximate to those lost.
- **Out-of-kind** – Providing or managing substitute resources to replace the value of the resources lost, where such substitute resources are physically or biologically different from those lost. This may include conservation or mitigation banking, research or other options.

Cost effective – Economical in terms of tangible benefits produced by money spent.

Covariate – Uncontrolled random variables that influence a response to a treatment or impact, but do not interact with any of the treatments or impacts being tested.

Critical habitat – For listed species, consists of the specific areas designated by rule making pursuant to Section 4 of the Endangered Species Act and displayed in 50 CFR § 17.11 and 17.12.

Cumulative impacts – See impact.

Curtailment – The act of limiting the supply of electricity to the grid during conditions when it would normally be supplied. This is usually accomplished by cutting-out the generator from the grid and/or feathering the turbine blades.

Cut-in Speed – The wind speed at which the generator is connected to the grid and producing electricity. It is important to note that turbine blades may rotate at full RPM in wind speeds below cut-in speed.

Displacement – The loss of habitat as result of an animal's behavioral avoidance of otherwise suitable habitat. Displacement may be short-term, during the construction phase of a project, temporary as a result of habituation, or long-term, for the life of the project.

Distributed wind – Small and mid-sized turbines between 1 kilowatt and 1 megawatt that are installed and produce electricity at the point of use to off-set all or a portion of on-site energy consumption.

Ecosystem – A system formed by the interaction of a community of organisms with their physical and chemical environment. All of the biotic elements (i.e., species, populations, and communities) and abiotic elements (i.e., land, air, water, energy) interacting in a given geographic area so that a flow of energy leads to a clearly defined trophic structure, biotic diversity, and material cycles. Service Mitigation Policy adopted definition from E. P. Odum 1971 Fundamentals of Ecology.

Edge effect – The effect of the juxtaposition of contrasting environments on an ecosystem.

Endangered species – See listed species.

Extirpation – The species ceases to exist in a given location; the species still exists elsewhere.

Fatality – An individual instance of death.

Fatality rate – The ratio of the number of individual deaths to some parameter of interest such as megawatts of energy produced, the number of turbines in a wind project, the number of individuals exposed, etc., within a specified unit of time.

Feathering – Adjusting the angle of the rotor blade parallel to the wind, or turning the whole unit out of the wind, to slow or stop blade rotation.

Federal action agency – A department, bureau, agency or instrumentality of the United States which plans, constructs, operates or maintains a project, or which reviews, plans for or approves a permit, lease or license for projects, or manages federal lands.

Federally listed species – See listed species.

Footprint – The geographic area occupied by the actual infrastructure of a project such as wind turbines, access roads, substation, overhead and underground electrical lines, and buildings, and land cleared to construct the project.

G1 (Global Conservation Status Ranking) Critically Imperiled – At very high risk of extinction due to extreme rarity (often five or fewer populations), very steep declines, or other factors.

G2 (Global Conservation Status Ranking) Imperiled – At high risk of extinction or elimination due to very restricted range, very few populations, steep declines, or other factors.

G3 (Global Conservation Status Ranking) Vulnerable – At moderate risk of extinction or elimination due to a restricted range, relatively few populations, recent and widespread declines, or other factors.

Guy wire – Wires used to secure wind turbines or meteorological towers that are not self-supporting.

Habitat – The area which provides direct support for a given species, including adequate food, water, space, and cover necessary for survival.

Habitat fragmentation – Habitat fragmentation separates blocks of habitat for some species into segments, such that the individuals in the remaining habitat segments may suffer from effects such as decreased survival, reproduction, distribution, or use of the area.

P21-36 cont.

Impact – An effect or effects on natural resources and on the components, structures, and functioning of affected ecosystems.

- **Cumulative** – Changes in the environment caused by the aggregate of past, present and reasonably foreseeable future actions on a given resource or ecosystem.
- **Direct** – Effects on individual species and their habitats caused by the action, and occur at the same time and place.
- **Indirect impact** – Effects caused by the action that are later in time or farther removed in distance, but are still reasonably foreseeable. Indirect impacts include displacement and changes in the demographics of bird and bat populations.

Infill – Add an additional phase to the existing project, or build a new project adjacent to existing projects.

In-kind compensatory mitigation – See compensatory mitigation.

Intact habitat – An expanse of habitat for a species or landscape scale feature, unbroken with respect to its value for the species or for society.

Intact landscape – Relatively undisturbed areas characterized by maintenance of most original ecological processes and by communities with most of their original native species still present.

Lattice design – A wind turbine support structure design characterized by horizontal or diagonal lattice of bars forming a tower rather than a single tubular support for the nacelle and rotor.

Lead agency – Agency that is responsible for federal or non-federal regulatory or environmental assessment actions. P21-36 cont.

Lek – A traditional site commonly used year after year by males of certain species of birds (e.g., greater and lesser prairie-chickens, sage and sharp-tailed grouse, and buff-breasted sandpiper), within which the males display communally to attract and compete for female mates, and where breeding occurs.

Listed species – Any species of fish, wildlife or plant that has been determined to be endangered or threatened under section 4 of the Endangered Species Act (50 CFR §402.02), or similarly designated by state law or rule.

Local population – A subdivision of a population of animals or plants of a particular species that is in relative proximity to a project.

Loss – As used in this document, a change in wildlife habitat due to human activities that is considered adverse and: 1) reduces the biological value of that habitat for species of concern; 2) reduces population numbers of species of concern; 3) increases population numbers of invasive or exotic species; or 4) reduces the human use of those species of concern.

Megawatt (MW) – A measurement of electricity-generating capacity equivalent to 1,000 kilowatts (kW), or 1,000,000 watts.

Migration – Regular movements of wildlife between their seasonal ranges necessary for completion of the species lifecycle.

Migration corridor – Migration routes and/or corridors are the relatively predictable pathways that a migratory species travel between seasonal ranges, usually breeding and wintering grounds.

Migration stopovers – Areas where congregations of wildlife assemble during migration. Such areas supply high densities of food or shelter.

Minimize – To reduce to the smallest practicable amount or degree.

Mitigation – (Specific to these Guidelines) Avoiding or minimizing significant adverse impacts, and when appropriate, compensating for unavoidable significant adverse impacts.

Monitoring – 1) A process of project oversight such as checking to see if activities were conducted as agreed or required; 2) making measurements of uncontrolled events at one or more points in space or time with space and time being the only experimental variable or treatment; 3) making measurements and evaluations through time that are done for a specific purpose, such as to check status and/or trends or the progress towards a management objective.

Mortality rate – Population death rate, typically expressed as the ratio of deaths per 100,000 individuals in the population per year (or some other time period).

Operational changes – Deliberate changes to wind energy project operating protocols, such as the wind speed at which turbines "cut in" or begin generating power, undertaken with the object of reducing collision fatalities. Considered separately from standard mitigation measures due to the fact that operational changes are considered as a last resort and will rarely be implemented if a project is properly sited.

Passerine – Describes birds that are members of the Order Passeriformes, typically called "songbirds."

Plant communities of concern –Plant communities of concern are unique habitats that are critical for the persistence of highly specialized or unique species and communities of organisms. Often restricted in distribution or represented by a small number of examples, these communities are biological hotspots that significantly contribute to the biological richness and productivity of the entire region. Plant communities of concern often support rare or uncommon species assemblages, provide critical foraging, roosting, nesting, or hibernating habitat, or perform vital ecosystem functions. These communities often play an integral role in the conservation of biological integrity and diversity across the landscape. (Fournier et al. 2007) Also, any plant community with a Natural Heritage Database ranking of S1, S2, S3, G1, G2, or G3.

Population – A demographically and genetically self-sustaining group of animals and/or plants of a particular species.

Practicable – Capable of being done or accomplished; feasible.

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Prairie grouse – A group of gallinaceous birds, includes the greater prairie-chicken, the lesser prairie-chicken, and the sharp-tailed grouse.

Project area – The area that includes the project site as well as contiguous land that shares relevant characteristics.

Project commencement – The point in time when a developer begins its preliminary evaluation of a broad geographic area to assess the general ecological context of a potential site or sites for wind energy project(s). For example, this may include the time at which an option is acquired to secure real estate interests, an application for federal land use has been filed, or land has been purchased.

Project Site – The land that is included in the project where development occurs or is proposed to occur.

Project transmission lines – Electrical lines built and owned by a project developer.

Raptor – As defined by the American Ornithological Union, a group of predatory birds including hawks, eagles, falcons, osprey, kites, owls, vultures and the California condor.

Relative abundance – The number of organisms of a particular kind in comparison to the total number of organisms within a given area or community.

Risk – The likelihood that adverse effects may occur to individual animals or populations of species of concern, as a result of development and operation of a wind energy project. For detailed discussion of risk and risk assessment as used in this document see Chapter One - General Overview.

Rotor – The part of a wind turbine that interacts with wind to produce energy. Consists of the turbine's blades and the hub to which the blades attach.

Rotor-swept area – The area of the circle or volume of the sphere swept by the turbine blades.

Rotor-swept zone – The altitude within a wind energy project which is bounded by the upper and lower limits of the rotor-swept area and the spatial extent of the project.

S1 (Subnational Conservation Status Ranking) Critically Imperiled – Critically imperiled in the jurisdiction because of extreme rarity or because of some factor(s) such as very steep declines making it especially vulnerable to extirpation from the jurisdiction.

S2 (Subnational Conservation Status Ranking) Imperiled – Imperiled in the jurisdiction because of rarity due to very restricted range, very few populations, steep declines, or other factors making it very vulnerable to extirpation from jurisdiction.

S3 (Subnational Conservation Status Ranking) Vulnerable – Vulnerable in the jurisdiction due to a restricted range, relatively few populations, recent and widespread declines, or other factors making it vulnerable to extirpation.

Sage grouse – A large gallinaceous bird living in the sage steppe areas of the intermountain west, includes the greater sage grouse and Gunnison's sage grouse.

Significant – For purposes of characterizing impacts to species of concern and their habitats, "significance" takes into account the duration, scope, and intensity of an impact. Impacts that are very brief or highly transitory, do not extend beyond the immediate small area where they occur, and are minor in their intensity are not likely to be significant. Conversely, those that persist for a relatively long time, encompass a large area or extend well beyond the immediate area where they occur, or have substantial consequences are almost certainly significant. A determination of significance may include cumulative impacts of other actions. There is probably some unavoidable overlap among these three characteristics, as well as some inherent ambiguity in these terms, requiring the exercise of judgment and the development of a consistent approach over time.

Species of concern – For a particular wind energy project, any species which 1) is either a) listed as an endangered, threatened or candidate species under the Endangered Species Act, subject to the Migratory Bird Treaty Act or Bald and Golden Eagle Protection Act; b) is designated by law, regulation, or other formal process for protection and/or management by the relevant agency or other authority; or c) has been shown to be significantly adversely affected by wind energy development, and 2) is determined to be possibly affected by the project. P21-36 cont.

Species of habitat fragmentation concern—Species of concern for which a relevant federal, state, tribal, and/or local agency has found that separation of their habitats into smaller blocks reduces connectivity such that the individuals in the remaining habitat segments may suffer from effects such as decreased survival, reproduction, distribution, or use of the area. Habitat fragmentation from a wind energy project may create significant barriers for such species.

String – A number of wind turbines oriented in close proximity to one another that are usually sited in a line, such as along a ridgeline.

Strobe – Light consisting of pulses that are high in intensity and short in duration.

Threatened species – See listed species.

Tubular design – A type of wind turbine support structure for the nacelle and rotor that is cylindrical rather than lattice.

Turbine height – The distance from the ground to the highest point reached by the tip of the blades of a wind turbine.

Utility-scale – Wind projects generally larger than 20 MW in nameplate generating capacity that sell electricity directly to utilities or into power markets on a wholesale basis.

Voltage (low and medium) – Low voltages are generally below 600 volts, medium voltages are commonly on distribution electrical lines, typically between 600 volts and 110 kV, and voltages above 110 kV are considered high voltages.

Wildlife – Birds, fishes, mammals, and all other classes of wild animals and all types of aquatic and land vegetation upon which wildlife is dependent.

Wildlife management plan – A document describing actions taken to identify resources that may be impacted by proposed development; measures to mitigate for any significant adverse impacts; any post-construction monitoring; and any other studies that may be carried out by the developer.

Wind turbine – A machine for converting the kinetic energy in wind into mechanical energy, which is then converted to electricity..

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Appendix C: Sources of Information Pertaining to Methods to Assess Impacts to Wildlife

The following is an initial list of references that provide further information on survey and monitoring methods. Additional sources may be available.

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Group	Common name	Scientific name	Features	Image
Dippers	American dipper	*Cinclus mexicanus*		
	American robin	*Turdus migratorius*	A resident species frequently seen in towns and lawns.	
	Western bluebird	*Sialia mexicana*	Uncommonly observed but known to breed in the Klamath Basin	
	Mountain bluebird	*Sialia currucoides*	Resident species	
Thrushes, bluebirds and solitaires	Townsend's solitaire	*Myadestes townsendi*	Commonly observed; sighting likelihood good in appropriate habitat especially in the fall and winter. Known to breed in the Klamath Basin	
	Swainson's thrush	*Catharus ustulatus*	Rarely observed, mostly in the spring through the fall; unlikely to be seen even in appropriate habitat but known to breed in the Klamath Basin	
	Hermit thrush	*Catharus guttatus*	Uncommonly observed but known to breed in the Klamath Basin	
	Varied thrush	*Ixoreus naevius* or *Zoothera naevia*	Rarely observed, mostly in the fall and winter; unlikely to be seen even in appropriate habitat but known to breed in the Klamath Basin	
	Anna's hummingbird	*Calypte anna*		
	Ash-throated flycatcher	*Myiarchus cinerascens*		

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	Barn swallow	*Hirundo rustica*		
	Bewick's wren	*Thryomanes bewickii*		
	Black-headed grosbeak	*Pheucticus melanocephalus*		
	Brewer's blackbird	*Euphagus cyanocephalus*		
	Brewer's sparrow	*Spizella breweri*		
	Brown-headed cowbird			
	California quail			
	California towhee			
	Calliope hummingbird	*Stellula calliope*		
	Canada goose	*Branta canadensis*		
	Canyon wren	*Catherpes mexicanus*		

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		Carpodacus mexicanus		
	House wren	*Troglodytes aedon*	Resident species	
	Juniper titmouse	*Baeolophus ridgwayi*		
	Lazuli bunting	*Passerina amoena*	Migrant species	
	Lewis's woodpecker	*Melanerpes lewis*		
	Loggerhead shrike	*Lanius ludovicianus*	Resident species	
	Mountain chickadee	*Poecile gambeli*		
	Mourning dove	*Zenaida macroura*		
	Northern flicker	*Colaptes auratus*		
	Northern mockingbird	*Mimus polyglottos*		
	Olive-sided flycatcher	*Contopus cooperi*	Migrant species	

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Cassin's finch	*Carpodacus cassinii*		
Chipping sparrow	*Spizella passerina*		
Clark's nutcracker	*Nucifraga columbiana*		
Common loon	*Gavia immer*	Uncommonly observed, mostly in the spring and then in the fall	
Common nighthawk	*Chordeiles minor*		
Common raven	*Corvus corax*		
Fox sparrow	*Passerella iliaca*		
Golden-crowned sparrow	*Zonotrichia atricapilla*		
Green-tailed towhee	*Pipilo chlorurus*		
Great blue heron	*Ardea herodias*		
Horned lark	*Eremophila alpestris*	Resident species	
House finch			

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cont.

				
	Pacific loon	*Gavia pacifica*	Rarely observed, mostly in the spring and then in the fall; unlikely to be seen even in appropriate habitat	
	Pygmy nuthatch	*Sitta pygmaea*		
	Red-breasted nuthatch	*Sitta canadensis*	A permanent resident and an acrobatic species, hitching itself up and down tree trunks and branches.[2]	
	Red crossbill	*Loxia curvirostra*	Migrant species	
	Red-naped sapsucker	*Sphyrapicus nuchalis*	Migrant species	
	Common pheasant	*Phasianus colchicus*	yrs ago none recently	
	Red-tailed hawk	*Buteo jamaicensis*		
	Red-winged blackbird	*Agelaius phoeniceus*	Resident species	
	Sage grouse	*Centrocercus urophasianus*		
	Sage sparrow	*Amphispiza belli*		

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Sage thrasher	*Oreoscoptes montanus*	Resident species	
Savannah sparrow	*Passerculus sandwichensis*		
Song sparrow	*Melospiza melodia*		
Spotted towhee	*Pipilo maculatus*		
Common starling	*Sturnus vulgaris*	Non-native species, common in widespread areas of the Upper Klamath Basin.	
Turkey vulture	*Cathartes aura*		
Western meadowlark	*Sturnella neglecta*	A resident and the official state bird of Oregon and other 5 US states.	
Western tanager	*Piranga ludoviciana*		
Western wood pewee	*Contopus sordidulus*		
White-breasted nuthatch	*Sitta carolinensis*		

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White-crowned sparrow	*Zonotrichia leucophrys*		
White-faced ibis	*Plegadis chihi*		
White-headed woodpecker	*Picoides albolarvatus*	Resident species	
Yellow warbler	*Dendroica petechia*	A migrant species that lives in the basin during the spring and summer.[3]	

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See also

- Amphibians and reptiles of Oregon
- List of birds of Oregon
- List of native Oregon plants
- Lists of Oregon-related topics
- Audubon Society of Portland

References

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2. Dunn, Jon L.; Alderfer, Jonathan, eds. (2006). *National Geographic Field Guide to the Birds of North America* (5 ed.). Washington DC: National Geographic. p. 341. ISBN 0-7922-5314-0.
3. Birds of the Basins by the Bureau of Land Management, Lakeview District; the Fremont National Forest; and the Klamath Basin Ecosystem Restoration.

This document contains numerous references to government code sections. Depending on thecode section and the purpose of the reference, only a portion of the government code section may be relevant to the subject being presented. In such cases, only the relevant portion of the code is presented, so for example, you may see a section "c" presented, but no section "a" or "b" (See for example Section 1.2 of this document).

GUIDELINES FOR DETERMINING THE SIGNIFICANCE OF AND IMPACTS TO CULTURAL RESOURCES- ARCHAEOLOGICAL, HISTORIC, AND TRIBAL CULTURAL RESOURCES

SIGNIFICANCE EVALUATION, IMPACT ASSESSMENT, AND MITIGATION

INTRODUCTION

This document provides thresholds and guidance for evaluating potential adverse environmental effects that a proposed project may have on cultural resources. Planners and decision makers should use this document in the evaluation of potential impacts to cultural resources as part of the environmental review of discretionary permit project applications and other projects required by the California Environmental Quality Act (CEQA). Projects that require a permit, but are usually exempt from CEQA review, are not exempt if the project for which the permit will be issued may have substantial adverse impacts to significant historical resources. This document also provides essential guidance to professional consultants who prepare detailed technical reports addressing cultural resources and sections on cultural resources in CEQA documents, such as Environmental Impact Reports. Finally, this document is an essential reference for stakeholders with interests in the proper treatment of cultural resources, including, but not limited to Native Americans, historical preservation organizations, and other community groups.

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The following discussion of Thresholds and Guidelines is divided into three parts. The first part identifies those characteristics or criteria that qualify a resource as a significant archaeological, historic, or tribal cultural resource. The second part addresses how to evaluate the *severity* of potential impacts to those resources. This is key to evaluating if an adverse change to a resource is substantial and significant. The third part of the document provides a discussion of mitigation, including some examples of mitigation measures which may avoid or lessen a potentially substantial adverse change.

Unlike most resource classes that are required to be considered during environmental review pursuant to CEQA, the CEQA Statute and CEQA Guidelines themselves contain numerous and detailed regulations and guidance specific to cultural resources. This document mainly relies on that guidance and those regulations. Many of the criteria in CEQA that address the significance and appropriate treatment of cultural resources derive from Federal, State, and Local registers of historical resources, including the National Register of Historic Places (NRHP), the California Register of Historical Resources (CRHR), and local registers of historical resources.

Additional guidance and requirements are also provided by the numerous goals, policies, and standards contained in local Comprehensive Plans, Community Plans, and Zoning Ordinances that address the treatment of local cultural resources in the context of discretionary land use permit projects. If a discretionary permit is being issued in a context where such plans and ordinances apply, projects must be designed and/or mitigation measures included such that findings of consistency can be made for those goals, policies and standards. Planners should consult the appropriate documents for these goals, policies, and standards in circumstances where they apply.

Cultural resources are the tangible or intangible remains or traces left by prehistoric or historic peoples who inhabited California. These typically include prehistoric and historic archaeological sites. Although most people think of Native Americans when they think about local archaeology, archaeological sites may also be the material remains of past non-native behavior, such as historical ruins, old trash dumps, and even shipwrecks. Another type of cultural resource includes historic resources, the most common form of which is the existing built environment. Historic resources (not to be confused with *historical* resources as used in CEQA, and defined below), include old houses, buildings, structures, roads, walls, and other important historic features. Cultural resources also include areas such as traditional cultural places and landscapes, and may even include objects, records, and manuscripts. A recently defined type of cultural resource that was added to CEQA in 2015 is the tribal cultural resource, resources with cultural value to a California Native American Tribe. Tribal cultural resources may include Native American archaeological sites, but they may also include other types of resources such as cultural landscapes or sacred places. The identification and appropriate treatment of tribal cultural resources is determined through consultation with tribes.

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Initial Study Questions

Specifically, this document addresses the threshold questions contained in CEQA's Initial Study section on cultural resources, which are based on CEQA Guidelines Appendix G (Environmental Checklist Form), but have been altered slightly here to more clearly differentiate archaeological from historic (i.e. the built environment) resources, both of which are considered *historical* resources by CEQA. Please refer to Appendix A to this document for a suggested set of CEQA Initial Study questions that pertain to cultural resources. Alternatively, you may use the cultural resources Initial Study questions as written in CEQA Appendix G. If the Initial Study determination is that there are only Class III impacts, a CEQA exemption or Negative Declaration may be the appropriate CEQA document from the perspective of cultural resources. If the Initial Study determines that there are Class II impacts, a Mitigated Negative Declaration may be the appropriate CEQA document from the perspective of cultural resources. If after redesign and/or mitigation, it is determined that the impact is a significant Class I impact, preparation of an Environmental Impact Report is required. Many lead agencies (i.e. state agencies, local governments, other local juridictions, etc.) have additional guidance on the discussion of existing setting, impacts, mitigation, Native American Consultation, and the application of these thresholds. Such guidance documents should be consulted when available.

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1.0 EVALUATING THE SIGNIFICANCE (i.e., *IMPORTANCE)* OF CULTURAL RESOURCES

As discussed in more detail in Section 1.3.3, below, the first step in determining a project's impacts to cultural resources is to identify whether or not cultural resources are present. Assuming such resources are present, there are a number of different perspectives when evaluating the importance or significance of a cultural resource during CEQA review, all of them equally valid. From the perspective of a historian, for example, the importance of a historical resource, such as a building, structure, object, or historic district, is what it can tell us about history. Such a resource may be associated with important events that contributed significantly to California history, associated with persons who were important in our past, embody distinctive historic characteristics, or represent the work of an important individual, such as a famous architect. To an archaeologist, the significance of a cultural resource most commonly lies in the information that it can provide about the past, which is important for reconstructing past cultures and testing hypotheses and models that seek to understand culture change. And for a Native American, significance includes resources that have cultural significance to a tribe, including but not limited to sacred places and cultural landscapes. Keep in mind that a single resource may be significant from more than one perspective. For example, an archaeological site may be significant both to archaeologists and Native Americans, but for very different reasons. P21-36 cont.

What follows is a discussion of the significance evaluation for the various kinds of cultural resources, as contained in CEQA Statute and CEQA Guidelines, as well as federal, state, and local codes and guidance. Depending on the nature of the cultural resource that is the subject of environmental review, one or more of these significance evaluation procedures may be appropriate.

1.1 California Register of Historical Resources

During environmental review, one of the most commonly encountered cultural resource types is the *historical resource*. Historical resources are broadly defined as those cultural resources that are considered significant under CEQA and may include sites, objects, structures, buildings, etc. Historical resources may be prehistoric or historic in age and may be archaeological resources, part of the existing built environment, other important historic resources, or a tribal cultural resource, such as a sacred place. The CEQA Guidelines contain specific direction as to what qualifies as a significant historical resource. CEQA Guidelines Section 15064.5(a) of the State CEQA Guidelines provides a definition of "historical resources." Resources that meet this definition are significant. Public Resources Code Sections 5020-5029.5 also contain many important definitions of terms used in the code section below, including historical resources, the California

Register of Historical Resources, the State Historical Resources Commission, the State Office of Historic Preservation, and others.

Historical Resources (CEQA Guidelines Section 15064.5 (a))

(a) For purposes of this section, the term "historical resources" shall include the following:

(1) A resource listed in, or determined to be eligible by the State Historical Resources Commission, for listing in the California Register of Historical Resources (Pub. Res. Code SS5024.1, Title 14 CCR. Section 4850 et seq.).

(2) A resource included in a local register of historical resources, as defined in Section 5020.1(k) of the Public Resources Code or identified as significant in an historical resource survey meeting the requirements of Section 5024.1(g) of the Public Resources Code, shall be presumed to be historically or culturally significant. Public agencies must treat any such resource as significant unless the preponderance of evidence demonstrates that it is not historically or culturally significant.

(3) Any object, building, structure, site, area, place, record, or manuscript which a lead agency determines to be historically significant or significant in the architectural, engineering, scientific, economic, agricultural, educational, social, political, military, or cultural annals of California may be considered to be an historical resource, provided the lead agency's determination is supported by substantial evidence in light of the whole record. Generally, a resource shall be considered by the lead agency to be "historically significant" if the resource meets the criteria for listing on the California Register of Historical Resources (Pub. Res. Code SS5024.1, Title 14, Section 4852) including the following:

(A) Is associated with events that have made a significant contribution to the broad patterns of California's history and cultural heritage;

(B) Is associated with the lives of persons important in our past;

(C) Embodies the distinctive characteristics of a type, period, region, or method of construction, or represents the work

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of an important creative individual, or possesses high artistic values; or

(D) Has yielded, or may be likely to yield, information important in prehistory or history.

(4) The fact that a resource is not listed in, or determined eligible for listing in the California Register of Historical Resources, not included in a local register of historical resources (pursuant to Section 5020.1(k) of the Public Resources Code), or identified in an historical resources survey (meeting the criteria in Section 5024.1(g) of the Public Resource Code) does not preclude a lead agency from determining that the resource may be an historical resource as defined in Public Resources Code Section 5020.1(j) or 5024.1.

1.2 National Register of Historic Places Criteria as Referenced in CEQA

National Register eligibility is also relevant to listing in the California Register. National Register criteria may also be applied to determine if a resource may be listed in the California Register of Historical Resources, and therefore significant pursuant to CEQA. Public Resources Code Section 5024.1(c) lists the National Register of Historic Places criteria that would also qualify a resource to be listed in the California Register of Historical Resources. Normally, most evaluations are done with the California Register criteria themselves, which are similar; but if a resource has already been formally evaluated as meeting National Register criteria, it may simplify the significance evaluation process. Please note that the following section of the CEQA Guidelines references the National Register criteria, but the specific wording of the criteria has been altered in order to apply specifically to resources from California. For the exact wording of the National Register criteria, go to National Register Bulletin 15 (https://www.nps.gov/nr/publications/bulletins/nrb15/).

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National Register of Historic Places Criteria (CEQA Guidelines Section 5024.1(c))

(c) A resource may be listed as an historical resource in the California Register if it meets any of the following National Register of Historic Places criteria:

(1) Is associated with events that have made a significant contribution to the broad patterns of California's history and cultural heritage.

(2) Is associated with the lives of persons important in our past.

(3) Embodies the distinctive characteristics of a type, period, region, or method of construction, or represents the work of an important creative individual, or possesses high artistic values.

(4) Has yielded, or may be likely to yield, information important in prehistory or history.

1.3 Archaeological Sites

Archaeological sites may be historic or prehistoric in age. As treated by CEQA, archaeological sites may qualify as historical resources or tribal cultural resources, or both. CEQA provides additional guidance specific to archaeological sites. The determination as to whether an archaeological site qualifies as an historical resource or a unique archaeological resource should be based on the evidence gathered and presented for each specific site and should be made by a trained professional archaeologist. CEQA Guidelines Section 15064.5(c)(2) makes it clear that if an archaeological site is determined to be an historical resource, the limitations on mitigation contained in CEQA Statute Section 21083.2 do not apply, and instead mitigation should be guided by CEQA Guidelines Section 15126.4. Additionally, CEQA Guidelines Section 15064.5 (c)(3) clarifies that if an archaeological site is not an historical resource, but does meet the definition of a unique archaeological resource, it should be treated according to CEQA Statute Section 21083.2 , but that the time and cost limitations for survey and evaluation activities contained in CEQA Statute Section 21083.2 (c-f) do not apply to surveys and site evaluation activities. If an archaeological site is neither an historical resource nor a unique archaeological site, the effects of the project on that site shall not be considered a significant effect on the environment.

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1.3.1 Archaeological Sites (CEQA Guidelines Section 15064.5 (c))

(c) CEQA applies to effects on archaeological sites.

(1) When a project will impact an archaeological site, a lead agency shall first determine whether the site is an historical resource, as defined in subsection (a).

(2) If a lead agency determines that the archaeological site is an historical resource, it shall refer to the provisions of Section 21084.1 of the Public Resources Code, and this section, Section 15126.4 of the Guidelines, and the limits contained in Section 21083.2 of the Public Resources Code do not apply.

(3) If an archaeological site does not meet the criteria defined in subsection (a), but does meet the definition of a unique archaeological resource in Section 21083.2 of the Public Resources Code, the site shall be treated in accordance with the provisions of Section 21083.2. The time and cost limitations described in Public Resources Code Section 21083.2 (c-f) do not apply to surveys and site evaluation activities intended to determine whether the project location contains unique archaeological resources.

(4) If an archaeological resource is neither a unique archaeological nor an historical resource, the effects of the project on those resources shall not be considered a significant effect on the environment. It shall be sufficient that both the resource and the effect on it are noted in the Initial Study or EIR, if one is prepared to address impacts on other resources, but they need not be considered further in the CEQA process.

1.3.2 Unique and Non-Unique Archaeological Sites

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Prior to the adoption of CEQA Guidelines Section 15064.5 in 1998 that defined and addressed the definition and treatment of historical resources, archaeological resources were primarily addressed in Appendix K to the Guidelines, which no longer exists. Appendix K was developed partly in response to CEQA Section 21083.2 that defined "unique" and "non-unique" archaeological resources. It placed significant time and cost limitations on the evaluation and mitigation of unique archaeological resources, and required no mitigation for a non-unique archaeological resource (see Section 3.6 of this document). You will see references to the old Appendix K related to archaeological resources in old reports and publications, but it no longer exists and has been replaced by CEQA Section 15064.5 that addresses historical resources.

As discussed above, the time and cost limitations for significance evaluation and mitigation for unique and non-unique archaeological resources (i.e., sites) have largely been obviated by the statute and guideline sections that address historical resources, archaeological sites, and tribal cultural resources. So if that is the case, why even discuss them in this document? CEQA recognizes the possibility that an archaeological site may not meet the definition of an historical resource but may meet the definition of a unique archaeological resource. In that case, the site shall be treated in accordance with the provisions of Section 21083.2. It is also necessary to discuss unique archaeological resource because unique archaeological resources may qualify as either tribal cultural resources or historical resources, so the definitions for unique and non-unique archaeological sites are presented here.

Unique and Non-Unique Archaeological Sites (CEQA Statute Section 21083.2 (g))

(g) As used in this section, "unique archaeological resource" means an archaeological artifact, object, or site about which it can be clearly demonstrated that, without merely adding to the current body of knowledge, there is a high probability that it meets any of the following criteria:

(1) Contains information needed to answer important scientific research questions and that there is a demonstrable public interest in that information.
(2) Has a special and particular quality such as being the oldest of its type or the best available example of its type.
(3) Is directly associated with a scientifically recognized important prehistoric or historic event or person.

(h) As used in this section, "nonunique archaeological resource" means an archaeological artifact, object, or site which does not meet the criteria in subdivision (g). A non-unique archaeological resource need be given no further consideration, other than the simple recording of its existence by the lead agency if it so elects.

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1.3.3 Significance Determination Process for Archaeological and Historic Sites

A detailed discussion of the requirements for archaeological and historic resource investigations and the format and content of technical documents that are to be submitted to lead agencies as part of the CEQA review process is included in a separate guidance document, *Fieldwork and Reporting Guidelines for Cultural Resources.* A brief summary of the archaeological and historic fieldwork and analysis process is included here. These activities are carried out by professional consultants and the results incorporated into CEQA documents, including Initial Studies, Exemptions, Negative Declarations, Mitigated Negative Declarations, and Environmental Impact Reports. Many lead agencies maintain a list of qualified professional consultants from which applicants may choose should a technical study be required. All reports, including those produced for Phase 1, 2, and 3 investigations, must be submitted to the appropriate California Information Center as well as the lead agency. An additional requirement for archaeological investigations involves the curation (See CEQA Guidelines Section 15126.4(b)(3)(C)) in perpetuity of excavated materials and associated documents from Extended Phase 1, Phase 2, and Phase 3 excavations, at a qualified curation facility, at the applicant's cost. Refer to *Fieldwork and Reporting Guidelines for Cultural Resources* and the discussion below of mitigation and design considerations for guidance and information on other requirements and possible mitigation measures. Note that all archaeological reports that disclose site locations will remain confidential (not distributed to the public).

Phase 1

Archaeological Resources

The first phase of the process, Phase 1, is an inventory to determine whether or not any archaeological sites exist within the project area. This most often begins with records search requests. One request is made to the appropriate Information Center, which maintains maps and records of all recorded sites, both historic and archaeological, as well as locations of past archaeological surveys. In addition, a Sacred Lands Search Request is submitted to the Native American Heritage Commission (NAHC) to find out if any sacred lands within or near the project site have been registered with the NAHC.[1] Once records have been obtained, a pedestrian survey of the project site is conducted by a qualified archaeologist who examines the ground surface to check for cultural materials such as chipped stone, shellfish remains, bone, groundstone, dark organic-rich midden soil, or other tell-tale signs of the presence of an archaeological site.

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Sometimes, an Extended Phase 1 is conducted if there is limited visibility due to dense vegetation cover, or the project is in an area likely to have buried remains due to the post-occupation deposition of soils by alluvial or other processes. An Extended Phase 1 essentially extends the examination to beneath the ground surface, and usually involves the use of shovel test pits or, on occasion, controlled backhoe trenching, with screening of soils to make sure cultural materials are not missed. If no archaeological materials are discovered, the conclusion is that no archaeological sites exist within the project area. In that case, the Initial Study question on archaeological sites would indicate that there is no impact and would be identified as a Class III impact in the CEQA document for the project.

If an archaeological site is determined to be present, then a Phase 2 significance evaluation is usually conducted, unless project redesign can avoid the site, in which case Phase 2 test excavations would not be necessary. If a site is avoided through project redesign, there would be no impact (Class III). In rare cases, an Extended Phase 1 investigation may generate enough information to establish that a site is significant and preclude the need for a Phase 2 investigation. If a site is determined not to be significant

[1] Note that in many cases, recorded cultural resources that have not been registered with the NAHC exist in any given area.

based on the results of an Extended Phase 1 investigation, the Initial Study question on archaeological sites would indicate that there is a less than significant impact and would be identified as a Class III impact in the CEQA document for the project. In some cases, monitoring of ground disturbance in or near to a less than significant site may be made a condition of project approval in order to ensure that undiscovered significant deposits are properly treated if found.

Historic Resources

Phase 1 investigations of historic resources (i.e., the built environment) include both an inventory and significance evaluation of the resources. The purpose of this investigation is to analyze and present the data relevant for determining if the resource is a significant historical resource based on the relevant criteria (e.g., CEQA Guidelines Section 15064.5 (a)(3)(A-D)), including a careful evaluation of the seven aspects of integrity. Phase 1 investigations of historic resources include historical research, an inspection of the property, and a preliminary evaluation of the potential presence of significant historic resources. Historical research includes review of all appropriate documents, including site records, maps, and other appropriate archival materials including pertinent grantor-grantee land ownership title record data for the period of historical significance. Institutions that may have pertinent maps and information include Information Centers, university departments of History, map and Imagery Libraries, historical societies, county and city halls of records, historic preservation organizations, and others. Institutions that may have pertinent archival materials, including written documents and photographs, include library special collections departments, historical societies, county and city halls of records, missions, other local historical society archives, and others. If no significant historic resources are present, a report of that determination, supported by appropriate evidence, is prepared and submitted (Phase 1 report). If the Phase 1 work results in the identification of potentially significant historic resources, then a Phase 2 investigation is conducted to assess the impacts of the proposed project and formulate appropriate mitigation measures. It is sometimes appropriate to conduct a combined Phase 1/Phase 2 investigation and prepare a single report that presents the results of both phases.

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If no significant historic resources are identified, the Initial Study question on historic resources would indicate that there is no impact and would be identified as a Class III impact in the CEQA document for the project.

Phase 2

Archaeological Resources

The purpose of Phase 2 is twofold: (1) to evaluate the significance of any discovered archaeological resources that cannot be avoided by project design or redesign, and (2) to assess project impacts and formulate mitigation measures for resources that are evaluated as significant under CEQA (i.e., historical resources). Fieldwork usually includes controlled and limited archaeological excavation by a qualified archaeologist, referred to as site testing. There are however some circumstances where significance determination may be made without excavation, such as a deflated archaeological site. Site testing follows a plan reviewed and approved by the jurisdiction or agency to gather and analyze data as necessary to evaluate the significance of the site pursuant to CEQA. Although significance evaluation is generally made for the site as a whole, in some cases there may be specific areas of a significant site that may lack the characteristics that impart importance or confer significance to the site due to the loss of integrity from prior disturbance, extremely low density of deposits, or other reasons. For archaeological sites determined to be significant by Phase 2 test excavations and analysis, mitigation is likely required. Avoidance of significant sites through project redesign is always the first choice, and is required by some jurisdictions and agencies if avoidance is possible. Most archaeological sites which retain their integrity can be placed within a temporal framework, and have sufficient density of material to answer research questions, are considered significant, and as such the preferred mitigation is avoidance and preservation in place. In some cases, in addition to avoidance, capping the site with sterile chemically neutral soil, geofabric, and some form of shallow-rooted landscaping may also be appropriate mitigation. A sample of the archaeological deposit should be recovered prior to capping. Additional mitigation should include analysis of the recovered materials in an analytical report. In rare cases a Phase 2 investigation may generate enough information to qualify as adequate mitigation and preclude the need for a Phase 3 investigation.

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If a significant archaeological site is avoided through project redesign, and possibly capped, based on the results of a Phase 2 investigation, the Initial Study question on archaeological sites would indicate that there is a less than significant impact with mitigation and would be identified as a Class II impact in the CEQA document for the project. Please note that if a project will affect a significant site (e.g., one that is eligible for inclusion on a federal, state or local list or register), then the project is not exempt from CEQA (CEQA Guidelines Section 15300.2(f); the "exception to the exemption"). This is the case even if the project only requires a simple or ministerial permit for construction or grading that would otherwise qualify for a CEQA categorical exemption. In such instances, an Initial Study should be prepared.

Historic Resources

If a potentially significant historic resource is identified in Phase 1, a Phase 2 investigation is conducted to assess project impacts and formulate appropriate mitigation measures. Avoidance and preservation in place is always the preferred mitigation. CEQA (CEQA Guidelines Section 15064.5(b)(3)) recognizes that a project that follows the *Secretary of the Interior's Standards for the Treatment of Historic Properties with Guidelines for Preserving, Rehabilitating, Restoring, and Reconstructing Historic Building* or the

Secretary of the Interior's Standards for Rehabilitation and Guidelines for Rehabilitating Historic Buildings (1995), Weeks and Grimmer, shall be considered as mitigated to a level of less than a significant impact on the historical resource. In addition, Historic American Buildings Survey /Historic American Engineering Record (HABS/HAER) documentation, or documentation similar to HABS/HAER may also be appropriate mitigation. See also the discussion of mitigation of impacts to significant historic structures in Section 2.3.3 of Appendix B.

If impacts to a significant historic resource are avoided through project redesign and preservation in place based on the results of a Phase 2 investigation, the Initial Study question on historic sites would indicate that there is a less than significant impact with mitigation and would be identified as a Class II impact in the CEQA document for the project. Note that if a project will affect a significant historical (e.g., one that is eligible for inclusion on a federal, state or local list or register), then the project is not exempt from CEQA (CEQA Guidelines Section 15300.2(f); the "exception to the exemption"). This is the case even if the project only requires a simple or ministerial permit (e.g., a Land Use Permit or Coastal Development Permit for demolition of a structure).In such instances, an Initial Study should be prepared.

Phase 3

Archaeological Resources

The purpose of a Phase 3 archaeological investigation is to carry out mitigation measures, including such measures as temporary fencing during construction, capping, or even dedication of a conservation easement over the site. The avoidance of significant archaeological sites is always the preferred mitigation and is required whenever possible by the policies of many jurisdictions and agencies. For significant sites that cannot be avoided through redesign, additional excavations may be appropriate mitigation. This type of mitigation is often referred to as data recovery. While information is obtained from a data recovery project, the excavated portion of the site, as well as the entire area impacted by the project, is destroyed. The purpose of Phase 3 is to recover, analyze, interpret, report, curate, and preserve archaeological data that would otherwise be lost due to unavoidable impacts to a significant resource. The method usually involves an archaeologist excavating in a controlled manner part of the site that will be impacted using a Lead Agency-approved data recovery plan that is informed by the results of the Phase 2 test excavations. The recovered materials are analyzed pursuant to specific research issues or questions and the results are included in an analytical report. If Phase 3 data recovery excavations are proposed, the Initial Study question on archaeological sites should indicate that there is a less than significant impact after mitigation and would be identified as a Class II impact in the CEQA document for the project, or that there is a

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potentially significant impact resulting in a Class I impact. Conducting Phase 3 data recovery excavations may not reduce the impact to the resource to less than significant. The determination whether the impact is Class II or remains Class I after data recovery depends on the nature of the site and the amount that is being destroyed. This determination should be based on careful consideration by professional archaeologists and consultation with the Native American community.

Historic Resources

Phase 3 work for historic resources which are not completely avoided involves carrying out the mitigation proposed in the Phase 2 report. Mitigation measures may include, but are not limited to, preservation in place, restoration, rehabilitation, reconstruction, relocation, and documentation through drawings, plans, and photographs. Phase 3 historic resource reports document the mitigation measures that were carried out and include the documentation produced.

If Phase 3 mitigation is proposed, the Initial Study question on historic resources should indicate that there is a less than significant impact after mitigation and would be identified as a Class II impact in the CEQA document for the project, or that there is a potentially significant impact resulting in a Class I impact. The determination whether the impact is Class II or Class I depends on the condition of the resource after mitigation. For example, a historic house that is relocated offsite may or may not constitute a Class I impact due to loss of integrity even though it is being preserved. Also, HABS/HAER documentation as mitigation may not fully mitigate the impact to a historic resource if, after such documentation, the resource is not preserved in place. This determination should be based on careful consideration by and consultation with professional historians and historical architects.

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1.4 Tribal Cultural Resources (AB52)

A resource type recently added to CEQA is the *tribal cultural resource*. This resource type was added to CEQA as a result of the passage of Assembly Bill 52 (Gato) in 2014 that took effect in July 2015. CEQA Statute Section 21074 contains guidance for determining what constitutes a tribal cultural resource. If a resource meets the definition of a tribal cultural resource, then it is a significant historical resource pursuant to CEQA. In addition, the statute contains direction concerning meaningful consultation regarding tribal cultural resources that must take place with California Native American tribes, should they request such consultation, on a project-by-project basis (CEQA Statute Section 21080.3.1). It is the obligation of the lead agency, not a professional consultant, to carry out the consultation process. Professional consultants may be involved in the process, but the lead agency is obligated to take the lead. A lead agency staff person will be identified as having the responsibility to conduct consultation with tribes. This consultation, which is confidential, recognizes that the tribes have expertise in determining if a tribal cultural resource is present within a project area, as well as proposing and determining the adequacy of mitigation measures proposed to avoid or substantially lessen potential significant impacts to a tribal cultural resource (CEQA Statute Section 21080.3.2). Required AB 52 consultation is carried out with tribes, not individuals, that have been recognized by the Native American Heritage Commission and who have requested to have such consultation with the lead agency.

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1.4.1 Tribal Cultural Resource Definition

Tribal cultural resources may be sites, features, places, cultural landscapes, sacred places, and objects with cultural value to a California Native American tribe (CEQA Statute Section 21074). While CEQA contains guidance regarding the identification and determination of the significance of some of these resource types (e.g., CEQA Guidelines Sections 15064.5), CEQA contains little to no guidance regarding cultural landscapes or sacred places. CEQA recognizes the expertise of tribes in identifying all tribal cultural resources, but additional guidance may be provided by the Native American Heritage Commission, which keeps an inventory of sacred lands, to the extent that tribes wish such lands to be included in that inventory. Additional guidance may also be found in *National Register Bulletin 38, Guidelines for Evaluating and Documenting Traditional Cultural Properties*. Although the National Register process uses evaluation criteria that are somewhat different than those used in CEQA, the general guidance provided in this bulletin is quite useful in the determination of significance of tribal cultural resources such as cultural landscapes.

Tribal Cultural Resources (CEQA Statute Section 21074)

(a) "Tribal cultural resources" are either of the following:

(1) Sites, features, places, cultural landscapes, sacred places, and objects with cultural value to a California Native American tribe that are either of the following:

(A) Included or determined to be eligible for inclusion in the California Register of Historical Resources.

(B) Included in a local register of historical resources as defined in subdivision (k) of Section 5020.1.

(2) A resource determined by the lead agency, in its discretion and supported by substantial evidence, to be significant pursuant to criteria set forth in subdivision (c) of Section 5024.1.

In applying the criteria set forth in subdivision (c) of Section 5024.1 for the purposes of this paragraph, the lead agency shall consider the significance of the resource to a California Native American tribe.

(b) A cultural landscape that meets the criteria of subdivision (a) is a tribal cultural resource to the extent that the landscape is geographically defined in terms of the size and scope of the landscape.

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(c) A historical resource described in Section 21084.1, a unique archaeological resource as defined in subdivision (g) of Section 21083.2, or a "nonunique archaeological resource" as defined in subdivision (h) of Section 21083.2 may also be a tribal cultural resource if it conforms with the criteria of subdivision (a).

1.4.2 Consultation with Tribes Regarding Tribal Cultural Resources

A critically important aspect of the evaluation and treatment of tribal cultural resources is consultation with tribes, who are recognized as experts for this type of resource. Once formally requested by a tribe, the lead agency must offer that tribe the opportunity for consultation on any project for which a Negative Declaration, Mitigated Negative Declaration, or Environmental Impact Report will constitute the CEQA document. Additional guidance documents exist, including a tribal consultation process timeline that details how and when a tribe must be given the opportunity to consult, and the Governor's Office of Planning and Research Tribal Consultation Guidelines (2005).

Three sections of the Public Resource Code discuss the requirements for consultation.

Tribal Consultation (CEQA Statute Section 21080.3.1)

(a) The Legislature finds and declares that California Native American tribes traditionally and culturally affiliated with a geographic area may have expertise concerning their tribal cultural resources.

(b) Prior to the release of a negative declaration, mitigated negative declaration, or environmental impact report for a project, the lead agency shall begin consultation with a California Native American tribe that is traditionally and culturally affiliated with the geographic area of the proposed project if: (1) the California Native American tribe requested to the lead agency, in writing, to be informed by the lead agency through formal notification of proposed projects in the geographic area that is traditionally and culturally affiliated with the tribe, and (2) the California Native American tribe responds, in writing, within 30 days of receipt of the formal notification, and requests the consultation. When responding to the lead agency, the California Native American tribe shall designate a lead contact person. If the California Native American tribe does not designate a lead contact person, or designates multiple lead contact people, the lead agency shall defer to the individual listed on the contact list maintained by the Native American Heritage Commission for the purposes of Chapter 905 of the Statutes of 2004. For purposes of this section and Section 21080.3.2, "consultation" shall have the same meaning as provided in Section 65352.4 of the Government Code.

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(c) To expedite the requirements of this section, the Native American Heritage Commission shall assist the lead agency in identifying the California Native American tribes that are traditionally and culturally affiliated with the project area.

(d) Within 14 days of determining that an application for a project is complete or a decision by a public agency to undertake a project, the lead agency shall provide formal notification to the designated contact of, or a tribal representative of, traditionally and culturally affiliated California Native American tribes that have requested notice, which shall be accomplished by means of at least one written notification that includes a brief description of the proposed project and its location, the lead agency contact information, and a notification that the California Native American tribe has 30 days to request consultation pursuant to this section.

(e) The lead agency shall begin the consultation process within 30 days of receiving a California Native American tribe's request for consultation.

Tribal Consultation (CEQA Statute Section 21080.3.2.)

(a) As a part of the consultation pursuant to Section 21080.3.1, the parties may propose mitigation measures, including, but not limited to, those recommended in Section 21084.3, capable of avoiding or substantially lessening potential significant impacts to a tribal cultural resource or alternatives that would avoid significant impacts to a tribal cultural resource. If the California Native American tribe requests consultation regarding alternatives to the project, recommended mitigation measures, or significant effects, the consultation shall include those topics. The consultation may include discussion concerning the type of environmental review necessary, the significance of tribal cultural resources, the significance of the project's impacts on the tribal cultural resources, and, if necessary, project alternatives or the appropriate measures for preservation or mitigation that the California Native American tribe may recommended to the lead agency.

(b) The consultation shall be considered concluded when either of the following occurs:

(1) The parties agree to measures to mitigate or avoid a significant effect, if a significant effect exists, on a tribal cultural resource.

(2) A party, acting in good faith and after reasonable effort, concludes that mutual agreement cannot be reached.

(c) (1) This section does not limit the ability of a California Native American tribe or the public to submit information to the lead agency regarding the significance of the tribal cultural resources, the significance of the project's impact on tribal cultural resources, or any appropriate measures to mitigate the impact.

(2) This section does not limit the ability of the lead agency or project proponent to incorporate changes and additions to the project as a result of the consultation, even if not legally required.

(d) If the project proponent or its consultants participate in the consultation, those parties shall respect the principles set forth in this section.

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Tribal Consultation (CEQA Statute Section 21082.3.)

(a) Any mitigation measures agreed upon in the consultation conducted pursuant to Section 21080.3.2 shall be recommended for inclusion in the environmental document and in an adopted mitigation monitoring and reporting program, if determined to avoid or lessen the impact pursuant to paragraph (2) of subdivision (b), and shall be fully enforceable.

(b) If a project may have a significant impact on a tribal cultural resource, the lead agency's environmental document shall discuss both of the following:

(3) Whether the proposed project has a significant impact on an identified tribal cultural resource.

(4) Whether feasible alternatives or mitigation measures, including those measures that may be agreed to pursuant to subdivision (a), avoid or substantially lessen the impact on the identified tribal cultural resource.

(c) (1) Any information, including, but not limited to, the location, description, and use of the tribal cultural resources, that is submitted by a California Native American tribe during the environmental review process shall not be included in the environmental document or otherwise disclosed by the lead agency or any other public agency to the public, consistent with subdivision (r) of Section 6254 of, and Section 6254.10 of, the Government Code, and subdivision (d) of Section 15120 of Title 14 of the California Code of Regulations, without the prior consent of the tribe that provided the information. If the lead agency publishes any information submitted by a California Native American tribe during the consultation or environmental review process, that information shall be published in a confidential appendix to the environmental document unless the tribe that provided the information consents, in writing, to the disclosure of some or all of the information to the public. This subdivision does not prohibit the confidential exchange of the submitted information between public agencies that have lawful jurisdiction over the preparation of the environmental document. P21-36 cont.

(2) (A) This subdivision does not prohibit the confidential exchange of information regarding tribal cultural resources submitted by a California Native American tribe during the consultation or environmental review process among the lead agency, the California Native American tribe, the project applicant, or the project applicant's agent. Except as provided in subparagraph (B) or unless the California Native American tribe providing the information consents, in writing, to public disclosure, the project applicant or the project applicant's legal advisers, using a reasonable degree of care, shall

maintain the confidentiality of the information exchanged for the purposes of preventing looting, vandalism, or damage to tribal cultural resources and shall not disclose to a third party confidential information regarding tribal cultural resources.

(B) This paragraph does not apply to data or information that are or become publicly available, are already in the lawful possession of the project applicant before the provision of the information by the California Native American tribe, are independently developed by the project applicant or the project applicant's agents, or are lawfully obtained by the project applicant from a third party that is not the lead agency, a California Native American tribe, or another public agency.

(3) This subdivision does not affect or alter the application of subdivision (r) of Section 6254 of the Government Code, Section 6254.10 of the Government Code, or subdivision (d) of Section 15120 of Title 14 of the California Code of Regulations.

(4) This subdivision does not prevent a lead agency or other public agency from describing the information in general terms in the environmental document so as to inform the public of the basis of the lead agency's or other public agency's decision without breaching the confidentiality required by this subdivision.

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(d) In addition to other provisions of this division, the lead agency may certify an environmental impact report or adopt a mitigated negative declaration for a project with a significant impact on an identified tribal cultural resource only if one of the following occurs:

(1) The consultation process between the California Native American tribe and the lead agency has occurred as provided in Sections 21080.3.1 and 21080.3.2 and concluded pursuant to subdivision (b) of Section 21080.3.2.

(2) The California Native American tribe has requested consultation pursuant to Section 21080.3.1 and has failed to provide comments to the lead agency, or otherwise failed to engage, in the consultation process.

(3) The lead agency has complied with subdivision (d) of Section 21080.3.1 and the California Native American tribe has failed to request consultation within 30 days.

(e) If the mitigation measures recommended by the staff of the lead agency as a result of the consultation process are not included in the environmental document or if there are no agreed upon mitigation measures at the conclusion of the consultation or if consultation does not occur, and if substantial evidence demonstrates that a project will cause a significant effect to a tribal cultural resource, the lead agency shall consider feasible mitigation pursuant to subdivision (b) of Section 21084.3.

(f) Consistent with subdivision (c), the lead agency shall publish confidential information obtained from a California Native American tribe during the consultation process in a confidential appendix to the environmental document and shall include a general description of the information, as provided in paragraph (4) of subdivision (c) in the environmental document for public review during the public comment period provided pursuant to this division.

(g) This section is not intended, and may not be construed, to limit consultation between the state and tribal governments, existing confidentiality provisions, or the protection of religious exercise to the fullest extent permitted under state and federal law.

1.5 Historic Resources

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Historic resources are typically structures and properties that make up the historically built environment. Most frequently, these include buildings constructed during the historic period, but historic resources may also include cultural landscapes, objects, places, linear features such as roads or walls, records, or even manuscripts that are historically significant. In general, a property or site must be at least 50 years of age to be considered for an assessment of significance. There are exceptions for properties that are less than 50 years of age that are of exceptional significance.

Significant historic resources qualify as historical resources. In order for a resource to be a significant historical resource pursuant to CEQA, it must meet one of the four significance criteria listed in CEQA Guidelines Section 15064.5(a)(3)(A-D) and retain integrity. Integrity is the authenticity of the resource's physical identity and usually applies to historic resources. Resources must retain enough of their historic character or appearance to be recognizable as historical resources and convey the reasons for their significance. Districts, sites, buildings, structures and objects that retain integrity of location, design, setting, materials, workmanship, feeling, and association, and meet the one or more of the four significance criteria qualify as significant historical resources. Historic properties either retain integrity or they do not. To retain integrity, a historic property should have several of the seven elements of integrity listed above. Guidance for evaluating integrity may be found in National Register Bulletin 15 (https://www.nps.gov/nr/publications/bulletins/nrb15/).

Generally, a historic resource is significant if it meets the significance criteria for listing in the California Register of Historical Resources, whether the resource is formally listed or not. Additionally, historic resources are considered significant if they are listed in or eligible for listing in a local register of historical resources (CEQA Guidelines Section 15064.5(a)(2)). Also, please refer to the document, *Fieldwork and Reporting Guidelines for Cultural Resources* for additional information.

1.5.1 Local Register of Historical Resources

In addition to the California Register of Historical Resources, a resource listed in or eligible for listing in a local register also qualifies as a significant historical resource. CEQA Statute Section 21074(a)(1)(B) and CEQA Guidelines Section 15064.5(a)(2)indicate that resources included in a local register of historical resources are presumed to be significant historical resources. Public Resources Code Section 5020.1(k) provides the following definition of local register of historical resources:

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Local Register of Historical Resources (Public Resources Code Section 5020.1(k))

(k) "Local register of historical resources" means a list of properties officially designated or recognized as historically significant by a local government pursuant to a local ordinance or resolution.

1.5.2 Historic Landmarks Advisory Commissions

Many local jurisdictions have historic landmarks advisory commissions that nominate properties to local registers of historical resources. A designated Landmark is usually preserved and protected by conditions restricting its demolition, removal, alteration, or use. The specific conditions for each landmarked property are usually spelled out in the official resolutions about the property, which finalized the property's Landmark status. Plans for alterations to Landmarks are often required to be reviewed by historic landmarks advisory commissions for approval. A benefit of obtaining Landmark status is the applicability of the provisions of the Historic Building Code, which may waive certain requirements such as those for parking and ADA improvements.

In addition to proposing landmark designation of historic properties or historic landmarks, advisory commissions may also play an important advisory role in the treatment of historic resources in the review of development projects.

1.5.3 Local Historical Resource Surveys

Historical resources listed in or eligible for listing in the California Register of Historical Resources or included in a local register. However, there are some circumstances where a resource identified in a local historical resource survey, but not included in a register, may also be significant. Specifically, historical resources that were identified as significant in an historical resource survey meeting the requirements of 5024.1(g) are presumed to be significant. Local historical resource surveys are previously existing formal inventories and evaluations of multiple historic properties and buildings located in a defined geographic area such as a neighborhood or community. Such surveys must have been carried out pursuant to the criteria listed in Public Resources Code Section 5024.1(g). Although resources identified in such surveys are presumed to be significant historical resources, these criteria are not requirements for determining that a particular resource is significant. These guidelines discuss additional methods for significance determination.

Requirements for Historical Resource Surveys (Public Resources Code Section 5024.1(g))

(g) A resource identified as significant in an historical resource survey may be listed in the California Register if the survey meets all of the following criteria: P21-36 cont.

(1) The survey has been or will be included in the State Historic Resources Inventory.

(3) The survey and the survey documentation were prepared in accordance with office procedures and requirements.

(4) The resource is evaluated and determined by the office to have a significance rating of Category 1 to 5 on DPR Form 523.

(5) If the survey is five or more years old at the time of its nomination for inclusion in the California Register, the survey is updated to identify historical resources which have become eligible or ineligible due to changed circumstances or further documentation and those which have been demolished or altered in a manner that substantially diminishes the significance of the resource.

1.5.4 Historic Districts and Landscapes

Although historic districts and historic landscapes are most commonly encountered in the context of nominations to and listing in the National Register of Historic Places, historical resources as defined by CEQA Guidelines Section 15064.5(a)(3) include "places" and "areas." Also, the definition of tribal cultural resource includes cultural landscapes. A cultural landscape is a geographic area, including both cultural and natural resources and the wildlife or domestic animals therein, associated with a historic event, activity, or person, or exhibiting other cultural or esthetic values. There are four non-mutually exclusive types of cultural landscapes: historic sites, historic designed landscapes, historic vernacular landscapes, and ethnographic landscapes.

Whether formally listed in the National Register of Historic Places or not, places and areas that may qualify as historical resources need to be evaluated and considered in the CEQA process. In the event that a place or area does qualify as a historical resource, CEQA provides little guidance as to their evaluation. Useful guidance may be found in the National Register Bulletins, including but not limited to:

- National Register Bulletin 15- How to apply National Register Criteria for Evaluation
- Bulletin 16- Guidelines for Completing National Register of Historic Places Form
- Bulletin 18- How to Evaluate and Nominate Designed Historic Landscapes
- Bulletin 30- Guidelines for Evaluating and Documenting Rural Historic Landscapes

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2.0 DETERMINING THE SEVERITY OF IMPACTS TO CULTURAL RESOURCES

2.1 Typical Adverse Effects

Significant cultural resources are non-renewable; therefore, they cannot be replaced. The disturbance or alteration of a cultural resource causes an irreversible loss of significant information from the perspective of science and history, and also the loss of sacred places, objects and traditional cultural properties from the perspective of Native Americans and other groups. Regionally, the loss of cultural resources results in the loss of our identity and our connection with the past. More specifically, these losses include the demolition, destruction, relocation, or the material alteration of a cultural resource or its immediate surroundings such that the significance of a cultural resource would be materially impaired. Typical impacts to cultural resources include:

- The non-scientific surface collection or subsurface excavation of an archaeological site, often called pot hunting.
- The destruction of cultural resources through project development (e.g., grading, clearing, demolition, trenching, road and utility construction, staging areas).
- The destruction of cultural resources through off-site improvements (e.g., road construction, utilities expansion, staging areas) associated with project development.
- An increase in development intensity which adversely affects cultural sites or landscapes (e.g., placement of a subdivision within a vacant parcel adjacent to/or surrounding a cultural resource where behavior patterns occur beyond the boundaries of a site).
- The introduction of visual, audible, or atmospheric effects that are out of character with the cultural resource or alter its setting when the setting contributes to the resources' significance (e.g. the construction of a large-scale building, structure, or object that has the potential to cast shadows patterns on a historic structure, intrude into its viewshed, generate substantial noise, or substantially increase air pollution or wind patterns).
- Damage to cultural resources or landscapes by human encroachment resulting in vandalism or site destruction (e.g., graffiti).
- The relocation of a historic structure such that its significance is reduced to a level whereby the resource no longer is considered significant.
- Modifications (e.g., remodeling, alteration, addition, demolition) to a historic resource that is not in conformance with the Secretary of Interior Standards .
- A change in use that is not compatible with the authenticity of a resource (e.g., the use of a historic house as a dollar retail store).

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- Development that changes the significance of a historic structure or the surrounding historic landscape.
- Deterioration of a resource by neglect.

Two types (direct, indirect) of typical adverse effects occur in relation to cultural resources. Direct impacts are caused by and are immediately related to a project. Examples of direct impacts would be the disturbance of an archaeological site by grading, or the demolition of a historic building. Indirect impacts are not immediately related to the project, but they are caused indirectly by a project. An indirect impact is to be considered only if it is a reasonably foreseeable impact that may be caused by the project. An example of an indirect impact would be the placement of trails in open space which has the potential to impact archaeological resources indirectly through the surface collection of artifacts by hikers.

2.2 Guidelines for Determining Impact Significance

CEQA Statute Section 21084.1 and CEQA Guidelines Section 15064.5(b)) define what constitutes substantial adverse change to the significance of an historical resource and that such adverse changes may constitute a significant effect on the environment.

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2.2.1 Substantial Adverse Change to a Historical Resource (CEQA Statute Section 21084.1)

A project that may cause a substantial adverse change in the significance of an historical resource is a project that may have a significant effect on the environment. For purposes of this section, an historical resource is a resource listed in, or determined to be eligible for listing in, the California Register of Historical Resources. Historical resources included in a local register of historical resources, as defined in subdivision (k) of Section 5020.1, or deemed significant pursuant to criteria set forth in subdivision (g) of Section 5024.1, are presumed to be historically or culturally significant for purposes of this section, unless the preponderance of the evidence demonstrates that the resource is not historically or culturally significant. The fact that a resource is not listed in, or determined to be eligible for listing in, the California Register of Historical Resources, not included in a local register of historical resources, or not deemed significant pursuant to criteria set forth in subdivision (g) of Section 5024.1 shall not preclude a lead agency from determining whether the resource may be an historical resource for purposes of this section.

2.2.2 Substantial Adverse Environmental Impact to an Historical Resource (CEQA Guidelines Section 15064.5(b))

(b) A project with an effect that may cause a substantial adverse change in the significance of an historical resource is a project that may have a significant effect on the environment.

(1) Substantial adverse change in the significance of an historical resource means physical demolition, destruction, relocation, or alteration of the resource or its immediate surroundings such that the significance of an historical resource would be materially impaired.

(2) The significance of an historical resource is materially impaired when a project:

(A) Demolishes or materially alters in an adverse manner those physical characteristics of an historical resource that convey its historical significance and that justify its inclusion in, or eligibility for, inclusion in the California Register of Historical Resources; or

(B) Demolishes or materially alters in an adverse manner those physical characteristics that account for its inclusion in a local register of historical resources pursuant to Section 5020.1(k) of the Public Resources Code or its identification in an historical resources survey meeting the requirements of Section 5024.1(g) of the Public Resources Code, unless the public agency reviewing the effects of the project establishes by a preponderance of evidence that the resource is not historically or culturally significant; or

(C) Demolishes or materially alters in an adverse manner those physical characteristics of an historical resource that convey its historical significance and that justify its eligibility for inclusion in the California Register of Historical Resources as determined by a lead agency for purposes of CEQA.

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CEQA Statute Section 21084.2 defines what constitutes substantial adverse changes to the significance of a tribal cultural resource and that such adverse changes may constitute a significant effect on the environment:

2.2.3 Substantial Adverse Change to a Tribal Cultural Resource (CEQA Statute Section 21084.2.)

A project with an effect that may cause a substantial adverse change in the significance of a tribal cultural resource is a project that may have a significant effect on the environment.

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3.0 MITIGATION AND DESIGN CONSIDERATIONS

Cultural resource mitigation measures and design considerations used in the planning approval process depend on the specifics of a project and resources under consideration. A few examples of mitigation measures are provided in Table 1. The kinds of mitigation measures appropriate for archaeological sites are generally different than those appropriate for the historic built environment. This section will provide guidance contained in CEQA. Many lead agencies have policies and standards defining appropriate mitigation measures. Some juridictions have manuals of boilerplate mitigation conditions that may be used as-is or amended to fit the individual circumstances of a project.

Table 1

Examples of Mitigation Measures/Conditions

Resource Type	Typical Measures Applied to Reduce Impacts to Below Significant
Archaeological Resources	Avoidance and Preservation in Place
	Archaeological Open Space Easement
	Data Recovery
	Temporary Fencing
	Site Capping
	Staging Area Limitation for Construction Activities
	Curation of Archaeological Collections[2]
	Agreement by Developer to Mitigation Conditions That Result From Consultation Between the County and a Tribe
	Public Displays/Media

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[2] State guidance is provided by CEQA Guidelines Section 15126.4.

Built Environment	Avoidance and Preservation in Place
	Historic Conservation Easement
	Historic Landscape Screening Plan
	Use, Maintenance, and Repair Easement
	Setback Easement for Lots Adjacent to a Historic Structure
	Historic Landscape Tree Preservation
	Historic Structure Rehabilitation Program
	Regulations of Uses in a Historic Structure
	Curation of Historic Collections
	Staging Area Limitation for Construction Activities
	Landmarking
	Public Displays/Media
	HABS/HAER Documentation, or Documentation Similar to HABS/HAER
	Secretary of Interior's Standards for the Treatment of Historic Properties with Guidelines for Preserving, Rehabilitating, Restoring and Reconstructing Historic Buildings
	Secretary of Interior's Standards for Rehabilitation and Guidelines for Rehabilitating Historic Buildings (Weeks and Grimmer 1995)

The ideal treatment for cultural resources is avoidance of impacts to and preservation in place of the resource. CEQA and the Coastal Act do not require avoidance of cultural resources. However, some lead agencies, such as Counties, have community or regional plans with policies that require avoidance of significant cultural resources if possible. Avoidance measures can be incorporated into project design. However, if a project has the potential to cause a significant adverse change in the significance of an historical or tribal cultural resource, then reasonable efforts must be made to mitigate the impact to a level below significant. Cultural resource mitigation may include data recovery, analysis, interpretation, reporting, and curation of collections and associated documents at a qualified curation facility, at the applicant's cost, thereby preserving what would otherwise have been destroyed and lost due to construction and development activities. The primary guidance on mitigation in the context of a CEQA review of a development project is found in CEQA guidelines Section 15064.5 (see also CEQA Statute Sections 21082.3 and 21083.2):

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3.1 Mitigation (CEQA Guidelines Section 15064.5(b))

(b) A project with an effect that may cause a substantial adverse change in the significance of an historical resource is a project that may have a significant effect on the environment.

(3) Generally, a project that follows the Secretary of the Interior's Standards for the Treatment of Historic Properties with Guidelines for Preserving, Rehabilitating, Restoring, and Reconstructing Historic Building or the Secretary of the Interior's Standards for Rehabilitation and Guidelines for Rehabilitating Historic Buildings (1995), Weeks and Grimmer, shall be considered as mitigated to a level of less than a significant impact on the historical resource.

(4) A lead agency shall identify potentially feasible measures to mitigate significant adverse changes in the significance of an historical resource. The lead agency shall ensure that any adopted measures to mitigate or avoid significant adverse changes are fully enforceable through permit conditions, agreements, or other measures.

(5) When a project will affect state-owned historical resources, as described in Public Resources Code Section 5024, and the lead agency is a state agency, the lead agency shall consult with the State Historic Preservation Officer as provided in Public Resources Code Section 5024.5. Consultation should be coordinated in a timely fashion with the preparation of environmental documents.

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3.2 Mitigation (CEQA Guidelines Section 15126.4(b))

Further detail concerning mitigation measures for historical resources, including both Archaeological and Historic Resources, is provided by CEQA Guidelines Section 15126.4(b):

(b) Mitigation Measures Related to Impacts on Historical Resources.

(1) Where maintenance, repair, stabilization, rehabilitation, restoration, preservation, conservation or reconstruction of the historical resource will be conducted in a manner consistent with the Secretary of the Interior's Standards for the Treatment of Historic Properties with Guidelines for

Preserving, Rehabilitating, Restoring, and Reconstructing Historic Buildings (1995), Weeks and Grimmer, the project's impact on the historical resource shall generally be considered mitigated below a level of significance and thus is not significant.

(2) In some circumstances, documentation of an historical resource, by way of historic narrative, photographs or architectural drawings, as mitigation for the effects of demolition of the resource will not mitigate the effects to a point where clearly no significant effect on the environment would occur.

(3) Public agencies should, whenever feasible, seek to avoid damaging effects on any historical resource of an archaeological nature. The following factors shall be considered and discussed in an EIR for a project involving such an archaeological site:

(A) Preservation in place is the preferred manner of mitigating impacts to archaeological sites. Preservation in place maintains the relationship between artifacts and the archaeological context. Preservation may also avoid conflict with religious or cultural values of groups associated with the site.

(B) Preservation in place may be accomplished by, but is not limited to, the following:

1. Planning construction to avoid archaeological sites;
2. Incorporation of sites within parks, greenspace, or other open space;
3. Covering the archaeological sites with a layer of chemically stable soil before building tennis courts, parking lots, or similar facilities on the site.
4. Deeding the site into a permanent conservation easement.

(C) When data recovery through excavation is the only feasible mitigation, a data recovery plan, which makes provisions for adequately recovering the scientifically consequential information from and about the historical resource, shall be prepared and adopted prior to any excavation being undertaken. Such studies shall be deposited with the California Historical Resources Regional Information Center. Archeological sites known to contain human remains shall be treated in accordance with the provisions of Section 7050.5 Health and Safety Code. If an artifact must be removed

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during project excavation or testing, curation may be an appropriate mitigation.

(D) Data recovery shall not be required for an historical resource if the lead agency determines that testing or studies already completed have adequately recovered the scientifically consequential information from and about the archaeological or historical resource, provided that the determination is documented in the EIR and that the studies are deposited with the California Historical Resources Regional Information Center.

The Secretary of the Interior's Standards for the Treatment of Historic Properties with Guidelines for Preserving, Rehabilitating, Restoring, and Reconstructing Historic Buildings (1995), has recently been updated and may be found at https://www.nps.gov/tps/standards/treatment-guidelines-2017.htm.

3.3 Tribal Cultural Resource Mitigation

CEQA Statute Section 21084.3 identifies appropriate mitigation for a Tribal Cultural Resource:

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3.3.1 Mitigation for Tribal Cultural Resources (CEQA Statute Section 21084.3)

(a) Public agencies shall, when feasible, avoid damaging effects to any tribal cultural resource.

(b) If the lead agency determines that a project may cause a substantial adverse change to a tribal cultural resource, and measures are not otherwise identified in the consultation process provided in Section 21080.3.2, the following are examples of mitigation measures that, if feasible, may be considered to avoid or minimize the significant adverse impacts:

(1) Avoidance and preservation of the resources in place, including, but not limited to, planning and construction to avoid the resources and protect the cultural and natural context, or planning greenspace, parks, or other open space, to incorporate the resources with culturally appropriate protection and management criteria.

(2) Treating the resource with culturally appropriate dignity taking into account the tribal cultural values and meaning of the resource, including, but not limited to, the following:

(A) Protecting the cultural character and integrity of the resource.

(B) Protecting the traditional use of the resource.

(C) Protecting the confidentiality of the resource.

(3) Permanent conservation easements or other interests in real property, with culturally appropriate management criteria for the purposes of preserving or utilizing the resources or places.

(4) Protecting the resource.

3.4 Treatment of Native American Human Remains

CEQA Guidelines Section 15064.5(d) addresses development of an agreement between the applicant and the appropriate Native Americans regarding treatment of human remains with appropriate dignity in circumstances where an initial study identifies the existence or probable likelihood of Native American human remains within the project.

3.4.1 Human Remains (CEQA Guidelines Section 15064.5(d))

(d) When an initial study identifies the existence of, or the probable likelihood, of Native American human remains within the project, a lead agency shall work with the appropriate Native Americans as identified by the Native American Heritage Commission as provided in Public Resources Code SS5097.98. The applicant may develop an agreement for treating or disposing of, with appropriate dignity, the human remains and any items associated with Native American burials with the appropriate Native Americans as identified by the Native American heritage Commission. Action implementing such an agreement is exempt from:

(1) The general prohibition on disinterring, disturbing, or removing human remains from any location other than a dedicated cemetery (Health and Safety Code Section 7050.5).

(2) The requirement of CEQA and the Coastal Act.

3.4.2 Accidental Discovery of Human Remains (CEQA Guidelines Section 15064.5(e))

CEQA Guidelines Section 15064.5 (e) specifically addresses what to do in the event that human remains are accidentally discovered in any location other than a dedicated cemetery:

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(e) In the event of an accidental discovery or recognition of any human remains in any location other than a dedicated cemetery, the following steps should be taken:

(1) There shall be no further excavation or disturbance of the site or any nearby area reasonably suspected to overlie adjacent human remains until:

(A) The coroner of the county in which the remains are discovered must be contacted to determine that no investigation of the cause of death is required, and

(B) If the coroner determines the remains to be Native American:

1. The coroner shall contact the Native American Heritage Commission within 24 hours.

2. The Native American Heritage Commission shall identify the person or persons it believes to be the most likely descended from the deceased Native American.

3. The most likely descendent may make recommendation to the landowner or the person responsible for the excavation work, for means of treating or disposing of, with appropriate dignity, the human remains and any associated grave goods as provided in Public Resources Code Section 5097.98, or

(2) Where the following conditions occur, the landowner or his authorized representative shall rebury the Native American human remains and associated grave goods with appropriate dignity on the property in a location not subject to further subsurface disturbance.

(A) The Native American Heritage Commission is unable to identify a most likely descendent or the most likely descendent failed to make a recommendation within 48 hours after being notified by the commission.

(B) The descendent identified fails to make a recommendation; or

(C) The landowner or his authorized representative reject the recommendation of the descendent, and the mediation by

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the Native American Heritage Commission fails to provide measures acceptable to the landowner.

3.5 Accidental Discovery of Non-Human Remain Archaeological Materials During Construction

CEQA Guidelines Section 15064.5 (f) specifically addresses provisions a lead agency should make regarding accidental discovery of historical or unique archaeological resources during construction.

3.5.1 Accidental Discovery of Historical or Unique Archaeological Resources (CEQA Guidelines Section 15064.5(f))

(f) As part of the objectives, criteria, and procedures required by Section 21082 of the Public Resources Code, a lead agency should make provisions for historical or unique archaeological resources accidentally discovered during construction. These provisions should include an immediate evaluation of the find by a qualified archaeologist. If the find is determined to be an historical or unique archaeological resource, contingency funding and a time allotment sufficient to allow for implementation of avoidance measures or appropriate mitigation should be available. Work could continue in other parts of the building site while historical or unique archaeological resource mitigation takes place.

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3.6 Limitations on Mitigation for Unique Archaeological Resources

The following is the section of the CEQA Statute that establishes limitations on the time and money that can be spent evaluating and mitigating unique archaeological resources. These limitations are not applicable to historical resources and are rarely applied. See Section 1.3.2 of this document for additional discussion.

3.6.1 Archaeological Resources; Determination of effect of Project; EIR Or Negative Declaration; Mitigation Measures (CEQA Statute Section 21083.2.)

(a) As part of the determination made pursuant to Section 21080.1, the lead agency shall determine whether the project may have a significant effect on archaeological resources. If the lead agency determines that the project may have a significant effect on unique archaeological resources, the environmental impact report shall address the issue of those resources. An environmental impact report, if otherwise necessary, shall not address the issue of nonunique archaeological resources. A negative declaration shall be issued with respect to a project if, but for the issue of nonunique archaeological resources, the negative declaration would be otherwise issued.

(b) If it can be demonstrated that a project will cause damage to a unique archaeological resource, the lead agency may require reasonable efforts to be made to permit any or all of these resources to be preserved in place or left in an undisturbed state. Examples of that treatment, in no order of preference, may include, but are not limited to, any of the following:

(1) Planning construction to avoid archaeological sites.

(2) Deeding archaeological sites into permanent conservation easements.

(3) Capping or covering archaeological sites with a layer of soil before building on the sites.

(4) Planning parks, greenspace, or other open space to incorporate archaeological sites.

(c) To the extent that unique archaeological resources are not preserved in place or not left in an undisturbed state, mitigation measures shall be required as provided in this subdivision. The project applicant shall provide a guarantee to the lead agency to pay one-half the estimated cost of mitigating the significant effects of the project on unique archaeological resources. In determining payment, the lead agency shall give due consideration to the in-kind value of project design or expenditures that are intended to permit any or all archaeological resources or California Native American culturally significant sites to be preserved in place or left in an undisturbed state. When a final decision is made to carry out or approve the project, the lead agency shall, if necessary, reduce the specified mitigation measures to those which can be funded with the money guaranteed by the project applicant plus the money voluntarily guaranteed by any other person or persons for those mitigation purposes. In order to allow time for interested persons to provide the funding guarantee referred to in this subdivision, a final decision to carry out or approve a project shall not occur sooner than 60 days after completion of the recommended special environmental impact report required by this section.

(d) Excavation as mitigation shall be restricted to those parts of the unique archaeological resource that would be damaged or destroyed by the project. Excavation as mitigation shall not be required for a unique archaeological resource if the lead agency determines that testing or studies already completed have adequately recovered the scientifically consequential

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information from and about the resource, if this determination is documented in the environmental impact report.

(e) In no event shall the amount paid by a project applicant for mitigation measures required pursuant to subdivision (c) exceed the following amounts:

(1) An amount equal to one-half of 1 percent of the projected cost of the project for mitigation measures undertaken within the site boundaries of a commercial or industrial project.

(2) An amount equal to three-fourths of 1 percent of the projected cost of the project for mitigation measures undertaken within the site boundaries of a housing project consisting of a single unit.

(3) If a housing project consists of more than a single unit, an amount equal to three-fourths of 1 percent of the projected cost of the project for mitigation measures undertaken within the site boundaries of the project for the first unit plus the sum of the following:

(A) Two hundred dollars ($200) per unit for any of the next 99 units.

(B) One hundred fifty dollars ($150) per unit for any of the next 400 units.

(C) One hundred dollars ($100) per unit in excess of 500 units.

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(f) Unless special or unusual circumstances warrant an exception, the field excavation phase of an approved mitigation plan shall be completed within 90 days after final approval necessary to implement the physical development of the project or, if a phased project, in connection with the phased portion to which the specific mitigation measures are applicable. However, the project applicant may extend that period if he or she so elects. Nothing in this section shall nullify protections for Indian cemeteries under any other provision of law.

(g) As used in this section, "unique archaeological resource" means an archaeological artifact, object, or site about which it can be clearly demonstrated that, without merely adding to the current body of knowledge, there is a high probability that it meets any of the following criteria:

(1) Contains information needed to answer important scientific research questions and that there is a demonstrable public interest in that information.

(2) Has a special and particular quality such as being the oldest of its type or the best available example of its type.

(3) Is directly associated with a scientifically recognized important prehistoric or historic event or person.

(h) As used in this section, "nonunique archaeological resource" means an archaeological artifact, object, or site which does not meet the criteria in subdivision (g). A nonunique archaeological resource need be given no further consideration, other than the simple recording of its existence by the lead agency if it so elects.

(i) As part of the objectives, criteria, and procedures required by Section 21082 or as part of conditions imposed for mitigation, a lead agency may make provisions for archaeological sites accidentally discovered during construction. These provisions may include an immediate evaluation of the find. If the find is determined to be a unique archaeological resource, contingency funding and a time allotment sufficient to allow recovering an archaeological sample or to employ one of the avoidance measures may be required under the provisions set forth in this section. Construction work may continue on other parts of the building site while archaeological mitigation takes place.

(j) This section does not apply to any project described in subdivision (a) or (b) of Section 21065 if the lead agency elects to comply with all other applicable provisions of this division. This section does not apply to any project described in subdivision (c) of Section 21065 if the applicant and the lead agency jointly elect to comply with all other applicable provisions of this division.

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(k) Any additional costs to any local agency as a result of complying with this section with respect to a project of other than a public agency shall be borne by the project applicant.

(l) Nothing in this section is intended to affect or modify the requirements of Section 21084 or 21084.1.

Review of Soil Corrosivity Testing for General Building Materials

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Abstract

This presentation will explain what corrosion engineers need to know to develop their corrosion control recommendations for common construction materials used in underground infrastructure to avoid costly future failures. The goal of a corrosion study is to know the corrosivity of the soil at the depth where infrastructure will be installed. Soil corrosivity can change dramatically per depth and location. Typically, builders rely on geotechnical engineers to provide soil reports which can consist of 100 pages of paragraphs describing the loads that the soils can support, the site's likelihood for landslides, the potential for seismic damage, and any potential pollution dangers or underground gas dangers. Of those 100 pages, there, may be a quarter page paragraph about soil corrosivity based upon one sample that was collected at the surface for a site as large as 20 acres. In the United States, geotechnical engineers rely on corrosion control recommendations described in American Association of State Highway and Transportation Officials (AAHSTO), State Transportation Departments such as Cal Trans, and American Concrete Institute (ACI). Very often by recommendation of these publications, no chemical analysis is performed if soil minimum resistivity is less than 1,100 ohm-cm. Every material has its weakness. Aluminum alloys, galvanized/zinc coatings, and copper alloys do not survive well in very alkaline or very acidic pH environments. Copper and brasses do not survive well in high nitrate or ammonia environments. Steels and iron do not survive well in low soil resistivity and high chloride environments. High chloride environments can even overcome and attack steel encased in normally protective concrete. Concrete does not survive well in high sulfate environments. And nothing survives well in high sulfide and low redox potential environments with corrosive bacteria. This is why Project X Corrosion Engineering tests for these eight factors to determine a soil's corrosivity towards various construction materials and wish geotechnical engineers would do so too. As general construction materials include concrete, steel, iron, stainless steel, copper, brass, aluminum, zinc coatings, and other materials, it is this author's opinion that geotechnical engineers should always have a corrosion engineer, familiar with soil corrosivity and material science, write their corrosion control recommendation paragraphs.

Keywords: General construction materials; bacteria, MIC, soil resistivity, water soluble ions

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Introduction

The goal of a corrosion study is to know the corrosivity of the soil at the depth where infrastructure will be installed. Soil corrosivity can change dramatically per depth and location. Typically, builders rely on geotechnical engineers to provide soil reports which can consist of 100 pages of paragraphs describing the loads that the soils can support, the site's likelihood for landslides, the potential for seismic damage, and any potential pollution dangers or underground gas dangers. Of those 100 pages, there, may be a quarter page paragraph about soil corrosivity based upon one sample that was collected at the surface for a site as large as 20 acres. The sample is typically tested for minimum resistivity, water soluble salts such as sulfates, water soluble chlorides, and pH by geotechnical engineers to evaluate corrosivity but sulfate testing is the only one required to be tested per the international building code. In the United States, geotechnical engineers rely on corrosion control recommendations described in American Association of State Highway and Transportation Officials (AAHSTO), State Transportation Departments such as Cal Trans, and American Concrete Institute (ACI). Very often by recommendation of these publications, no chemical analysis is performed if soil minimum resistivity is less than 1,100 ohm-cm [1] [2] [3] [4], thus the soil is categorized as non-corrosive. Water soluble sulfate is the only required test for general construction for the sake of choosing the proper concrete type. [5] These recommendations focus on evaluating soil so that the correct concrete mix is chosen and to determine if a corrosion engineer should be contacted. Unfortunately, the materials mostly protected by these recommendations are concrete and steel. General construction materials will consist of a variety of materials each with a different corrosion weakness. [6] [7] [8] [9] [10] [11] [12] [13] [14] [15] [16] [17] As general construction materials include concrete, steel, iron, stainless steel, copper, brass, aluminum, zinc coatings, and other materials, it is this author's opinion that geotechnical engineers should always have a corrosion engineer, familiar with soil corrosivity and material science, write their corrosion control recommendation paragraphs.

As of 2018 Cal Trans Corrosion Guidelines, for structural elements, a site is considered corrosive if one or more of the following conditions exist for the representative soil/water sample taken from the site [1]:

- Soil/Water with less than 1,100 ohm-cm resistivity must be tested for chloride and sulfates
- Chloride concentration is 500 ppm or greater
- Sulfate concentration is 1,500 ppm or greater
- pH is 5.5 or less

Deciding on the correct amount of due diligence in evaluating a site can be a mystery to investors and developers who are not themselves experts in corrosion or familiar with the cost of future corrosion failures and construction defect lawsuits.

I recommend collection of soil samples at every acre of a site plan. Collecting in this grid pattern will allow identifying corrosion hotspots at a site enabling the corrosion engineer to isolate expensive corrosion control recommendations to the hotspots. Our clients have told us that this protocol often saves them US$5,000 per residential lot. The savings are significantly greater than the cost of the corrosion study itself. Pricing for a corrosion study is often US$150

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per soil sample plus US$1,200 for the corrosion control recommendations report plus other indirect costs if client requires extra paperwork, insurance, or meetings.

Eight different factors in soil which affect the corrosion rates of general construction materials such as steel, copper, brass, galvanized steel, concrete, iron, stainless steels, and aluminum are recommended to be tested. These are minimum resistivity, pH, water soluble sulfates, chlorides, ammonia, nitrate, sulfide, and REDOX potential [13]. With this information, the situation for each material buried will be known and corrosion control recommendations for each material can be provided.

Every material has its weakness. Aluminum alloys, galvanized/zinc coatings, and copper alloys do not survive well in very alkaline or very acidic pH environments. Copper and brasses do not survive well in high nitrate or ammonia environments. Steels and iron do not survive well in low soil resistivity and high chloride environments. High chloride environments can even overcome and attack steel encased in normally protective concrete. Concrete does not survive well in high sulfate environments. And nothing survives well in high sulfide and low redox potential environments with corrosive bacteria. This is why Project X tests for these 8 factors to determine a soil's corrosivity towards various construction materials and wish geotechnical engineers would do so too.

It should not be forgotten that import soil should also be tested for all factors to avoid making your site more corrosive than it was to begin with. Composite samples, those samples that combine samples from different depths and locations, should not be used in corrosion studies. Composite samples are typically used in agriculture to determine a field's fertilizer mix design. The field will eventually be thoroughly plowed and mixed.

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Experimental

To study the correlation of corrosive elements and soil minimum resistivity as assumed in Caltrans 2018 Corrosion Guidelines, we compared data of hundreds of soil tests performed at Project X Corrosion Engineering. The soil samples were tested for the following:

1. Minimum electrical resistivity per ASTM G187
2. Water Soluble Sulfates per ASTM D516
3. Water Soluble Chlorides per ASTM D512B
4. Water Soluble Nitrates per SM 4500-NO3-E
5. Water Soluble Ammonia per SM 4500-NH3-C
6. Water Soluble Sulfide per SM 4500-S2-D
7. Oxidation Reduction Potential per ASTM G200
8. pH per ASTM G51

Soil samples were prepared per CalTrans methods described in CTM 643, 417, & 422 in which soil is dried below 140F (60C), sieved thru a #8 (2.36 mm) sieve, with 1:3 extract of 100 grams of sieved soil to 300 mL water.

Seven graphs were created to search for correlation of elements versus minimum resistivity such as (1) Min-Resistivity vs Sulfates PPM, (2) Min-Resistivity vs Chlorides PPM, (3) Min-Resistivity vs Ammonia PPM, (4) Min-Resistivity vs Nitrates PPM, (5) Min-Resistivity vs Sulfides PPM, (6) Min-Resistivity vs Oxidation Reduction Potential, (7) Min-Resistivity vs pH.

Per generally accepted recommendations, the following graph would be expected.

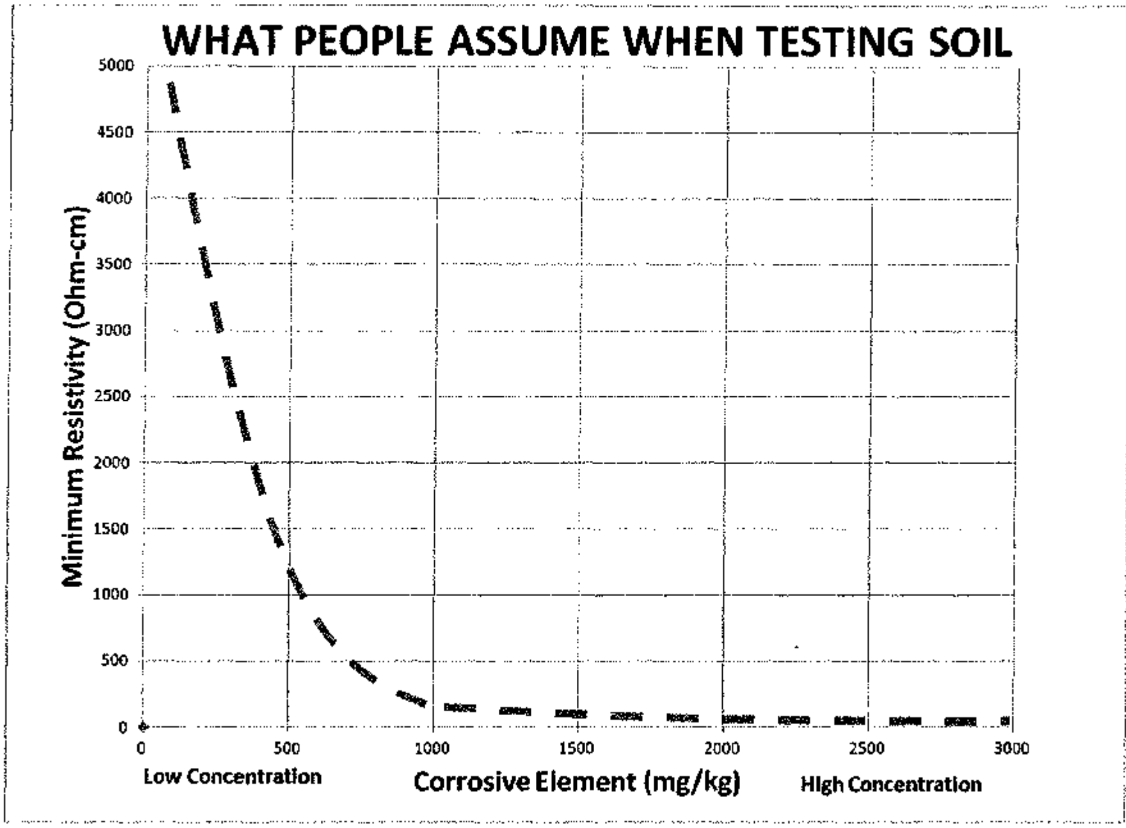

Figure 1 – Assumed trend of Min-Resistivity versus Corrosive element concentration

Results

The following graphs were created from 482 soil tests from various locations across the United States. The red vertical dash lines represent concentration limits generally accepted by corrosion engineers per various publications. The green dash line represents the assumed corrosive element concentration if soil minimum resistivity is the determining factor as is generally explained in most agency corrosion guidelines and accepted by most cathodic protection engineers.

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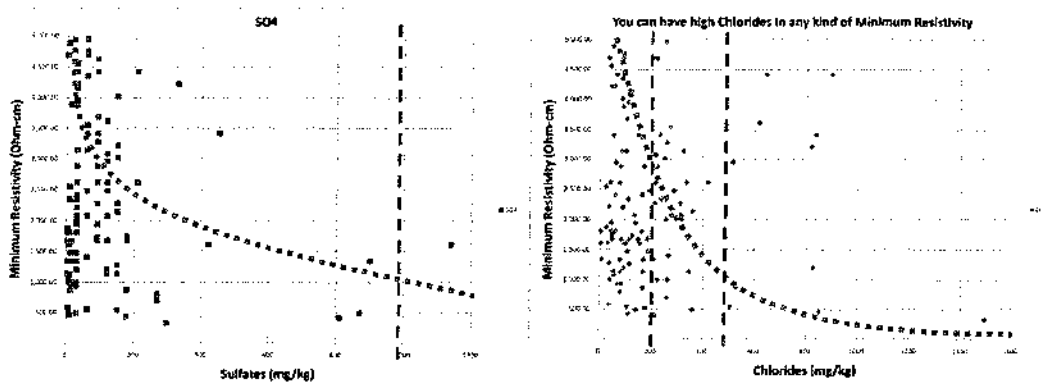

Figure 2 - Min-Resistivities versus Sulfate (left) versus Chloride (right). Overlaid generally assumed trendline from Figure 1.

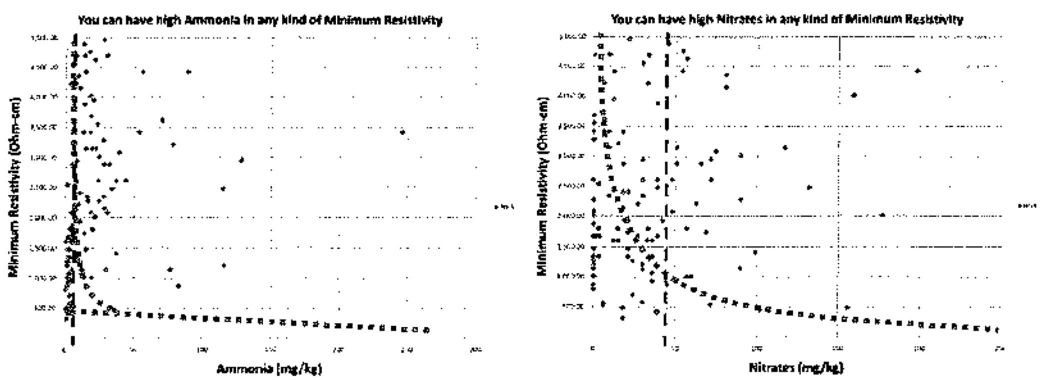

Figure 3 - Min-Resistivities versus Sulfate (left) versus Chloride (right). Overlaid generally assumed trendline from Figure 1.

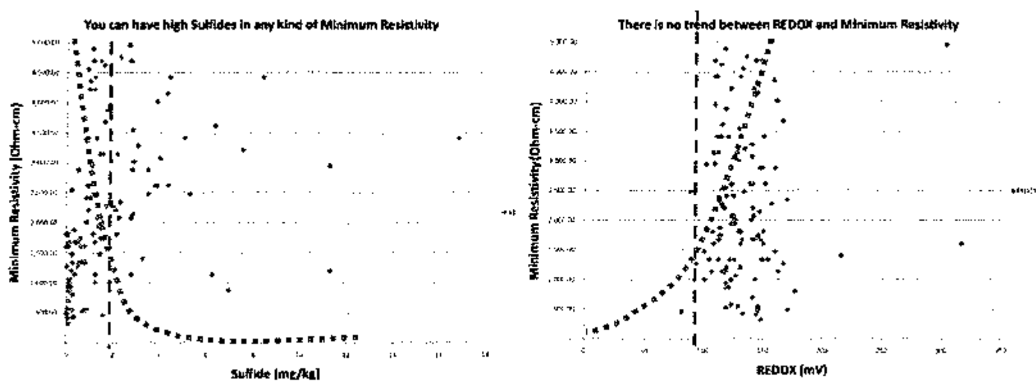

Figure 4 - Min-Resistivities versus Sulfate (left) versus Chloride (right). Overlaid generally assumed trendline from Figure 1.

P21-36
cont.

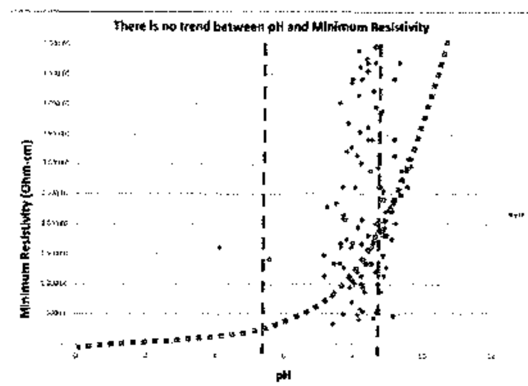

Figure 5 - Min-Resistivities versus Sulfate. Green dashed line represents general expectations per current agency corrosion guidelines.

Discussion

As can be seen in the graphs presented, there is no significant correlation between the assumed corrosive element concentrations versus the soil minimum resistivity in any of the graphs.

The lack of awareness of these facts places geotechnical engineers who provide preliminary corrosion results into dangerous liability. The industry's desire to keep material selection and corrosion control recommendations as simple as possible has led to oversimplification of material selection leading to cycles of construction defect lawsuits due to corrosion that could have been avoided had proper corrosion studies been carried out. P21-36 cont.

All corrosion engineers will agree that in order for the soil side corrosion to occur, there must be moisture present to allow ion exchange in the oxidation reduction reactions. Thus many people assume that if there is no recent rain, the soil must be dry. People who camp outdoors or wake up early in the morning remember that there is dew falling to the ground every night. Most people remember that pipes carrying cold fluids such as water, form condensate on pipe exterior surfaces but they forget that condensate can also form underground.

As corrosion is a surface phenomenon, even a thin layer of moist corrosive soil on a material is enough to cause corrosion. This is why measurement of minimum resistivity is important as opposed to simply reading as-received soil resistivity or in-situ Wenner 4 pin soil resistivity per ASTM G57. In-situ Wenner 4 pin resistivity can change seasonally depending on the weather and moisture in the ground. This reading alone can be misleading for a corrosivity study because condensation or minor water leaks will occur underground along pipe surfaces creating a saturated soil environment in the trench along infrastructure surfaces. This is why minimum or saturated soil resistivity measurements of soil from depth of infrastructure are more important than as-received resistivities. Wenner 4 pin testing is more important and properly applied for the design of electrical grounding systems and cathodic protection system anode beds.

All corrosion engineers also agree that corrosion reactions occur most when oxygen is plentiful. Thus expansive soils which can form cracks as deep as five feet deep will allow oxygen to penetrate deeper into soils.

Shallow underground water tables can lead to underground splash zones as well as high humidity under large structures. These factors should also be taken into consideration when selecting materials and making corrosion control recommendations.

Conclusions

The limited testing required by today's building code focuses too much on steel or concrete ignoring other general construction materials such as copper, brass, aluminium, and stainless steels. These other materials are affected by other corrosive elements commonly not required to be tested by governing building codes. To aid builders and geotechnical engineers in deciding what soil factors should be tested at a construction site, the following table was created.

Table 1

What Makes an Environment Unsafe/Corrosive to a Material?								
	Full Corrosion Series Soil Test							
	Typical Geotech Test Order						Bacteria	
Material	Low Resistivity (Ω-cm)	pH	SULFATE	CHLORIDE	NITRATE	AMMONIA	Redox (mV)	SULFIDE
Copper & Brass	X	X		X	X	X		
Steel & Iron	X	X		X	X		X	X
Stainless Steel	X			X	X		X	X
Aluminum Alloys	X	X	X	X	X	X	X	X
Concrete (no rebar)		X	X				X	X
Galvanized Steel	X	X	X	X	X		X	X

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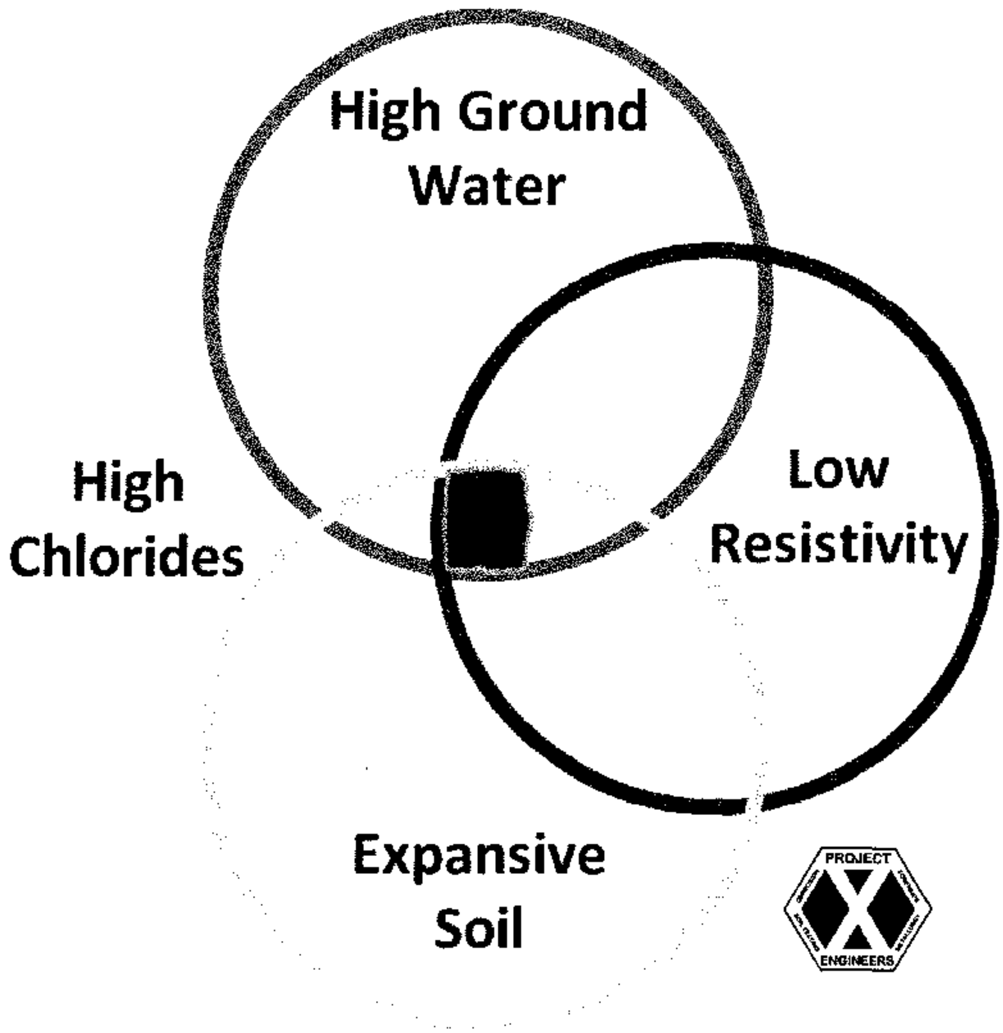

Figure 6 – Most undesirable combinations

P21-36 cont.

Acknowledgements

All corrosion researchers and publishers are to be thanks for adding to the science of corrosion control as well as the California Ridgecrest earthquake that occurred July 5th, 2019 helping me stay awake to write this paper.

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[3] American Association of State Highway and Transportation Officials (AASHTO), T 288, Standard Method of Test for Determining Minimum Laboratory Soil Resistivity, Washington DC: American Association of State Highway and Transportation Officials (AASHTO), 2012.

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