ORAU-142

A Proceedings:

Impacts of Transmission Lines on Birds in Flight

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ORAU-142

Impacts of Transmission Lines on Birds in Flight

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Preface

Progress to alleviate the national and world energy problem will come as individual issues are identified and acceptable solutions implemented. One of the specific issues to emerge in the last few years in the United States and one that is delaying construction of electrical distribution grids is the real—or potential—impact on birds in flight. Therefore, the National Power Plant Team, Office of Biological Services, U.S. Fish and Wildlife Service, requested ORAU to organize and convene a workshop of knowledgeable experts to examine this issue and options for dealing with it. The participants are listed at the end of this report.

Dr. Stanley Anderson ably served as Conference Chairman. He was assisted by a Steering Committee consisting of Kenneth Hoover, Philip Johnson, Roger Kroodsma, and Robert Welford. Prepared papers were invited and are included here as authored contributions. Five working groups were organized, and we express appreciation to the following individuals for their service as chairmen or rapporteurs of these sessions:

Bird Behavior—Sidney Gauthreaux, Jr.

Habitat—James Tanner

Mitigation—Daniel Willard and Larry Thompson

Management Options—Spencer Amend

Research Needs—Milton Friend

Their efforts in capturing the often spirited discussion and recording both agreement and lack of agreement—a difficult proposition at best—are appreciated. All of the authors are indebted to David Armbruster, ORAU, for editorial assistance.

Funds for support of this workshop were provided by the Office of Biological Services, U.S. Fish and Wildlife Service, and by the Environmental Protection Agency. Clearly, the ideas and suggestions expressed in this report do not represent or imply any policy or position on behalf of sponsoring agencies or participants' institutions.

Philip L. Johnson
Executive Director, ORAU

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Introduction

Kenneth Hoover
U.S. Fish and Wildlife Service

The amount of land used for electric power generation and transmission in the United States is expected to triple during the next 30 years. Current and future patterns of electric power transmission and distribution lines across the country will increase the potential for interference with the daily, seasonal, and migrational movements of birds.

Habitats and flight pathways of birds are unavoidably altered by the presence of overhead powerlines and associated structures. Migration and distribution patterns will also be affected if birds avoid areas adjacent to these structures. The overall impact of transmission lines on bird movements, however, is not fully understood, although it has been the subject of an increasing amount of research in recent years. While there are many documented cases of birds of prey, waterfowl, and other large birds found dead or injured near transmission lines and towers, the exact cause of death or injury has often been indeterminable. Virtually no data are available on the impacts of transmission lines on smaller birds.

Biologists and other decisionmakers are often called upon to determine if proposed lines will, or existing lines do, cause bird collisions, or whether nearby habitats may be affected by the presence of such lines. Frequently they must rely on inadequate information to address these problems or attempt to predict such impacts in a variety of experimental ways.

Currently, proposed sites for transmission lines are evaluated on the basis of several considerations. Among these are

1. Proximity of these sites to certain types of habitat
2. Probability of seasonal inclement weather
3. Use of these areas by birds during the migratory, breeding, and wintering seasons
4. Use of these areas by individual species and the behavioral characteristics of those species
5. Design of proposed transmission lines and towers
6. Possible mitigation to reduce the impacts of birds in flight

The lack of a unified body of data from previous research and the absence of a universal approach to study the problem have hindered its resolution. The U.S. Fish and Wildlife Service and others have frequently faced the question of impacts of transmission lines on birds; however, no one individual or agency has been able to answer this question adequately. Furthermore, much existing information is not specific to transmission line impacts.

To review the current state of knowledge on this subject and to draw together sources of information, the National Power Plant Team (U.S. Fish and Wildlife Service) recently sponsored a "Workshop on the Impacts of Transmission Lines on Birds in Flight." Three major questions were addressed during this workshop:

1. What is the magnitude of the problem of birds striking transmission lines and related structures?

2. What are possible short-term solutions to this problem?
3. What are the best approaches to use in the future to solve this problem?

Resolution of these questions will enable those groups concerned with transmission line impacts on birds, such as the U.S. Fish and Wildlife Service and other federal conservation and regulatory agencies, state fish and game commissions, electric utility companies, and conservation organizations, to more accurately predict such impacts.

Pooling of information was facilitated by the presence of professionals from diverse technical backgrounds representing many of the organizations mentioned above. A group discussion on each major issue was followed by working sessions during which participants combined their expertise to draw specific conclusions and develop recommendations. Although participants represented groups with different interests and goals, much valuable information on organizational structure, hierarchy, and responsibility was exchanged and enhanced communication between these organizations.

Finally, the workshop has stimulated the formulation of research plans and coordination of research efforts resulting in studies utilizing similar research techniques. Thus, the first step has been taken toward creating a data base which will be useful in answering the three questions the workshop addressed.

Keynote Address

The Impact of Transmission Lines on Birds (and Vice Versa)

Daniel E. Willard
School of Public and Environmental Affairs
Indiana University

There is no controversy about whether birds collide with transmission lines. Almost anyone who watches birds in the vicinity of lines has seen a collision. Gary Krapu (1974) has reported several well-documented cases in North Dakota, and Bill Anderson (in press) has done the same for Illinois. The question turns on the importance or value of the fatalities. Anderson and Roger Kroodsma (1977) have questioned the importance of the collisions in terms of the bird populations. Roy Hamilton asks, further, how much is it worth to try to avoid collisions.*

Transmission lines seem to have two kinds of effects on birds: physical and electromagnetic. I will discuss only the physical in terms of collisions. (There is good evidence that birds are electrocuted by towers and lines, but the number seems small. Some authors have reported navigational disorientation and physiological damage resulting from birds' passing through electric fields. The evidence is inconclusive, but, given the increasing number of ever higher voltage powerlines, it would appear that serious and careful study by unbiased—or several equally, but

* Roy Hamilton 1977: personal communication.

oppositely, biased—groups is called for. The importance of electrical effects needs discussion here.

Several authors have reported on the fatality rate due to collisions. Stout and Cornwell (1976) summarized the causes of death reported in all the literature they could get. They estimated that 0.1 percent of the deaths were caused by collisions. The largest category of collision was transmission lines of one kind or another. Roger Kroodsma (1977) reported that less than 1 percent of the nonhunting waterfowl deaths in the vicinity of the Red Wing Minnesota Power Plant were powerline related. He, like others, points out the much higher mortality rate due to botulism and, of course, hunting. Of the waterfowl populations he studied at a power plant in Southern Illinois, Anderson (in press) reported 0.4 percent mortality due to powerlines. Over a period of a a decade, biologists at the Patuxent Wildlife Research Center have analyzed all the dead bald eagles they could get. In a series of articles (herein called Patuxent Eagle Papers) authored by several researchers, about 6 percent to 8 percent of the bald eagle deaths were due to transmission lines. At least twice as many were shot.

However, these sorts of calculations do not tell the whole story for three reasons. First, fatalities and injuries are inadequately reported. Second, a number of species may have higher death rates that, because of their small populations, do not show in these data but, because of their small numbers, are nonetheless important. Third, some species are more biologically sensitive at specific places and seasons.

Before continuing with these points in detail, I want to describe two kinds of significance: biological and political. Biologists generally think in terms of birth rates, death rates, population growth rates, carrying capacity, and so on. A particular form of mortality becomes important when it affects the ability of a species to survive or maintain itself. We use bag limits to regulate the death rate of game species to maintain healthy populations. For example, about one-third of all pintails are killed by hunters every year. In the Pacific Flyway, that means hunters will kill between 1 and 1.5 million pintails each year. They will take home only about one-third of those because many will die of lead poisoning and some cripples will not be recovered by hunters. In any case, if about a thousand pintails run into a transmission line, it does not make much difference to the survival of the species; the loss of a single California condor or whooping crane may have considerable biological significance.

Now, take those thousand dead pintails and place them so that some hunter or environmental group finds them and calls the governor, the police, the national guard, or the media—that is political significance. Change the pintails to a species with an even wider constituency, such as Canada geese, and the political significance increases. Game species have a greater clout in some ways than rare and endangered species, even though the biological threat to the latter is greater.

A few years ago I reviewed the literature on bird collisions with various obstacles. While much of the data was circumstantial, people reported dead, usually maimed, birds under or near television towers, bridges, transmission lines, fences, lighted buildings, unlighted buildings, trolleys, the Cliffs of Dover, moving vans, airplanes, steam shovels, fire towers, roller coasters (lighted and unlighted), smokestacks, radar antennas, ships, grain elevators, and even a mounted horseman. There are surely other obstacles. The amazing thing is not that there are so many deaths or maimings but that there are so few.

The literature reports collisions for about 280 species representing almost all taxa (penguins, for example, are not represented). Swans, pelicans, cranes, and eagles are reported in much greater numbers than their populations would suggest. Either big, strikingly marked birds are easier to find and are more noteworthy or they have more collisions per individual. In intensive studies of television towers, it is obvious that passerines are not immune.

At first blush, I thought that regular, intensive dead bird searches under obstacles would reveal some reliable information about the risk to bird populations from these obstacles. This reasoning is particularly seductive for a linear net or fence like a transmission line. It seems so simple to walk along under the lines looking for downed birds.

Most birds that strike a powerline do not fall directly beneath it and do not get counted, however. The majority fly off and at some distance from the line either recover or die. Althouth I have no evidence, I suspect the crippling and recovery rates vary with the nature of the line, species, and behavior at the time. I have seen a number of such bird collisions with lines and have never seen a bird come down, which leads me to believe proportionally much greater numbers hit and run. There is no way I know to estimate what happens to these birds.

Assuming there is a dead bird somewhere, probably no one looks for it. (While the literature tells us there is an agency which records the falling of each sparrow, that agency has not seen fit to make its/his/her data available to me.) It is safe to say most nongame bird deaths are unrecorded. Again, I cannot quantify further.

Suppose someone looks. What are the odds he will find a bird in the area he searches? Bill Anderson's paper (in press) is most revealing. Dogs increase the likelihood of finding downed birds. Anderson also used boats and an organized search team. However, when tested against planted birds, his crew found only 58 percent of the birds. Depending on the terrain and size and coloration of the birds, I suspect discovery would vary considerably.

While the literature is replete with reports of dead birds under lines, it is not always clear how the birds died. Unfortunately, in our Oregon study (Willard and Willard in press), waterfowl chose to succumb to lead poisoning, botulism, shot wounds, and other undetermined causes under our study lines.

Our studies did not show, nor is there literature that indicates, whether removal by scavengers is an important factor. In summary, so far it appears that dead bird studies, even of game species, are inconclusive enough to limit their usefulness as predictive tools.

I mentioned above that some species have such a small population that the absolute number of deaths may be small but highly important to the particular population. Louise Young (1975) reported on the powerline induced deaths of 30 mute swans over 15 years. This population on the Jordan River in Michigan has dropped from 70 to 25 since 1959. Two birds per year could make a difference in such a small population. In this species, not widely spread in North America, death becomes doubly critical.

In the Klamath Valley of Oregon we found that 10,000 of the world's 40,000 Ross's geese passed through one of the alternative routes (Willard, Harris, and Jaeger 1977). We were forced to evaluate whether it was worse to threaten 10,000 Ross's geese or, alternatively, 3 million pintails. Although we were able to avoid both, the question remains. Can we really compare the value of individuals of one species with the value of individuals of another? Is this really a biological question?

This experience suggests to me that we should take guidance from the new strip mining legislation. This statute requires that federal, state, and local agencies list areas of such ecological significance that strip mining should be forever prohibited. We might set aside buffer zones around areas of ecological importance to avian populations so that all presumptively detrimental impacts would be forever prohibited. One vehicle might be the Rare and Endangered Species Act. Obvious suggestions are in the localities of the Arkansas National Refuge (whooping cranes), Red Rock Lake (trumpeter swans), Lake Okeechobee (Everglade kites), and the Los Padres National Forest (condors).

Some species are more in jeopardy during the breeding season when their population can least afford it. About 200 pairs of white pelicans breed on the Lower Klamath Lake Wildlife Refuge. Raising a brood requires both parents to forage extensively. The pelicans fly along the canals about 30 feet high. While white pelicans do not dive into the water like brown pelicans, they do watch the water, locate prey, land, and fish. As they watch the water while flying, they are distracted and run into lines crossing the canals. During the 1976 breeding season, four adult female pelicans were found dead under wires. Autopsy showed wires were a likely cause of death. Four out of 200 pairs were unsuccessful in raising young. A 2-percent reduction is significant in a small, otherwise threatened population. We see, then, that some species have more significance than others and that certain times and places are more important than others.

Where do we stand predictively? We know some things and we do not know some others. Anderson (in press) lists at least five factors which influence the frequency of waterfowl collisions with powerlines:

1. Number of birds present
2. Visibility
3. Species composition or behavior of birds
4. Disturbance
5. Familiarity of birds with the area

We know how to count birds in the area. It may take time but it can be done; in fact, in many cases it is being done. Our method in Oregon will give us accurate data on where and how high birds will move in an area. We know enough to predict changes in bird movements in response to land use changes in our area.

We know less about visibility. Stout and Cornwell (1976), Krapu (1974), Johnsgard* and others agree that the worst cases occur when visibility is obscured. Therefore, Kroodsma (1977) and others have suggested marking wires in some manner. Young (1975) points out that marking wires did not reduce the killing of mute swans. My own studies are similar to Anderson's (in press) in that birds seem to be able to avoid any wire they see, and birds have good vision (except swans, perhaps) They get into trouble when they are preoccupied with landing, other members of their own species, and most of all predators, or, like the pelicans, with hunting. Waterfowl, particularly, panic with the sudden appearance of an airborne predator. In short, like humans, birds will run into things when they are not watching where they are going.

Species vary in adeptness at avoiding lines. None seems immune. Swans and pelicans seem particularly vulnerable, but this may be a result of their detectability as corpses.

Disturbance seems important. We can calculate the probability of a disturbance within broad limits: we cannot be sure when it will occur. It appears that many kills occur when large numbers of birds are surprised in conditions of

*Paul Johnsgard 1977: personal communication.

poor visibility. In Oregon, waterfowl move about and feed at night to avoid hunters. Because only a few fields are optimum foraging areas at any one time, the birds gather in only a few special fields. There they eat quite greedily in huge, mixed flocks. Toward morning, fog forms. Normally, birds will wait until visibility improves, but the hunters come at legal dawn. Years of daily walking powerline paths might result in a researcher's missing this worst-case event when the independent variables of farm practice, hunting pressure, fog, and disturbance occur.

Bird familiarity with the area is hard to calculate. In Oregon, we found migrating birds generally flew about 300 yards high, much too high to interact with powerlines. However, birds passed through the proposed powerline route at least twice daily on feeding flights. During hunting season, they crossed the "firing line" well above shot range. On the few windy and foggy days we experienced, the flocks flew about 20 yards over the "firing line." I suspect bad weather would change their normal behavior, even if they were familiar with the presence of powerlines.

All of this leads me to make some recommendations. Each point is arguable depending on your relative values for powerlines and birds.

1. Avoid ecologically sensitive areas.
2. Avoid vulnerable species.
3. Determine what it is worth to avoid sensitive areas and vulnerable species.
4. Critically reexamine the value of devices increasing the visibility of wires.
5. Control access to waterfowl areas with existing lines.
6. Study the electromagnetic effects of powerlines on birds.
7. Assume no correlation between conductor size and damage. (There is no evidence that 745-kv lines are a worse impact threat than 69-kv lines. Perhaps the converse is true.)
8. Control land use within 1 mile of new lines.

9. Accept dead bird studies with a certain degree of skepticism.

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Keynote Response

Dale K. Fowler
Tennessee Valley Authority

Dr. Willard has done a masterful job of describing the state of the art of this relatively new area of environmental concern. I know that many of the thought provoking points he has made will be vigorously debated over the next 2 days.

I am particularly intrigued by Dr. Willard's interpretation of existing wire strike mortality data. If this information is relatively meaningless, then we are not in a position to conclude that a serious problem exists. We can speculate that more birds die from wire collisions than are found, but we can also speculate, with some support from existing data, that the number of dead birds in the vicinity of transmission lines reflects a low incidence of fatal collisions. The magnitude of the problem (or the lack of one) is a function of the number of dead birds. Are these collision-related deaths frequent enough to justify the added transmission line construction costs that some of Dr. Willard's recommendations would require? Good mortality data is a prerequisite to answering this question.

Dr. Willard's comments regarding species with dangerously low populations are well taken. Any added source of mortality would be a blow to such populations, and measures to reduce the likelihood of wire strikes to these species should be weighed heavily against all the other factors that are considered when siting and constructing new lines. However, I would expect that potentially serious, collision-related situations such as proximity to threatened and endangered species habitats would be localized, highly site-specific, have a predictable distribution, and include only small portions of a given power system. I also suspect that the potential for such problems would vary among power systems due to differences in land use, height of vegetation, topography, climate, and other factors that would affect avian flight patterns. Therefore, mortalities for one region, such as the West, may not be representative of other regions, such as the Northeast or Southeast.

We know of very few documented bird collisions with TVA transmission lines. Occasionally we receive reliable reports that large birds, such as great blue herons, have been found dead beneath our lines, so collisions do occur. However, these reports are infrequent, and there has been no feedback from our biologists, from biologists of other agencies, or from the general public to indicate the existence of a serious problem.

Although we do not consider TVA transmission lines a significant mortality factor to migratory bird populations, potential bird/wire collisions are evaluated during the siting of new lines. Our TVA biologists closely scrutinize corridors that pass near waterfowl refuges and other sensitive habitats, and their recommendations are considered, along with many other factors, in final route selection. Most potential environmental problems can be identified and resolved during transmission line siting. However, there are many interest groups to be considered in final route selection and the choice is seldom easy.

We realize there might be specific sites within our power system where factors could create a high probability of bird/wire collisions. There are over 17,000 miles of transmission lines within the TVA system, and obviously one cannot be absolutely sure about the likelihood of site-specific problems being absent or present. However, it has been our experience that where TVA-related environmental problems do occur, there is little time lag between the occurrence of the problem and our attention being drawn to it.

If we do have areas within the TVA power system that constitute significant wire strike mortality problems, we want to know where they are. Professionals in a diverse array of disciplines are employed by TVA, and the agency is involved in many natural resource programs. Among these is a very promising cooperative program, involving several other agencies, aimed at establishing resident flocks of giant Canada geese in the Tennessee Valley. Wire strike mortalities involving these geese, or some of the other water and shorebirds we are working with, would not be welcome news to our waterfowl biologists.

We are conducting research to better understand the environmental effects associated with TVA's right-of-way construction and maintenance programs. We also have a cooperative, cost-sharing program available for landowners who are interested in managing wildlife on TVA rights-of-way on their land. Although these efforts do not directly pertain to this workshop, they illustrate that where problems related to transmission line and opportunities have been clearly identified, TVA has been responsive. We intend to do the same in the area of wire strikes if a serious problem is quantitatively documented.

We do feel that this workshop will greatly clarify the present confusion concerning avian mortalities associated with transmission lines. Many utilities are understandably apprehensive about economic ramifications of this relatively recent environmental consideration. A logical, objective evaluation of this situation is clearly needed.

Keynote Response

Spencer Amend
Kansas Forestry, Fish, and Game Commission

Approximately 1 year ago [January 1977], Lawrence Livermore Laboratory sponsored a gathering similar to this one in an attempt to identify potential environmental hazards associated with geothermal development. Shortly after that meeting Ken Hoover [U. S. Fish and Wildlife Service] and I, as well as some others, discussed the possibility of using this approach to identify and, in an orderly manner, establish priorities for efforts at obtaining information we do not have concerning the relationships between powerlines and bird movement patterns. So I feel some sense of satisfaction in the fact that we are gathered for this purpose today.

When we were initially considering an appropriate composition for this workshop, we agreed to be guided by the level of professional expertise of those we would invite; that is, for the moment we are not representing those who happen to be paying your salaries. A critical factor in determining our final success will be the degree to which each of us approaches this problem on a strictly professional and scientific basis.

Perhaps just a brief comment is in order concerning my perception of the role of a reviewer in a situation such as this. I feel it is appropriate for someone in this position to identify potentially controversial areas in order that subsequent discussion can focus on and clarify those areas.

I suggest that there is a very basic question which needs to be addressed: "Just why are we interested in birds anyway?" My answer is based on that first wildlife text, to which Dr. Willard referred, specifically the part about man's having dominion over the creatures of the sea, land, and air. I suggest that indeed the purpose for our interest in birds relates to our desire to enjoy and use them for our own purposes, both consumptive and nonconsumptive. Indeed, the entire science of wildlife management is predicated on the notion of manipulating wildlife populations for man's enjoyment. This brings me to my first point of issue with Dr. Willard. He states that the question turns on the importance or the value of the fatalities involved. A more accurate statement would encompass the importance relative to our abilities to manage and subsequently to enjoy the birds involved. Apparently, both Dr. Willard and Dale Fowler missed the principal point — at least from my perspective — by focusing their attention solely on the collision aspect and, more importantly, by overlooking the impact through habitat use or behavioral changes on man's use of the bird resource.

I concur with the approach of recognizing the important distinction between biological and political significance in discussing powerline/bird interaction. Biological significance, while no doubt an overall issue of considerable importance, is, I think, not likely to be demonstrable in relation to a single powerline, except in rare cases. The cumulative effect of many lines in many locations within the areas traversed by birds throughout their life cycles may be of greater significance when considered along with other mortality factors. The size of the species population in question really serves only to increase the significance.

The next point I would like to deal with briefly is the scavenging issue raised by Dr. Willard when he indicated there is no literature indicating that removal by scavengers is an important factor. My own recollection on this point is somewhat hazy; perhaps the computer bibliography can help clarify this point. As with many issues, I suspect we will need to consider this one on a rather site-specific geographical basis, and it is reasonable to expect considerable variation.

Dr. Willard raised the question of whether we can really compare the value of individuals of one species with the value of individuals of another and implied that we would not wish to do so. I submit, however, that this is quite a common and very realistic management question, one which is often dealt with in setting priorities and determining how best to direct our attention or to utilize our scarce resources.

I would like to endorse, for discussion purposes at least, the suggestion that geographical areas be inventoried from the standpoint of their sensitivities to adverse impacts of powerlines. This kind of inventory should be quite useful in not only allowing powerline construction to avoid highly sensitive areas but also helping resource agencies focus data gathering efforts.

In considering Dan's nine recommendations, I feel a bit inadequate in that no additional ones occur to me. I am particularly pleased with the recommendation concerning land use within 1 mile of new lines, although this does not appear to follow from the logic developed in the paper. It arises generally and speaks to the point I made earlier about habitat use and availability.

In conclusion, I believe Dan gave us a good keynote speech which identifies several potential points of discussion, and I look forward to attempting to resolve with you any conflicts I may have been able to generate.

Migratory Behavior and Flight Patterns

Sidney A. Gauthreaux, Jr.
Clemson University

INTRODUCTION

Since the beginning of recorded history the migration of birds has attracted the attention, and intrigued the imagination, of man. Bird migration has likewise been of considerable interest to biologists, and myriad studies have sought answers to the *how's* and *why's* of bird migration. Many of these studies have been summarized in books devoted entirely to the subject (e.g., Brewster 1886, Clarke 1912, Coward 1912, Cooke 1915, Thomson 1926, Wetmore 1926, Tinbergen 1949, Rudebeck 1950, Lincoln 1952, Dorst 1962, Schüz 1971, Bykhovskii 1974, Griffin 1974). The amount of data that have been collected and the published findings on all aspects of bird migration is truly staggering, and even the most comprehensive reviews have been able to provide little more than a sketchy overview of the subject.

In this paper I will review some facts about bird migration with an emphasis on the geographical distribution of migrants; the seasonal and daily timing of migration; the direction, route, and altitude of migratory flights; and the influence of weather on the density of migration. This information will permit a better appreciation of the potential impact of transmission lines on all kinds of migratory birds. Although we cannot say what this impact is because of the lack of carefully designed, quantitative studies, reports of bird fatalities at TV towers, tall buildings, and the like during migration suggest that on certain occasions the impact could be considerable.

GEOGRAPHICAL DISTRIBUTION OF MIGRANTS

A wealth of information on the distribution of North American migrant birds can be gleaned from the pages of *American Birds* (formerly *Audubon Field Notes*) and the range maps of Robbins et al. (1966). Additional information on the geographical pattern of the breeding density of certain migrant species can be obtained from the "Breeding Bird Survey of the United States Fish and Wildlife Service." MacArthur (1959) analyzed the breeding distribution of North American passerines wintering primarily in the neotropics (Figure 1). He found that the eastern deciduous forests contained far more neotropical

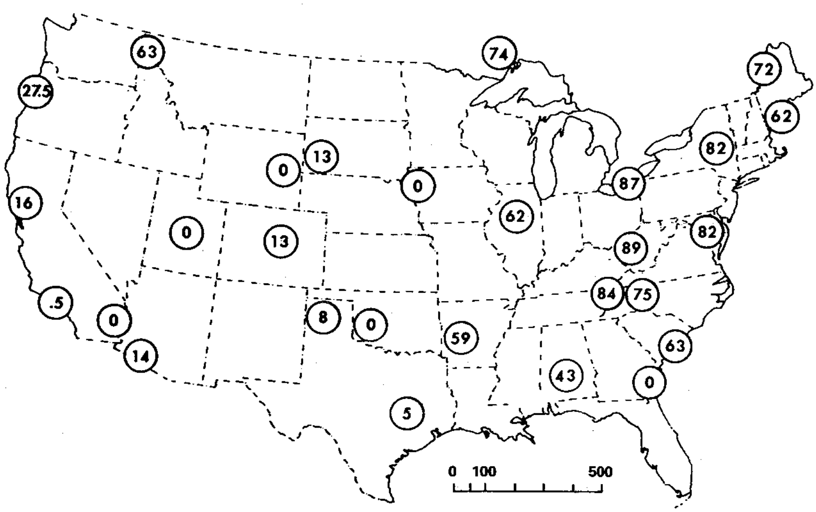


Figure 1. The distribution of the percentages of bird species breeding in the United States but overwintering in the neotropics. Note that the eastern third of the country contains the greatest percentages of neotropical migrants (after MacArthur 1959).

migrants than northern coniferous forests and grasslands, and he correlated these differences with the contrast between winter and summer food supplies in the given habitat. Willson (1976) in a partial reanalysis of MacArthur's (1959) findings showed that

1. North American neotropical migrants are less prevalent in grasslands than in forests, but there is no significant difference in the proportion of neotropical migrants in deciduous and coniferous forests.
2. Coniferous forests have relatively fewer year-round resident individuals than grasslands or deciduous forests, and grasslands and coniferous forests have slightly fewer resident species than deciduous forests.
3. Most neotropical migrant birds breed primarily in deciduous forests, and most of those that breed in coniferous forests are parulids (e.g., American warblers).

In the northeastern deciduous forests, on the average 62 percent of the breeding species and 75 percent of the individuals are migrants. In the northern coniferous forests 80 percent of the breeding species and 94 percent of the individuals are migrants, while in the grasslands 76 percent of the breeding species and 73 percent of the individuals are migrants. Although similar analyses for waterfowl and shorebirds are not available, distribution and migration data can be found in Bellrose (1976) and Palmer (1976) for waterfowl and in Stout et al. (1968) and Sanderson (1977) for shorebirds.

In general there is considerably more bird migration in the eastern two-thirds of the United States than in the West (Lowery 1951; Lowery and Newman 1955, 1966). One basis for this pattern is that more migrants (species and individuals) breed in the East, but another basis is exemplified in Figure 2. The breeding range of the Philadelphia vireo extends toward the northwest into Canada, but its migration is restricted to the eastern United States. Approximately 33 species of land bird migrants conform to this pattern. Thus, even though a number of land bird

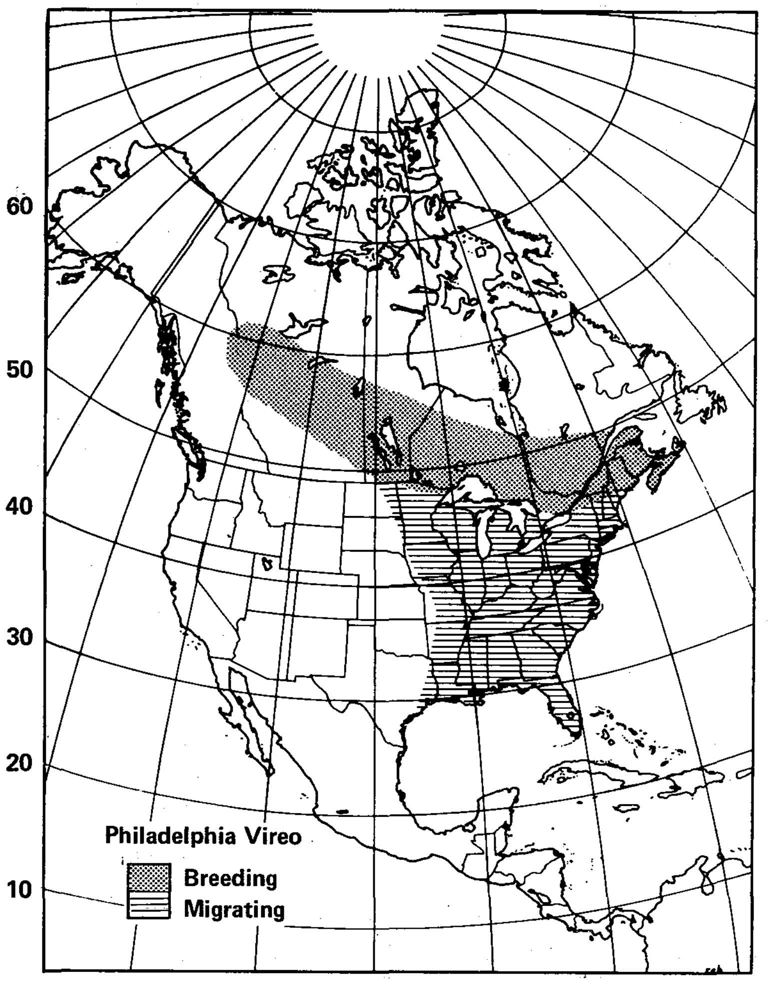


Figure 2. The breeding distribution and migration area of the Philadelphia Vireo (*Vireo philadelphicus*). Although the breeding range of this species extends into northwestern Canada, its migration through the United States is confined to the eastern half of the country (after Robbins et al. 1966).

migrants breed considerably farther west and north of the eastern forests of the United States, they migrate through the eastern states. The white-throated sparrow is an example of a short-distance migrant that winters in the southern portions of the United States (Figure 3). Even though the breeding and wintering ranges extend westward, the spring and fall migration of the species is almost exclusively east of the Rocky Mountains.

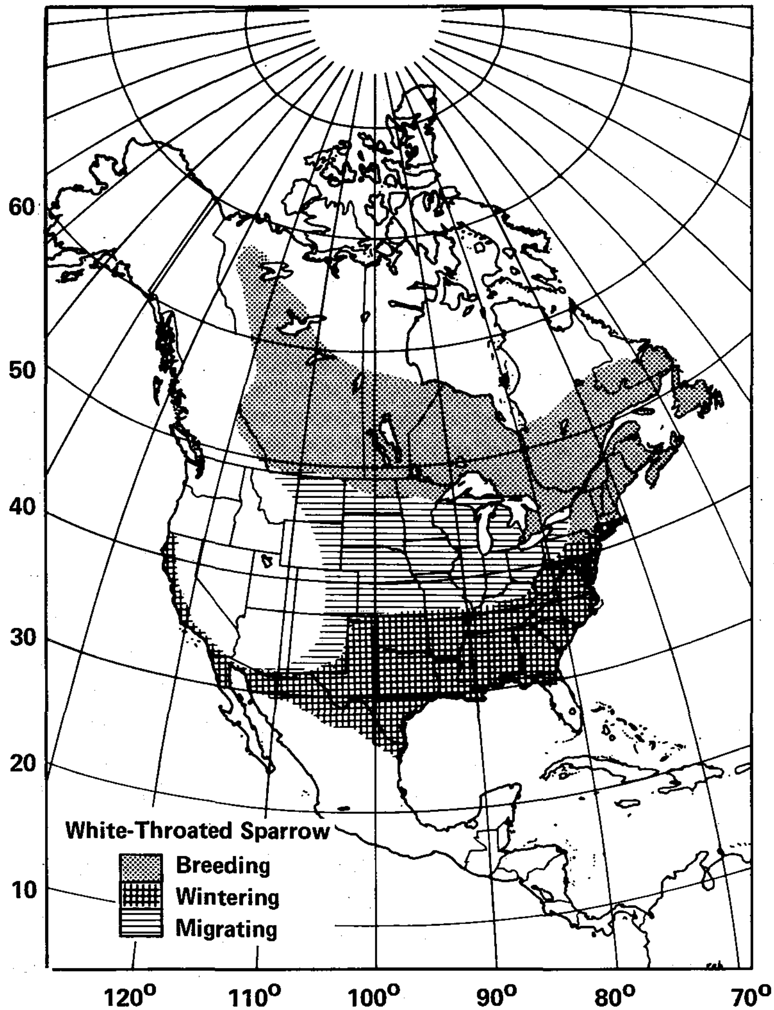


Figure 3. The breeding and wintering distribution of the white-throated sparrow (*Zonotrichia albicollis*) in North America. Although the breeding range and wintering range of this species extend beyond 120°W, the species migrates almost exclusively to the east of the Rocky Mountains (after Robbins et al. 1966).

SEASONAL TIMING

Much of what we know about the seasonal timing of bird migration in North America comes from the work of field observers and birdbanders, and their findings have been regularly summarized in the spring and fall migration issues of *American Birds*. Virtually every state has a checklist or bird book containing information on the seasonal occurrences of migrant birds. Saunders (1959) examined the variation in the timing of spring arrivals among 50 different species in comparison with the mean 40-year arrival dates and found that in late, cold springs migrants arrived later than in early, warm springs. Gauthreaux and LeGrand (1975) associated the advancement or retardation of the seasonal timing of migration with year-to-year changes in continental wind patterns. Robbins et al. (1966) has summarized considerable data on the seasonal timing of bird migration for most North American species. This information is presented on species maps as isochronal lines that show the average first-arrival date where birds migrating to the north may be seen about the first of March, April, May, and June. Preston (1966) has analyzed mathematically the timing of spring and fall migration and found that in general those species that go early return late (e.g., waterfowl, sparrows). Preston discusses evidence that shows breeding birds occupy their summer habitat as soon as it is habitable and depart as soon as they have finished breeding. The standard deviation of the timing of a species' migration is less in spring than in fall, hence the birds are better synchronized in spring. During fall migration some species show an almost bimodal timing with young and adults traveling at somewhat different times (see Murray 1966). In the spring, males of most species arrive before the females, and adults precede young (Gauthreaux 1978a).

A number of factors must be considered in discussing the seasonal timing of migration. The more important of these are vegetational development in the spring, food availability, and climatic factors in spring and fall. Weydemeyer (1973), in a 48-year study of spring arrivals of migrants in Montana, found that ranges in dates of arrival were greatest during late March and April and least in late May and June. Slagsvold (1976) working in Norway found that for the country as a whole there was a 6-day delay in bird arrival for each 10-day delay in vegetation development. Thus, the arrival of migrants at higher latitudes and altitudes was faster than the development of vegetation. Slagsvold also found that earlier arriving species varied considerably in arrival date at a particular locality from year to year, but late arriving species had much less variation in arrival time. Pinkowski and Bajorek (1976) examined the spring arrival dates of 29 common or conspicuous migrants and summer resident species in southern Michigan over a 7-year period. They concluded that granivorous, omnivorous, and aquatic species tend to arrive earlier than strictly insectivorous species, and that earlier arriving species have a greater variance in arrival time than the later arriving species.

DAILY TIMING OF MIGRATION

The majority of small birds, including most passerines, migrate at night, and most waterfowl and shorebirds migrate both at night and during the day. Raptors, several woodpeckers, swallows, several corvids, bluebirds, and blackbirds migrate during daylight hours. The determination of whether a species migrates at night or during the day has come from laboratory studies of *Zugunruhe* — migratory restlessness in caged birds (Gwinner 1975); from data gathered when migrating birds collide with TV towers, buildings, or powerlines or when migrants are attracted to, and killed at, lighthouses and ceilometers (see Weir 1977 for review); and from direct visual studies of daytime migration in progress. According to data gathered by surveillance radars at several localities in the United States and Canada, considerably more birds migrate at night than during the day (Gauthreaux 1975).

A number of studies have shown the temporal pattern of nocturnal migration (e.g., Lowery 1951, Sutter 1957a, Harper 1958, Gauthreaux 1971). As can be seen in Figure 4, the initiation of nocturnal migration occurs about 30 to 45 minutes after sunset; the number of migrants

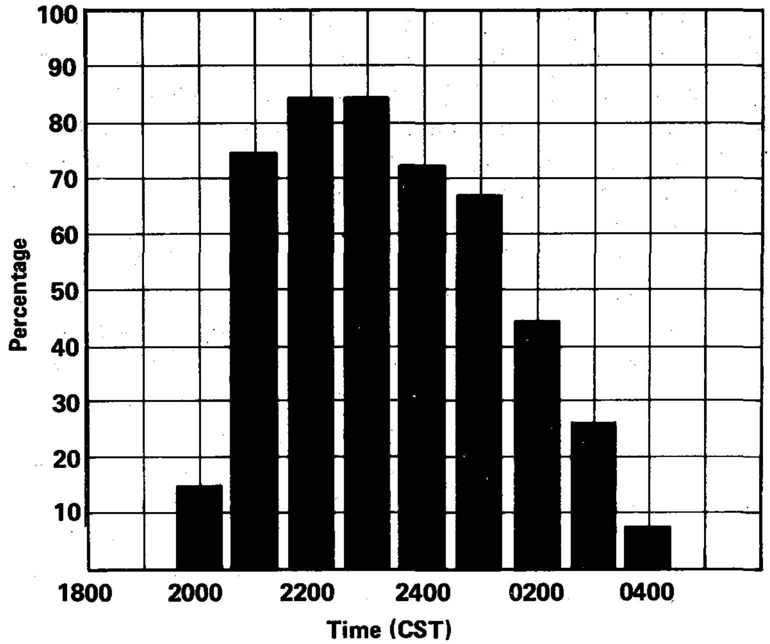


Figure 4. The average hour-to-hour variation in the quantity of nocturnal migration plotted as the percentage of peak density. The data for 8 nights were gathered using WSR-57 weather radar during the spring of 1965 in southwestern Louisiana (see Gauthreaux 1971 for more details).

aloft increases rapidly, peaking between 2200 and 2300 hours. Thereafter, the number of migrants aloft decreases steadily until dawn, indicating that migrants are landing at night. Daytime migration is initiated near dawn (sometimes earlier), peaks around 1000 hours, and declines to minimal density shortly after noon (Sutter 1957b, Gehring 1963, Gauthreaux 1978b).

DIRECTIONS AND ROUTES OF BIRD MIGRATION

Although considerable attention has been directed to laboratory studies of direction finding in migratory birds (Emlen 1975), there is an increasing emphasis on field studies of migratory orientation using direct visual means (Lowery 1951, Lowery and Newman 1963, Gauthreaux 1969) and radar (Eastwood 1967, Gauthreaux 1975).

Radar can provide detailed information on the direction of migratory movements when conditions for direct visual studies are poor while at the same time sample a fairly large geographical area. Figure 5 is a photograph of the display of the ASR-4 radar operated by the Federal Aviation Administration at the Greenville-Spartanburg Airport in northwestern South Carolina. Similar radar systems are operated at many medium-sized and large airports throughout the United States. Echoes from individual birds can be seen moving toward the north-northeast. Movement is indicated by the "tails" of echoes produced by the fading of previously registered echoes.

Radar studies of bird migration have been conducted in Illinois (Graber and Hassler 1962, Bellrose and Graber 1963, Hassler et al. 1963, Bellrose 1964, Graber 1968), coastal New England (Drury and Keith 1962, Nisbet 1963a, Drury and Nisbet 1964, Nisbet and Drury 1968),

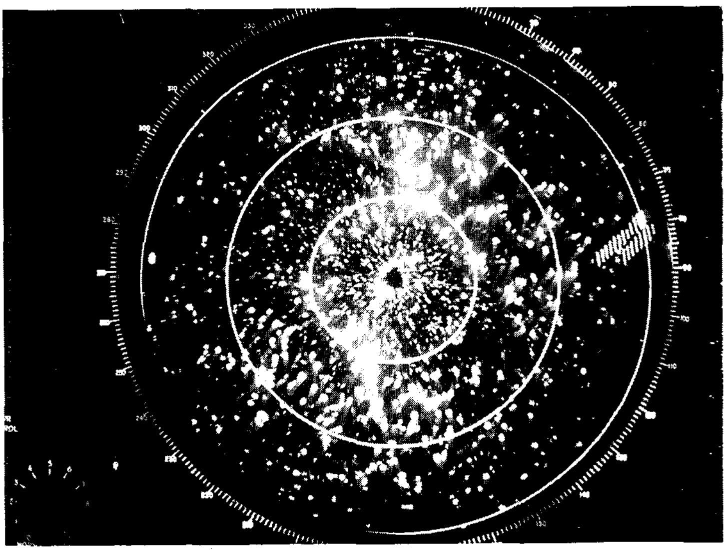


Figure 5. A photograph of the ASR-4 radar screen showing echoes from birds migrating toward the NNE. The range marks are located every 2 nautical miles. Echoes from aircraft appear near 6 nm range at 80° and 10° azimuths. The photograph was made on 27 April 1972 at Greenville, South Carolina (Federal Aviation Administration ASR-4 radar installation), at 1947 EST.

eastern New Jersey (Swinebroad 1964), coastal Virginia (Williams et al. 1972, 1977), in South Carolina (Gauthreaux 1974, 1976, 1978b), northern Georgia (Gauthreaux and Able 1970; Able 1973, 1974; Gauthreaux in prep.), coastal Louisiana (Gauthreaux 1971, 1972; Able 1972, 1973, 1974; Fuller 1977), in northern Ohio (Tolle and Gauthreaux in prep.), Arizona, New Mexico, and western Texas (Beason 1978), several locations in Canada (Richardson 1969, 1971, 1972; Blokpoel and Defosses 1970; Myres and Cannings 1971; Richardson and Gunn 1971; Speirs et al. 1971; Blokpoel 1974; Blokpoel and Gauthier 1974), and in northwestern Alaska (Flock 1972, 1973; Hubbard and Flock 1974). Although there are many geographical gaps in the coverage and some studies have concentrated on waterfowl migration (e.g., Bellrose 1964, Blokpoel et al. 1975), particularly west of the Rocky Mountains (Beason 1978), a continental pattern of bird migration in North America is beginning to emerge.

In general, the axis of migration for most passerines is northeast to southwest in the eastern two-thirds of the United States, but in central southern Canada the axis of passerine migration is northwest to southeast. Bellrose (1964, 1976) has shown that most waterfowl in the Mississippi valley move more north-south with eastward and westward deviations depending on topographic factors (lakes, marshlands, and river systems). Wind direction exerts a strong influence on the direction and timing of migration (Gauthreaux and Able 1970, Able 1974, Alerstam 1976), and the routes birds fly appear to be determined, at least in part, by the prevailing wind patterns in North America during spring and fall (Gauthreaux 1972). For example, in northwestern South Carolina in spring the prevailing winds blow to the northeast, and the average distribution of the directions of nocturnal migration on calm nights (that is, when wind directions are not an influencing factor) in spring is toward the northeast (29.5°). Thus, in spring the preferred direction of migrants closely matches the prevailing wind direction. In fall the winds in the same area usually blow toward the southeast, and the average distribution of the directions of nocturnal migration on calm nights is toward the southwest (231.5°). These data were gathered using direct visual means, moon-watching (Lowery 1961), and ceilometer-watching (Gauthreaux 1969), but data gathered from radar conform to the above pattern (see Gauthreaux 1978b for details). Wind direction in relation to the normal direction of migration can also influence the altitude of migration as well as the number of migrants aloft, and these topics are discussed below.

There have been very few field studies of the influence of powerlines or other electromagnetic devices on bird migration, but there is some evidence that when local magnetic fields are disrupted by electrical currents, the orientation of birds is affected slightly (see discussions by Southern 1975, Larkin and Sutherland 1977, Moore 1977). The magnetic disturbance produced by electrical current in powerlines is generally localized and does not extend beyond a distance of several meters. Thus, the effects on the orientation of migrating birds may be minimal when birds fly well above the powerlines, but clearly more work is needed on this subject.

ALTITUDE OF MIGRATION

Radar has provided the best data on the altitude of bird migration, and radar studies have shown that *most* bird migration normally occurs at altitudes below 500 meters above ground level (Nisbet 1963b; Eastwood and Rider 1965; Able 1970; Bellrose 1971; Blokpoel 1971a, 1971b; Bruderer and Steidinger 1972; Gauthreaux 1972). In general, the larger the bird species and the faster its airspeed, the higher it flies during migration for minimum cost of transport (Tucker 1975).

The distribution of nocturnal migrants in the airspace is strongly skewed to the lower altitudes. In Table 1 the quantity of nocturnal migration per altitudinal stratum is expressed as the percentage of the total number of birds aloft. The data were gathered using WSR-57 weather radar at New Orleans, Louisiana, in the spring of 1967 (see Gauthreaux 1970, 1972). Seventy percent of the migrants at night were most frequently between 241 meters (800 feet) and 1127 meters (3718 feet), and within this zone approximately 75 percent were between 241 meters (800

Table 1. Altitude of Nocturnal Migration at New Orleans (Expressed as Percentage of Total Number of Birds Aloft)

Antenna Elevation		Altitudinal Zones in Meters			
2.5°		241-1127	482-1690	724-2254	965-2817
(N = 34)	$\bar{x}$	70	20	8	4
	S.D.	19	13	10	8
(N = 30)		241-482	482-724	724-965	965-1206
	$\bar{x}$	74	18	7	2
	S.D.	17	14	8	3

feet) and 482 meters (1600 feet). In Table 2 the altitudes of peak densities of migrants aloft on 70 spring nights and 35 fall nights are given. These measurements were made with the WSR-57 radar at weather stations in New Orleans and Lake Charles, Louisiana; Athens, Georgia; and Charleston, South Carolina. Seventy-three percent of

Table 2. Altitude of Greatest Concentration of Nocturnal Migrants Aloft

Altitude		Number of observations	
Meters	Feet	Spring	Fall
152	500	1	–
305	1000	57	22
457	1500	3	2
610	2000	6	3
762	2500	2	1
914	3000	–	1
1219	4000	2	1
1372	4500	3	–
1524	5000	1	3
1676	5500	1	2
1829	6000	2	2
2134	7000	1	1
2286	7500	–	1
Total		**79**	**39**

the 79 altitude measurements on 70 spring nights showed the altitudes of peak densities of migrants to be at 305 meters or lower. In the fall 56 percent of the 39 measurements on 35 nights indicated that the greatest concentrations of migrants aloft were at 305 meters. As Table 2 shows, on some occasions the altitude at which most birds were migrating was considerably higher than the usual 305 meters.

Most radar cannot detect birds very close to the ground (but some shipboard navigation radar can), and consequently the *minimum* altitude of nocturnal migration displayed on radar cannot be measured accurately. Studies using direct visual means to detect migrating birds as they pass through a narrow vertical beam of light (Gauthreaux 1969) suggest that a considerable number of birds fly within 100 meters of the ground at night. This is particularly so within an hour after the initiation of nocturnal migration and at the time birds are landing during the night. On some misty, cloudy nights tremendous numbers of call notes from migrants aloft can be heard, and on many of these occasions the distance of the call notes overhead indicates the birds are flying within a few meters of the ground. The altitude of migration changes throughout the night. Usually the maximum mean altitude of migration is reached about 2 hours after the initiation and thereafter slowly declines as birds begin to terminate their nightly migration (Able 1970).

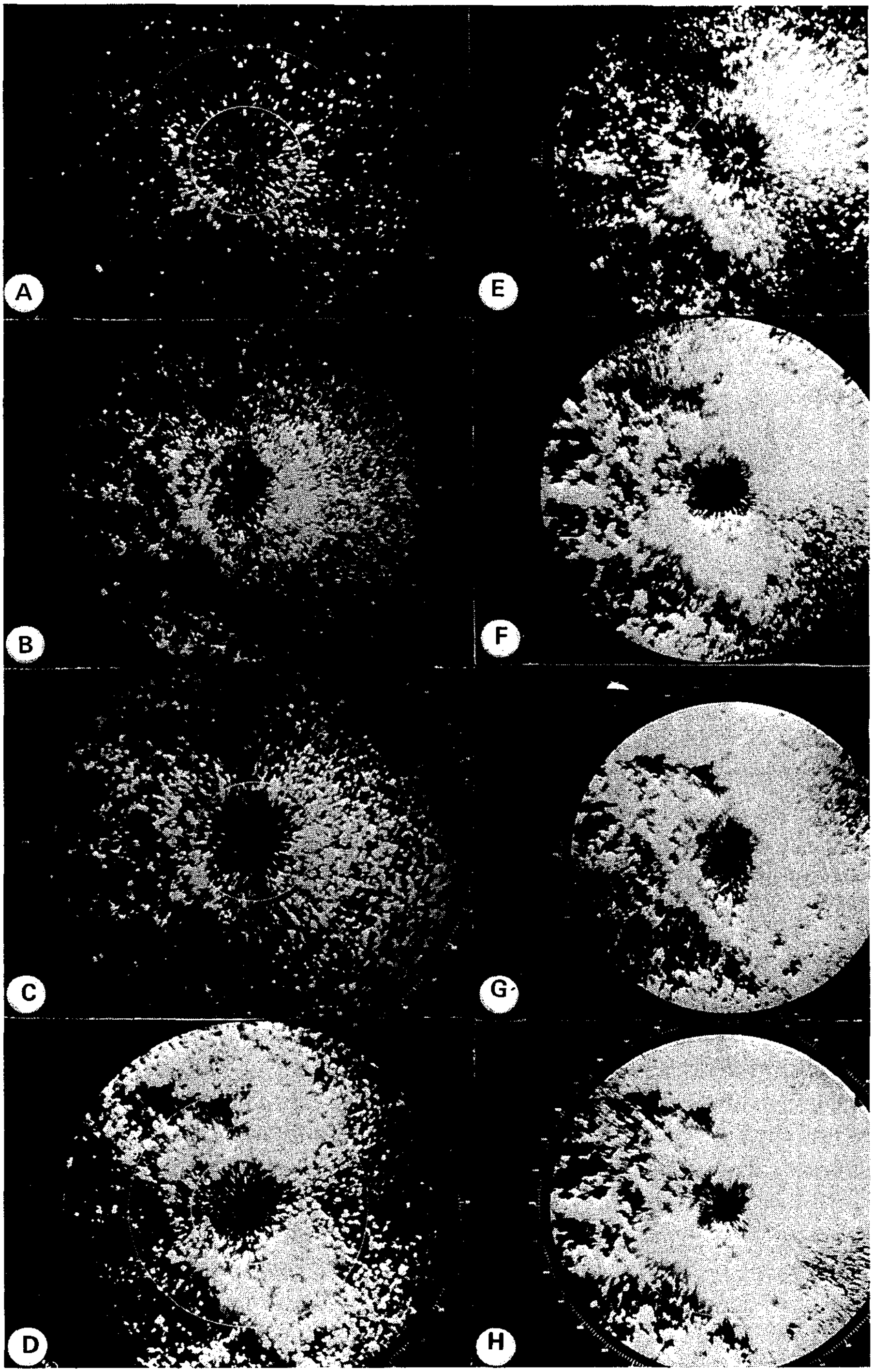
Daytime migration usually occurs at altitudes below 300 meters, and quite often flocks of daytime migrants can be seen moving just above tree level. This, however, is not always the case. When migrants are arriving on the northern coast of the Gulf of Mexico during daylight hours in spring after a trans-Gulf flight, they are usually at altitudes above 1500 meters (Gauthreaux 1971, 1972). When the migrants encounter a cold front and headwinds before they make their landfall, they will often fly within a few meters of the water's surface. On these occasions when the flights are delayed and most of the migrants arrive at night, tremendous numbers will strike wires, towers, and the like. In general, daytime migrants will fly lower when there is poor visibility, dense cloud cover, and drizzle.

WEATHER INFLUENCES ON THE DENSITY OF MIGRATION

Figure 6 shows the radar displays of nocturnal migration on ASR-4 radar with different migration traffic rates (Gauthreaux 1978b). These displays were quantified by direct visual means (moon-watching [Lowery 1951] and ceilometer observations [Gauthreaux 1969, Able and Gauthreaux 1975]). Once calibrated, the radar can be used to measure the quantity of migration, and it is possible to study the weather factors responsible for the different night-to-night variation in the quantity of migration. It is generally accepted that in spring more migration occurs on the west side of a high pressure system and before a cold front and low pressure system (zones 4 and 5 in Figure 7). In fall very large migrations occur just after a cold front on the east side of a high pressure system (zones 1 and 2 in Figure 7). But what weather factors or combination of weather factors influence the density of migration?

In the last several years a number of studies have attempted to answer this question (see Richardson 1978 for a detailed review of this subject). Because weather factors interact in complex ways, multivariate statistical analyses must be used, and the results of studies using such analyses have been summarized in Tables 3 and 4. Table 3 gives the weather factors that have been shown to significantly influence the quantity of spring migration. Of all the weather factors listed, wind and temperature are clearly the most consistently important factors. In fall

Figure 6. Photographs of the ASR-4 radar screen showing the changes in the density of bird echoes as a function of migration traffic rate (the number of birds crossing 1 mile of front per hour). All photographs were made with the radar adjusted to 6 nautical mile range, the same high gain setting, Moving Target Indicator (MTI) engaged, and no attenuation circuits engaged. As can be seen, once the traffic rate (TR) is about 30,000 birds, the screen is essentially saturated with bird echoes. (A) 9 May 1977, TR = 2000; (B) 12 May 1977, TR = 5000; (C) 24 April 1977, TR = 10,400; (D) 21 April 1977, TR = 12,000; (E) 28 April 1977, TR = 21,600; (F) 11 May 1977, TR = 32,400; (G) 26 September 1977, TR = 52,000; (H) 28 September 1977, TR = 218,700.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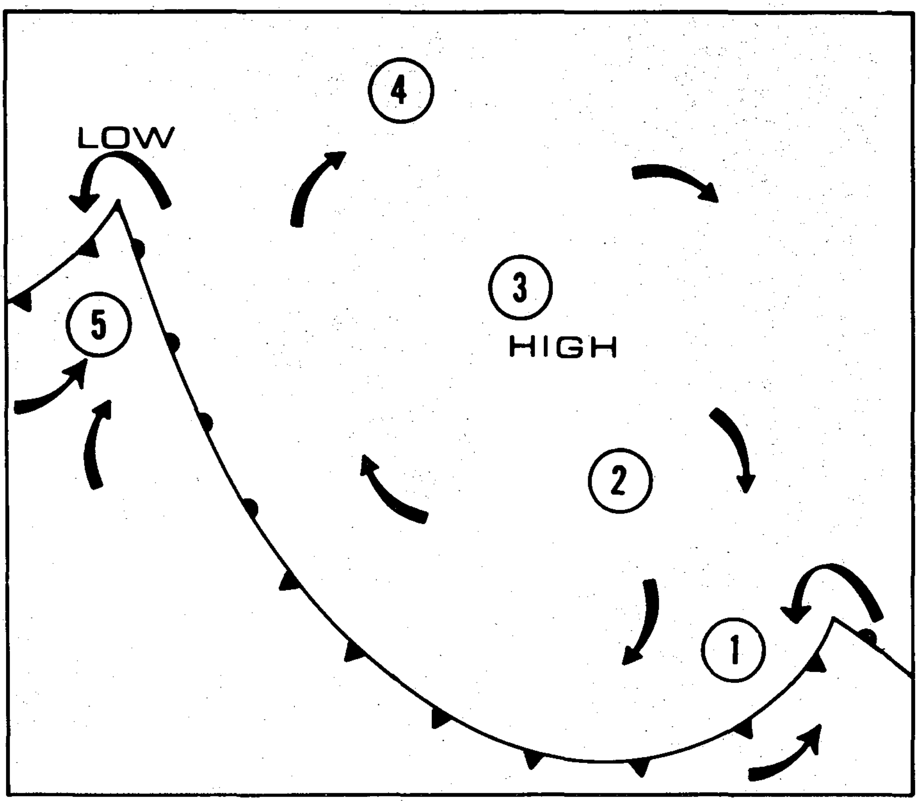

Figure 7. A generalized synoptic weather pattern showing zones used in analyzing the relationship between synoptic weather and the density of bird migration in spring and fall. The arrows indicate the general pattern of airflow.

(Table 4) the same pattern is found. Both wind and temperature are, of course, significantly intercorrelated. Thus, the largest spring migrations occur with winds from the south and southwest, which bring warming temperatures, and the largest fall migrations occur with winds from the northwest and north, which usually bring colder temperatures to an area. Another point regarding the influence of weather on the quantity of bird migration should be mentioned. The amount of night-to-night variation in the quantity of migration explained by weather is 50 percent to 60 percent on the average. The remaining variation is undoubtedly due to the internal conditions of the

Table 3. Influence of Weather Variables on Spring Migration (Multivariate Analyses)

	General Weather Variables[a]							
	Temperature	Wind	Cloud	Relative Humidity	Barometric Pressure	Precipitation	General Weather	R^2 or Rc^2
Lack (1960)	*	*	*			*		
Lack (1963b)	*	*	*				*	
Nisbet and Drury (1968)	*	*		*	*	*		0.60
Richardson (1971, 1974b)	*	*	*					0.62
Geil et al. (1974)[b]	*	*		*	*			0.61
Geil et al. (1974)[c]	*	*	*			*		0.43
Richardson (1974a)[d]		*			*			0.51
Richardson (1974a)[e]		*						0.40
Alerstam (1976)		*		*	*		*	0.44
Gauthreaux (1976)	*	*				*	*	0.54

[a] Specific weather variables (e.g., 24-hour change in temperature, temperature departure from normal) are included in general variable (e.g., temperature).

[b] March.

[c] April.

[d] Offshore.

[e] Overland.

Table 4. Influence of Weather Variables on Fall Migration (Multivariate Analyses)

	General Weather Variables[a]									
	Temp	Wind	Cloud	Visibility	Relative Humidity	Barometric Pressure	Precipitation	General Weather	Magnetic Disturbance	R^2 or Rc^2
Lack (1963a)[b]		*								
Lack (1963a)[c]	*	*	*					*		
Able (1973)	*	*						*		0.54
Geil et al. (1974)[b]	*	*				*				0.44
Geil et al. (1974)[d]	*			*	*					0.48
Richardson (1974b)	*	*			*	*	*			0.51
Alerstam (1976)	*	*	*	*	*	*		*		0.61
Richardson (1976)		*				*			*	0.26
Bruderer (1978)		*				*				0.52

[a]Specific weather variables (e.g., 24-hour change in temperature, temperature departure from normal) are included in general variable (e.g., temperature).

[b]September.

[c]October-November.

[d]November.

migrants (e.g., energy for migration, physiological readiness to migrate) and the actual number of ground migrants in an area.

The weather conditions most often associated with migrants colliding with man-made objects (poor visibility, low ceiling, drizzle) are not those conducive to very large migratory movements. Why, then, do tremendous numbers of migrants collide with TV tower guylines, buildings, and other obstructions during migration? The answer to this question is rather straightforward. When birds initiate a migration with favorable weather conditions, they sometimes move into areas where the weather has deteriorated (e.g., a stalled frontal system), and this combination of events is usually associated with such disasters. Occasionally disasters occur under ideal weather conditions for migration, but these are exceptional (Avery et al. 1977).

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Transmission Line Wire Strikes: Mitigation Through Engineering Design and Habitat Modification

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INTRODUCTION

Collisions of birds with overhead utility wires are nothing new. Over a century ago, Coues (1876) documented bird kills resulting from collisions with overhead telegraph lines, and wire strikes have probably been a continuing source of avian mortality ever since. Wire strikes have not received a great deal of public or scientific attention, however, until the last few years as more and more overhead utility lines are built, heavy bird losses are reported with increasing frequency, and public concern over future losses becomes great. Unfortunately, much of the existing problem stems from the fact that nearly all utility lines operating today were built without knowledge of the causes, magnitude, or importance of wire strikes — and, hence, without considering wire strikes in siting or line design. Thus, we are suddenly realizing that the thousands of miles of overhead wires strung across the continent — many crossing wildlife refuges and other areas heavily used by migratory birds — may pose a very real threat to migratory bird populations, and we must try to do something about it. Also, the probability of wire strikes is acknowledged to be an important consideration in the environmentally sound design and siting of new lines. We are therefore faced with the dual problem of doctoring existing lines in an effort to correct past mistakes and of ensuring that new lines will result in the least possible collision mortality.

In this paper, I will summarize factors influencing the probability of wire strikes and discuss means whereby such losses can be mitigated or prevented. While the small body of literature developing on wire strikes provides invaluable information relevant to the mitigation of wire strike mortality, most of the material presented here is based upon unpublished data and on conversations with many knowledgeable individuals. I will also discuss the significance of wire strikes and the relative cost effectiveness of efforts toward mitigation.

FACTORS INFLUENCING THE PROBABILITY OF WIRE STRIKES

Predictability, or the *a priori* estimation of the probability of wire strikes under certain conditions, is a requisite to mitigation. However, there is a dearth of quantitative information in the literature on specific circumstances or rates of collision mortality, information which is essential to predicting high-risk situations.

In certain circumstances, overhead wires may cause a small but regular loss of birds, which can be measured over time to estimate rate of kill. This has been attempted by Willard et al. (1977) who derived estimates of rates of wire strikes in the Klamath Basin of Oregon ranging from 0.4 to 162 birds per mile per year. Anderson (1978) estimated that from 0.2 percent to 0.4 percent of the maximum number of waterfowl present were killed by twin 345-kv transmission lines crossing a slag pit in Illinois. By observing diurnal waterfowl flights in this area, Anderson found that 0.01 percent of the total flights observed in the vicinity of the lines (only 4 percent of all flights in the area) resulted in fatal collisions. Similar results were reported by Lee (1978), who found 0.03 percent to 0.05 percent of the estimated total number of flights near the lines resulted in collision mortality during periods of good visibility.

Nevertheless, the most dramatic bird kills caused by collisions with overhead wires are often catastrophic, irregular in time, and hence unpredictable. A given stretch of line may result in negligible bird mortality for many years, then suddenly — during the chance juxtaposition of a certain flock of birds with certain adverse weather conditions and a certain disturbance — cause dramatic kills of hundreds of birds overnight. Thus, it may be argued that specific mortality rates cannot be quantified, except after many decades of exhaustive study.

While many questions remain unanswered, sufficient information exists to draw the following qualitative conclusions regarding factors influencing the probability of wire strikes. This information will serve to guide our efforts toward mitigation until more quantitative data becomes available.

Species of Bird

Over 80 species of birds, representing 13 orders, have been documented as victims of wire strikes or electrocutions in the United States (Table 1). Although this table represents only a small sample of total mortality, it serves to illustrate the wide variety of guilds, sizes, and behaviors of birds — from hummingbirds to swans — which are vulnerable to this source of mortality. Scott et al. (1972) reported 74 species killed by powerlines in England (represented among these species is one order — Cuculiformes — not reported in Table 1.)

Estimates of relative or absolute numbers of birds of various species killed by wire strikes are subject to serious limitations. First, most published accounts of dead birds may be biased toward larger or light-colored birds, which are more conspicuous, and may also overestimate rates of losses, as only unusually heavy kills are discovered and published. Second, reported losses may be only the tip of this iceberg, as only a very small percentage of the total kill is actually reported; most casualties are either destroyed by predators, hidden or swept away by water, or left to decompose along some remote marsh far from the eye of the biologist.

Table 1. Bird Species for Which Mortality due to Overhead Utility Wires has been Documented in the United States.

Order, Species, and Source of Data	Indicated Cause of Mortality[1]	Type of Wires Involved[2]
PODICIPEDIFORMES (Grebes)		
Horned grebe (L. S. Thompson unpubl., J. R. Waters unpubl.)	S	P
Eared grebe (D. C. McGlauchlin pers. comm., McKenna and Allard 1976)	S	P
Western grebe (D. C. McGlauchlin pers. comm., McKenna and Allard 1976)	S	P
Pied-billed grebe (Anderson pers. comm., Krapu 1974 pers. comm., D. C. McGlauchlin pers. comm., McKenna and Allard 1976)	S	P,T
PELECANIFORMES (Pelicans)		
White pelican (G. L. Krapu pers. comm., D. C. McGlauchlin pers. comm., McKenna and Allard 1976, Peterson and Glass 1946, J. R. Waters unpubl., Willard et al. 1977)	S	P
Brown pelican (Willard 1977)	S	U
Double-crested cormorant (D. C. McGlauchlin pers. comm., McKenna and Allard 1976, von Bloeker 1927, J. R. Waters unpubl.)	S	P,T
CICONIIFORMES (Herons)		
Great blue heron (Lee 1977, 1978; Lano 1927; Willard 1977)	E,S	D,P
Black-crowned night heron (J. R. Waters unpubl.)	S	U
Heron spp. (Boeker 1972)	E	U
Cattle egret (J. Weise pers. comm.)	S	U
Egret spp. (Boeker 1972)	E	U
Wood stork (D. Tiller *fide* G. Grant)	S	U
Least bittern (Guillory 1973)	S	F

ANSERIFORMES (Waterfowl)

Whistling swan (Willard et al. 1977)	S	U
Trumpeter swan (Banko 1960, H. H. Burgess pers. comm.)	S	U
Mute swan (D. Willard pers. comm.)	S	U
Canada goose (H. H. Burgess pers. comm., McKenna and Allard 1976, Willard et al. 1977)	S	P
White-fronted goose (H. H. Burgess pers. comm., Willard et al. 1977)	S	U
Snow goose (incl. blue goose) (Anderson 1978, Blockpoel and Hatch 1976, H. H. Burgess pers. comm., G. L. Krapu pers. comm., Peterson and Glass 1946, Stout and Cornwell 1976, Willard et al. 1977)	S	D,P
Mallard (Anderson 1978; Krapu 1974; Lee 1977, 1978; D. C. McGlauchlin pers. comm.; McKenna and Allard 1976; Siegfried 1972; Stout and Cornwell 1976; Willard et al. 1977)	S	D,P,T
Bufflehead (Lee 1978)	S	U
Black duck (Anderson 1978)	S	P
Gadwall (Anderson 1978, Krapu 1974)	S	D,P
Pintail (Anderson 1978; Cornwell 1968; Griffith 1977; Krapu 1974; Lee 1977, 1978; McKenna and Allard 1976; Siegfried 1972; Stout and Cornwell 1976; Willard et al. 1977)	S	D,F,P,T
Green-winged teal (Anderson 1978; Coues 1876; Lee 1977, 1978; D. C. McGlauchlin pers. comm.)	S	P,T
Blue-winged teal (Anderson 1978, Cornwell and Hochbaum 1971, Krapu 1974, D. C. McGlauchlin pers. comm., McKenna and Allard 1976, Siegfried 1972, Stout and Cornwell 1976, J. R. Waters unpubl.)	S	F,P,T
American wigeon (Anderson 1978, Willard et al. 1977)	S	P
Northern shoveler (Anderson 1978, D. C. McGlauchlin pers. comm., McKenna and Allard 1976)	S	P
Wood duck (Anderson 1978, Stout and Cornwell 1976)	S	P
Redhead (H. H. Burgess pers. comm., D. C. McGlauchlin pers. comm., McKenna and Allard 1976)	S	P
Ring-necked duck (Boyd 1961)	S	P

Table 1. **Bird Species for Which Mortality due to Overhead Utility Wires has been Documented in the United States.** *(continued)*

Order, Species, and Source of Data	Indicated Cause of Mortality[1]	Type of Wires Involved[2]
ANSERIFORMES (Waterfowl) *(continued)*		
Canvasback (McKenna and Allard 1976, Willard et al. 1977)	S	P
Lesser scaup (Anderson 1978, Krapu 1974, D. C. McGlauchlin pers. comm., McKenna and Allard 1976, J. R. Waters unpubl., Willard et al. 1977)	S	P,T
Ruddy duck (Krapu 1974; Lee 1977, 1978; D. C. McGlauchlin pers. comm.; Siegfried 1972; Stout and Cornwell 1976; J. R. Waters unpubl.; Willard et al. 1977)	S	D,P
Fulvous tree duck (McCartney 1963)	S	U
Common merganser (Willard et al. 1977)	S	P
Merganser spp. (Stout and Cornwell 1976, J. R. Waters unpubl.)	S	U
FALCONIFORMES (Hawks and Falcons)		
Red-tailed hawk (Boeker and Nickerson 1975, Crawford and Dunkeson 1973, USF&WS unpubl.)	E	D
Rough-legged hawk (USF&WS unpubl.)	E	D
Golden eagle (Baglien 1975, Boeker 1972, Boeker and Nickerson 1975, Crawford and Dunkeson 1973, Hannum et al. 1974, Richardson n.d., USF&WS unpubl.)	E	D
Bald eagle (Boeker 1972, Boeker and Nickerson 1975, Crawford and Dunkeson 1973, Sprunt et al. 1973, USF&WS unpubl.)	E	D
Marsh hawk (J. R. Waters unpubl.)	?	–
American kestrel (USF&WS unpubl.)	?	–
GALLIFORMES (Gallinaceous Birds)		
Greater prairie chicken (Krapu 1976)	S	T
Sage grouse (Borell 1939, Myers 1977)	S	P,T

Ring-necked pheasant (Krapu 1974, D. C. McGlauchlin pers. comm.)	S	P
Gray partridge (Krapu 1974)	S	T
Turkey (Boeker 1972)	E	D
GRUIFORMES (Cranes and Allies)		
Whooping crane (J. Reed pers. comm.)	S	—
Sandhill crane (Walkinshaw 1956)	S	D
Sora (D. C. McGlauchlin, pers. comm.)	S	U
Virginia rail (D. Kiel and F. Cassel unpubl.)	S	P
Black rail (Emerson 1904)	S	—
American coot (Anderson 1978; Krapu 1974; Lee 1977, 1978; D. C. McGlauchlin pers. comm.; McKenna and Allard 1971; L. S. Thompson unpubl.; Siegfried 1972; J. R. Waters unpubl.; Willard et al. 1977)	S	P,T
CHARADRIIFORMES (Shorebirds and Gulls)		
Killdeer (Lee 1977, 1978)	S	P
American golden plover (Krapu 1974)	S	T
Common snipe (Lee 1977, 1978; D. C. McGlauchlin pers. comm.)	S	P
Solitary sandpiper (Krapu 1974)	S	T
Least sandpiper (Emerson 1904, Willard et al. 1977)	S	T
Western sandpiper (Emerson 1904; Lee 1977, 1978)	S	P,T
Buff-breasted sandpiper (Krapu 1974)	S	T
Marbled godwit (Krapu 1974)	S	P
American avocet (McKenna and Allard 1976)	S	P
Northern phalarope (Emerson 1904, Willard et al. 1977)	S	T
Glaucous-winged gull (Lee 1977, 1978)	S	P
California gull (Krapu 1974)	S	D
Ring-billed gull (McKenna and Allard 1976, J. R. Waters unpubl., Willard et al. 1977)	S	P
Laughing gull (Willard 1977)	S	—

Table 1. **Bird Species for Which Mortality due to Overhead Utility Wires has been Documented in the United States.** *(continued)*

Order, Species, and Source of Data	Indicated Cause of Mortality[1]	Type of Wires Involved[2]
CHARADRIIFORMES (Shorebirds and Gulls) *(continued)*		
Franklin's gull (D. Kiel and F. Cassel unpubl., Krapu 1974, D. C. McGlauchlin pers. comm., J. R. Waters unpubl.)	S	P,T
Common tern (McKenna and Allard 1976)	S	P
Black tern (D. C. McGlauchlin pers. comm., J. R. Waters unpubl.)	S	—
Woodcock (Bailey 1929)	S	—
COLUMBIFORMES (Doves)		
Rock dove (L. S. Thompson unpubl.)	S	D
Mourning dove (Lee 1977, 1978; D. Kiel and F. Cassel unpubl.; Stahlecker 1975)	S	P
STRIGIFORMES (Owls)		
Great horned owl (Boeker and Nickerson 1975, Edeburn 1973, Emerson 1904, Fitzner 1975, McCarthy 1973, USF&WS unpubl.)	E,S	D,F
Short-eared owl (Fitzner 1975, L. S. Thompson unpubl., Willard et al. 1977)	S	D,F
Great grey owl (Nero 1974)	S	F
APODIFORMES (Swifts and Hummingbirds)		
Allen's hummingbird (Hendrickson 1949)	S	D
PICIFORMES (Woodpeckers)		
Yellow-bellied sapsucker (Weston 1966)	S	U

PASSERIFORMES (Perching Birds)

Horned lark (Coues 1876, D. Kiel and F. Cassel unpubl., Stahlecker 1975, L. S. Thompson unpubl.)	S	F,P,T
American robin (Lee 1978)	S	P
Starling (Lee 1978)	S	P
Vireo sparrow (Anderson pers. comm.)	S	P
Thrush sparrow (Anderson pers. comm.)	S	P
Grosbeak sparrow (Anderson pers. comm.)	S	P
Purple martin (Anderson 1933)	E	D
Common raven (Boeker 1972)	E	D
Common crow (Boeker 1972; Lee 1977, 1978)	E,S	D,P
Bohemian waxwing (L. S. Thompson unpubl.)	S	F
Yellow warbler (D. Kiel and F. Cassel unpubl.)	S	P
Western meadowlark (Coues 1876, D. Kiel and F. Cassel unpubl., D. C. McGlauchlin pers. comm.)	S	–
Yellow-headed blackbird (L. S. Thompson unpubl.)	S	P
Red-winged blackbird (Anderson pers. comm., Lee 1978, McKenna et al. 1976)	S	P
Common grackle (D. C. McGlauchlin pers. comm.)	S	–
Brown-headed cowbird (D. C. McGlauchlin pers. comm.)	S	–
Song sparrow (Lee 1977)	S	P
Savannah sparrow (D. Kiel and F. Cassel unpubl.)	S	P
Lincoln's sparrow (D. Kiel and F. Cassel unpubl.)	S	P
Chestnut-collared longspur (D. Kiel and F. Cassel unpubl.)	S	P,T
McCown's longspur (Coues 1876)	S	T
Lapland longspur (Swenk 1922)	S	–

[1] E = electrocution; S = wire strike; ? = uncertain.

[2] D = distribution line (less than 50 kv); F = fence; P = transmission line (greater than 50 kv); T = telephone or telegraph line; U = unspecified powerline.

It appears, however, that the most consistent victims of wire strikes are large migratory water birds of the orders Podicipediformes, Pelecaniformes, Ciconiiformes, Anseriformes, Gruiformes, and Charadriiformes. Among these, species whose flocking behavior during migration brings large numbers of birds together in dense flocks in wetlands of relatively small extent are most frequently reported. Field-feeding puddle ducks are especially susceptible to collisions with overhead wires due to the high speed and low altitude of their flights (Boyd 1961, Krapu 1974, Stout and Cornwell 1976, Willard et al. 1977). Anderson (1978) found blue-winged teal to be more vulnerable than coots or mallards. Swans, pelicans, cranes, and "white" geese are also particularly vulnerable due to their great size, low maneuverability, and flocking behavior (Beer and Ogilvie 1972, Harrison 1963, Ogilvie 1967, Perrins and Reynolds 1967, Sauey pers. comm., Walkinshaw 1956, Willard et al. 1977). Scott et al. (1972) reported that nocturnal migrants appear to be more susceptible than diurnal migrants. Raptors, due to their great visual acuity, are rarely the victims of wire strikes but are vulnerable when distracted or blown off course by gusts of wind. Whether or not birds of different species are killed in proportion to their relative abundance has not been shown.

Condition of Birds

Most authors concur that young, inexperienced birds, as well as migrants in unfamiliar terrain, appear to be more vulnerable to wire strikes than resident breeders. Stout and Cornwell (1976) found negligible sexual differences in susceptibility of waterfowl. However, Anderson (1978) found adult mallards to be more vulnerable than juveniles and male blue-winged teal to be more vulnerable than females.

Many species appear to be most highly susceptible to collisions when alarmed, pursued, searching for food while flying, engaged in courtship, following cones of light at night, taking off, landing, or when otherwise preoccupied and not paying attention to where they are going (Lee 1977, Willard et al. 1977).

Weather and Visibility

Wire strikes appear to be most frequent at night and during windstorms, snowstorms, periods of heavy fog, or other meteorological phenomena which reduce visibility and/or cause birds to fly lower. Several researchers, however, have noted both fatal and nonfatal collisions during periods of clear, calm, daytime weather when visibility is optimal (Anderson 1978, Krapu pers. comm., Lee 1977, Walkinshaw 1956, Willard et al. 1977).

Habitat Adjacent to Right-of-Way

Wire strikes of water birds are, of course, most frequent where lines cross water areas or grainfields used by the birds or where they separate feeding and roosting areas. Water bird strikes are seldom reported other than in these situations, but passerines have been found beneath lines crossing upland habitats (Cassels pers. comm., Stahlecker 1975). Gull concentrations near a sanitary landfill were reported by Lee (1977) to suffer heavy losses. Willard et al. (1977) suggest that lines within a single habitat, e.g., a grainfield, are more likely to cause bird/wire strikes than lines running between different habitats.

Type of Wires

The physical configuration of lines in space (the strike zone) is of great importance in determining risks of wire strikes. It is also perhaps easier to change than the characteristics of birds in attempting to mitigate losses. Wires of all sorts, including fences, telegraph lines, telephone lines, power distribution lines, guy wires, and power transmission lines, have resulted in bird casualties (Table 1). The small diameter, low (less than 20 feet), high-density lines (especially telephone lines, which may have 20 or more small wires strung between structures, and lower-voltage transmission and distribution lines, which are often underbuilt at various heights on the same set of poles) appear to be the major source of wire strikes, but they are also much more abundant than transmission lines. There is some evidence that the large conductors of extra-high voltage lines are more visible than smaller conductors or ground wires, especially when strung in bundles, and hence result in fewer wire strikes (Lee 1977, Willard et al. 1977). These extra-high voltage conductors may also alert birds to their presence through corona discharge and associated noise or by electromagnetic field effects, although this has not been demonstrated (Lee 1977). The overhead ground, or static, wire is often implicated as a major culprit in bird losses involving higher voltage lines because birds will fly over the more visible conductor bundles only to collide with the relatively invisible, thin static wire (R. Hamilton pers. comm., R. A. Hunt pers. comm., R. Johnson pers. comm., D. Loomis pers. comm., Scott et al. 1972, Willard et al. 1977).

OPPORTUNITIES FOR MITIGATION

Transmission line siting is often approached initially by identifying a corridor, often several kilometers wide, which is broadly suitable for a transmission line. Corridor selection is followed by centerline selection, or on-the-ground determination of the precise route of the line, which in turn is followed by actual engineering and construction of the line. It is essential to consider mitigation at each of these three stages of the facility siting process, as described below. Since very few specific mitigating measures have actually been implemented and studied, I am unable to present here a definitive, state-of-the-art report as to relative effectiveness. Instead, I will summarize feasible suggestions and ideas with the hope they will be pursued in greater depth as a result of this workshop.

Corridor Selection

The decision where—or whether—to build a new line may be the most important mitigative tool we have. If it can be shown that broad geographical areas between proposed endpoints of a new line differ in risk for wire strikes, mortality can obviously be reduced by staying well away from areas with a high-risk potential. These areas include wetlands in general, waterfowl concentration areas, flyways, roosting areas, feeding areas, low passes, breeding areas, and especially the paths used by migrants for periodic feeding flights. If the area between line end-points is of uniform impact risk, losses may be mitigated only by *not* building the line overhead or by selecting a feasible engineering alternative with other endpoints.

Corridor selection—depending on the width of the corridor—provides a very coarse, but nevertheless important, means of mitigation. If wetlands or other high-risk areas can be avoided by distances of several miles, the probability of catastrophic losses will be greatly reduced. Unfortunately, moving a corridor to bend around a critical area increases both the length and the cost of the line. Figure 1 shows approximate costs per circuit kilometer of lines of different voltages and indicates costs involved in deviating from a straight line. Also, wire strikes are not the only consideration in corridor selection. They may be treated with low priority when land use, socioeconomic problems, human populations, and physical characteristics of the landscape are simultaneously considered. Thus, even with the best planning, new corridors may have to include wetlands or other high-risk areas, and we must look toward other means for mitigation.

Centerline Selection

Within a corridor several kilometers wide, there are an infinite number of possible centerline locations, and centerline placement provides the opportunity for a much finer degree of spatial mitigation than does corridor selection. In water bird concentration areas, a four-season study of the corridor by a waterfowl specialist should be conducted to determine local movement patterns and optimum line placement. The studies carried out by Willard et al. (1977) and proposed by Lee and Meyer (1977) provide excellent models for such investigations. Local low-level feeding flights are of particular concern, and utilities should be required to obtain information regarding the size, composition, seasonality, and repetition of such flights so that flight paths can be avoided wherever possible.

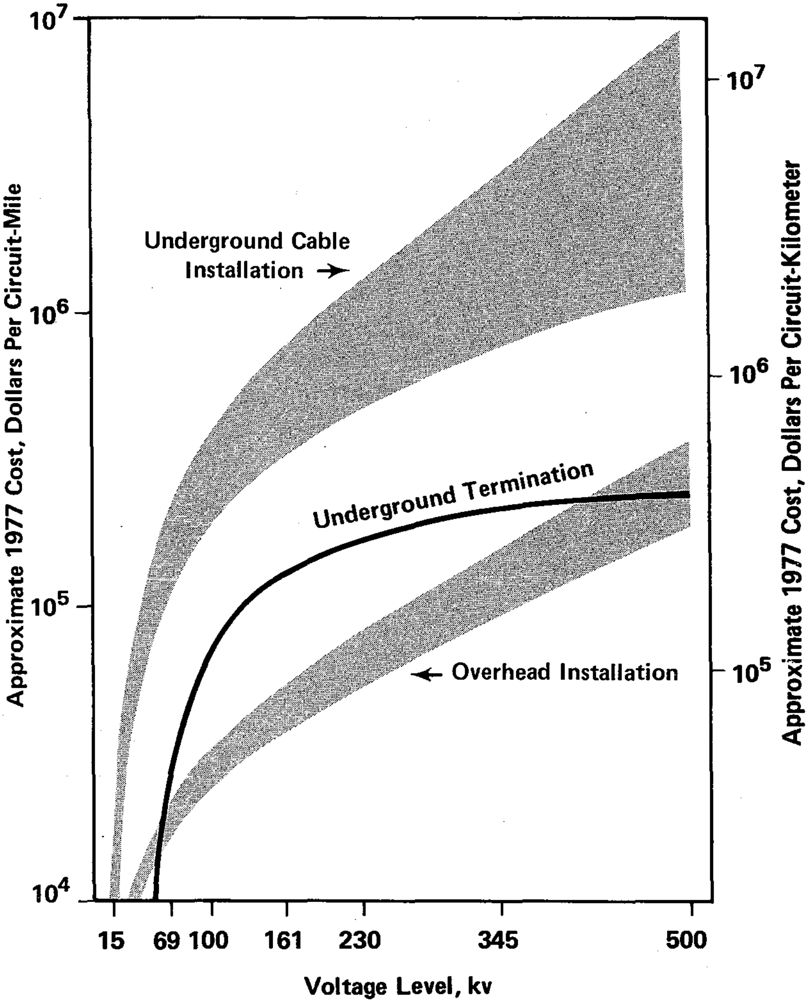
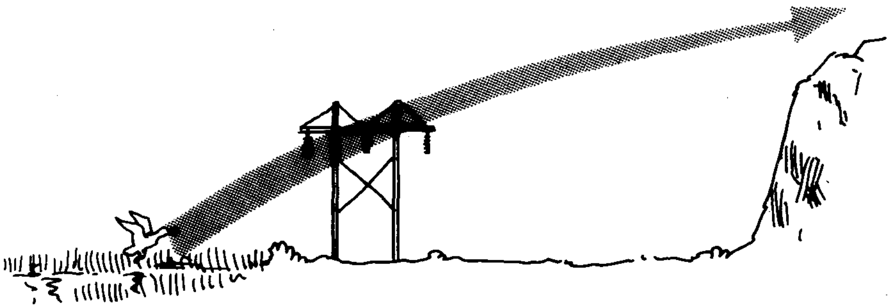
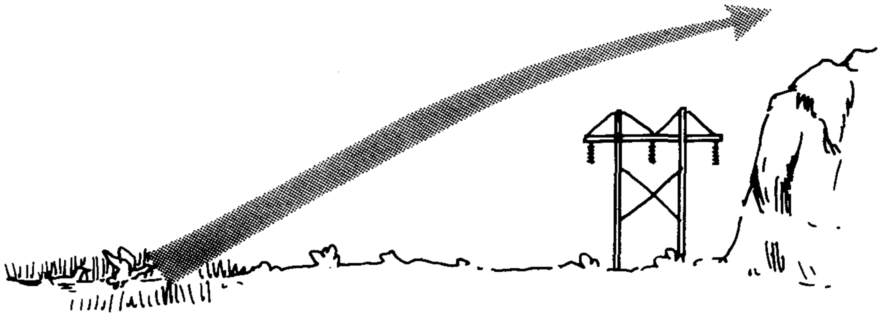


Figure 1. Estimated costs of overhead and underground powerline installation.

Several specific mitigative measures involving centerline siting may be effective where waterfowl concentration areas cannot be avoided. Scott et al. (1972) suggest line placement parallel, rather than perpendicular, to predominant lines of flight. It is also likely that lines sited adjacent to cliffs, tall buildings, windbreaks, or at the base of low hills (Figure 2) will result in fewer losses than lines in flat terrain as birds in flight begin gaining altitude in response to these highly visible features and thus fly well over the lines. Also, clustering lines, or sharing the same right-of-way with several types of lines, may be preferable because the network of wires is more visible and confined to a smaller area. Birds in flight would have to make only one climb and descent to cross a cluster of lines, whereas separate lines would require many such maneuvers (Figure 3). However, the hazard to birds during periods of decreased visibility may be greater where many lines are clustered together, forming a virtual obstacle course to flocks flying at many different heights (Figure 4). The relative effect on mortality rates of separate versus clustered lines depends on many site-specific factors and deserves careful study.



A. High-Hazard Situation



B. Corrected Situation

Figure 2. Mitigation by judicious line placement relative to local topography.

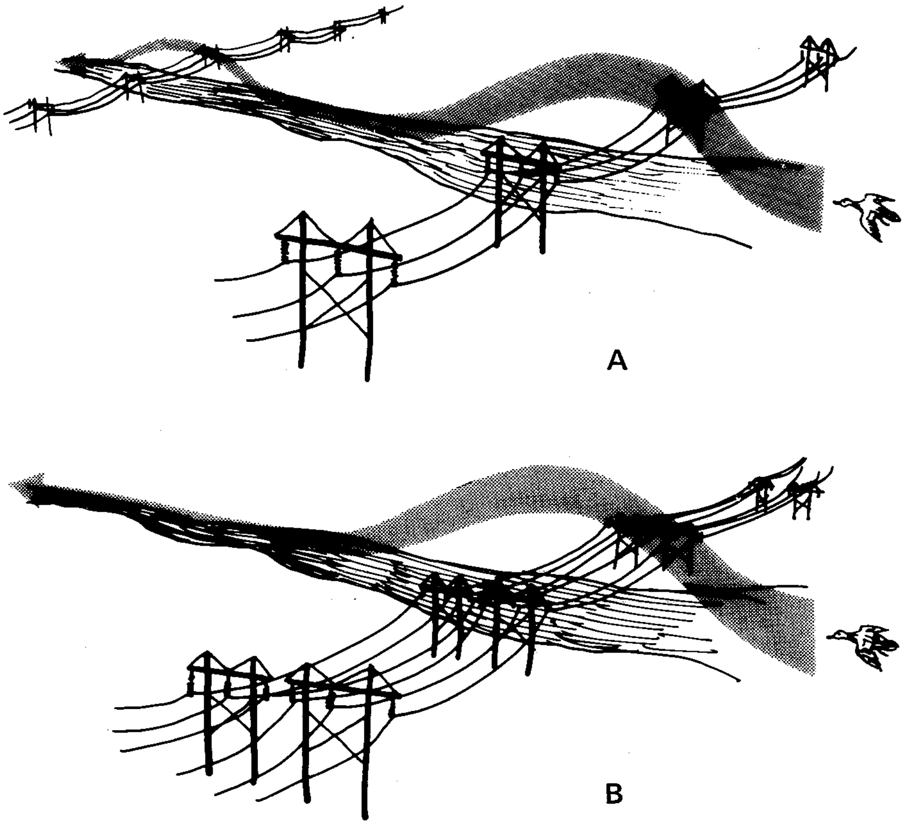
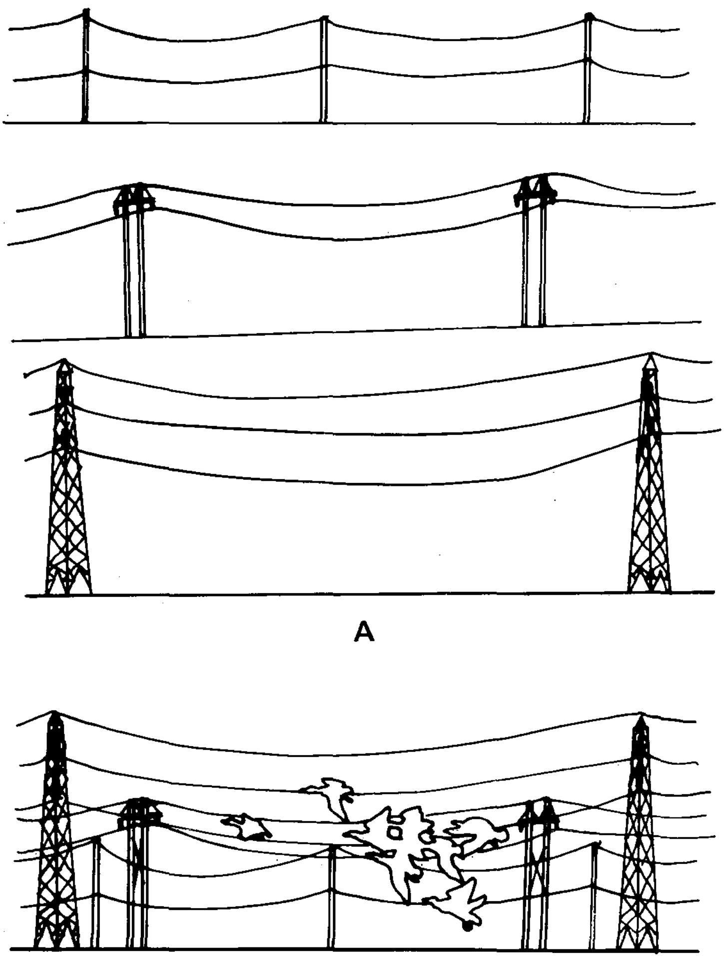


Figure 3. Mitigation by clustering lines at river crossings. Note that two climbs and descents are required at A while only one is necessary at B.

Another possibility for mitigation involves judicious centerline placement in relation to local climate. Avoiding areas of frequent and heavy fog can reduce the probability of wire strikes. It may also be possible to locate conductors parallel, rather than perpendicular, to prevailing winds, thereby reducing the likelihood birds will be blown perpendicularly into wires. Wind roses, as shown in Figure 5, could provide useful information applicable to centerline placement, although prevailing wind direction may not be clear in some areas (Figure 5A) or may differ in the same area between seasons (Figures 5B and 5C). In the latter example, siting the centerline parallel to prevailing spring winds would result in crosswinds and a greater probability of wire strikes in the fall. Wind direction is probably more important in fall than in spring, since hunting pressure has been shown to increase the nocturnality of duck movement (Willard et al. 1977). This type of mitigation is probably most applicable to lines in river canyons where winds are topographically confined yearlong to a certain direction (Figure 6).



A

B

Figure 4. Separate lines (A) versus clustered lines (B). While the probability of a flock of birds encountering a line is greater at A, the risk of collision in a flock of birds passing through the lines during poor visibility is greater at B.

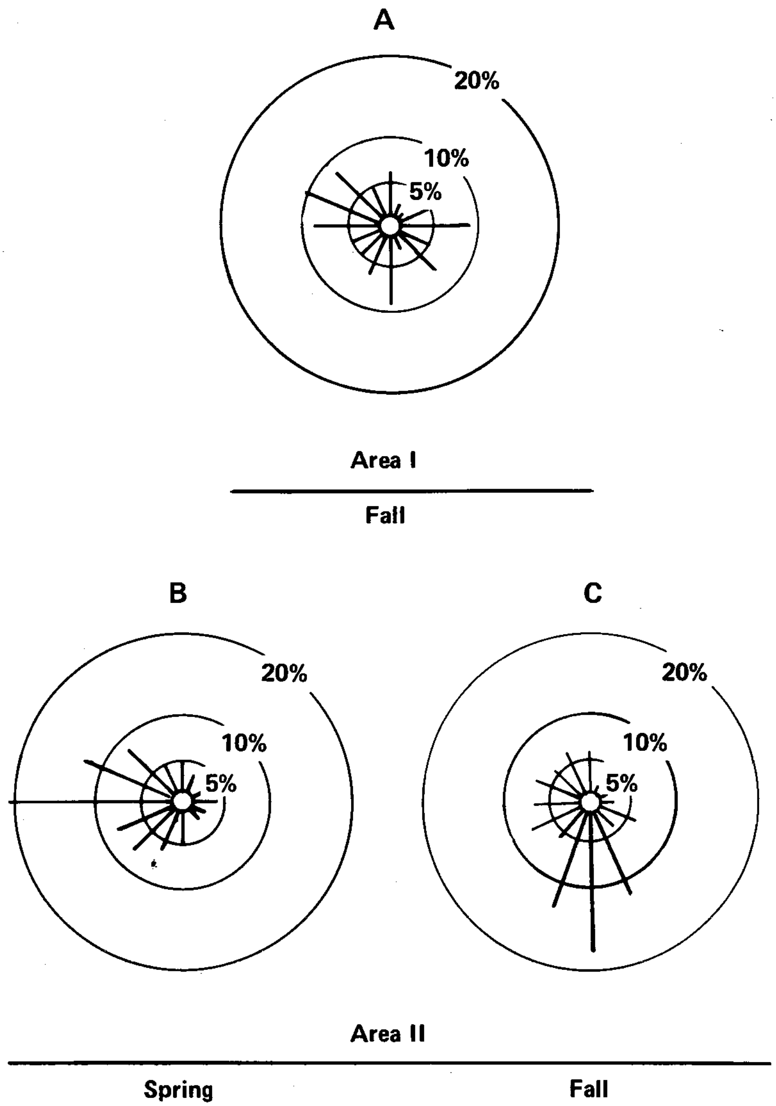


Figure 5. Hypothetical wind roses for two areas, the first (Area I) showing little predominance of wind direction and a second (Area II) showing strong seasonal predominance of direction which differs from spring to fall. Direction of lines indicate wind direction in each of 16 compass points, and length of lines indicates the percentage of time the wind blows in that direction.

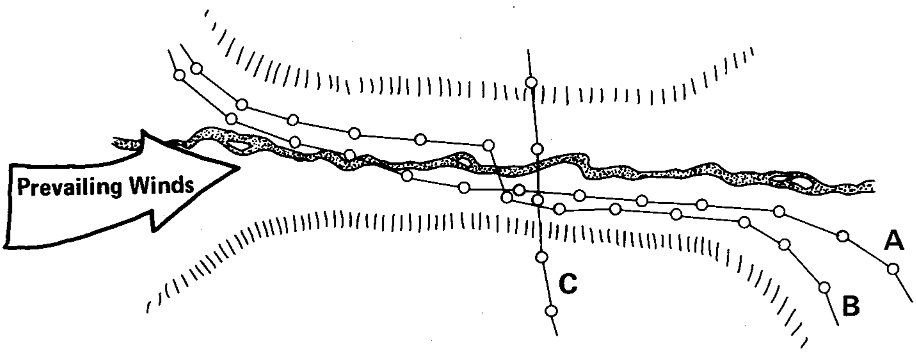


Figure 6. Where winds are confined by topography, as in major river canyons, wire strikes can be mitigated by line placement parallel, rather than perpendicular, to wind direction and by crossing the river obliquely rather than perpendicularly. In this figure, A is preferable to B or C.

Mitigation by Engineering Design

The following mitigative measures may be applicable both to designing new lines and to reducing losses on existing lines which are causing considerable bird mortality and which cannot feasibly be moved.

Undergrounding. If conductors are buried, the chances of wire strikes are, of course, reduced to zero. This is quite feasible for telephone and power distribution lines, and in certain cases it may actually be cheaper than overhead construction. However, as voltage rating increases, cost increases exponentially, and risk for detrimental impacts to resources other than waterfowl may also increase significantly (see Schiefelbein 1977). Figure 1 compares costs of overhead and underground transmission for a variety of voltages, based on currently available technology. Termination costs, or the costs of "going under" at each end of the underground segment, are considered separately as these are roughly the same regardless of line length. (Total underground costs are calculated from Figure 1 by multiplying the cost per unit length by total length and adding twice the indicated termination costs.) Technology has been proven only for voltages of 69 kv and below; high voltage underground technology is presently in prototype stage. In fact, out of 5373 miles of 100-kv lines projected over the period 1976 to 1981, only 56 miles are planned as underground (Federal Power Commission, Bull. 22175, February 26, 1976). Less than 1 mile of gas-insulated, prototype, underground, 500-kv transmission line has actually been built (Ray pers. comm.).

Tower Design. For 500-kv metal-lattice towers, two basic tower designs are available — guyed and free-standing (Figure 7). Guyed towers are relatively lightweight and are used exclusively as suspension towers, that is, towers which simply hold the wires off the ground. The guy wires leading from these towers may pose an additional collision hazard, which can be mitigated by using self-supporting towers at river crossings or in wetlands. Self-supporting towers are also used as suspension structures, but the larger and sturdier designs may be used as dead-end structures (capable of withstanding a strong lateral pull, as from unbalanced conductor tension) as well. Although the range of costs of self-supporting towers ($24,000 to $72,000) is greater than that of guyed towers ($18,000 to $23,000), self-supporting towers are often required in any case at water crossings, since the long spans involved require greater tower strength.

Presence of Static Wires. As mentioned above, the static wire is smaller and hence less visible than conductors on higher voltage lines, and it appears to be a major cause of collision mortality. This hazard may be reduced simply by eliminating the static wire from spans crossing wetlands. However, there are two major objections. The purpose of the static wire is to intercept and drain the electrical charge from a lightning strike; if the wire is not present, the lightning bolt can strike conductors and cause relays to trip out. Indeed, lightning appears to be the major single cause of powerline outages in the U. S. (Schiefelbein 1977). In many areas, charts of lightning frequency are available, and the probability of lightning striking a given span may be calculated. Even in areas of low lightning frequency, though, eliminating the static wire will slightly increase the probability of lightning-caused outages. Since eliminating the static wire over a

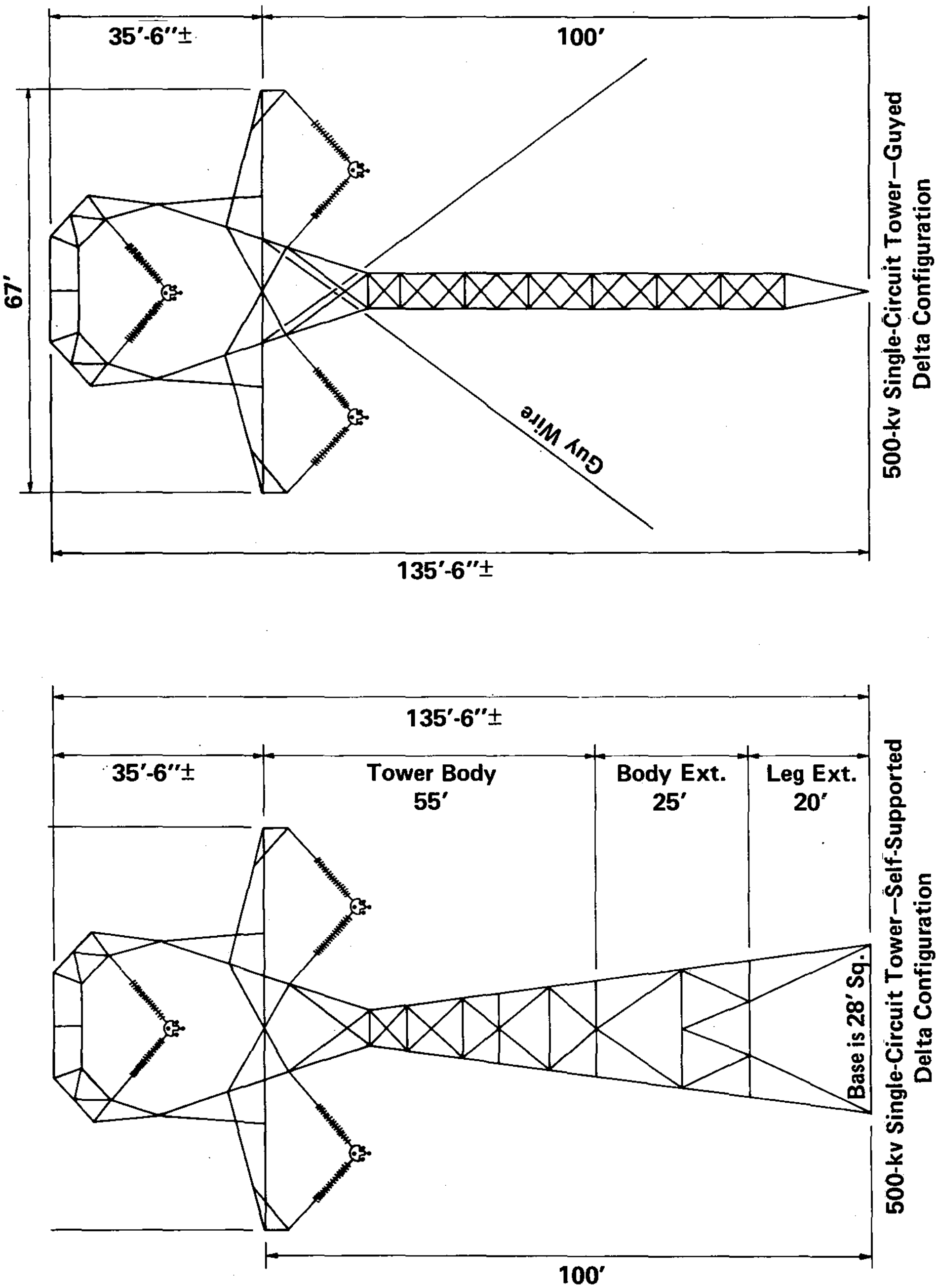


Figure 7. Self-supported and guyed 500-kv tower designs.

certain span causes lateral stress on the towers at the ends of the span, dead-end structures, at a greatly increased cost, would be required. This increased cost could be somewhat offset by savings in the price of the static wire, which has been estimated by Bonneville Power Administration to exceed $13,000 per mile of single-circuit 500-kv line (Schiefelbein 1977).

Height of Conductors. One suggested means of mitigation is to adjust the height of conductors above ground to avoid predominant approach flight path heights of those birds using nearby water areas. However, there are several serious problems with this approach. First, flying heights and approach patterns of birds vary greatly by species, season, and weather conditions. Birds which fly at great heights during clear, calm weather may fly very close to the ground during periods of poor visibility and thus be vulnerable to wires of varying height. Also, conductors sag in the middle and may be over twice as high near the tower as at midspan. Upper and lower bounds are put on the available range of heights of conductors by the increasing costs of taller towers and by minimum ground clearance standards, respectively (Table 2).

Since wire strikes are so often associated with low visibility, some advantage may be gained by installing conductors on the highest towers possible. This may cause additional problems, though, with species reluctant to fly under the conductors, thereby increasing their chances of collision with the static wire, not to mention the problem of increased cost.

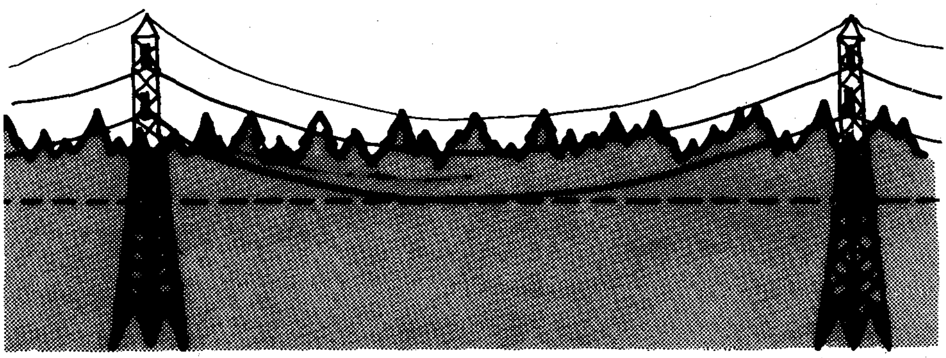
Where lines cross forested lands, tower height can sometimes be reduced to that of the trees, reducing above-canopy exposure and thus lowering the risk of collision to

Table 2. Approximate Minimum Ground Clearance for Powerlines of Different Voltages

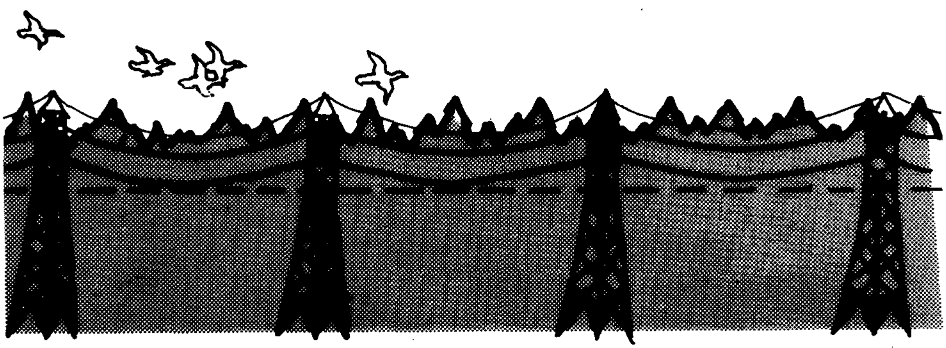
Voltage (kv)	15	69	115	161	230	500
Clearance (ft)	22	24	25-27	27-29	30-31	35
Clearance (m)	6.7	7.3	1.6-8.2	8.2-8.8	9.1-9.5	10.7

birds flying over the treetops (Figure 8). This requires shorter spans and more towers to maintain minimum ground clearance, and it may be costly. Losses might be reduced by keeping all lines between towers in roughly the same horizontal plane, that is, employing a flat conductor configuration rather than a delta or stacked configuration. This effectively reduces the vertical dimension of the potential strike zone. To be effective, however, the static wire must remain above the plane of the conductors.

Increasing Visibility of Wires. Measures which



A. High-Hazard Situation



B. Corrected Situation

Figure 8. In areas where flocks of birds commonly fly just above the forest canopy, wire strikes can be mitigated by placing the lines just below the treetops. The horizontal, dotted line indicates minimum ground clearance of the conductors, and lowering the line while maintaining this clearance requires more towers and shorter spans.

increase the visibility of wires (especially static wires) would theoretically decrease the probability of birds' colliding with the wires. Daytime wire visibility may be enhanced by increasing the diameter or by changing the color or reflectivity of the wire. Collision hazard seems to be roughly inversely proportional to wire diameter, and although larger diameter conductors are preferable electrically, they are also more expensive and require stronger towers. Stringing conductors in bundles, a common practice for higher voltage lines, increases apparent conductor diameter and hence visibility. No information is available on the relative visibility of different color wires to birds, although dark wires would probably be most visible against an overcast sky and bright, reflective wires would likely be most visible on sunny days.

Visibility of wires may also be increased by attaching highly visible objects to them. Large, colored spheres of the type frequently used on lines near airports or on long, high spans may be installed at a cost of approximately $100 each. While birds may very well see these spheres, they may still fail to see the wires between and may strike the wires while swerving to miss the spheres. Scott et al. (1972) reported that 15-centimeter black tapes tied at 1.9-meter (6-foot) intervals along static wires have been effective in reducing bird casualties in England. The same authors reported an experiment in England in which static wires were marked at 1.2-meter (4-foot intervals) with 5-centimeter bands of luminous orange tape, or with luminous orange strips having a free-hanging tail 5 centimeters long. Casualties were somewhat lower on marked spans during the 3 years after marking than during the preceding 3-year period. The number of casualties at marked spans was also lower than at adjacent unmarked spans during the 3 years after marking. However, differences were not significant and were probably overridden by effects related to line placement. The relative effectiveness of the two marking techniques could not be determined, although the orange strips faded to white 18 months after marking. Marking wires with other devices such as ribbons, streamers, flags, or even plastic windmills of the type seen in used car lots may be effective in reducing losses and should be tested in the future. Disadvantages of this type of mitigation are the aesthetic impact of such marking and nighttime ineffectiveness.

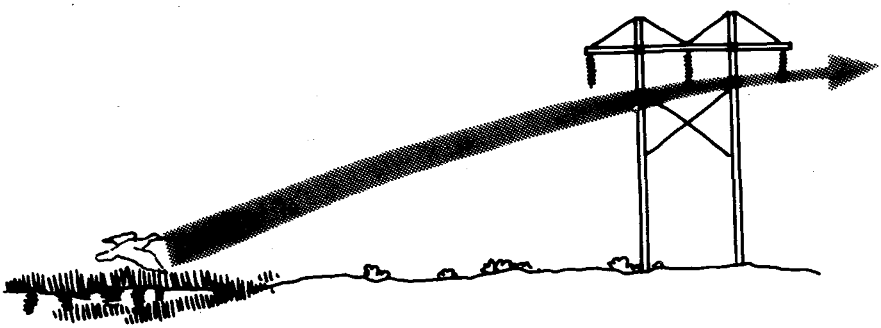
Wire visibility may be increased at night by attaching reflective or luminous objects to the wires or by giving the wires a reflective or luminous coating and providing a nighttime light source. The expense and logistical problems of illuminating long spans of transmission lines would be formidable, and there is some evidence that night floodlighting may be countereffective. Several authors (Avery et al. 1976, Cochran and Graber 1958, Johnston and Haines 1957, Laskey 1960, Rybak et al. 1973, Weir 1976) found that nocturnally migrating birds are attracted to the "white hole" created by a bright beam of light; they become blinded or disoriented, often flying around within the beam for hours or until exhausted or killed by striking objects. Avery (pers. comm.) and Weir (1976) suggest that strobe lights may be much more effective than floodlights in reducing collision mortality, although in at least one case (Whelan 1976) strobes did not provide an improvement over continuous light. Some evidence suggests red strobe lights may be preferable to white (Weir 1976), but much work is needed to determine optimum frequency, color, intensity, direction, and location relative to the lines. One manufacturer (Flash Technology of America pers. comm.) has developed a strobe model (FTB-205 B) specifically for use on transmission towers. Nighttime illumination of wires has not been adequately tested; it certainly could not be expected to prevent losses due to the preoccupation of startled or flocking birds or to birds being thrown off course by gusts of wind.

Repelling Birds from the Vicinity of Conductors. The probability of wire strikes can be reduced if the birds are somehow kept away from the vicinity of the lines. This may be accomplished by making habitat near the lines relatively less attractive than habitat farther from the lines (as discussed above) or by chasing or scaring birds away from the lines with some sort of auditory or visual stimulus. Wind-operated whistles or bells have been suggested, but they would probably be of limited effectiveness. A device known as Av-alarm™, which produces high-frequency "distress" sounds effective in repelling certain species of birds, has been used in connection with TV towers and airport ceilometers with limited success These devices are rather expensive, of unknown effectiveness in repelling water birds (which may habituate to a constantly repeated sound), and impractical to install along long lengths of powerline. Windmills or wind-animated scarecrows made to resemble hunters, canids, or raptors may be effective in repelling birds during daylight hours. Raptor silhouettes cut from paper have reduced avian collisions with a glassed-in walkway in Pullman, Washington (Johnson and Hudson 1976), and owl dummies have reduced the number of pigeons roosting on an interstate highway bridge just east of Seattle, but similar devices to repel waterfowl have not been tested. Encouragement of raptor nesting on towers as a waterfowl deterrant merits study.

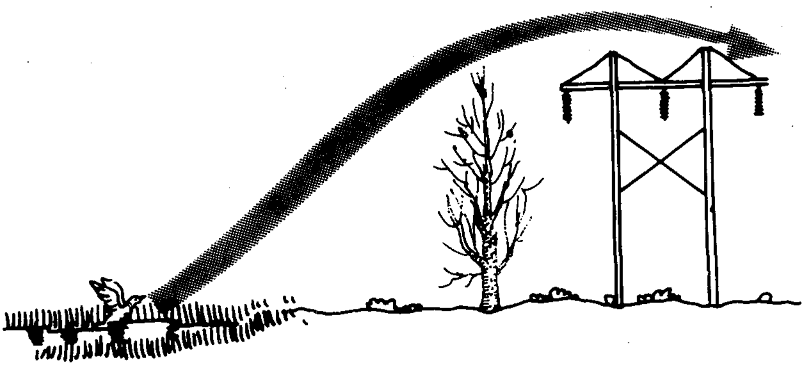
A problem with this type of mitigation is that otherwise attractive habitat is rendered unavailable to a segment of the bird population, forcing it into less suitable habitat elsewhere. This may have an effect on carrying capacity as great, or greater than, wire strike mortality and may render this type of mitigation counterproductive. Again no data is available to document this supposition.

Shielding Structures. If wires can be screened by trees, billboards, or other man-made structures, it is quite likely collisions can be reduced or prevented. Many bird species are reluctant to fly *under* objects, and ducks in particular begin gaining altitude well ahead of an obstacle in their path (Fog 1970, Gunter 1956). Shelterbelts, bridges, billboards, high wooden fences, walls, or other highly visible structures can force birds to fly *over* lines even if they cannot see the wires (Figure 9). These flight path barriers could probably be effective even if much lower in height than conductors or if some distance from the right-of-way, provided they are located optimally along the flight path of the birds. Further study of the behavior of birds in relation to obstacles in their flight path would allow optimum placement of such barriers. Of course, such structures would have to be designed to prevent birds from colliding with them, and they have the potential of being eyesores. This type of mitigation would probably be most effective for smaller lines (especially telephone and distribution) or at multiple-line river crossings.

Preventing Distraction of Birds. It has been noted that birds are highly vulnerable to collisions when startled or distracted. Prohibiting hunting or travel (perhaps by closing access roads parallel to lines through wetlands) may serve to reduce collision losses.



A. High-Hazard Situation



B. Corrected Situation

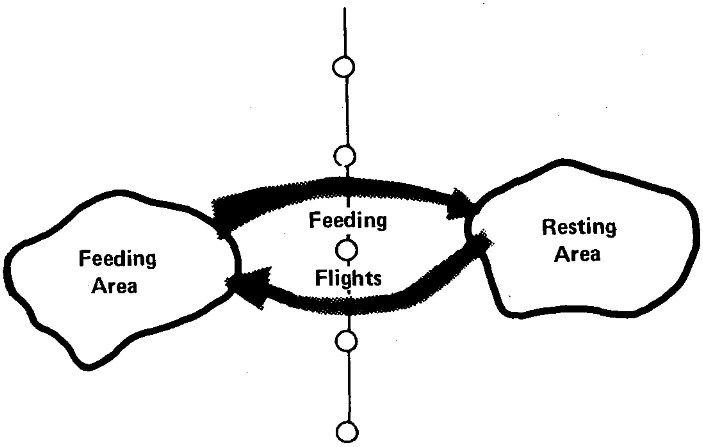
Figure 9. Mitigation by placing highly visible structures next to the line to alter flying height of birds.

Mitigation by Habitat Modification

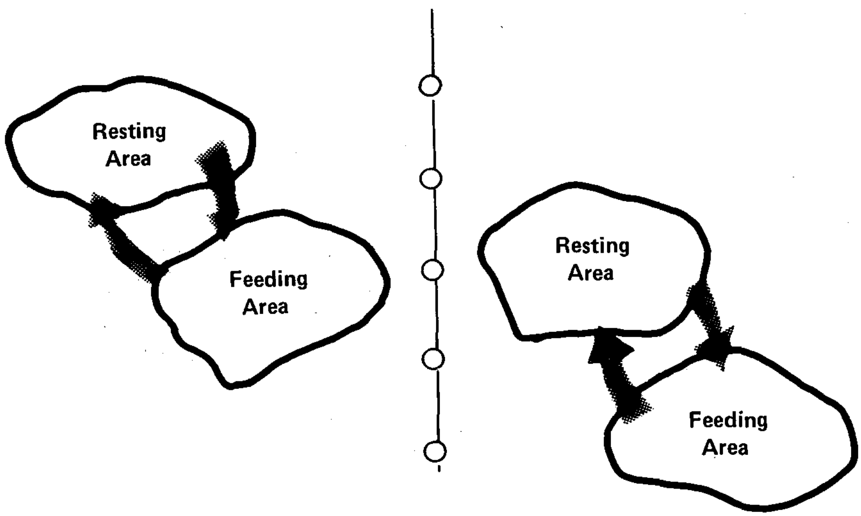
If the habitat factors which make certain powerline rights-of-way attractive to birds are known, the opportunity exists to mitigate wire strikes by making certain habitats *relatively* less suitable or attractive to high-risk species. I emphasize *relatively* since it may not be desirable to degrade right-of-way habitat quality, and hence carrying capacity, simply to lower mortality rates—no one is going to recommend draining or filling a wetland crossed by a powerline simply to lower the incidence of collision mortality. Perhaps a better approach would be to make nearby habitat *more* attractive, thereby not only attracting birds away from a high-risk situation but benefiting the population as well. This means may be particularly effective with respect to feeding flights; in cases where feeding and roosting areas are separated by a powerline, it may be advantageous to create new feeding and resting areas, as shown in Figure 10. Lee (1977) mentioned large kills of gulls flying between a wetland and a sanitary landfill; changing the location of the landfill could reduce these losses. Although these measures may be expensive, they may very well be less expensive and more beneficial than some of the contrived engineering solutions noted above. They will certainly not be applicable, however, in all situations.

A corollary measure involves changes in local land use patterns on and near the right-of-way in order to change local flight patterns of migratory birds. For example, reversing the locations of a grainfield used as a feeding area and an alfalfa field (Figure 11) may reduce collision mortality. Willard et al. (1977) found that grainfields in the Klamath Basin of Oregon were more attractive to waterfowl than pastures, especially just before or just after harvest, and that plowing greatly reduced attractiveness while flooding increased it. It is thus possible to remove or relocate the feeding enticement by changing the timing or location of flood irrigation.

Experience has shown that landowners are often reluctant to make such dramatic changes voluntarily, and it would pose considerable problems to force them to do so outside the right-of-way. Consequently, these habitat



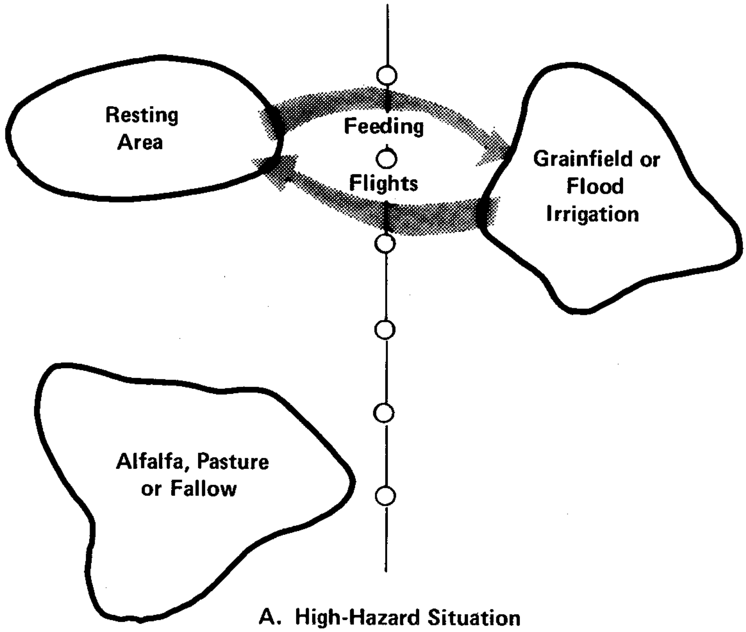
A. High-Hazard Situation



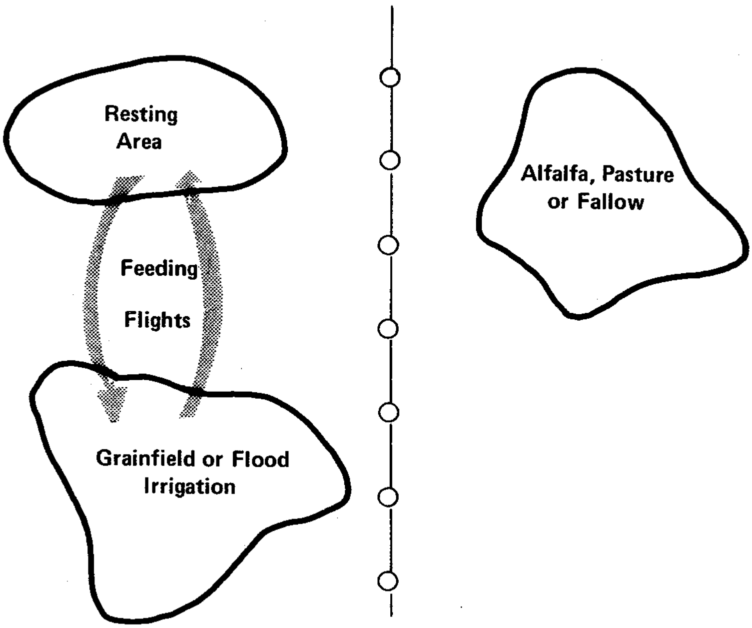
B. Corrected Situation

Figure 10. In some cases, local feeding flight patterns may be changed by creating new feeding and/or resting areas.

changes may be most practical on public land or along multiple corridors. Also, traditional flight patterns may be difficult to change through habitat modification.



A. High-Hazard Situation



B. Corrected Situation

Figure 11. Mitigation by local land use change. Reversing the locations of attractive and unattractive land uses in the vicinity of a powerline may change waterfowl feeding flight patterns.

DISCUSSION

Significance of Wire Strikes

The "significance" of an adverse impact to wildlife really incorporates two distinct concepts — biological significance and social acceptability (Buffington 1976). A biologically significant impact is one which is long-term and which results in a measurable change in carrying capacity or ultimate population size. In this respect, the impact of wire strike mortality on bird populations can be judged biologically significant only if it exceeds the compensatory response capability of the population and thus results in a measurable population decline. That this is the case with any waterfowl species is highly doubtful, since waterfowl populations are able to compensate for substantial hunting mortality, which is much greater than collision mortality (Anderson and Burnham 1976). Stout and Cornwell (1976) estimate that wire strikes comprise about 0.1 percent of total waterfowl nonhunting mortality in their sample; hunting mortality, in comparison, probably affects 20 percent to 30 percent of waterfowl populations (Anderson and Burnham 1976, McGregor pers. comm., Willard et al. 1977). Losses of certain rare species with lower compensatory ability may indeed be biologically significant — loss of five whooping cranes to wire strikes could be disastrous to the population. The extent of our knowledge today is such that we may not be able to perceive or measure changes in carrying capacity attributable to wire strikes, even if they are sizable and long-term.

Should wire strikes be found *not* to significantly affect population size over the long-term, they may be important in another respect, namely, social acceptability. The public sensitivity may be so affronted by the loss of 10 whistling swans that this loss constitutes a very real social impact and is deemed by society to be unacceptable, although the loss may not be biologically significant. The recent public outcry over the proposed Midpoint to Medford 500-kv lines (which would cross Oregon's Klamath Basin, a very important waterfowl concentration area) illustrates this point well: The public simply does not want to see birds killed by powerlines, regardless of the biological significance of such losses.

The concern has also been raised that, while losses may not affect ultimate population size, they may be reducing the harvestable surplus of waterfowl available to hunters. The assumption that nonhunting mortality is largely replaced by hunting mortality may not be true above certain threshold values (Anderson and Burnham 1976, Stout and Cornwell 1976), and post-hunting season mortality may have an important effect on populations. Cornwell (1968) believed that wire strike losses add to, rather than replace, hunting mortality.

It may be relevant at this point to bring up the concept of *maximum sustainable yield* (see Sharma [1976] for a discussion of this concept in relation to impact significance). If we assume that a fixed proportion of the population of migratory birds can and will be lost to various types of mortality (predation, disease, starvation, shooting, wire strikes, etc.) each year without affecting carrying capacity — that is, the maximum sustainable yield — we may allocate certain portions of this harvestable surplus to the various sources of mortality (Figure 12) and manage accordingly.

Society may deem wire strike mortality to be an unfortunate but unavoidable phenomenon and thus allocate a certain percentage of the harvestable surplus to these losses rather than accept the costs of mitigation. This nonaction amounts to saying that a certain amount of wire strike mortality is part of the cost society must pay for a convenient source of energy. If carrying capacity is to remain constant, the magnitude of other types of mortality will have to adjust downward. This includes hunting mortality, and the social impact of reduced availability of waterfowl to hunters hardly needs mention.

On the other hand, wire strike losses may be judged unacceptable, and society must then attempt to channel money, energy, and resources into efforts to mitigate or prevent losses. Society is then faced with the problem of optimizing the balance between various social costs of mitigation and the benefits of reduced wire strike mortality.

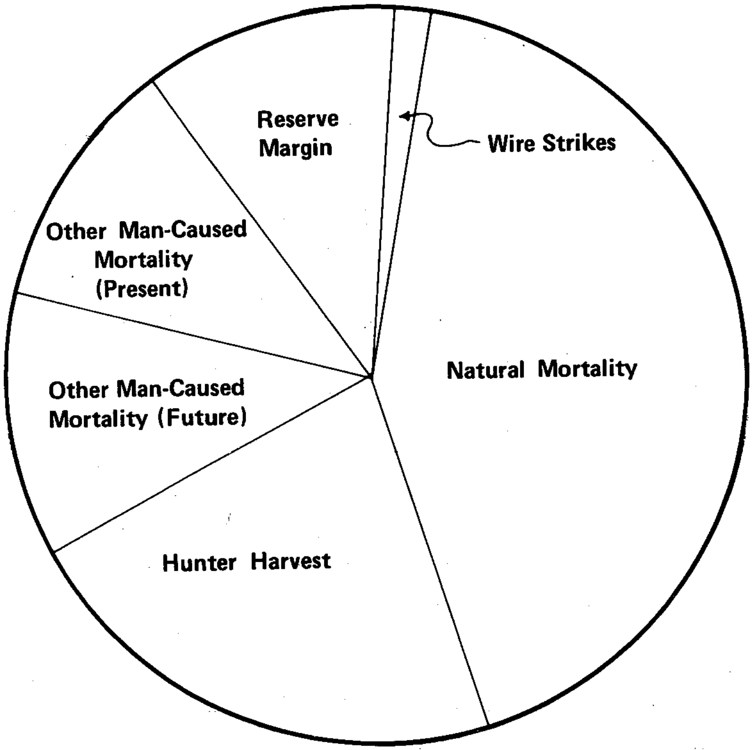


Figure 12. The maximum sustainable annual mortality of populations can, to some extent, be differentially allocated to specific types of mortality without affecting carrying capacity or long-term population size. (Modified from Sharma 1976.)

Costs Versus Benefits of Mitigation

A couple of hypothetical examples may best serve to illustrate the difficulty of balancing the costs and benefits of mitigation. Let us assume we could accurately predict the rate of wire strike mortality of a proposed twin 500-kv transmission line through the center of a circular wetland 10 kilometers in diameter to be 100 kilograms of waterfowl per circuit-kilometer per year. In order to skirt this wetland completely, each line would have to be increased in length by $({}^{10\pi}/_{2} - 10)$ kilometers, or 5.7 kilometers. The increased cost of doing so, assuming a cost of $125,000 per circuit-kilometer, would be $1,425,000. This compares with 80,000 kilograms of waterfowl that would be "saved" assuming a 40-year life of the line (100 kilograms per circuit-kilometer per year times 2 circuits times 10 kilometers times 40 years). Thus, the cost to society per kilogram of waterfowl would be $17.81. This may be unreasonably expensive, especially since the losses may not be biologically significant and the "lost" kilograms of waterfowl are never actually recovered.

For another example, let us consider a pond 0.1 kilometer wide which will be spanned by a 500-kv line using 23-meter guyed structures on each side. Using the same hypothetical rates of wire strikes noted above, approximately 400 kilograms of waterfowl would be lost over the 40-year life of the line. Assuming these losses could be prevented by eliminating the static wire, thus requiring self-supporting towers which are (by best 1977 estimates) approximately $100,000 more expensive to install, society is, in effect, paying $250 per kilogram of waterfowl. If losses could be prevented by installing colored flags on the guy wires at a cost of $1,000, the cost to society could be reduced to $2.50 per kilogram of waterfowl.

These may be artificial examples, but they serve to illustrate an important point: Costs of mitigation must be weighed carefully against the benefits to be obtained. This problem would be sufficiently difficult to solve under any circumstances, but it is compounded by the fact that wildlife values (despite several recent attempts) are essentially unquantifiable. How much is a duck worth? a cormorant? a whooping crane? The U.S. recently settled a Canadian claim for ducks killed by an oil spill by paying the Canadian government $2 per duck (Efford 1976), and the possibility exists that utilities may be required to reimburse the public a dollar value for waterfowl losses attributable to wire strikes. But what is the monetary value of a lost opportunity for a hunting experience? In another recent case, the court awarded a wetland owner $90,000 damages for alleged avoidance by birds of his land because of nearby powerlines (Bonde 1970).

Obviously, whatever the value of waterfowl, the point is ultimately reached where further investments in mitigating measures yield diminishing returns in terms of waterfowl abundance. Long before this point is reached, serious consideration should be given to compensation of wire strike losses as an alternative to mitigation.

Compensation of an Alternative to Mitigation

In the example of the twin 500-kv lines through a circular wetland, $1,425,000 was the cost estimate of mitigation through centerline placement, and the benefits to be obtained amounted to 2,000 kilograms of waterfowl saved annually. If the line were built as originally planned, through the center of the marsh, the money is saved while the ducks are lost. What benefits could be obtained by using this same amount of money instead for waterfowl habitat improvement, wetland acquisition, winter feeding, law enforcement, or other long-term increases in carrying capacity? It is likely they could far exceed the benefits to be obtained by merely preventing a relatively small percentage of nonhunting mortality.

While compensation is an attractive alternative to mitigation, it is not the final answer, especially where "out-of-kind" compensation is involved. No amount of mallard habitat improvement can compensate for the loss of a flock of whooping cranes to wire strikes. Serious logistical difficulties may be encountered by efforts to compensate snow geese losses in the U.S. by improving breeding habitat in Canada, although Pacific Power and Light is considering a proposal by Ducks Unlimited to compensate for collision losses in Oregon by contributing $248,000 to habitat acquisition in Canada. Problems in forcing utilities to make such compensation would be formidable. Nevertheless, it is an alternative which, in some cases, would yield greater benefits than mitigation and should be considered on a case-by-case basis.

The point is not that mitigation is unimportant. The point here is simply that creating additional habitat may, in some cases, be a better use of available money than developing more and more sophisticated and energy-intensive "technological fixes" such as strings of lights or electronic noisemakers.

SUMMARY AND CONCLUSIONS

Transmission line wire strikes by migratory birds are an increasingly serious problem in the United States. While a great many species are affected, large water birds are the most consistent victims, and losses are heaviest in waterfowl concentration areas during periods of wind, fog, rain, or nighttime feeding activity. Initial siting of lines away from hazard areas is perhaps the most direct approach to mitigation but cannot always be implemented because of other siting constraints. Where lines cross high-risk areas, losses may be reduced by a variety of means, including underground installation, changes in tower design, removal of static wires, changes in conductor height, increasing wire visibility, repelling birds from the vicinity of conductors, installing shielding structures, preventing distraction of birds, and local habitat modification. Most of these mitigating measures have not been tested, but the most promising short-term solutions appear at this time to be the following: marking wires (especially static wires and guy wires) with permanent, highly visible flags or strips; changing flight patterns of birds by installing highly visible banners parallel to the lines or by altering land use patterns adjacent to the right-of-way; and clustering lines at river crossings. The biological significance of wire strikes may not be great, but the public relations value to utilities of attempting mitigation can be high. The costs of many potentially effective mitigating measures outweigh the benefits to be obtained, and in some cases compensation by habitat improvement may be preferable to mitigation. Priorities for future research should be the evaluation of rates, causes, circumstances and populational significance of wire strikes on different types of lines (with particular reference to the importance of the static wire); development of wire markers, warning devices, or alternative tower designs which are effective but not prohibitively expensive; and exploration of the many untested mitigative measures discussed above.

ACKNOWLEDGMENTS

I extend my sincere thanks to the many individuals who took time to discuss this topic with me and whose ideas form the bulk of this paper. Much of the material presented here was gathered during the course of transmission line impact evaluations carried out by the Energy Planning Division, State of Montana.

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Effects of Transmission Lines on Bird Flights: Studies of Bonneville Power Administration Lines

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Bonneville Power Administration

INTRODUCTION

Bonneville Power Administration (BPA) is the agency within the U.S. Department of Energy responsible for marketing power generated by federal hydroelectric dams in the Columbia River Basin. BPA operates over 19,000 kilometers of transmission lines (115 kv-to-500 kv a.c., ±400 kv d.c.) located throughout the Pacific Northwest. As a federal agency, BPA is subject to provisions of the National Environmental Policy Act which require that the environmental impact of major actions be identified.

In 1974, BPA began a research program to obtain specific information on the environmental impact of transmission facilities. The program was designed to be responsive to concerns identified during the environmental impact statement process by BPA, other agencies, and the public. Initial research was directed at the impact of extra-high voltage (EHV) (above 230 kv) transmission lines on plants and animals (Goodwin 1975, Lee and Rogers 1976, Griffith 1977). This reflected the wide interest in the possible biological effects associated with corona and electric and magnetic fields of EHV transmission lines. To date, this research has shown that most impacts on wildlife that are detectable by field observation are due primarily to habitat modifications resulting from construction and maintenance operations (Lee 1977).

In recent years, a growing number of comments on the possible effects of BPA transmission lines on migratory birds have been received. These comments have been primarily in the form of questions rather than reports of observed effects. Research on the BPA system so far has concentrated on possible effects of transmission lines on bird distribution and abundance (Lee and Rogers 1976, Lee and Griffith 1977, Griffith 1977) and on the use of transmission line structures as nesting sites (Lee 1976). Preliminary information has also been collected on the effects of transmission lines on bird flight behavior, including collisions with wires. This last subject has received considerable attention in recent years, and the need for quantitative data is generally recognized. In this paper, I will point out the distinguishing characteristics of transmission lines, briefly review relevant literature, and report on studies and observations of the effects of BPA transmission lines on bird flight behavior and collision mortality.

TRANSMISSION LINES

Transmission lines are used to transmit electric power from generation sources to load centers. In 1975, there were an estimated 408,930 circuit kilometers of overhead transmission lines (in this group 110 kv to 800 kv) in the U.S. with EHV (345 kv to 800 kv) lines constituting approximately 6.3 percent of this total (Edison Electric Institute 1976). Currently, the highest voltage for operational a.c. transmission lines in the U.S. is 765 kv. BPA has constructed a 1200-kv a.c. prototype transmission line, and such ultrahigh voltage (above 800 kv) lines are expected to be in use in the 1980s.

Compared with power distribution (below 115 kv) and communication (telephone and telegraph) lines, transmission lines usually have much larger support towers and conducting wires (conductors) (Figure 1). At voltages

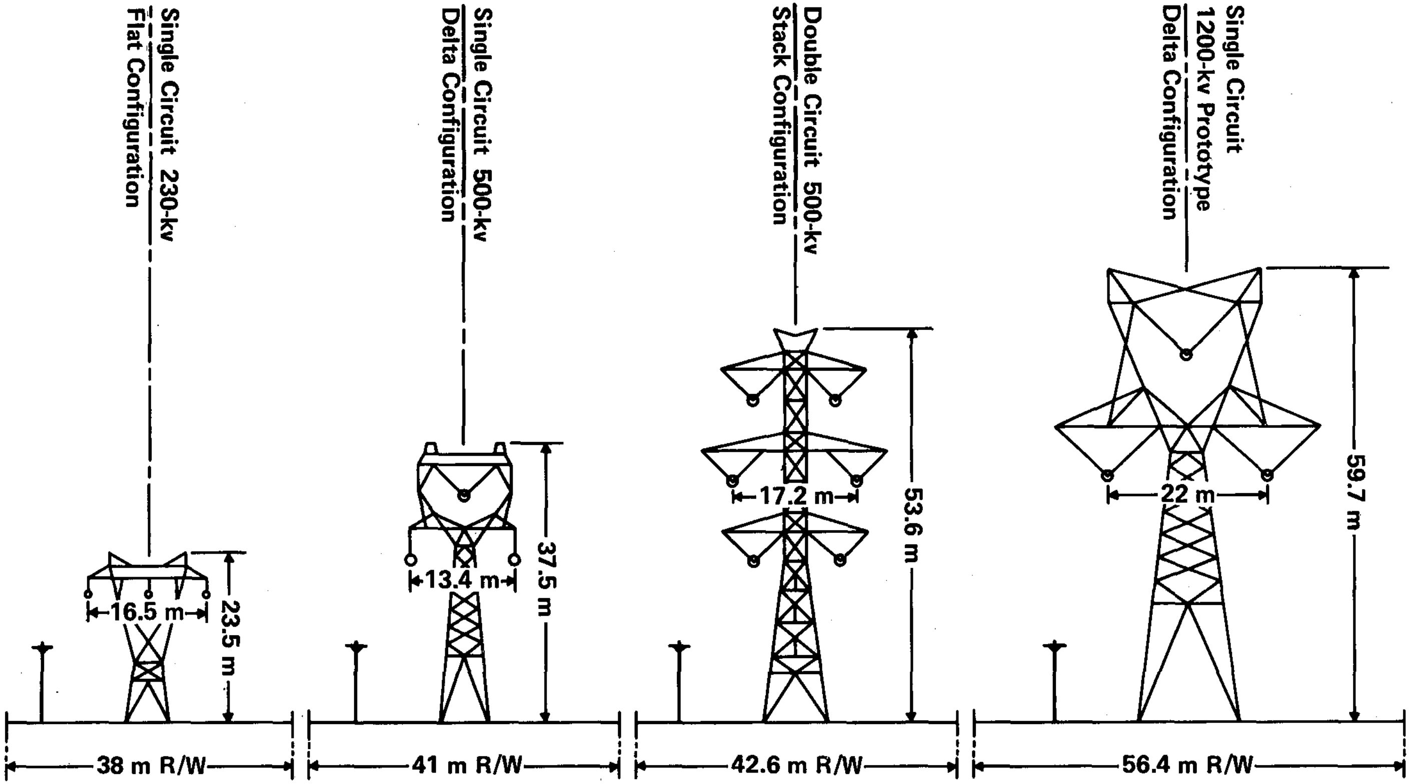

Figure 1. Configurations of typical BPA transmission towers. For comparison, a typical 12.5-kv distribution line pole, 10.4 meters high, is shown to the left of each transmission tower.

above 345 kv, multiple conductor bundles are usually used. For example, the 4.07-centimeter diameter conductors used on high capacity BPA 500-kv lines, which are in bundles of three for each of the three-line phases, are over four times larger than the single conductors used on some 12.5-kv distribution lines. The conductors on the BPA 1200-kv prototype line are 4.07 centimeters in diameter, and there are eight of them in each phase arranged in 1.1-meter diameter circular bundles. On some transmission lines, one or two overhead groundwires (also referred to as shield wires or static wires) are used for protection against lightning. These are usually of small diameter compared with conductors.

For EHV lines, effects from the electric and magnetic field and from corona are more apparent than from lower voltage lines (Lee et al. 1977). The calculated electric field strength at conductor height at 1 meter, 10 meters, and 50 meters from the conductors of a 230-kv a.c. transmission line is about 20 kv per meter, 1.3 kv per meter, and 0.05 kv per meter, respectively. For a 500-kv line at these distances, these values are approximately 70 kv per meter, 4.3 kv per meter, and 0.3 kv per meter, respectively. For comparison, the d.c. electric field strength of the earth is about 0.13 kv per meter at the surface (Polk 1974). Magnetic field strength is a function of current rather than voltage as in the case of the electric field. At distances greater than about 10 meters, field strength is usually of less magnitude than the 0.6 Gauss of the earth's d.c. magnetic field.

Corona occurs when the electric field on the surface of a transmission line conductor exceeds the breakdown strength of air (Deno and Comber 1975). Audible noise and flashes of light are among the products of corona. With a.c. transmission lines, corona is most noticeable during inclement weather. The noise consists of a broadband hissing, crackling component with a 120-Hz tone or multiples of this frequency occasionally present. The amount of audible noise produced by transmission lines varies considerably depending on a number of factors including weather, voltage, and conductor configuration. With BPA's present 500-kv line design, audible noise during rain averages about 50 dB(A) at the edge of the right-of-way.

LITERATURE REVIEW

Bird deaths due to collisions with powerlines have been documented in several reports (Table 1). In a number of reports, there is insufficient information with which to determine whether the line involved was a transmission or distribution line. Terms such as "powerlines" or "overhead lines" are frequently used without qualification, and the latter can include communication lines. As a comparison with the reports in Table 1, I found at least nine reports which describe bird collisions with distribution lines and five reports which do not distinguish between power and communication lines.* It should be pointed out that in some reports the birds found dead beneath distribution lines may have been electrocuted. Electrocution is generally not a problem with transmission lines because of the greater distance between conductors.

In general, reported mortality levels due to bird collisions with transmission and even distribution lines are low compared with those reported for certain other types of obstacles (e.g., television transmitting towers) as described in reviews by Vosburgh (1966) and Weir (1976). Currently, it is not clear how "reported" mortality due to collisions with various obstacles compares with actual mortality.

Reported collision mortality due to wire strikes has been related to other nonhunting mortality in waterfowl by Stout and Cornwell (1976). In their paper, reported mortality due to collisions with objects accounted for 2,299 (0.1 percent) of the 2,108,880 birds in their sample. Of the former number, 1,487 were reported collisions with telephone and powerlines. Cornwell and Hockbaum (1971) have pointed out bird collisions with lines largely go unnoticed and unreported. I believe this can probably also be said of many other types of collisions.

*An annotated bibliography listing these reports is available from the author.

Table 1. Reports of bird collisions with transmission lines and with "powerlines" which may have included transmission and/or distribution lines.

Reference	Line Type	Location	Number Birds Found	Circumstances
Anderson 1978	Two 345-kv transmission lines	Central Illinois	343 dead or crippled waterfowl	Birds were found in a water-filled slag pit near lines during the fall over a 3-year period. Anderson estimated approximately 400 birds killed each year during fall and winter.
Arend 1970	500-kv transmission line	Sutter N.W.M.A., Ca.	50 ducks	Birds apparently startled into flight by illegal hunters at night.
Scott et al. 1972	Two 400-kv transmission lines	Dungeness, Great Britain	1,285 birds of 74 species	Birds found near three line spans between January 1964 and November 1970. Actual number of casualties estimated at 6,000.
Willard et al. 1977	230-kv transmission line	Klamath Basin, Oregon	12 waterfowl and shorebirds	Birds were found at three sites during searches conducted during fall 1976 and spring 1977.
Blokpoel and Hatch 1976	"Powerline"	Manitoba, Canada	An estimated 25-75 snow geese	Light airplane startled birds into flight.
Gollop 1965	"Powerlines"	Saskatoon, Canada	15 birds of 12 species	Birds found during one fall where series of powerlines crossed sandbar.
Krapu 1974	"Powerlines"	North Dakota	15 birds	Mortality includes Krapu's own observations over several years plus reports from other persons.
Stout 1967	"Powerlines"	California	235 ruddy ducks	Report did not indicate when collisions occurred other than that losses were greatest during foggy periods.

Concerns have also been expressed which are somewhat contradictory to those related to the collision potential of transmission lines. During a court case involving an Illinois duck hunting club and a power company, witnesses testified that transmission lines adversely affected waterfowl flight behavior to the extent that birds were reluctant to fly near such lines (Anonymous 1968). Similar testimony was given during a 1977 court case in Washington State (United States vs. Chadbourne). The latter case involved a BPA 500-kv transmission line which was constructed across land leased by a private duck hunting club. In both of these cases, the court, in effect, found that a transmission line would have some adverse influence on waterfowl flight behavior resulting in adverse effects on waterfowl hunting near the line. The possibility that powerlines could change waterfowl hunting success was also suggested in a study of the interaction between birds and obstacles by Willard and Willard (1972).

These reports and testimony raise the question as to whether birds react to the electrical effects of transmission lines. There is evidence that birds can at least perceive such effects. The range of frequencies heard by most birds is very similar to man's range (Bremond 1963), and it is reasonable to assume that corona noise is audible to birds. Although birds are commonly seen perched on distribution and communication lines, I have never seen a bird attempt to land on an energized transmission line conductor. Unsuccessful landing attempts have been reported to me on a few occasions. Graves et al. (1977) reported that, in a laboratory test, pigeons were apparently able to detect a 60-Hz electric field of 32 kv per meter (the lowest field strength tested) This is the field strength at approximately 2 meters from the conductors of a 500-kv line. Two reports have indicated birds are able to perceive electric and magnetic a.c. fields at levels comparable to those of the earth's d.c. fields (Southern 1975, Larkin and Sutherland 1977).

STUDIES OF BPA TRANSMISSION LINES

Prior to the start of a study in October 1977, which is described below, most observations of the effects of BPA transmission lines on bird flights were made incidentally to collecting other biological data. For example, during a 13-month study of the ±400-kv d.c. Intertie in Oregon, Griffith (1977) observed a juvenile pintail sustain fatal injuries by colliding with the overhead groundwire. Visibility was good at the time of the collision. One of the duck's eyes had an opaque appearance which did not appear to have been caused by the collision. On another occasion, Griffith and I watched a turkey vulture collide with a conductor of a 230-kv line located adjacent to the d.c. line. This collision also occurred when visibility was good, although in this case the bird apparently was not seriously injured.

Griffith's study was not specifically designed to provide information on bird collisions; however, after several hundred hours of field observations and after traveling hundreds of kilometers on the right-of-way access road, he found only five dead birds, some of which may have collided with the line. The d.c. Intertie line has metal towers approximately 36 meters tall and two sets of 4.47-centimeter conductors in bundles of two. The line also has a single overhead groundwire. Most of the line is located in western juniper and sagebrush, and only a few small areas utilized by waterfowl are crossed.

I made an interesting observation while conducting breeding bird counts on the right-of-way of two 500-kv transmission lines in central Oregon. A golden eagle being chased by two ravens collided with the conductors on one of the 500-kv lines. Although the bird exhibited some erratic flight behavior after the collision, it did not appear to be injured. The line had two 4.07-centimeter diameter conductors for each phase. The most extensive bird collision mortality which has been reported for a BPA transmission line occurred near Portland, Oregon, and involved a 230-kv line. This study is described below.

Bird Collisions With a 230-kv Transmission line

On 29 January 1977 while observing bird flights near Bybee Lake, I began finding birds between towers 7/2 and 6/6 of the BPA Ross-St. Johns 230-kv transmission line (Figure 2). The line carries two electrical circuits (double circuit). Between structure 6/6 and the St. Johns Substation 2.5 kilometers to the southwest, there is a single

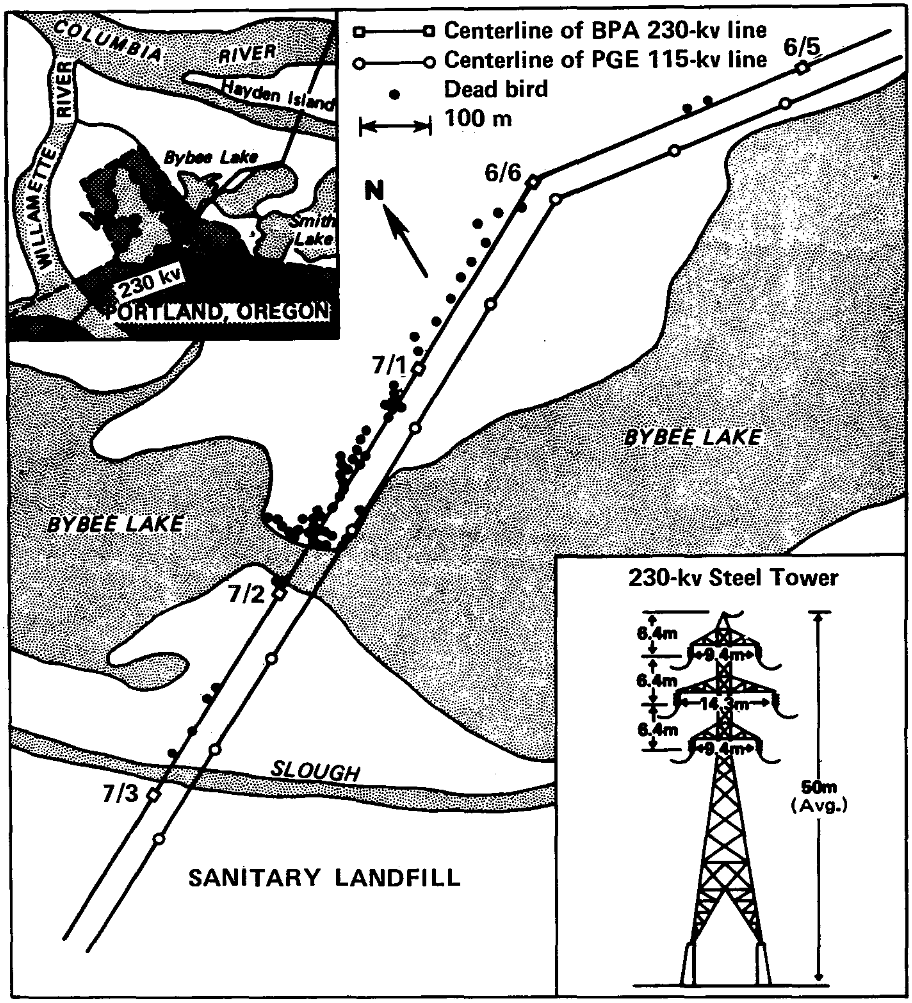

Figure 2. Approximate locations of 60 dead birds found near two transmission lines in Oregon during periodic searches conducted from 29 January through 28 April 1977.

1.6-centimeter diameter overhead groundwire. Overall dimensions of the steel support towers and conductor configurations are shown in Figure 2. Each of the six conductors is 2.7 centimeters in diameter and consists of outer aluminum wire strands and inner steel strands. At midspan, the lower-most conductors are approximately 20 meters above the ground. At the Bybee Lake crossing, the lowest conductors are about 25 meters above the water. The line was energized in 1952.

A 115-kv transmission line operated by Portland General Electric Company (PGE) runs parallel to the BPA 230-kv line. The 115-kv line has three 2.6-centimeter diameter conductors spaced 3.8 meters apart on a horizontal plane. The conductors are supported by wood pole, H-frame structures which average 21 meters in height. The conductors are approximately 16 meters above the water at the Bybee Lake crossing. The horizontal distance between the outermost conductors of the two transmission lines is about 22 meters. The 115-kv line was energized in 1974.

Bybee Lake is utilized by waterfowl, shore and waterbirds, and large numbers of gulls (primarily glaucous-winged). The gulls and crows are attracted to a sanitary landfill southwest of Bybee Lake. Waterfowl hunters utilize the area and fisherman, bird watchers, and other recreationists are present at various times.

Dead Bird Counts. Initially, 41 dead birds were found between towers 7/2 and 6/6. It appeared the length of time the birds had been dead ranged from a few days to about 2 months. Additional searches between towers 7/2 and 7/1 were made on 5, 16, 19, and 26 February; 5, 12, and 19 March; and 28 April 1977. The span between 7/1 and 6/6 was searched on all these days except 16 February. The section between tower 6/6 and 6/5 was also searched every day except 5 February. Searches were made between 7/3 and 7/2 only on 11 and 26 February.

Between 29 January and 28 April 1977, a total of 60 dead birds was found during the searches (Table 2). Thirty percent of the birds had externally noticeable collision-type damage such as broken wing bones and lacerations about the head, neck, or breast. Twenty-one birds eventu-

Table 2. Identification of dead birds found between towers 7/3 and 6/5 of the BPA Ross-St. Johns 230-kv transmission line from 29 January through 28 April 1977

Species	Number Found
Gull	29
Green-winged teal	7
Pintail	7
American coot	3
Ruddy duck	2
Western sandpiper	2
Great blue heron	2
Common crow	2
Mallard	1
Unidentifiable duck	1
Killdeer	1
Common snipe	1
Mourning dove	1
Song sparrow	1
Total	**60**

ally could not be relocated during the dead bird searches. Most of them were probably removed by scavengers, although some may have been missed by searchers. Other biases exist because an unknown number of birds probably fell into Bybee Lake and were not found, and others may have sustained mortal collision injuries but were able to hide or move away from the right-of-way before they died. Anderson (1978) estimated his dead bird count was about 58 percent of the actual mortality, and the corresponding estimate reported by Scott et al. (1972) was about 20 percent.

Flight Counts. Observations of bird flights across the spans where the dead birds were found were made on four occasions (Table 3). These, plus observations made incidentally to conducting the dead bird searches, indicated that the heaviest gull flights were during early morning when the birds flew south across the line to Bybee Lake

Table 3. Summary of counts of bird flights[1] across the right-of-way of the BPA Ross-St. Johns 230-kv transmission line where dead bird counts were made.

Flight Direction	Between Line Structures 7/3-7/2	7/2-7/1	7/1-6/6	6/6-6/5	Total Each Direction
	30 January 1977, 0700-0900				
Northwest	N[2]	82	31	N	113
Southeast	N	547	75	N	622
	19 February 1977, 0700-0900				
Northwest	54	80	47	83	264
Southeast	478	253	51	68	850
	26 February 1977, 1700-1730				
Northwest	133	259	34	134	560
Southeast	4	11	2	5	22
	5 March 1977, 1000-1100				
Northwest	37	14	22	380	453
Southeast	306	29	8	143	486
Total					**3,370**

[1] Approximately 77 percent of these flights were by gulls.

[2] No counts made.

and the landfill and during evening when they returned to their roosting sites to the north. Flights continued across the spans in both directions throughout the day, however, at reduced intensities. The gull population using the sanitary landfill appeared to number several thousand birds. Other birds observed in smaller numbers included ducks, crows, great blue herons, shorebirds, and passerines.

I estimate that on the days counts were made, between 2,000 and 6,000 bird flights occurred across the 230-kv line between towers 7/3 and 6/5. Using a conservative estimate of 2,000 bird flights per day and assuming similar flight intensities in late fall, at least 354,000 bird flights occurred during the time (1 November

1976 to 28 April 1977) in which the 60 birds were killed. Tripling this latter number to 180 to allow for sample biases mentioned above indicates roughly 0.05 percent of the estimated total flights resulted in fatal collisions.

My data suggest the actual percentage of flights resulting in fatal collisions probably varied by species. However, because of the limited amount of diurnal flight counts and a lack of data on nocturnal flights, an estimate of such variations was not attempted. My overall estimate is one order of magnitude smaller than that interpreted from the data reported by Anderson (1978). Anderson's data indicate an average of 1,700 daily diurnal bird flights during the fall of 1974 when there were an estimated 338 collision casualties. Depending on the extent of nocturnal flights in Anderson's study area, the actual percentage of collisions in his study may have been closer to the magnitude estimated for Bybee Lake.

Bird Collisions. During the flight observations (tabulated in Table 3), a gull collided with a 230-kv conductor. During incidental flight observations, a shorebird collided with the overhead groundwire. Although the gull fell to the ground and the shorebird fell into Bybee Lake, both were subsequently able to fly away. The frequency of an observed collision during periods of good visibility, one collision per 3,370 flights, is in contrast to the corresponding ratio of one in 11,061 interpreted from the data reported by Anderson (1978). Anderson reported this ratio as one in 250,000; however, this was apparently based on two observed collisions out of the 553,059 total flights observed at the slag pit. Only 4 percent (22,122) of the birds actually flew across the transmission lines, and I believe this latter number is the appropriate value to relate to observed collisions.

Eighty-nine percent of the birds counted flew above the overhead groundwire (or conductors in the span between 6/6 and 6/5) of the 230-kv line with most birds just clearing the line. Nine percent of the birds flew under the conductors of the 230-kv line, and only about 2 percent flew between the upper and lowermost conductors. On 58 (1.7 percent) occasions, birds were observed to turn back as they approached the line. In most cases, after flying parallel to the line and gaining altitude, the birds flew over the line.

The bird flight observations and the locations of the dead birds suggest that of those birds which bore no apparent collision damage, most were probably killed by colliding with the 230-kv line. I hypothesize that the birds were flying in a northerly direction with the wind (prevailing wind direction was from the south during my visits to the study area). The birds struck the line and momentum caused most of them to fall north of the center of the right-of-way. Although the two collisions described above occurred when visibility was good, reduced visibility was probably a determining factor in the fatal collisions. Climatological data obtained from Portland International Airport (9.4 kilometers southeast of the study area) showed that between 1 November 1976 and 29 January 1977 fog occurred on 21 days and heavy fog (visibility 0.4 kilometer or less) occurred on 44 days. Between 30 January and 28 April 1977 (during which only 11 dead birds were found), fog was present on 16 days and heavy fog on 12 days.

In addition to monthly differences in collision mortality, there were large differences in the number of dead birds found in each of the four spans of the 230-kv line (Figure 2). The heaviest mortality, including all 21 ducks listed in Table 2, occurred between towers 7/2 and 7/1. This is consistent with flight observations which showed almost all duck flights were across this span. The limited amount of data collected on bird flights, however, does not provide an adequate basis for explaining differences in mortality among the spans. Related factors which may have determined the incidence of collisions include the proximity of the spans to the sanitary landfill and Bybee Lake and the presence of the overhead groundwire.

With the large number of birds flying across the two transmission lines and with the formidable array of wires perpendicular to a low-altitude flyway, one might expect to find more dead birds than we did. Most birds were able to avoid the lines even, perhaps, during night or in time of poor visibility during the day. Through social interaction, most gulls in the area had probably learned the location of the transmission lines as they learned the location of the sanitary landfill. Other resident birds also were probably quite aware of the location of the lines, at least during times when visual cues were available. Low-level corona noise from the 230-kv line was usually audible during my visits to the area. It is possible that corona noise and electric and magnetic fields may provide location information to flying birds during periods of reduced visibility (Lee and Griffith 1977). Whether such information is an aid to birds in avoiding collisions with transmission lines has yet to be determined.

WICHE Transmission Line/Bird Study

In October 1977, a 1-year study began which was designed to provide additional quantitative data on the effects of BPA transmision lines on bird flights and collisions. This study is being conducted by James R. Meyer, an intern with the Western Interstate Commission for Higher Education (WICHE). Most of the field data for the study will be obtained in three geographic areas having two or three primary sample sites per area. These areas have been selected to include a variety of environmental and transmission line conditions so the factors which may determine the kinds and magnitude of effects on birds can be studied.

All sample sites contain some form of water or wetland habitat. This type of habitat frequently attracts large numbers of birds including waterfowl. These areas and the birds inhabiting them usually have high ecological and social values. This study is, therefore, designed to look at "worst-case" situations. By taking this approach, if problem areas exist, they would most likely occur in these situations. Therefore, an estimate of the seriousness of the problem can be more reasonably made.

Study Areas. Sample site 1 in the Portland-Longview study area is Bybee Lake, described above. Site 2 is near Longview, Washington, where two 500-kv lines and two 230-kv lines cross the Columbia River. This site is used by small to moderate numbers of ducks, and smaller numbers of geese and swans are present at various times. Some of the towers have red aircraft warning lights. Waterfowl hunters use the area at times.

A second study area is the Willapa National Wildlife Refuge on the Washington coast; the refuge contains a 115-kv wood pole transmission line. The section of line to be studied is from U.S. Highway 101 to near the Long Beach Substation. Two sites will be studied, each having a different type of line construction. Most of the line crosses wetland habitat, and it crosses the Bear River. Moderate to large numbers of ducks and geese utilize the area. Some waterfowl nesting also occurs during the spring. The refuge is open to waterfowl hunting on certain days during the season.

The central Washington study area extends from near Ephrata, Washington, south to State Highway 7. Sample site number 1 in this area is at Rocky Ford Creek, and BPA lines at this site include a 500-kv line and two 230-kv lines. Site 2 is in the Frenchman Hills Wasteway Area and includes only a 500-kv line. Site 3 is Lower Crab Creek and also includes the 500-kv line. This part of Washington is utilized by moderate to large numbers of ducks and geese during fall and spring migration. Some waterfowl nesting also occurs. This is also an important waterfowl hunting area, and both public and private shooting areas are found near the lines.

Study Methods. Data collection consists of two primary activities; dead bird counts and bird flight observations. Because few studies of this type have been conducted, the development and evaluation of methods of data collection and analysis are important parts of the study. Suitable portions of right-of-way of the lines in the primary study areas are periodically and systematically searched for dead birds. If the habitat permits, the entire right-of-way including a strip of adjacent land (approximately 45 meters out from the right-of-way) is searched. Birds found are examined for cause of death, and their location is mapped. During each search, an effort is made to locate all birds previously found and left onsite as well as to locate new birds. By tagging and leaving birds on the site, information on removal and decomposition rates can be obtained. To obtain information on recovery success, a sample of dead birds is randomly planted at least once on each site immediately prior to beginning regular searches for dead birds. The location and number of birds planted are not known to the searchers.

For all sections of lines where dead bird searches are conducted, periodic and systematic observations of bird flights are made. Information obtained by these observations will provide a basis for interpreting the mortality levels obtained with the dead bird counts. The following information will be noted for all birds approaching the section of line under observation: species or type of bird, number in flock, direction and altitude of flight, and behavior when approaching the line. Most flight observations will be done during daylight including some counts from daylight to dark. Beginning in January 1978, a night viewing device ("Javelin" model 226) will be used for nocturnal flight observations and to observe the behavior of predators and scavengers. A 16-mm movie camera will be used to document the various types of flight behavior which are typically observed in each study area.

The feasibility of various methods to remotely monitor bird flight behavior and collisions will be studied. These methods will include time-lapse photography, closed circuit television, and devices which monitor collision impacts with conductors or overhead groundwires.

Between 22 October 1977 and 28 January 1978, each of the three study areas will be sampled during alternating 2-week periods. From February through June 1978, observations will be concentrated primarily in the Bybee Lake and Central Washington study areas.

Preliminary Results. Data from the study are still being collected and analyzed, so only preliminary information is available at this time. During the initial dead bird counts between 22 October and 21 December 1977, a total of 19 birds was found in the three study areas along a total of about 5 kilometers of lines.* This number included seven green-winged teal, two red-winged blackbirds, one robin, two mourning doves, four starlings, two glaucous-winged gulls, and one bufflehead. Ten of these were found in the Central Washington study area near a 0.6-kilometer long section of the 500-kv line at the Lower Crab Creek site. All

*James S. Meyer 1978: personal communication.

but 5 of the 19 birds found had collision-type damage detectable by field examination.

During 8 days of flight observations, Meyer saw five ducks and three blackbirds collide with the overhead groundwire of the 500-kv line. Five of the birds fell to the ground and at least two of these received fatal injuries. The collisions occurred during good visibility. During the time period in which the collisions were observed, 17,867 birds were counted flying across the line. These data show that, on the average, there was one collision observed for every 2,233 flights counted. This ratio is similar in magnitude to that described previously for the 230-kv line at Bybee Lake. The 500-kv conductors are 3.3 centimeters in diameter and are in bundles of three for each phase of the delta configuration. The two overhead groundwires are each 9.78 millimeters in diameter.

Exact flight counts have not yet been tabulated for the other sites; however, waterfowl flight intensities at the Lower Crab Creek site were the highest of any of the sites during the initial phase of the study. By making flight observations during both day and night, Meyer expects to express the collision mortality as a percentage of the overall flight intensity and species composition. The final results of the WICHE study may indicate the need for additional research including the need to develop measures to mitigate adverse effects.

DISCUSSION AND CONCLUSIONS

Experience with BPA transmission lines indicates such lines can affect bird flights and that birds at times collide with conductors or overhead groundwires. To date, however, I am not aware of situations where BPA transmission lines represent a significant avian mortality factor. Only preliminary data currently exists for basing such conclusions, so any such conclusions must be considered tentative. Until more definitive information is available, it seems reasonable to consider the potential for bird strikes when evaluating the impacts of transmission lines. This is especially so if areas utilized by threatened or endangered birds may be affected. Even relatively small increases in mortality from whatever source may be significant when these kinds of birds are involved.

Based on studies of BPA lines and on my review of the literature on bird collisions with powerlines and other obstacles, it appears that several factors need to be considered when predicting the effects of existing or planned transmission lines on birds (Table 4). Currently, information with which to evaluate the relative importance of these and other factors in determining the incidence of bird collisions with transmission lines is extremely limited. For example, little is known about whether the structural and electrical differences between transmission lines and other types of utility lines also result in different effects on birds. Therefore, I believe it is not desirable to attempt to predict impacts of transmission lines on birds by using information based only on observations of distribution or communication lines. It may well be that the larger size of the transmission line conductors and the electrical fields and noise which they produce combine to decrease the potential for bird collisions—especially during the critical times when visibility is poor. It also appears that the presence of one or more small diameter overhead groundwire on a transmission line may greatly increase the potential for bird collisions. For all studies and reports involving transmission lines and birds, it is, therefore, important that details of the lines be given along with information on pertinent environmental conditions. As a minimum, information should be given on the number and voltage of all lines present and the size and number of conductors and overhead groundwires. For all studies involving dead bird counts, information on bird flight intensities, altitudes, timing, and species composition during the time the mortality occurred should be provided.

As a biologist, I am concerned with all sources of avian mortality. As a biologist for a power marketing agency, I devote most of my research efforts toward identifying the mortality associated with transmission lines. I believe that collision mortality should be considered in relation to other possible adverse effects of transmission lines (e.g., increased vulnerability of birds using towers to illegal shooters) and to possible beneficial effects (e.g., use of

Table 4. Factors which may determine the number of bird collisions expected with a transmission line during some specific period.

General Category	Factor	Suspected High Collision Risk Situations
Bird biology	Species	Nocturnal fliers or those with awkward flight characteristics
	Age	Immature birds with limited flight experience
	Health	Sick or injured birds
	Migration	Migrants as opposed to resident birds
	Sex	Birds involved in nuptial displays
Flight	Flight intensity	Large numbers of birds crossing the right-of-way during all times of day
	Altitude of flights	Altitudes equal to or lower than the uppermost wires
	Size of flocks	Large flocks with small spacing between birds
	Time of flights	Nocturnal flights and diurnal flights during inclement weather
Transmission line	Tower type	Guyed structures or tall towers near river crossings
	Voltage	Lower voltage lines with reduced electric field and corona effects
	Conductor characteristics	Small diameter, single conductor/phase configurations
	Number of lines	Double-cirucit lines with wire at different heights
	Overhead ground wire	Multiple wires small in diameter compared with conductors
	Line length	A long line through a high-use area
	Age of line	A newly constructed line before birds can habituate
	Aircraft warning lights	Nonflashing lights on towers in established flyways
Environment	Weather	Fog, snow, rain, sleet, or high winds
	Habitat	Attractive bird habitat on and surrounding the right-of-way
	Human activity	Hunting and other human activities which startle or distract birds
	Geographical location	Lines located perpendicular to a narrow, low-altitude flyway

towers by birds for perching and nesting). Although there is a need for research on the effects of transmission lines on birds, this need also applies to other types of utility lines and perhaps even to other types of man-made structures. For transmission lines, at least, a goal should be to develop models with which to predict the impact of existing and proposed lines on birds with some degree of confidence. This will require multidisciplinary studies conducted in a variety of environmental settings which include the various types and configurations of lines.

Research may reveal areas where significant mortality (whether defined in a political or ecological context) is occurring as a result of birds colliding with transmission lines. Likewise, in some areas, transmission lines may affect local flight patterns. In the case of waterfowl, effects on flight behavior may result in either increased or decreased waterfowl mortality if waterfowl hunting success near the lines is changed. Until information derived from sound research is available, utilities may be reluctant to expend the effort and funds to develop means to mitigate suspected adverse effects. Likewise, until information is available on the effects of existing transmission lines on birds, decisionmakers may be reluctant to commit financial resources to minimize potential effects on birds when new transmission lines are designed and located.

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Evaluation of a Proposed Transmission Line's Impacts on Waterfowl and Eagles

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INTRODUCTION

This paper summarizes an environmental assessment of the potential impacts of a proposed transmission line on waterfowl and bald eagles. This transmission line would be one of three 345-kv lines servicing the nuclear-powered Tyrone Energy Park (TEP), which is proposed by the Northern States Power Company (NSP) to be constructed near Eau Claire, Wisconsin. The line would cross the Mississippi River just north of Red Wing, Minnesota, through important waterfowl and bald eagle habitat. The U.S. Nuclear Regulatory Commission (NRC) has reviewed NSP's application to construct TEP, has prepared a Final Environmental Statement (NRC 1977), and has completed public hearings. The Wisconsin Public Service Commission is presently reviewing the TEP application.

As an ecologist, I was a reviewer for the NRC and prepared the portions of the Environmental Statement dealing with impacts of transmission lines. The purpose of this paper is to discuss potential impacts of transmission lines on migratory waterfowl and eagles, to present the TEP case as an example problem, and to suggest possible mitigation techniques and needed research.

POTENTIAL IMPACTS

The potential impacts of transmission lines on both waterfowl and bald eagles include mortality due to collisions (not electrocution) with lines and towers and disturbance of important habitat (e.g., eagle nest sites, important waterfowl resting and feeding areas). Electrocution is not considered a problem with high voltage transmission lines (in contrast to the smaller distribution lines), because conductors are far enough apart to prevent simultaneous contact of a bird's extremities with adjacent conductors.

Waterfowl collisions with lines appear to be responsible for a very small fraction of hunting and nonhunting mortality. Nationwide data reported by Stout and Cornwell (1976) indicates that about 0.07 percent of *nonhunting* mortality results from collisions with lines. This figure includes data not only for transmission lines, but also for the smaller distribution lines and telephone wires. Thus, deaths caused by transmission lines would appear to have had no significant impact on waterfowl populations. As transmission lines proliferate, however, impacts will increase and become of more concern. Most collision mortality probably occurs near breeding, feeding, or resting areas where birds fly low. On long-distance migratory flights and flights between feeding and resting areas, flocks generally fly high enough that collision with lines is unlikely. As far as disturbance of waterfowl is concerned, a few observers (no published accounts as far as I know) believe that large transmission lines cause some avoidance of habitats within roughly 0.25 mile of the lines.

For eagles, collision with powerlines would not seem to be a problem, because the species has keen sight, flies relatively slowly, and maneuvers well. However, if eagles often fly during poor visibility (e.g., fog, dusk), collision potential is increased. Also, because of their hunting behavior, eagles may not always be attentive of powerlines. Several papers (Table 1, Beecham and Kochert 1975) have reported deaths of eagles due to collisions with powerlines. The type of lines usually involved have apparently been distribution lines, with which electrocution would also have been a possibility. Mortality data for immature and adult bald eagles indicate that about 10 percent of the known deaths from 1960 through 1972 resulted from impact injuries, many of which resulted from collisions with powerlines (Table 1). Authors of these papers, however, stated in personal communications with me that electrocution may have, in fact, accounted for some, if not most, of these "collision" deaths. Electrocution may have been mistakenly omitted as the cause of death because of the lack of obvious electrocution burns. Thus, it appears that collision with lines may not account for as large a fraction of mortality as the literature reports. The effect of disturbance caused by the presence of powerlines in important habitats would probably be more critical in breeding areas than in nonbreeding areas. Assuming that eagle breeding activity is relatively sus-

Table 1. Mortality of fledged bald eagles in the United States.

Source	Years				Total	Percent
	1960-65	1966-68	1969-70	1971-72		
Shot	45	28	18	13	104	47
Unknown[1]	18	20	3	4	45	20
Impact[2]	7	10	4	1	22	10
Poisoning	1	1	7	14	23	10
Electrocution	1	2	2	1	6	3
Trapped	2	2	1	0	5	2
Miscellaneous	2	6	4	4	16	7

[1] No diagnosis could be made on the basis of autopsy findings.

[2] Impact injuries resulted from the eagles striking some object, frequently a powerline or tower (the sources below gave no more breakdown for impact).

Sources: Beliste et al. 1972, Coon et al. 1970, Cromartie et al. 1975, Mulhern et al. 1970.

ceptible to disturbance, one might conclude that the proximity of transmission lines would adversely affect eagle reproduction. However, many other raptor species have been observed nesting in transmission line structures, primarily where other suitable nest sites were not available. Raptors in general seem to become accustomed to various man-made structures, and their use of habitat may not be greatly disturbed by nearby transmission lines. Nevertheless, effects on rare or endangered raptors, such as eagles, should receive attention.

THE TYRONE ENERGY PARK CASE

One of the 345-kv lines of the TEP is proposed to run west from the plant, cross the Mississippi River, and connect with the existing Prairie Island Nuclear Station on the west bank of the river about 5 miles north of Red Wing, Minnesota (Figure 1). This region of the Mississippi River, like much of the river, is used by large numbers of migrating waterfowl and bald eagles. An assessment of the potential impacts of a powerline crossing the Mississippi River in this area was needed for the environmental impact statement. Initially, NSP proposed two possible routes ("proposed" and "lock and dam," see below). One route passed near a wetlands complex of about 1100 acres (Gantenbein Lake and associated wetlands, see Figure 1) that is heavily used by migrating waterfowl, while the other passed through the wetlands complex. The Gantenbein wetlands constitute a private hunting preserve which is managed to attract waterfowl, and in hunting season it is hunted only every other morning every other week. During the NRC review of the NSP application, several other alternate routes were investigated by both groups as described below.

As seems to be the case in most environmental assessments, there was less information available on which to assess the impacts and identify the best route than an ecologist would like. Concentrations of overwintering eagles had been observed at several sites along the Mississippi River near Prairie Island, and the number in each area had been estimated. Also, 15 or 20 eagles had occasionally been seen in a forested area at dawn and dusk, indicating the birds roosted there. However, the exact roost site had not been sought or located. Frequency of migrating eagles in the area had not been documented. Eagles were not known to inhabit the area during late

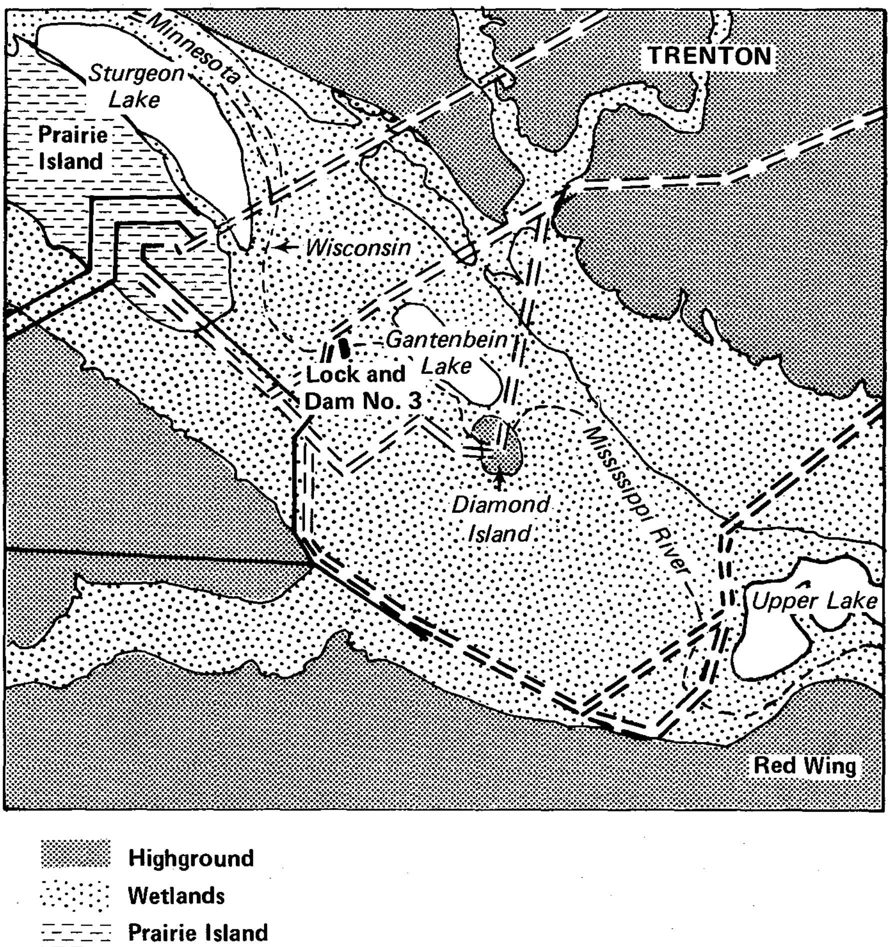

Figure 1. Proposed and alternate routes crossing the Mississippi River and leading to the existing Prairie Island Nuclear Station. Solid lines show existing transmission lines. Double-dashed lines represent possible routes to Prairie Island, including the proposed route at Sturgeon Lake, the lock and dam route at Lock and Dam No. 3, the Trenton route at Diamond Island, and the Red Wing route at Red Wing.

spring and summer. Numbers of migratory waterfowl frequenting various wetland sites in the area had not been documented. However, the number of each species passing through the Mississippi Flyway in this region (Table 2) could be roughly estimated from Bellrose (1976). A small fraction of this number of birds would be expected to occur near Prairie Island. Persons familiar with the area believed that much larger numbers of waterfowl frequented the Gantenbein wetlands than other wetlands in the area. In an attempt to characterize waterfowl distribution in the area, NSP personnel prepared a map of the region within which alternate routes were located. The map was based on study of aerial photographs and showed locations of wetlands and forests. Also shown were major waterfowl use areas and local flight lanes as determined from persons familiar with the area. Additionally, NSP personnel determined from aerial photos the height of trees along various routes; this was done with the idea of routing the lines at or below treetop height through or adjacent to forests so waterfowl would pass over the structures and avoid collision.

Four routes across the Mississippi River were examined in detail. Each route had advantages and disadvantages, but no route appeared obviously superior in terms of overall impact on wildlife, vegetation, land use, and people.

Proposed Route

The proposed route, passing west through the Mississippi Valley, would first cross about 0.7 mile of bottomland forest interspersed with wetlands. Here the line span would be reduced from the normal 1200 feet to 500 feet to minimize the height of the lines and towers. The towers would be only about 70 feet high (normally they would be 94 feet or more), which approximates the height of the taller trees in the area. To maximize the advantage of reduced line height, the lines would be routed through or adjacent to forest wherever feasible rather than through the middle of wetlands. The reason is that as waterfowl and eagles fly over the forest, they would pass over and above the towers and lines, thereby avoiding collision. Also, the line might be less of a visible disturbance if it were in or adjacent to the forest. After crossing this area, the line would cross the Mississippi River channel (0.3

Table 2. Estimated numbers of waterfowl passing through the Minneapolis-Prairie Island-Red Wing region during spring and fall.

Species	Number	Corridor Status[a]
Whistling swan	30,000-60,000	1
Snow goose	50,100-100,000	3 (fall)
	0-1,000	0 (spring)
Canada goose		
Small races	500-2,500	5
Larger races	15,100-50,000	3
American widgeon	201,000-400,000	2 (fall)
Gadwall	11,000-25,000	4
Green-winged teal	2,000-25,000	5
Mallard	201,000-375,000	4
Black duck	1,000-10,000	5
Pintail	10,000-75,000	5
Blue-winged teal	501,000-750,000	1
Shoveler	2,000-15,000	5
Canvasback	51,000-100,000	1
Redhead	40,100-100,000	2
Ring-necked duck	36,000-60,000	1
Greater scaup	0-500	0
Lesser scaup	76,000-250,000	2
Bufflehead	2,100-4,000	4
Common goldeneye		b
Hooded merganser		b
Red-breasted merganser		b
Common merganser		b
Ruddy duck	30,100-60,000	1

[a] Corridor status is the rank of the migratory corridor through the Prairie Island region as compared with other corridors, according to five categories of decreasing species abundance from one to five.

[b] No recognized corridors.

Source: Bellrose 1976.

mile wide) to a narrow spit of forested land separating the channel from Sturgeon Lake. The line would then cross Sturgeon Lake (0.4 mile wide) to the west shore where the existing Prairie Island Plant is located. This route is the only one that crosses a lake. Sturgeon Lake is used considerably by diving waterfowl. Towers roughly 200 feet high would be required on the east channel bank, on the spit, and on the west shore of Sturgeon Lake. These tall towers and lines over open water would be a collision hazard to both waterfowl and eagles. Just to the south of this route are the Gantenbein wetlands, which are heavily used by migrating waterfowl. Almost all of these wetlands lie more than one-third of a mile from the proposed route; because of this distance a powerline through this route may have little impact on waterfowl's use of this area. However, major waterfowl flight lanes connecting with the wetlands pass over this route. Therefore, collision with lines on the proposed route is a potentially serious problem, unless flights are usually high enough at this distance from the wetlands that collisions are unlikely. In summary, the major disadvantages of this route are the proximity to the high waterfowl use area and the crossing of Sturgeon Lake. An advantage of the proposed route is that eagles do not frequently use this particular area.

Lock and Dam Alternate

The lock and dam route passes near the center of the Gantenbein wetlands. Therefore, it is considered an unacceptable route. The only advantage of this route is that the lines would need to cross only the river channel, and this crossing would be adjacent to a lock and dam with some existing tall structures.

Trenton Alternate

The Trenton alternate would cross the Mississippi River below the lock and dam and pass through much forested land in the Mississippi Valley. The primary advantage of this route is that it is distant from the high waterfowl use area. Also, much of the line could pass through, or adjacent to, forest (using short spans as in the proposed route) thereby reducing collision potential for waterfowl and eagles. The major disadvantages are that the river crossing is located in a relatively major eagle use area compared with other areas along the river and that evidence indicates there is an eagle roost somewhere in the forest in this area. Wintering eagles are apparently attracted to this area because the river remains open longer than at many other areas.

Red Wing Alternate

The Red Wing alternate crosses the Mississippi River adjacent to Red Wing, Minnesota. Its primary advantage would be little impact on waterfowl. The line would pass primarily near areas of human disturbance (residential, commercial, and industrial areas and corridors with existing transmission lines) where waterfowl are relatively scarce. Disadvantages are that the line would use more land with a relatively high dollar value, would be near and visible from several residential areas, would cross the Mississippi River in an area having a wintering eagle concentration equal to that at the Trenton crossing, and would be from 3 miles to 5 miles longer than the proposed route.

Conclusion

Selecting one of these four routes involves various tradeoffs: waterfowl versus eagles, waterfowl versus people, and waterfowl versus economic costs. The Trenton route might have minimal impact on waterfowl and people but greater impact on eagles than the proposed route. If the potential for eagle collisions with powerlines is low enough to be of little concern, the Trenton route might be the best. This potential, however, is not well known. The NRC staff has concluded that no route has obvious overall advantage in terms of wildlife, environment, aesthetics, and land use. This conclusion has been presented to the NRC Atomic Safety and Licensing Board for Tyrone, which is an NRC decisionmaking body. As of this writing, the Board has not yet ruled on the Tyrone application.

RESEARCH NEEDS

For site-specific cases where a proposed line would pass near important waterfowl or eagle habitats, the following information should be obtained for use in route determination: local distribution, including population estimates; flight patterns; and flight height. This information should be provided by species, season of the year, and daytime and nighttime periods, as appropriate.

In general, better knowledge of waterfowl and eagle behavior would have helped this assessment of impacts, route selection, and possible mitigation. Knowledge of the height above treetops at which waterfowl and eagles fly during short-distance flights would help determine the value of reducing tower and line height and routing through or adjacent to forest. Information is needed on the extent to which waterfowl and eagles fly at low altitudes or fly to and from resting and feeding areas during poor visibility (e.g., fog and darkness). Use of habitats near lines should be studied to determine the degree to which lines disturb waterfowl and eagles.

Also useful would be studies of mortality at existing lines. For a waterfowl breeding population or migratory flock using a given area containing a powerline, the fraction lost due to collision should be determined. Such a study would require both estimates of the number of waterfowl susceptible to collision and the actual number that collide. The number killed by a particular length of line is generally very difficult to determine because of the difficulty of finding dead birds in dense vegetation, predator removal of dead birds, and escape of injured individuals that die later. Because of these difficulties, accurate estimates would require intensive searches, possibly with the use of trained dogs, and experiments to determine rates of predator removal. Vibration detection devices should be investigated and developed for use in detecting collisions of birds with powerlines.

Finally, the effectiveness of mitigation techniques should be investigated. Such techniques would include reducing line height and routing through or adjacent to forest, using horizontal instead of vertical configurations of conductors so that less vertical flying space is occupied and conductors can more readily be seen by approaching waterfowl, marking lines in various ways for better visibility, and routing lines parallel to existing transmission lines and other structures.

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Transmission Line Engineering and Its Relationship to Migratory Birds

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INTRODUCTION

In addition to its charge to provide electric power for the Tennessee Valley region, the Tennessee Valley Authority has a broad commitment to coordinated resource development. While some of TVA's programs actively promote migratory bird life — particularly waterfowl — TVA's power transmission system probably has the potential, in some places, to harm birds. Although there have been no reports of significant collision-related bird mortalities in the TVA service region, TVA has attempted to address the potential for bird collisions in a positive manner, preventing the problem or mitigating its seriousness, primarily by balanced location of transmission routes. No extensive research programs have been undertaken within TVA as of the date of this conference to attempt an assessment of the causes and extent of any bird deaths.

This paper will not be an attempt to provide pat answers to the questions before this conference. Its purpose is to introduce to the conference some of the procedures and constraints controlling the development of TVA's transmission lines and TVA's attitudes and efforts with respect to resident and migratory birds. This discussion will identify meaningful areas of flexibility in transmission engineering. If this conference concludes that a problem exists with respect to birds colliding with transmission lines, these will likely be some of the areas in which the solutions will be sought.

Transmission engineering is a multifaceted operation encompassing network load flow analysis, system planning, facility location, design construction, and operation. The only two distinct transmission engineering operations which could have an influence on the potential for bird collisions are transmission route selection and transmission line design.

TRANSMISSION ROUTE SELECTION

The route selection process begins with identifying the need for a transmission line. Each transmission line built is designed to meet a specific need. There are different types of transmission need. Some lines are built to transfer fixed levels of power from point to point. Some are dedicated to serve variable loads. Others may be built entirely to reinforce the transmission network or provide interconnections with other power systems.

There is a great deal of variety in the degree to which the terminal ends of needed transmission lines are geographically established. Some conditions may permit considerable flexibility in choosing potential transmission routes, while other lines may be narrowly constrained.

In a broad sense, the costs of alternative routes help to define the study area. Good planning will eliminate unnecessary distance, minimize the use of expensive angle structures, and avoid land where social costs would be excessively high. These cost considerations, however, are not all the criteria used to select transmission line routes. Economic considerations are balanced against the extremely weighty environmental considerations — among them, habitats and flyways of migratory birds. Significant environmental issues which can be quantified might dictate, for example, that a route simply bypass a critical location, despite increased construction costs. The principal efforts in route planning are to eliminate or diminish possible land use and visual conflicts, avoid sensitive natural areas, and yet remain responsive to the engineering costs and requirements of the job.

The methods used to identify and evaluate alternative transmission routes involve field reconnaissance and mapping procedures along with consultation and coordination with public representatives. Natural and man-made features in the study area are examined and analyzed for relationships to transmission line location. Information is gathered from various sources within TVA; municipal officials; federal, state, and regional agencies; and from any other sources available. U.S. Geological Survey 7.5-minute series topographic maps are commonly used as a base to organize geographically referenced data for display and analysis. Tentative routes which generally best avoid conflicts are then selected. These tentative routes are often modified and refined by field surveys which identify smaller scale conflicts.

The process of selecting a proposed route is one of adjustment, accommodation, and "fitting-in," and in this process the early identification of potential conflicts is paramount. Land use conflicts are a prime consideration in transmission line location. Heavily urbanized areas and areas of dense residential development obviously pose the most immediate land use conflicts. New TVA transmission lines located through these areas have a high priority placed on the use of existing utility corridors and the reduction of visual impacts. Undeveloped industrial sites, the value of which often lies in the unencumbered state of large parcels of land, are often avoided as well, when site development cannot be ascertained.

In areas where unique wildlife or plant habitats might be harmed by construction activities or the continued presence of a line or right-of-way, routes are generally chosen to avoid the more sensitive locations. Care is taken to review projects against cataloged information systems operated by the various state and federal agencies, and the routes are closely reviewed by TVA staff biologists, historians, and archaeologists.

The Tennessee Valley region is liberally endowed with parks, recreation areas, and wildlife management areas. It is essentially impossible for an agency assigned the responsibility of serving area electric needs to state categorically that it will completely avoid these areas. TVA's record will show that a reasonable effort has been made to avoid these areas, and where it was impossible to avoid them, that TVA has worked with any other parties involved to create the least possible environmenta impact.

TRANSMISSION LINE LOCATION EXAMPLE

This location example will serve to illustrate TVA's efforts to minimize conflicts and impacts in potentially sensitive areas and show how these unavoidable situations can occur. This example involves a proposed transmission line to supply power to an industrial plant at Decatur, Alabama, in 1974 (Figure 1).

The situation, very briefly, was this: The city of Decatur had developed along the south shore of Wheeler Lake. On the north side of the reservoir is a small airport in an area of prime industrial and commercial development potential; this area was mostly open farmland at the time of the study. Between the city and this developing area, along the north shore of the lake, is a wooded green belt approximately 1 mile in width and projecting for a way up some of the inlet creeks. This green belt consists of Wheeler National Wildlife Refuge and the Swan Creek Wildlife Management Area, together totaling over 37,000 acres.

General Motors was locating a new plant in this industrializing area near the airport. The transmission line to supply power to the plant lay some 4 miles away across two major four-lane highways and a railroad. The plant operations required a high degree of reliability of electric power supply. For this reason a loop line — actually two lines — was required so the plant could eventually be supplied power from either direction on the existing 161-kv transmission line. The power requirements of the plant were phased so that only one line was required initially.

That is the essence of the situation. The primary factors influencing the location of a 161-kv loop line to General Motors were these:

1. *Airport.* The line had to be kept far enough away so that it would not encumber the airspace and emergency glide paths.
2. *Development Potential.* Most of the open land

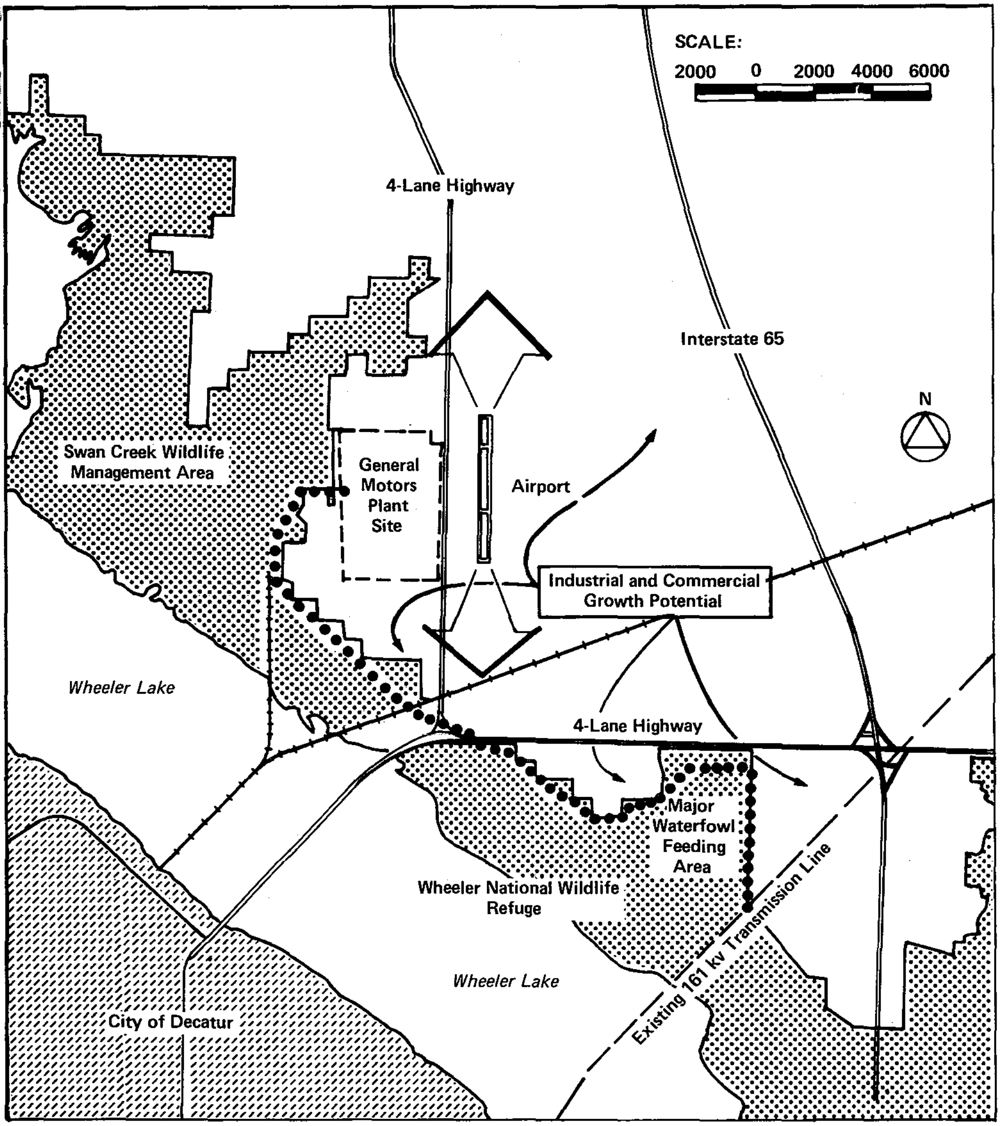

Figure 1. Route location example: Huntsville to Decatur, Alabama, 161-kv transmission line loop to General Motors.

near the highways and airport had been designated by local planning authorities for industrial and commercial development. The value of these properties lay in the unencumbered state of these large expanses of land. The spatial arrangements of future plants or shopping centers were unpredictable, and it was impossible to guarantee in advance there would be no conflicts. Some development had already occurred, and functional conflicts with these had to be avoided as well.

3. *Visual Considerations.* The highways indicated are main entrances to Decatur, so it was important to avoid deterioration of the view. The generally flat, open land contributes to long vistas.
4. *Wildlife Refuges.* The management of these refuges naturally is disturbed by any potential encroachments on the areas. The management was concerned with the reduction of habitat and the possibility that birds might die from collisions with lines.

Constraints were thus identified for practically the entire study area. There was no neutral ground where a transmission line could be built without some conflict. The only course left was to work out a location with full knowledge of the situation and full participation of those affected.

In this instance, avoiding encumbrances on the developable land and maintaining an adequate distance from the airport runways mandated a location near the green belt. Once there, the location had to be reconciled, to the extent possible, with the remaining constraints: visual considerations and the wildlife refuges.

From a visual design standpoint, the "edge" between landscape features is often the most acceptable location for a transmission line. In this case, the margin between the open farmland and the wooded wildlife areas was the strongest permanent edge. The irregular woods margin could not be followed precisely. Instead, the route was set back into the projecting wooded areas both to straighten the lines and to gain a degree of concealment from the highway vantage points.

By staying at the edges of the wildlife area and against or among the trees as much as possible, instead of out in the open, three things were accomplished: (1) The largest possible parcels of wildlife refuge were left undisturbed, (2) crossing a major waterfowl feeding area was avoided, and (3) there was an attempt to keep the wood poles and conductors from presenting unpredictable obstacles to birds in flight.

The precise location of the line was worked out in close, on-the-ground cooperation with the U. S. Fish and Wildlife Service and the Alabama Game and Fish Commission. These people then monitored the survey and construction activities on the line as it was built. At the end of the process the rights-of-way through the wildlife areas were revegetated with wildlife food seed mixtures preferred by the U. S. Fish and Wildlife Service.

An attempt was made in the design of the transmission line to take into account the issue of bird collisions. The single wood pole construction used for the General Motors line permitted a greater degree of location flexibility than steel tower construction. Wood pole lines presented a profile on the same order of height as the adjacent forest. By maintaining a low profile, by staying either against or amidst the wooded areas, avoiding primary feeding areas, and by designing the lines so the poles of the parallel lines would be side by side as much as possible, the location participants believed the potential for bird collisions with the transmission lines was minimized.

The use of wood poles also helped reduce the additional cost incurred by approximately 2 miles of extra line.

TRANSMISSION LINE DESIGN CONSTRAINTS*

The design of transmission lines is not inherently very flexible. The physical characteristics of powerlines are determined for the most part by engineering perfor-

*The examples used are generalized from TVA standards and are intended for illustrative purposes only. They should not be construed as nationwide engineering standards for transmission line design.

mance, reliability, public safety, and economics. This leaves little opportunity for design compromises to reduce bird collision potential. Electrical performance characteristics determine wire sizes, spacing, configurations, and number of circuits. These characteristics combine with economics, topography, climate, strength of materials, and many other factors to form the constraints which guide transmission engineering. Let me briefly discuss some of these constraints on line design and point out areas where some flexibility exists.

Except in localized situations, our society is basically dependent upon transmission lines to deliver electric energy from remote generating sources. Transmission facilities also tie adjacent electric power systems together so that generating capacity at various locations can be made available to the demand on any one system. For technological and related economic reasons, almost all such electric power in this country is transmitted on overhead, three-phase, alternating current lines. Each one of the phase conductors must be kept separate.

Electrical Insulation

Except at supporting tower locations, insulation for these conductors is the air around them. The clearances between overhead transmission lines and nearby objects are set primarily to avoid the possibility of flashover. The flashover distance—the distance an arc will jump and short out the circuit—varies with the voltage rating of the circuit but is well within the prescribed design distances. Conductors on a TVA 500-kv transmission line, for example, have a phase-to-tower clearance of 12 feet. That is, the nearest grounded object (including the supporting tower and shield wires) must be at least that far away from the conductor. The individual phases must be spaced at least 30 feet apart.

Lightning Protection

Lightning storm activity in most parts of the country presents a real hazard to powerline reliability through direct lightning strikes which can cause power outages by flashing over insulators. In some cases lightning can seriously damage insulators and/or sections of wire. To provide protection against lightning, a smaller shield wire is placed above the phase conductors to intercept the strikes. This wire (or wires) in effect provides a "tent" of protection for the line. This electrical shadow concept is considered in most cases to extend protection at an angle of 30 degrees from vertical. The coverage in relation to the conductors and other surrounding influences determines the number and placement of these shield wires.

Wind Pressure Effects

Wind pressure can cause conductors to swing. In the free spans between towers and under some wind conditions, the possibility exists that individual conductors will swing "out of phase," so to speak, and move toward each other. Therefore, the conductors have to be spaced far enough apart at the towers to control the unrestrained midspan phase-to-phase distance. For a 500-kv powerline with horizontally spaced conductors restrained at each structure, the distance from one phase to the next is 30 feet. Side swing also has a direct bearing on the width of rights-of-way and on the separation between parallel powerlines.

Conductor Height Relative to Ground

The height of a conductor at any given location depends upon (1) minimum safety codes based on the flashover distance for a particular operating voltage, (2) topography under the line and objects that can intrude into the free space, (3) climatic factors and power flows that influence conductor sag, (4) electric field effects, and (5) spacing between towers along the transmission line.

Conductor heights above ground are set primarily by the electrical flashover distance in air which varies with the line operating voltage level. This flashover distance must be set liberally because of the many changes that can occur for a variety of reasons in the free airspace. Air pressure, temperature, humidity, and airborne particles can alter the insulating value of air. People, animals, and mobile objects frequently occupy space under the line. Trees and fast growing shrubs can, in a short period, significantly reduce conductor clearances.

Electrostatic fields, which are most noticeable in the extra-high voltage range, introduce another design parameter to be considered in selecting minimum conductor heights. By maintaining adequate conductor heights, the ground level strength of these fields can be controlled to avoid excessive induced voltages, currents, or other undesirable effects.

Conductor heights are not uniform along the length of a line. Conductors, supported between towers, sag under their own weight along catenary curves. Naturally, in hot weather or when conductor temperatures are increased by heat from resistance, the conductors will sag even lower than normal. Conversely, under low ambient temperatures the conductors will stretch tighter and higher. All points along these catenary curves must maintain at least the regulated minimum height regardless of operating temperatures or topography extremes.

Structure Spacing

Although structure spacing is by no means a random process, it does represent one of the more flexible areas of transmission engineering. Tower spacing is heavily dependent on topography with the design attempt made to spot towers along the rights-of-way where the greatest design and cost advantages can be realized. The optimum tower locations, though, often must be compromised to avoid or minimize land use conflicts. A variety of spacing and structure height combinations can be used to maintain minimum ground clearances. A great many closely spaced, low structures can accomplish essentially the same task as fewer tall structures with long spans.

The types of structures used for a line also influence the spacing of structures. Shorter spans in the range of 400 feet to 600 feet are characteristic of wood pole construction, while spans may range from 700 feet to 1400 feet for steel construction. The height and strength limitations on wood structures are the basic reasons for their shorter span capabilities.

Structure Strength

The reliability of transmission support structures is a vital link in the reliability of the transmission system. Transmission structures must be able to withstand tremendous forces. They must bear the weight and stabilize the placement of the conductors, insulator strings, and groundwires not only under normal circumstances but under the most extreme conditions predictable for the location. Ice and wind loads on the conductors and on the towers themselves can more than double normal loads.

Because of the side loads on structures at transmission line angle points, the support structures must be much stronger (and more expensive) than the straight-line "tangent towers." Multicircuit transmission towers have much greater loads to support than single-circuit towers. Although transmission lines are built so that loads are normally static, the towers are designed so that even if one conductor were to break, the dynamic forces resulting will not destroy the tower or the remaining conductors.

Structure Selection

Within these parameters there is enough design latitude to allow many different tower styles and configurations. The variety of aesthetic structures available attests to that. Not all of the tower designs available, however, are suitable for general use in a transmission system. Many of the aesthetic structures are limited in their loading capacities so that their potential usefulness is reduced. Other practical, economic, and environmental factors must also be considered in selecting structure types.

Because of the number of towers used, the cost of each must be kept as low as possible. It must also be possible to construct towers in the nearly impossible places transmission lines sometimes must cross. The traditional self-supporting, laced-steel structures meet these requirements. They provide the flexibility in design to assemble a very strong structure from lightweight, relatively inexpensive parts. The self-supporting feature eliminates the additional encumbrance of the right-of-way which a guyed structure would cause. In construction, these lightweight parts provide a bonus in reduced impacts and costs of hauling heavy structures over the rights-of-way. Except at sharp angles (over 20 degrees), these towers normally do not require concrete foundations—a major cost and construction impact savings.

CONCLUSION

The purpose of this discussion of transmission engineering is to identify the reasonable—and unreasonable—avenues of pursuit for attempts to adapt transmission lines to reduce or avoid bird collisions. These areas of flexibility may be summarized briefly:

1. Attempts can be made to identify significant problem areas in advance so they can be avoided to the extent possible through sensitive route selection.
2. Some transmission line design flexibility exists, in many cases, in the choice of support structure heights and spacing.
3. There is a degree of latitude in the choice of support structure materials and configurations.

It bears emphasizing that these areas of flexibility do not indicate randomness in transmission engineering. These areas still are bounded by strict engineering constraints and guided by economic responsibilities.

Although bird collisions with transmission lines have not become a significant issue in the TVA region, it is recognized that some bird collisions occur. In study areas where line locations might raise the likelihood of bird mortalities—whether through habitat alteration or collision potential—then the transmission line engineering processes attempt to take this into account and work to minimize damaging effects. In the near absence of research-influenced and cost-effective design measures to reduce bird collisions, TVA's efforts to mitigate collision impacts currently rely heavily on sensitive route selection.

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Routing Transmission Lines Through Water Bird Habitat in California

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Pacific Gas and Electric Company (PG and E) first became involved in bird/powerline interactions in 1970. At that time, concern was raised about the ecological impact of electric power transmission lines and their supporting steel towers on wildlife within the South San Francisco Bay of California. Mr. Philip Arend of Wildlife Associates, Inc., was consulted to evaluate the effects of existing powerlines in the bay and to offer his professional opinion of the impacts these facilities pose for wildlife. (Mr. Arend, formerly a waterfowl biologist with the California Department of Fish and Game, has over 40 years' experience working with waterfowl and marsh management.) His report was based on a comprehensive literature review, interviews with numerous wildlife refuge managers and other field workers, and personal observations. Mr. Arend concluded, "Electric power transmission lines mounted on steel towers cause very minor avian loss, and their adverse ecological impact on avian populations is negligible." Mr. Arend cited several instances of bird mortality in water bird habitat mostly attributed to small diameter distribution lines, not high-voltage large diameter transmission lines. In most reported cases, adverse weather or human disturbance may have contributed to the mortality incident.

Since 1970, PG and E has prepared many environmental impact reports, and discussions of bird/powerline interactions are included as appropriate. Specific studies to determine the scope of bird/powerline interactions in northern California have not been conducted because our company was not convinced bird/powerline interactions were significant or because most projects did not enter water bird concentration areas.

Recently, PG and E has considered major transmission line projects through water bird habitat in three separate areas: the South San Francisco Bay area, Sacramento Valley, and the San Joaquin Valley of California. These areas all contain important waterfowl wintering areas within the Pacific Flyway. According to the U.S. Fish and Wildlife Service, 60 percent of the migratory waterfowl on the Pacific Flyway (approximately 4 million ducks and 700,000 geese) winter in California. Large numbers of shorebirds also winter in the state. Concern for bird/powerline interactions has been raised locally by the California Department of Fish and Game, the U.S. Fish and Wildlife Service, the California Energy Resources Conservation and Development Commission, and various public interest groups. I will briefly summarize these project concerns.

STANISLAUS NUCLEAR POWER PLANT PROJECT

This project involves three possible power plant sites* and several related alternative 500-kv transmission line corridors within California's San Joaquin Valley. Important water bird habitat exists in many areas of the valley, and it is virtually impossible to avoid crossing wetland habitat with all transmission line corridors. While one corridor was adjusted to avoid the Kesterson National

*According to California Energy Resources Conservation and Development Commission (ERCDC), utility companies are required to submit development plans on a minimum of three proposed power plant sites. The ERCDC—through a 36-month process of reports, workshops, and hearings—may issue a decision to construct on one site and one (or more) land banked alternative.

Wildlife Refuge, another 4-mile-wide corridor incorporates part of the Grasslands Water District. This area, in private ownership, receives federal assistance for maintaining wintering water bird habitat. The Grasslands Water District and California Department of Fish and Game oppose transmission lines through the area because they believe habitat loss will occur due to the presence of transmission lines. They suggest that direct habitat losses will occur when birds avoid habitat near newly constructed powerlines, and a decrease in hunter experience will result since birds may flare over lines beyond shooting range. A reduction in hunter bag would reduce revenues and could force landowners to alter their land management practices and possibly convert the wetlands to other uses.

SAN FRANCISCO BAY AREA COMBINED CYCLE PROJECT

This project includes four possible power plant sites and several alternative 230-kv transmission line corridors within the vicinity of San Francisco Bay. One of the proposed sites, North San Jose, includes a perferred alternative transmission line route adjacent to the South San Francisco Bay National Wildlife Refuge. The refuge serves an estimated 360,000 wintering waterfowl and 740,000 shorebirds. In addition, there are numerous existing transmission lines crossing the bay in all directions. Although PG and E proposed an alternative corridor adjacent to an existing transmission line outside the refuge boundary, the U.S. Fish and Wildlife Service and the California Energy Resources Conservation and Development Commission have recommended additional studies of water bird flight patterns and undergrounding alternatives before a final transmission line corridor is selected.

COAL POWER PLANTS

This project consists of studies of four possible power plant sites and several alternative 500-kv transmission line corridors in the Sacramento Valley. Several of the proposed corridors traverse water bird habitat, including freshwater marsh and rice fields. The Sacramento Valley supports an estimated 2 to 3 million wintering waterfowl and thousands of shorebirds. The U. S. Fish and Wildlife Service has expressed concern that bird/powerline interactions, similar to what Dr. Willard has described for the Klamath Basin in the keynote address, are possible. The presence of existing powerlines, dense tule fog, and high concentrations of water birds provide conditions for possible bird/powerline interaction studies.

I have only briefly discussed these three examples of bird/powerline interaction concerns expressed in these projects. It is important to point out that the projects differ considerably.

TRANSMISSION LINE ROUTING PROCEDURE

PG and E has developed a sound transmission line routing procedure that addresses engineering, economic, and environmental concerns. The possibility of bird/powerline interactions is included in all planned transmission line projects. The first step in the routing process is to locate a study area, usually encompassing several potential power plant sites and desired alternative power delivery points. The next step is to select alternative straight-line corridors (usually 4 miles wide) between the power plant sites and the designated delivery points. All existing transmission line corridors are mapped and examined, and, whenever possible, proposed corridors are modified to parallel existing routes. A regional study is conducted to identify major constraints to transmission line development. Environmental considerations at this phase of the process include wildlife refuges, national and state parks, natural areas, and other officially dedicated lands that may be affected by the presence of transmission lines. Corridors are adjusted, where possible, to avoid these designated areas. Adjustments based on continuing economic and engineering studies and land use may also lead to changes in the corridors. Each corridor must contain at least one feasible transmission line route.

The next step in the routing process is to choose potential transmission line routes within the 4-mile-wide corridors. Here, specific resource elements that could be adversely impacted by transmission line development are identified and, in most cases, avoided. Examples include heron rookeries, eagle nests, and rare/endangered plant locations. Eventually, an acceptable transmission line route is chosen through the corridor.

The ecological studies for transmission line routing involve literature reviews, agency and public interest group input, field studies, and report preparation. Studies on large projects may take from 1 to 3 years to complete. Routing transmission lines in California, as in many other parts of the nation, is a difficult and complex task. Many issues and concerns develop regardless of the process used to locate a powerline. Within the PG and E service area, the concern with bird/powerline interactions is another factor that is evaluated for all new powerline construction projects.

SUMMARY

The concern that transmission lines may pose a threat to some avian species has been raised periodically in California since 1970. However, little data existed until recently to indicate that bird/powerline interactions were worthy of specific study. The utility industry has spent millions of dollars in research to address such concerns as thermal effects on aquatic life, cooling tower drift effects, stack emission effects, noise effects, and electromagnetic effects; and, until recently, the concern with bird/powerline interactions simply was not being addressed. Even now, with an estimated 100,000 circuit miles of transmission lines located in all representative habitats across the nation and with millions of resident and migratory birds, incidents of bird losses have seldom been reported.

The study of bird/powerline interactions is warranted to place these interactions in perspective. This will require sound research, time, and money. To explore the possible scope of this concern, we will be seeking information on collision potential, noise effects, electromagnetic effects, and avoidance of habitat.

A cooperative research approach, with industry and the agencies working together to develop a predictive model to help us avoid areas of potential significant impact and possibly to predict the consequences of locating a powerline in a given area, should be our goal. I believe the industry is now willing to accept this opportunity and challenge.

The Klamath Basin Case

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BACKGROUND AND HISTORY*

Pacific Power & Light Company is in the process of constructing generating facilities in Wyoming to utilize its strippable, low-sulfur coal in that state. These facilities, Jim Bridger and Wyodak, together with existing generating facilities would provide electric generation in excess of Pacific Power's Wyoming load requirements for the immediate future.

To utilize the large blocks of excess Wyoming power, Pacific Power proposes to transmit it to load centers in the Pacific Northwest, and southwestern Oregon in particular. Since Pacific Power has insufficient transmission capacity to transmit this power from Wyoming to the Northwest, it proposes to construct a new 500-kv powerline between the Midpoint, Idaho, substation and a proposed substation near Medford, Oregon. To implement this proposal, Pacific Power f·led two applications with the

*All data presented here is either directly quoted or summarized from the report, "Final Environmental Statement. Pacific Power & Light Company, Proposed 500 KV Powerline, Midpoint, Idaho, to Medford, Oregon," by U.S. Department of the Interior, Bureau of Land Management.

Bureau of Land Management, U.S. Department of the Interior, for a 175-foot-wide right-of-way between Midpoint, Idaho, and Medford, Oregon, a distance of approximately 480 miles (Figure 1).

According to Pacific Power, the proposed transmission line will serve the following purposes:

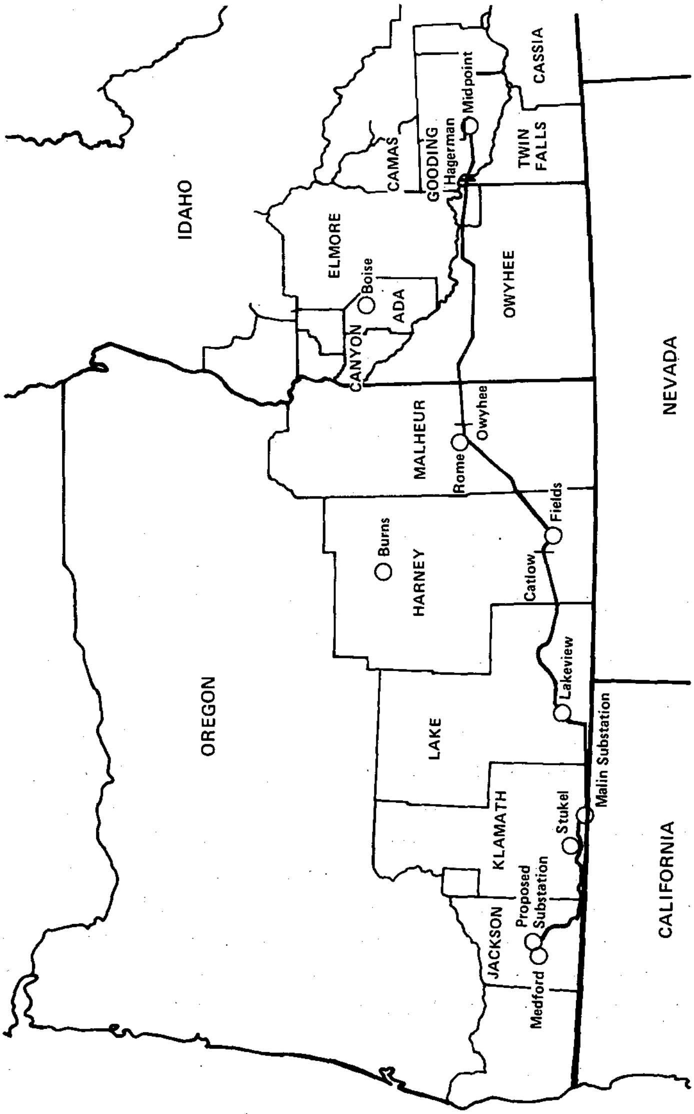

Figure 1. Proposed powerline route, Midpoint to Medford.

1. Provide a means of transferring surplus electrical energy from Wyoming coal-fired thermal plants to load centers in the Pacific Northwest
2. Provide a direct means of supplying power to meet the energy growth needs of southern Oregon
3. Be available for backup transmission capacity from the Pacific Northwest to the Rocky Mountain area in emergency situations
4. Contribute to the reliability of the interconnected transmission grid in the Pacific Northwest

The proposed route passes over several areas important to waterfowl for migration, resting, breeding, feeding, and wintering. Some examples along the route follow (see Figure 2).

The Bruneau Valley and adjacent Strike Reservoir in Idaho are used by thousands of waterfowl. Major waterfowl concentrations occur along the Snake and Bruneau Rivers and Klamath and Warner Valley Lakes. These waters serve as habitat for resident species and provide food and resting areas for the many migrants moving north and south through the area east of the Cascade Mountains.

The Warner Lakes in Warner Valley are a major nesting and feeding area in the Pacific Flyway and undergo the greatest seasonal bird use of any area along the proposed Midpoint to Malin right-of-way. This area is also an important rookery for herons and cormorants. Some 200,000 migrating birds are believed to pass through the Warner Valley area annually.

Pelican Lake and Crump Lake, just south of the area that would be crossed by the proposed right-of-way, contain one of the two white pelican rookeries in Oregon. The valley is an important migration flyway for ducks, geese, swans, sandhill cranes, and many other waterfowl and marsh birds.

South of Klamath Falls, Oregon, the proposed right-of-way would cross the Klamath Basin, site of one of the world's greatest waterfowl concentrations. The combination of proximity to open water, marshlands, grainfields, and federal and state refuges makes the basin a waterfowl habitat that is unexcelled. The route would skirt part

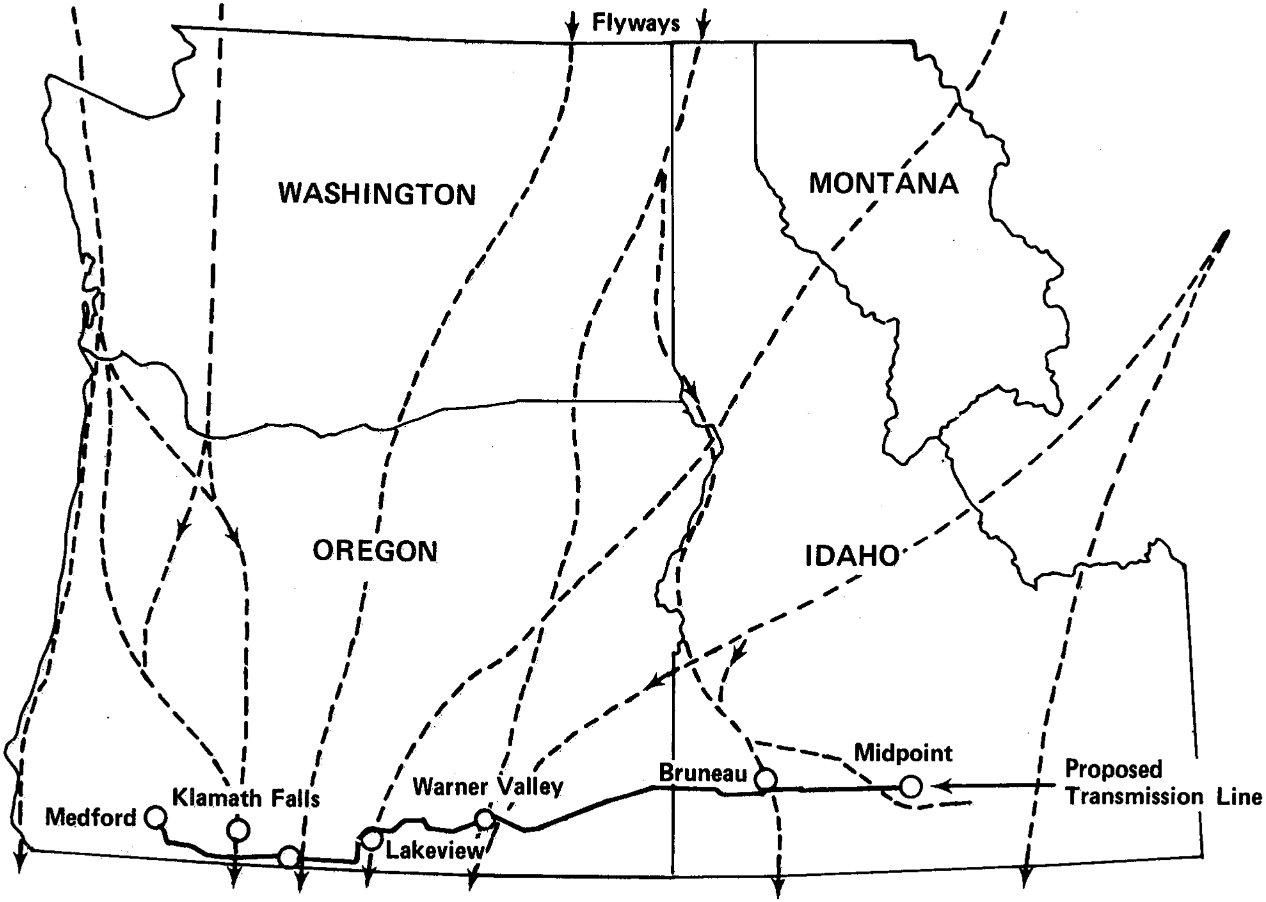

Figure 2. Major flyways in relation to the proposed transmission line.

of the Klamath Basin National Wildlife Refuge (see Figure 3).

These, and adjacent farmlands, are part of an extremely productive waterfowl area and flyway route. The refuges list over 180 species of birds nesting in the basin. All the common dabbling and diving ducks are abundant, with pintails predominating. Geese include cackling, white-fronted, snow, and Canada geese. The Ross's goose, smallest of all North American geese, passes through the Klamath Basin on its annual migration. According to the U.S. Fish & Wildlife Service, this flight represents the world population of Ross's geese.

It is estimated that over 5 million waterfowl pass through the Klamath Basin annually. In addition, an estimated 4,000 grebes, 1,000 white pelicans, 800 cormorants, 1,000 gulls, and 4,000 terns migrate through this area.

A unique phenomenon in the Klamath Basin is the mass waterfowl feeding flights. A waterfowl feeding flight can be defined as one which is local in nature, relatively low in altitude, and pursued by waterfowl for the purpose of ingesting food. A feeding flight originates at a resting area and terminates at a feeding area and vice versa. Within the Klamath Basin, by far the largest and most important feeding flight is the one that at least once in each 24-hour period traverses the flight corridor between the Lower Klamath Wildlife Refuge portion (almost all of which is located in California) of the Klamath Basin National Wildlife Refuges and the agricultural grainfields which lie in southern Oregon, some 5 to 7 miles north of the Lower Klamath Refuge. This feeding flight is referred to as the "Lower Klamath feeding flight." The bulk of this flight originates in the Lower Klamath Wildlife Refuge (the resting area) and terminates in the grainfields to the north (the feeding area) to the south of Midland and north of Township Road, principally in the area known as Tulana Farms. A return flight to the resting area (the Lower Klamath Wildlife Refuge) is usually made within 12 hours of the initial flight.

According to Tom Roster, an instructor at the Oregon Technical Institute and shotgun ballistician who has

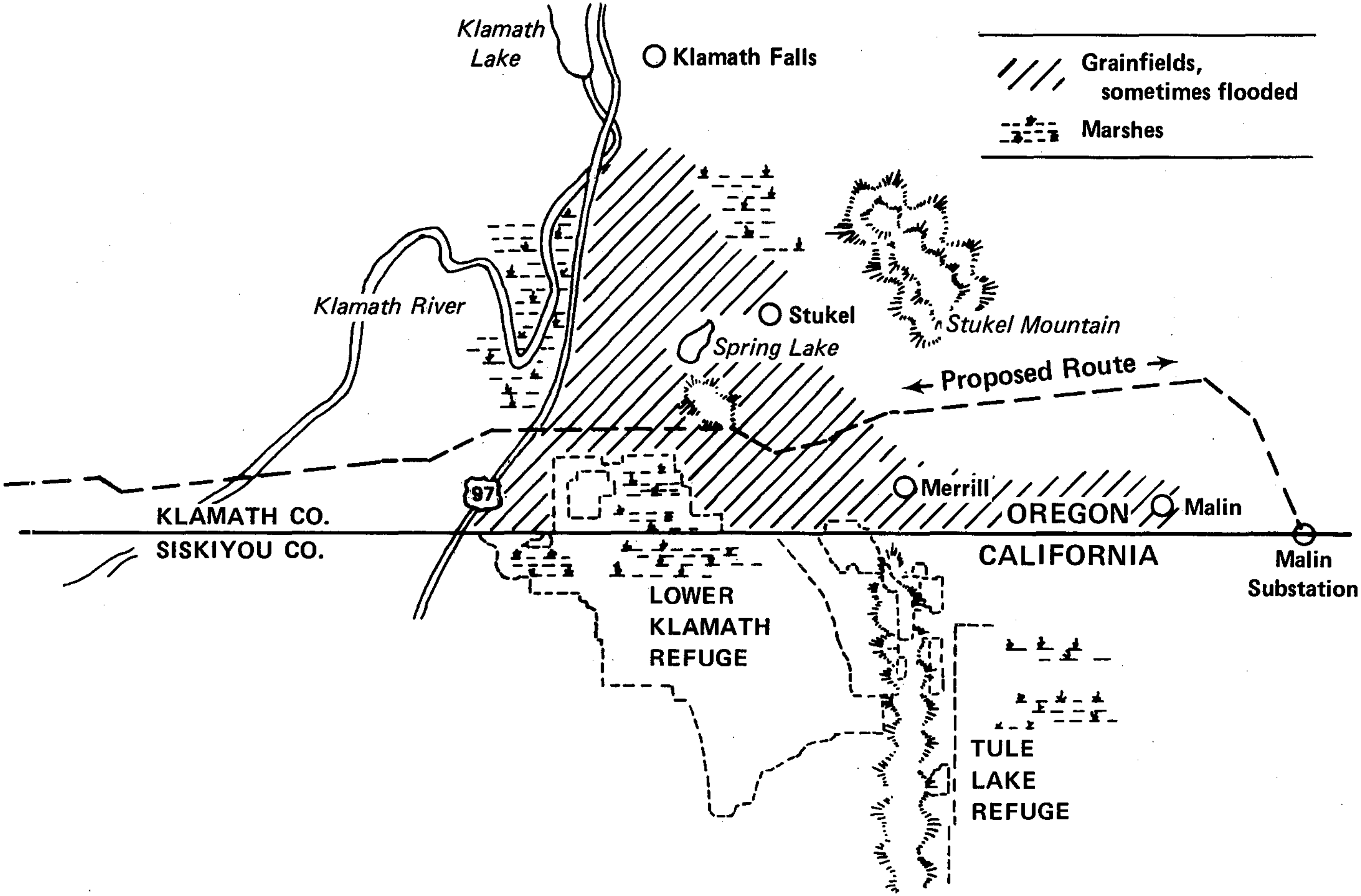

Figure 3. Klamath Basin with proposed route.

studied the local feeding flights extensively, the Lower Klamath feeding flight numbers from a minimum of 30,000 waterfowl to a maximum of 800,000 waterfowl. These birds (30,000 to 800,000) travel the feeding flight route at least once each day. (This feeding flight phenomenon should not be confused with the reference to over 5 million waterfowl that pass through the Klamath Basin at the peak of each fall migration.)

The area is heavily hunted. The Oregon Department of Fish & Wildlife estimates more than 83,000 ducks, geese, and coots were harvested in the Klamath area in 1973. Several private gun clubs are located near the Worden area. The Oregon Wildlife Commission operates the Klamath Wildlife Management Area north of Worden for waterfowl and upland game use. South of Worden lie three Fish & Wildlife Service Klamath Basin National Wildlife Refuges. These refuges contain approximately 116,400 acres along both sides of the California-Oregon line. The Lower Klamath Refuge lies 1 mile south of the proposed right-of-way. The area is mainly flat farmland with no natural obstruction to waterfowl flights. Heavy fogs often prevail during the migration season.

ADVERSE IMPACTS TO WILDLIFE

It is believed that the construction, operation, and maintenance of Pacific Power's proposed Midpoint to Medford right-of-way and 500-kv transmission facilities would cause the loss of bird life through collision with lines and towers. The design of the proposed powerline is such that it could result in bird losses of considerable importance over the life of the project from collision with the transmission facilities. The towers, conductors, and shield or ground wires would impose serious barriers to birds during migrating, feeding, and nuptial flights and would kill or cripple birds colliding with them.

Nocturnal avian migrants and local feeding and nesting populations are especially prone to collide with man-made objects. Magnitude of losses would depend on tower height, visibility, bird density, and flight patterns. Most birds normally migrate at a height that clears most man-made obstacles, but when blinded or confused, losses could occur. This subject is controversial and needs further study. Arend (1970), in a report for the Pacific Gas & Electric Company, states that "electric power transmission lines mounted on steel towers cause a very minor avian loss and that the adverse ecological impact on avian populations is negligible." The Fish & Wildlife Service, however, does not accept this as a blanket conclusion and has indicated that major losses of migratory birds would likely occur in areas of intensive use and low-level flights, such as in the Klamath Basin and Warner Valley. A literature review shows that much of the data concerning collisions is based on migrating passerines striking TV antennas and tall lighting structures at airports. Most of these towers are above the height of Pacific Power's proposed 500-kv lines and towers. It is known, however, that during periods of storm and poor visibility, resident and migrating birds decrease elevation, become confused, and tend to strike lower structures. Also, waterfowl feeding flights are usually much lower to the ground, making the probability of collisions with powerlines much greater than for migrating birds (Roster 1976, USFWS 1976).

The following are examples of bird losses from collisions:

1. An estimated 50,000 birds lost through collision with a ceilometer at Warner Robins Air Force Base in Georgia. These birds were all passerines (Johnston and Haines 1957).
2. Thirty thousand birds killed by a TV tower and guy wires at Eau Claire, Wisconsin; 15,000 killed in one night, nearly all passerines. This was a 1,000-foot tower (Kemper 1964).
3. Twenty-one mute swans killed by impact and electrocution by an overhead powerline above a reservoir in England. This was 30 percent of the total flock (Harrison 1963).
4. One hundred night migrants killed at Oak Ridge, Tennessee. An airport ceilometer contributed to most of the passerine losses (Johnston and Haines 1957).

5. Twenty-three Franklin gulls and 20 blue-winged teal killed by powerlines. Dabbling ducks, with mallards predominating, appear to be most vulnerable to wire collisions (Krapu 1973). Seven hundred and sixty passerines killed at the Omega Navigation Tower, La Moure, North Dakota (USDI, 1974).
6. Anderson (1978) discusses losses of waterfowl by collisions with powerlines across a 2,155-acre lake near a large power plant in Indiana. An estimated 300 waterfowl (out of 100,000) were killed during a 4-month period. The study concludes that the mortality was relatively minor in terms of the total population, since the vast majority of birds had flight patterns that did not bring them near the powerline.
7. Scott, Roberts, and Cadbury (1972) state that in England powerlines of 400 kv, 275 kv, 132 kv "sited near estuaries, river valleys or between bodies of water provide a particular hazard when they lie across flight paths used by waterfowl, waders, gulls, or other water birds between feeding and roosting area." Their study accounted for a known loss of 1,285 migratory birds, with 6,000 (including passerines, gulls, rails, and ducks) estimated killed over a 6-year interval at Dungeness, Kent.

The Fish & Wildlife Service states that

> "the greatest threat occurs when large numbers of birds concentrate in an area for resting, feeding, or nesting purposes. These birds stay for a period of time ranging from a few days to 3 or 4 months. Soon after arriving at such an area the birds develop a series of flight patterns that are not similar to migration flights. These movements are usually most pronounced between sunset and sunrise when lighting and visibility are poor. Another characteristic of these flights is the low elevation at which they occur, especially within or adjacent to the feeding and resting sites. It is during these local flights that collisions are most likely to occur rather than during migration flights, which often cover hundreds of miles nonstop at high elevations. The problem is increased by inclement weather conditions such as local fog or snowstorms which

restrict visibility and often cause the birds to fly at low elevations" (USFWS 1976).

While the anticipated loss of waterfowl and other migratory birds on the proposed line is speculative, the Fish & Wildlife Service feels strongly that major losses would probably occur. Intensive waterfowl flights in the Hagerman area, especially during migrations down the Snake River, would be subjected to possible losses due to collisions with the powerlines and towers. Birds would be most vulnerable during periods of low visibility and inclement weather. Migrating birds, including passerines and waterfowl, would be lost through collisions. For example, if 0.05 percent of over 2 million waterfowl migrating through Idaho across the proposed route were lost, it would amount to 10,000 birds; however, it is not possible to quantify numbers or species.

Waterfowl concentrations are found at the Bruneau River crossing and adjacent C. J. Strike Reservoir, during both feeding activities and migration. The proposed right-of-way crossing at the Bruneau River would result in losses similar to those anticipated at Hagerman. Other migrating birds, including such passerines as mourning doves, are vulnerable where an unknown number of flights would cross the proposed right-of-way. Concentrations of many other birds are found along the Snake River parallel to the proposed right-of-way from Hagerman to the Bruneau River, a distance of nearly 60 miles, increasing the likelihood of powerline collisions.

A major wildlife concentration occurs at Warner Valley. It is one of the most vulnerable areas along the proposed Midpoint to Malin right-of-way. More than 10,000 waterfowl use the Warner Lakes as a breeding-feeding area. An unknown, but substantial, number of migrants — including other ducks, geese, coots, shorebirds, terns, cranes, pelicans, cormorants, passerines, and raptors — pass through this area. In addition, the area is heavily used by waterfowl, pelicans, and other migrants for feeding. Annual counts have shown nearly 200,000 birds in the area.

The greatest potential hazard to wildlife would come from placement of the powerline from the west edge of the

Klamath Hills to the Worden area on Highway 97 — a distance of approximately 7 miles. This part of the proposed right-of-way would cross the major portion of the migration route for nearly 5 million waterfowl and thousands of other migratory birds that move through the Klamath Basin. In addition, an unknown number of daily feeding flights of resident waterfowl would pass across the proposed right-of-way. There are no natural obstructions in this 7-mile area to screen the proposed transmission line or make waterfowl rise to higher flight elevations. While losses of waterfowl and other migrants are speculative, the references indicate that losses will occur. They could also be very high (USF&WS 1976).

Since the area is also important to breeding birds, there would be losses of ducks during erratic nuptial flights. During periods of poor visibility, such as at night when many migrations and feeding flights occur, the birds would have a barrier of 11 conducting and ground wires to fly past along a 14-mile segment of the proposed right-of-way. Heavy fogs, storms, and wind cause elevation variations in feeding flights in that area, increasing the possibility of collision.

Besides the ducks, geese, and swans using this area, gulls and terns, grebes, and white pelicans counted annually by the Fish & Wildlife Service as well as cranes, herons, shorebirds, and passerine species would have to cross this aerial barrier. Based on losses in other areas, losses of thousands of birds could be anticipated in the Klamath Basin.

In his testimony before the Public Utilities Commission hearings officer, Roster (1976) described mass feeding flights of nearly 800,000 birds in the Klamath Basin. Since these low elevation flights between marshlands and grainfields occur at dawn and dusk when visibility is poor, he believes the proposed powerline would present an especially dangerous obstacle.

If the birds should change their flight routes to avoid collisions with the powerline, the result could be an adverse economic and recreational impact on Klamath Basin residents, especially if the birds move across the state line into California (Roster 1976). The U.S. Fish &

Wildlife Service indicates that landowners in Illinois were awarded compensation of up to $100,000 for decreased hunting opportunity attributed to a powerline. Martinka (1974) states that duck shooting declined by two-thirds after a powerline crossed a Wisconsin hunting area and that Canada geese in normal flight would not fly under the line.

As cited above, loss of migrant birds is speculative, and opinions about the probable magnitude and significance of bird kills vary greatly. Power company representatives indicate that minor losses will occur. On the other hand, the Fish & Wildlife Service has indicated that major losses will probably occur.

MITIGATIONS

Of the mitigations cited for wildlife in Chapter IV of the powerline impact statement by the Bureau of Land Management (USDI 1976), only one pertained indirectly to collisions of waterfowl with conducting lines and towers. It stated that towers should not be placed in open expanses of water and marshland, particularly those utilized as flight lanes, nesting, rearing, or feeding sites by migrating waterfowl and other birds. It is hoped that this action would mitigate, to an unknown degree, wildlife habitat destruction and wildlife displacement, and possibly collision with the towers.

Overall, it was felt that collisions of waterfowl and passerines with towers, conductors, and shield wires were an unavoidable wildlife impact that could not be mitigated. This is especially true at key migration and feeding sites such as the Snake and Bruneau Rivers, Warner Valley, and the Klamath Basin.

Long-term impacts are feared, especially if the powerline route selected becomes a transmission corridor through waterfowl and other migrating bird concentration areas. Adverse effects in migration and feeding patterns and direct losses by collisions with towers, conductors, and shield wires would be anticipated. Annual losses would be expected to continue over the life of the project, especially in the case of multiple lines or a power corridor (see Figure 4).

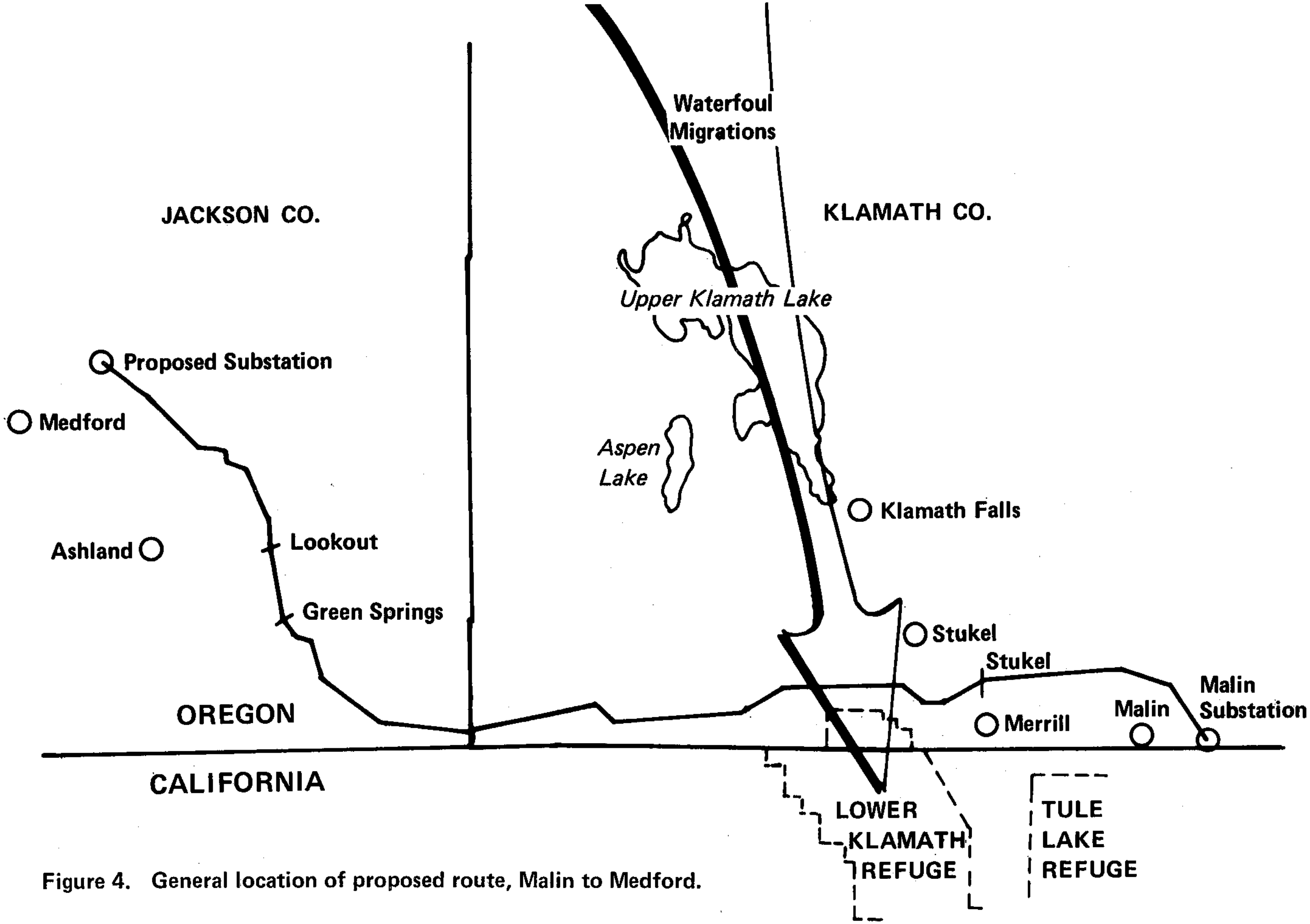

Figure 4. General location of proposed route, Malin to Medford.

ALTERNATE ROUTES

In addition to the proposed route from Midpoint, Idaho, to Malin, Oregon, four alternate routes have been studied, some of which bypass the Bruneau River and Warner Valley areas. These will not be discussed in detail. In every case, however, all routes terminate at Malin, Oregon. In the segment from Malin to Medford through the Klamath Basin, it is very difficult to find an alternate route that would effectively cross migration routes without adverse impacts to the waterfowl flights through that area.

One alternate route (Route II) would parallel the proposed route, passing slightly to the north, with the same anticipated impacts as for the proposed route and alternate route I. Alternate route III would begin at Malin, then turn north almost to the city limits of Klamath Falls, crossing the Klamath River east of the Weyerhauser sawmill, then heading west north of the proposed route. This route would parallel most of the flyway patterns except for the one-half mile long crossing near Klamath Falls, where it would again bisect major waterfowl flight patterns. It would also cross Ross's geese feeding flights in the east side of the Klamath Basin, and it would cross near the Miller Island Wildlife Management Area (Oregon).

Alternate route IV would dip down into northern California, going south and west of Fish & Wildlife's Lower Klamath Refuge and close to some large private hunting clubs. It would parallel Sheepy Ridge, which divides the Lower Klamath Refuge from Tule Lake Refuge and which also constitutes an important hunting area. This refuge area is heavily used by waterfowl, shorebirds, and other migrants for feeding and nesting, and the alternate route would be crossed by extensive feeding flights near Merrill. Migration flights would probably be well above the powerline since it would be under the crest of or through some low hills on the south, southeast, and southwest sides of the Lower Klamath Refuge (see Figure 5).

SUMMARY

The problem of waterfowl and other migrants colliding with powerlines is well documented where feeder lines

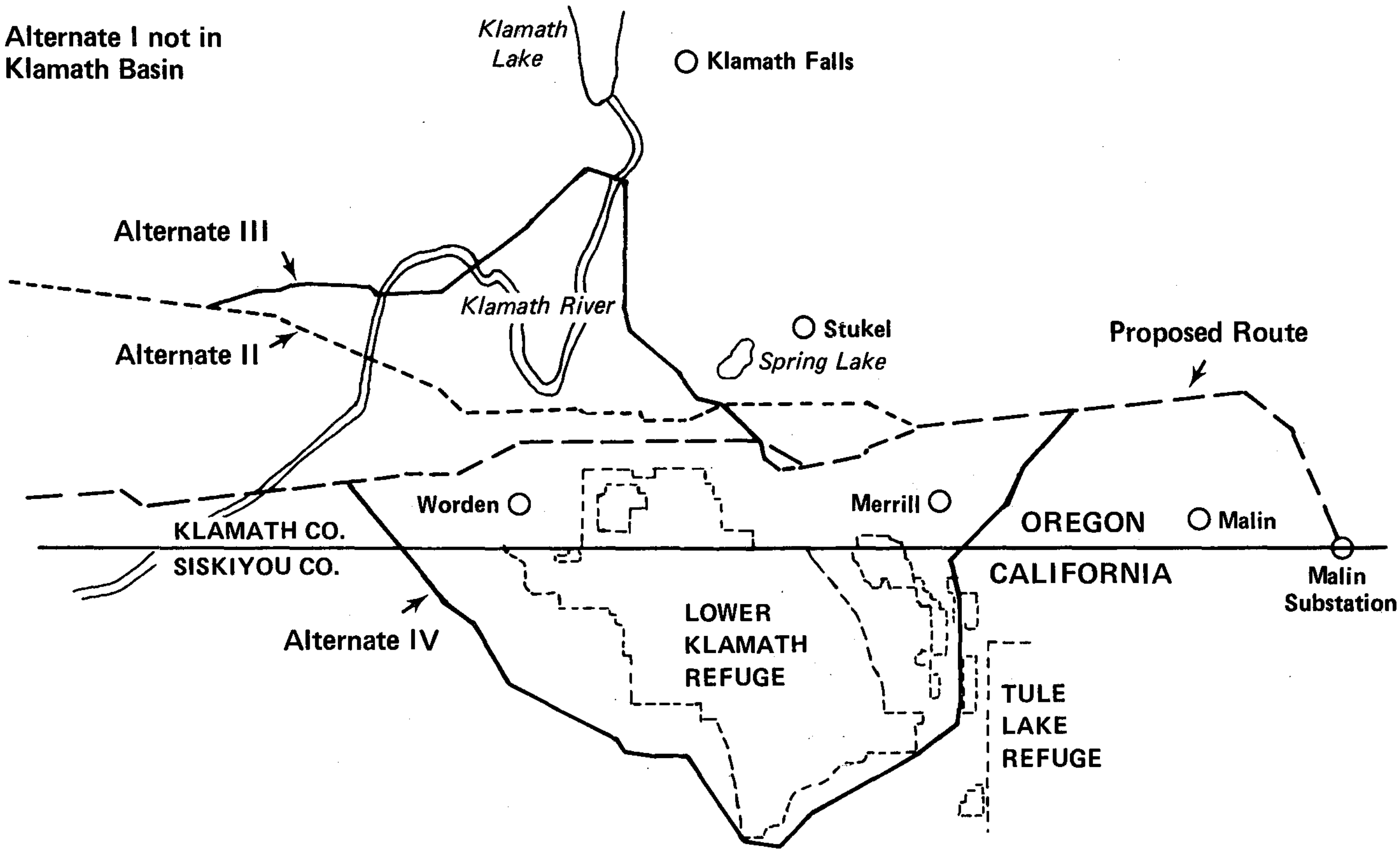

Figure 5. Alternate powerline routes.

and other small conductors are concerned and where TV towers, airport lights, etc., have caused heavy losses — especially to passerines in bad weather. The problem is not well documented where large diameter conductors, bundled conductors, or large multiple lines are concerned. Based on the literature, however, heavy losses to waterfowl, cranes, pelicans, other shore and water birds, as well as migrant passerines are anticipated in areas of heavy bird concentration, such as in the Klamath Basin.

On November 21, 1977, the Secretary of the Interior informed Pacific Power that the Department of the Interior has determined that alternate route I, between Midpoint and Malin, is clearly the preferred one, and Pacific Power has indicated it will make application for that route. Between Malin and Medford, the Secretary recommended alternate route III or to construct the project along the proposed route, but he also indicated to mitigate the impact by undergrounding through the critical area in the Lower Klamath Basin.

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Working Group Summaries

Behavior

The working group on behavior addressed the aspects of bird behavior that would enhance bird strike probabilities at powerlines, and the group attempted to identify those circumstances most closely associated with bird collisions at powerlines. This was done whenever possible according to bird species grouped into four general categories: (1) waterfowl, (2) shorebirds, (3) raptors, and (4) small nongame birds.

We first considered the importance of weather conditions in evaluating the risk of powerline collision for birds. The weather conditions that influence visibility or detectability of transmission lines were treated separately from those influencing flight activity of a local movement nature and of a migratory nature. The group generally agreed that conditions of low visibility (very low ceiling of thick clouds and precipitation) are the major weather conditions that

William L. Anderson, Frank Cassel (recorder), Milton Friend, Sidney A. Gauthreaux, Jr. (chairman), Gilbert S. Grant, Donald A. Hammer, Carl Korschgen, Richard L. Morgan, Richard L. Plunkett, Kent Schreiber, Bob Welford.

affect detectability of transmission lines. With regard to detectability, the contrast of the wires or cables against a background should be considered. Rendering lines more conspicuous to birds could have potential problems, and more work is needed in this area. Weather conditions that enhance low-level local movements of birds and the volume of these movements are basically the same as those that decrease powerline detectability. Waterfowl in general are quite active in such weather, particularly with wind. Raptors may move and feed at lower altitudes during low visibility conditions, and passerines are probably less active in terms of flight activity. Very few quantitative studies exist that address the influence of weather conditions on the amount of local movement in bird species. Most of the evidence is somewhat anecdotal.

With regard to spring and fall migration, we know the weather conditions that contribute to massive movements of birds (see Gauthreaux this proceedings). In general, once migrants are aloft in large numbers and weather conditions deteriorate to those of low ceiling and visibility, bird strikes at powerlines increase. Also, when favorable conditions for migration occur in the lowest stratum above the ground (even under clear skies), the number of collisions may be considerable (see Avery et al. 1977).

The time of day when collisions are most likely to occur largely depends on the activity cycles of the species. At night, powerline detectability is lower, so birds, such as waterfowl and shorebirds, moving into feeding areas at dark or after nightfall on full moon nights are particularly susceptible. Early morning and late afternoon are usually periods of elevated flight activity (e.g., roosting flights), but some raptors are active only after sufficient thermal activity has developed late in the morning. With regard to migratory activity, Gauthreaux (this proceedings) has summarized the hour-to-hour variation in the quantity of migration in species that migrate at night, during the day, or both.

The time of year is also important in assessing the probability of bird collisions with transmission lines. Courtship activities involving flight displays enhance the chances of a collision on a local scale. Similarly, the accumulations of birds during winter at places of food concentration or in areas of open water (e.g., "cooling" ponds near nuclear reactors during winter when other areas are frozen over, see Anderson 1978) strongly increase the chances of birds hitting transmission lines. The seasonality of weather conditions at a locality must also be included in this section, because low visibility weather conditions may occur at a particular time of year at a certain locality. It is rather obvious that seasonal migrations will drastically alter the probabilities of bird strikes at transmission lines on a month-to-month basis. The periods of spring and fall migrations should be of particular concern.

The group considered next the special behavioral characteristics of birds that would greatly increase their chances of colliding with transmission lines. It would appear that raptors actively pursuing prey in flight are more vulnerable to a collision with transmission lines, but factors such as size of bird, wing span, and maneuverability (erratic or straight flight) should be considered. The group agreed that when birds are pursuing prey, engaged in courtship flights, defending a territory, or escaping from a predator, they are particularly prone to collide with a powerline, because they are preoccupied and are not very alert to the hazards that transmission lines pose.

The altitude of flight is also an important behavioral characteristic that contributes to the probability of a collision. For example, blue-winged teal are more vulnerable to collision than mallards, for the latter usually fly higher. Local movements of birds are usually at lower altitudes than migratory movements. During hunting season waterfowl fly higher, but they may be startled from a lake and fly into powerlines. In migration birds fly at different altitudes depending on their size, the time of day, and their destination (see Gauthreaux this proceedings). During the day, some species usually fly over transmission lines (e.g., Canada geese, larger ducks, gulls), while others often fly under the lines (e.g., many songbirds) unless on a migratory flight. Another important aspect to be considered relates to learning and habituation. Local birds are more likely to know the location and perhaps even the danger of a particular transmission line, while transients will not be so conditioned. Birds certainly are capable of learning about the hazards associated with a transmission line. Another important point discussed by the working group concerned the closing rate and maneuverability of a species. Intuitively, it appears that those species with greater powers of maneuverability will have a reduced risk of colliding with transmission lines. Flight speed, wing loading, and other aerodynamic aspects of bird flight should be examined in terms of the species that actually hit transmission lines. Little can be said about the differential risk of powerline collision in flocking and nonflocking species, and more work is needed in this area.

The placement of transmission lines is important in assessing the risk of collision. The vertical array of wires should be minimized. If at all possible transmission lines should be kept on a single horizontal level. Thicker lines are more conspicuous, and the ground or static lines above transmission lines should be made more conspicuous or put at the level of the transmission lines, if possible. Transmission lines should be kept below the level of the forest canopy. Because forest birds have greater maneuverability in flight and fly slower than those species flying above the level of the forest canopy (e.g., ducks, raptors, doves), the former are less likely to sustain heavy powerline strikes. Powerlines should not under any circumstances be positioned just above the level of the forest canopy. Self-supporting towers present less of a hazard to birds than towers supported by guylines. In particularly hazardous areas, powerlines should be placed underground. It should be pointed out that platforms and perches on powerline towers have, under certain conditions, proved beneficial to nesting raptors (see Gilmer and Wiehe 1977).

Construction of powerlines in critical habitats where local or migratory movements are very predictable should be avoided. Such areas might include wildlife or waterfowl refuges with tremendous concentrations of bird life, shorelines, mudflats, or entrances to estuaries. Modification of habitat should be considered with caution.

Although fast growing tree rows may render powerlines less conspicuous and effectively block the flow of low flying birds, the ultimate "benefit" of such a practice should be carefully evaluated. The working group discussed a specific problem of powerline location in the Phepp's Bend area 100 miles northeast of Oak Ridge, Tennessee, where a powerline will cross a ridge. In this case the potential risk to migrating raptors along the ridge is of particular concern. Once again, it was stressed that the powerline should be kept below the level of the canopy as much as possible to minimize the risk.

Finally the group recommended that the terms *corridor* and *row* be carefully distinguished. Perhaps a term such as *impact area* that is not necessarily as large as a corridor or as small as a row should be used in addressing habitat in the powerline area. The impact area would be the area in which powerlines and towers have a behavioral or ecological effect.

The group was in general agreement that more carefully designed and quantitative studies are needed to fully evaluate the overall impact of transmission lines on various groups of birds, and that the deliberations of the working group represent but a modest and somewhat hesitant first step in that direction.

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Habitat

The habitat group considered and discussed four general topics: (1) relationships between habitats and the frequency of bird strikes, (2) use of this information in siting transmission and distribution lines (we did not discriminate between types of overhead lines), (3) research needed, and (4) general procedures for selecting the best routes for lines.

A list of more than 80 bird species that have been recorded as killed by striking utility wires was distributed (see Thompson this proceedings, Table 1). Approximately 50 percent of these species typically inhabit lakes and marshes. (Species of prairie habitats and of seashore or saltmarsh ranked second and third in this list.) Considering the preponderance of geese, ducks, pelicans, herons, etc., in this mortality and recognizing the public interest in these birds and their economic, political, and ecological importance, we discussed primarily the importance of marshes, ponds, and lakes in the bird strike problem.

The available data indicate that routing lines to avoid wetlands is desirable, and that the location of these habitats warrants special attention in any plan for power-line siting. In particular the following must be noted:

1. Corridors between two bodies of water or marshes should be avoided.
2. Corridors that intersect known flight paths of waterfowl and similar species should be avoided. To identify these flight paths, intensive studies are needed, especially of flights of local populations between feeding and resting areas or between feeding and nesting areas such as heron rookeries.
3. Corridors across estuaries, because these may be important routes for both local movements and migrations, should be located only after investigation of bird movements at all seasons.

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In addition to studies of flight paths in local areas, several other subjects were proposed for needed research. One subject was suggested by the steering committee: the width of a zone on either side of a transmission line in which birds are vulnerable. This is clearly a subject for research. However, the vital question is how important to local bird populations is mortality from wire strikes. Much more data will be needed on the mortality rates of different species in different areas if resolution of the problem is based on a cost-benefit analysis. We all appreciate the difficulty of obtaining such data, yet at the same time we believe better decisions would be made if cost-benefit analysis could be used. We suggest, for practical and political reasons, that studies of this nature be initiated on waterfowl and later extended to other species.

Another type of habitat was briefly considered: obvious topographical features. Ornithologists, especially in Europe, have studied the migrations of birds through mountain passes and have found that large numbers of many species migrate both day and night through these passes, often at very low heights above the ground. There appears to be no data on birds being killed by wire strikes at these places, but mortality seems very possible. The group suggests that studies might be made at ridges, mountain gaps, and other topographical features that tend to channel or concentrate flight paths.

As in almost all environmental problems, the essential question is how can information of all sorts, including that from wildlife biologists and ecologists, be best used to influence decisions, in particular, to choose. We are here concerned with the choice of a "best" route for a transmission line. We urge that biological and ecological input be introduced into powerline planning at the very earliest stages. In addition to the previous discussion on the habitats which should be identified for best routing, certain other areas need to be excluded categorically: national and state parks, national and state wildlife refuges, wilderness areas, critical habitats for endangered species of both plans and animals. By compiling an inventory of the various habitat types and land uses in the area under study and by categorizing them as to their use and relative importance to man and to wild species, decisionmakers should be able to balance the information to arrive at a "good" decision.

Mentioned above are some of the particular points concerning habitats and transmission lines which need to be included in this inventory and classification. A conclusion of the working group on mitigation that bird losses might be reduced by placing utility lines adjacent, and parallel, to natural barriers suggests that the location of such barriers should also be included. We would suggest also that it might be practical to computerize all this information to provide a readily accessible data base with which the desirability of various alternative routes could be evaluated.

Mitigation

The working group on mitigation began its work by examining the initial notion that powerlines can cause significant adverse effects to waterfowl, raptors, shorebirds, passerines, and threatened and endangered species. The group did not reach a consensus on this, but it did agree that local areas of potential conflict may occur in any part of the nation and that the conflict in local areas may have national interest. In other words, there is a national problem with varying local manifestations. However, *all* transmission lines at potential routes throughout the nation do not *a priori* cause conflict. The committee did think *each* of the conflicts was important, but could not or would not deal with "significance" or "nationalness." The utility members tended to downplay the importance of the conflicts. (It is not important to them.) For the conservationists and wildlife biologists, the converse is true. (It appears that a compromise statement serves no one.)

Possible conflict between powerlines and birds is of

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such importance that biologists should designate areas in which powerline impact must be studied on a site-specific basis. Because of the difficulty of this task, the geographic areas that industry engineers believe will be soonest in jeopardy should be studied first.

Specific Mitigation Practices

Using a nominal small group process, we developed a list of 17 mitigation practices:

I. Methods that simply avoid bird concentration areas in corridor selection

1. Siting
2. Upgrading the existing system
3. Removing conductors
4. Not building
5. Creating load-center generation

II. Methods that adjust the right-of-way to reduce conflict.

6. Following and being compatible with existing barriers
7. Scattering lines
8. Clustering lines

III. Methods that modify conductors and structures to reduce the probability of collision

9. Diverting birds by modifying habitat and creating alternate habitat
10. Placing lines underground
11. Increasing visibility
12. Changing conductor configuration
13. Creating shelter belts
14. Repelling birds with corona noise and predator and distress calls
15. Controlling human access
16. Changing the shape of towers

IV. Compensating for damage to bird populations

Each method was considered in terms of the following questions:

1. Is this method effective in reducing bird strikes and habitat destruction?
2. If it is effective only in special conditions, what are they?
3. What costs are involved?
4. What disadvantages are there?
5. Are we confident of the method? If not, what is needed?
6. Is it feasible and worthy of further consideration?

Consistent with our initial remarks, we caution that solutions must address specific target species. These measures apply only in cases where potential collision losses are great enough to warrant the mitigation expense. We did not address ourselves to a method for making these comparisons except to note that this problem needs much work.

In contrast to the earlier emphasis on site-specific planning, we believe that, in the area of physical alterations to transmission facilities, generic solutions are desirable. However, they should be tested for effectiveness against a reasonable variety of target species and specific localities.

Avoiding Areas of Bird Concentrations

Obviously, if the powerline avoids birds, collisions will be nonexistent. The conditions that make this option most effective include a variety of considerations. Transmission route planners need to know early in the planning phase where the significant areas are located. Areas in which there are high concentrations of birds and areas which conflict with socially important species (e.g., Ross's geese, limpkins, Kirtland's warblers) should be avoided.

We note that routing around these significant areas is easier when there are few and localized concentrations along the proposed route. There are many different and often conflicting interests pressuring route selectors. Along a proposed route in southwestern Minnesota, state and federal wildlife experts and sportsmen's groups argue that this corridor should avoid potholes, sloughs, and marshes that contain waterfowl. The marshes are surrounded by wheat farms, and farmers do not want the lines or towers either. This sort of competition from special interest groups is not unusual, and routing decisions require hard data on waterfowl concentration areas. Engineers claim that each additional mile of transmission line costs about $250,000, which is passed on to the rate payer.

Avoiding wildlife concentrations is quite feasible, but it is absolutely essential that they be positively and aggressively delineated, their locations mapped, and these maps widely circulated. Other land uses compete and longer lines cost somewhat more so line routing involves weighty decisions. Because of the complexities and uncertainties involved, utility planners were eager to discuss such options as not building the line at all.

Where a suitable line and right-of-way exist most environmental impacts can effectively be reduced. System planners routinely consider this option, as well as the no-build and load-center questions. No-build and load-center generation (many small generating facilities located close to users so virtually no lines are used) meet or guarantee peak capability better than base loads.

Upgrading has long been used when it costs less than new construction. However, upgrading sometimes costs more, reduces system reliability, and aggravates existing land-use conflicts. The no-build situation should properly be called "not build this segment" for something else will be done, at some cost, somewhere else. Load-center generation may worsen local air quality and deplete the supply of hydrocarbon fuels.

Adjusting the Right-of-Way To Reduce Collisions

Two kinds of options were considered in this category: routing to follow natural barriers and the placement of lines relative to each other.

Following Existing Natural Barriers. Generally, lines placed next to objects that birds already avoid (for example, along the bases of ridges or along highways) would reduce the probability of collision. Placing lines within a forest canopy presents both advantages and disadvantages. With higher voltages, structures rise well about 100 feet. A line protruding just above the canopy was thought to be quite dangerous to some species that move swiftly above the canopy. On the other hand, placing structures below the top of the canopy would be a hazard for forest species. In addition, the forest itself will be destroyed along the route. Adverse aesthetic consequences may also result.

Anything that lengthens a route will increase the cost and require more land. The latter aggravates the difficulties inherent in the right-of-way acquisition process. However, lengthening the route is entirely possible with today's technology.

Line Placement in Relation to Other Lines. The group discussed whether collisions can be reduced through alternate line placement. Some suggested placing new lines close to existing lines, making one big hazard rather than two small ones. Others preferred placing a new line some distance from the first to reduce the complexity and solidity of the barrier. Observations were reported to support both views. Either method is feasible, and additional expense is related only to line length. Higher voltage conductors must have more ground clearance, and systems of widely differing voltage are less compatible than systems of the same voltage.

Modifying Conductors and Structures

The group examined the following eight specific suggestions, many of which can be used on existing conductors. All assume a fixed route.

1. Modifying habitat
2. Placing conductors underground
3. Increasing wire visibility
4. Changing wire configurations in space
5. Screening lines with trees
6. Removing the static wire
7. Repelling birds
8. Preventing distractions to birds

Modifying Habitat. Theoretically, flight routes go from one resource to another. The suggestion here is that when the flight route and line route conflict, one of the attractive bird habitats can be moved to reduce the conflict. The committee reported no evidence to support or deny the usefulness of this suggestion. Members did, however, have several reservations, and it is symptomatic of our knowledge that some of the reservations conflict.

Several waterfowl biologists contended that birds fly traditional patterns and changing them would be difficult. Others noted that flight patterns change from year to year in response to both changing winds and land-use practices. Additional costs might arise from land acquisition or leasing. The suggestion contains no technical limitations.

Placing Conductors Underground. Utility engineers agreed that in situations with no great construction problems, such as shallow bedrock, distribution lines would not be prohibitively expensive to put underground. However, they felt strongly that putting higher voltage (110 kv and above) lines underground was still economically and technically impossible. Buried lines are not reliable, and in rural conditions they are difficult to maintain.

Burying lines disturbs the soil, although no comparison was made with soil disturbance caused by aboveground structures. If cooling oil leaked, soil organisms would be damaged.

Burying is feasible for distribution lines, but the costs and advantages should be carefully compared with aboveground systems.

Increasing Wire Visibility. There is no data to determine the effectiveness of various devices for increasing the visibility of conductors and other structures, but the costs are low and, in some cases, markers could be helpful. These mitigations merit further investigation. Some devices are summarized below:

1. Aircraft warning balls are already available; probably effective in clear, lighted conditions; and cause no harm in low visibility conditions. However, they may be aesthetically displeasing to humans.

2. Lighting conductors is technically difficult, aesthetically displeasing, and perhaps countereffective in poor visibility situations.
3. Reducing the size of, and brightly marking, the static wire presents no technical difficulties or change in new construction. However, these mitigations have unknown effectiveness in reducing bird strikes. Because the static wire has been implicated in many documented collisions, marking it might be helpful.
4. Coloring conductors is feasible and inexpensive. It could decrease collisions and cause no harm. Here, particularly, we find a conflict in regulatory priorities. Conductors made more visible to birds are also more visible to humans, and national tendency recently has been to reduce the aesthetic impact of conductors.
5. Strobe lights placed on towers appear to be ineffective and unsightly.

Changing Wire Configurations in Space. The evidence now available does not indicate whether any certain line height or shape decreases collisions. Bird/wire collisions might decrease if parallel conductors were at the same level.

Within rather broad technical limits, many configurations are feasible. It must be remembered, however, that more towers mean more cost.

Screening Lines with Trees. This would be effective in reducing jeopardy to species that naturally avoid trees. While many forest species are quite agile and avoid collisions, trees in open country would attract raptors and herons which are less agile.

Although this method may be feasible for distribution lines, high-voltage lines often exceed 100 feet in height. Trees of this size are not easily acquired or moved. Mass grown trees for use with distribution lines would not be expensive. The costs should be similiar to those of windbreak trees used in the plains states.

Removing the Static Wire. There is evidence showing that many birds are killed by collision with this small high wire: thus, its removal would reduce the probability of collision.

This suggestion is feasible and reduces line construction costs. However, the static wire deflects lightning strikes from the conductors. Because lightning can cause outages, this will work only in lightning-free areas.

Repelling Birds. Scare devices have considerable success when birds do not remain in the area long enough to become accustomed to, and unafraid of, them. Flocking species appear to acclimate more quickly (e.g., starlings and Canada geese). However, there is no evidence that scare devices attract or disorient birds.

Cost is quite low, and many methods such as flashers, explosions, predator models, and various noises are available.

Preventing Distractions to Birds. Data indicate that many collisions occur in conditions of good visibility when the birds are distracted by predators, hunters, or other human activities. The suggestion was made to eliminate human access to areas of bird concentration and powerlines. The difficulties lie in enforcement and land-use control. These difficulties make such isolation impossible except on refuges and other areas already controlled principally for wildlife protection purposes. Obviously, this situation applies only to bird concentration areas with existing lines; new lines should not be built in such areas.

In those cases in which the land is already regulated, costs are low. If land acquisition or easements are needed, costs will increase quickly.

Compensating for Bird Losses

A fourth strategy suggested that both habitat and individual birds are replaceable. When habitat conflicts with lines that particular habitat can be sacrificed and other similar habitat purchased. Alternatively, game farms can be built so birds can be raised to compensate for those lost to collision.

The notion seems feasible if one thinks only of those species such as mallards, which can be easily raised. In 1978, however, we simply do not know enough to raise and restore all of the more than 200 species known to be killed by powerlines. Line builders contend that the number of some species killed is insignificant and can be ignored.

Habitat replacement is limited by available similar habitat. Many of our bird concentrations today exist because all other habitat has been destroyed.

The cost for either of these programs could be inexpensive to very expensive, depending on local land prices or which species are jeopardized. There was no consensus about who should pay for compensation.

SUMMARY

Most methods suggested here simply have not been studied enough. Scientists, though personally convinced the problem is serious, are reluctant to take a stand because they lack an empirical basis for any position. Utility people, thinking of vast sums of money and equipment involved in mitigation, find little data to convince them to voluntarily change their route selection priorities.

Management Options

The group first addressed the question: What is the extent of the bird/powerline problem? The following statement summarizes most of the substantial comments: "It is the concensus of this group that powerlines have not been proven to be a general hazard to bird movements. However, there is a high likelihood that adverse impacts would occur in a limited number of cases and under certain specific circumstances. Furthermore, although significant mortality may not be proven for most individual situations, we recognize the implications of small, cumulative impacts. The best solution to avoiding signifi-

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cant individual problems and to minimizing overall adverse impacts appears to lie in early communication between powerline planners and wildlife interests. An acceptable goal would be to identify potential problems far enough in advance that needed facilities could be constructed with minimum delays and with minimum adverse impacts on bird movements."

The group's second topic of discussion was an appropriate definition of *management* in this context. The first proposed definition was one limited to the traditional wildlife management approach—i.e., the manipulation of various factors to produce a desired result. After some discussion, the definition was broadened to encompass those elements of powerline decision processes that relate to interactions with bird movements.

The management options identified by the group were, therefore, three:

1. Determine whether a potential problem exists.
2. Avoid problem areas.
3. Mitigate.

Mitigation, the subject of another working group, is recognized as being highly site and species specific. Because the mitigation and management options groups considered similar situations, we focused on *who* has responsibilities for exercising the three broad options and *when* they should do so. The table on the next page summarizes the various responsibilities, times, and options discussed.

Several portions of the discussion led to the frustrating conclusion that adequate data bases do not exist in many areas. This problem was considered by the research priorities working group.

One suggestion that deserves consideration is that permit approval might be conditional where a problem is suspected but cannot be proven. The condition would be that the line be built and monitored and that if damage is shown to occur, mitigation measures—including compensation for losses—be initiated.

The final recommendation is that a reporting system utilizing a standard form be tested by workers in industry, government, and the private sector to document bird collisions. This system, if proven workable on a small scale, could be expanded to provide a source of useful data not now available.

Management Options: Responsibilities, Priorities, and Timing

Option	Powerline Construction Phases		
	Planning	Construction	Operation
Identify potential problems	*A, B, C	A, B, C	A, B, C
Avoid problem areas	A, B, C	*A, B, C	
Mitigate	A, B, C	A, B, C	*A, B, C

*Identifies priority option at each phase.

A Identifies responsibility by *utilities* to exercise appropriate option.

B Identifies responsibility by *wildlife interests* to exercise appropriate option.

C Identifies responsibility by *licensing and regulatory authorities* to exercise appropriate option.

Research Needs

The work group on research needs considered five questions. The essence of these deliberations is provided below.

1. *What gaps of knowledge exist in determining the impact of transmission lines on migratory birds?*

It is easier to state what is known, rather than what is not known, in addressing this question. We can state with

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confidence that birds of a wide variety of species are killed by collisions with powerlines. These collisions occur in different types of habitats and at a variety of locations throughout the United States. We also know that the probability of birds' being in flight is influenced by physical factors such as weather conditions and patterns and the biological characteristics of individual species as they relate to time of year, breeding biology, and feeding behavior. Flight must also occur within the vicinty of powerlines and within an elevation range at which a collision is possible (the strike zone).

The potential strike zone has three dimensions: the length of the powerline, the vertical plane of wires (perpendicular to the ground), and the horizontal plane of wires (parallel to the ground). The vertical plane appears to be far more important than the horizontal plane. However, the latter is important when birds are flushed from below a powerline, when avian predators such as raptors are pursuing prey in flight below them or on the ground, and when birds are descending from high elevations to land.

From this knowledge we can predict the general types of conditions most likely to present the greatest probabilities for bird collisions with powerlines. For example, deteriorating weather conditions that lower the elevation of migrating birds to the strike zone and reduce the visibility of birds in flight within this zone increase the probability of collisions. Distractions to birds in flight within this zone also increase the probability for collisions. Distractions include the active pursuit of food while in flight (e.g., a raptor pursuing a prey species or an insectiverous feeder pursuing a swarm of invertebrates), courtship flights (e.g., the pursuit flight of one or more drake mallards and a hen mallard), and escape flights (e.g., the flushing of birds due to the approach of a predator, aircraft, or man).

Biological and physical characteristics of various avian species are also important in evaluating the potential for collisions in the strike zone. The large body size and wing span of eagles, cranes, and herons result in a large surface area and a higher probability for a collision with a wire than for blackbirds or teal. However, the visual acuity of the species; its speed of flight; maneuverability; and whether its flight tends to be solitary, in loose aggregations, or in dense aggregations interact with body size and wing span as do the weather conditions and distractions described above.

Species that feed their young at the nest have a greater probability for wire strikes during the nesting season than species that lead their young from the nest area at hatching, provided the feeding flights pass through the strike area. For example, herons must make numerous daily flights to provide food for both themselves and their young until the young can leave the nest, while mallards leave the nest with their broods as soon as the clutch hatches.

The physical location of powerlines relative to daily and migratory flight patterns and the familiarity of the population at risk with the location of these lines influences the probability of collisions. Resident species, or those present in an area for an extended period of time, undoubtedly learn the location of powerlines, thereby reducing their probability per flight for a collision with these lines from that of migrants passing through the area. However, a line that separates feeding areas from resting and roosting areas necessitates that local birds traverse the strike area at least twice a day.

Even though local birds may be aware of the location of powerlines, this advantage may be lost over time *because* of the frequency of travel within the strike zone. Avoidance of the lines from familiarity can also be negated by weather conditions or an escape flight, during which time the bird's attention is elsewhere.

We know that habitats for migratory birds are altered by powerlines. What we do not know is the magnitude of bird losses due to collisions with powerlines, the long-term effects of habitat alterations due to the construction of these lines, or the indirect effects on bird populations and movements that may result from the placement of a powerline at a particular site. Therefore, the biological significance of powerlines cannot be adequately assessed at this time.

It is essential to recognize that the number of birds killed is not by itself an adequate measure of biological significance. The number of individuals killed at a given location must be related to population numbers for that species at local, regional, and national levels. For example, a powerline kill of 1,000 pintails in California has far less biological significance than the loss of a single California condor or the loss of an acre of critical breeding habitat for a threatened or endangered species.

The effects of various physical factors such as visibility, size, and configuration of lines and the design and height of supporting structures are totally unknown. Also, the contributions of various biological factors such as the relative importance of collisions during migration movements versus local movements, the frequency of collisions within daily and seasonal time frames, and differences due to behavior and biology for various species are insufficiently understood to allow comprehensive evaluations. Even less is known about nonlethal effects of powerline placement: avoidance of areas by birds following the construction of powerlines, altered migrational movements, altered physiological responses due to electromagnetic fields, and habitat alterations.

None of the above should be construed to mean that bird collisions with wires or the placement of powerlines are unimportant, only that many facts remain obscure. These data must be obtained to effectively evaluate the biological effects of powerlines at site-specific locations (present or planned) and to develop mitigation against bird collisions.

The following key questions represent data gaps that deserve priority attention:

a. Where are the high risk areas?

b. What are high risk habitats?

c. What is the magnitude of bird collisions with powerlines for the various bird species over specific time periods?

d. What are the effects of powerlines on mortality, flight behavior, and local distribution of birds; what is the biological significance at local, regional, and continental levels?

e. What are the specific conditions that influence the probability of bird collisions with powerlines?

f. What standard methods are available to develop these missing data?

g. What are the relative effects of powerlines on birds in migration, on birds in local movement, and on birds in concentrations?

2. *How can these questions be addressed on a short-term basis?*

Considerable data are available to evaluate the potential for bird collisions with powerlines. These are deficiencies, however (for instance, the inadequacy of species and site-specific data for local situations). Therefore, care must be exercised when extrapolating from general to specific situations.

Bird movement and bird concentrations are of primary concern in evaluating the potential for collisions with a proposed powerline. National and regional information on bird migration patterns and corridors is available for many species. However, the more local the area, the more inadequate the information tends to be. Principal information sources are the United States Fish and Wildlife Service (Migratory Bird Habitat Laboratory and the Bird Banding Laboratory), various state conservation agencies, the Illinois Natural History Survey and others involved in radar studies of bird migration, and field guides and other publications dealing with the seasonal and geographical distribution of birds.

Bird concentrations for some species can be obtained from various surveys conducted by natural resource agencies and the National Audubon Society. Periodic bird counts by local Audubon groups, counts conducted on national wildlife refuges, and aerial surveys by federal and state conservation agencies provide local data relative to species diversity and relative abundance. These and other data sources, fully utilized, will provide a reasonable evaluation of bird populations within a proposed powerline corridor during various periods of the year.

Information on the types of birds likely to collide with powerlines can be partially obtained from a review of wildlife mortality data. Primary sources of information include diagnostic laboratory records, bird rehabilitation and rescue center records, national wildlife refuge records, field notes, and the scientific literature. United States Fish and Wildlife Service records on causes of eagle mortality represent a substantial data base that extends over a broad geographic area and spans more than 10 years. These data provide an estimate of the proportion of deaths due to collisions relative to other types of mortality in the eagles examined.

Mortality data must be interpreted with great caution due to inherent biases and variability. It is important to assess the completeness of the examinations leading to the diagnosis of mortality; to know how representative the birds examined are relative to others that died and were not examined; and, in some cases, it is important to assess the qualifications of the investigator who is determining the cause of mortality.

Despite the inadequacies of mortality data, they are valuable in evaluating the potential for bird collisions with powerlines, so long as the absence of records documenting collisions of various species is not interpreted as evidence that those species do not collide with powerlines. Biological characteristics of the species (e.g., size and coloration), habitat conditions, scavenger activities, the magnitude of search efforts to detect mortality, and the type of documentation of wildlife mortality (personal diary versus publication in the scientific literature) all influence the data base.

A better understanding of why birds collide with wires and other inanimate objects is essential to minimize the potential for such collisions. Therefore, considerable insight can be gained by examining available information on bird collisions with aircraft, radio towers, buildings, and other objects. Literature searches on these subjects will provide information relative to the circumstances involved in bird collisions and will identify site-specific locations in which long-term studies have been or are being carried out.

The effects of powerlines on migratory birds extend beyond direct mortality as a result of collisions. The influence of these lines on bird migration and behavior is poorly understood but must be considered in evaluating powerline corridors. Electromagnetic effects have been a subject of continued controversy. Review of the literature on Project Seafarer (Sanguine) and electric fields currently provides the best information on electromagnetic effects.

Animal damage studies provide another potential source of data for understanding bird/powerline interactions. The Denver Wildlife Research Center of the U.S. Fish and Wildlife Service has pioneered in the area of electric fields and electronic devices to repulse birds and animals from crops and livestock. The theoretical considerations involved in these techniques and the results of field and laboratory testing are relevant to predicting the outcome of bird/powerline interactions involving electromagnetic fields. These studies are also relevant in developing methods for repulsing birds from powerlines.

In addition to using existing data bases more advantageously, a comprehensive response to each of the seven questions outlined above should be formulated based on what is already known. Individuals from various disciplines should be involved to ensure the broad coverage needed. Publication of these findings would provide a reference manual to guide power producers, consumers, and natural resource agencies. Specific information needs regarding what is not known will become readily apparent as a result of this effort.

The development of standard methods for obtaining this information represents the next logical short-term step. This will help eliminate differences in interpretation. Part of this step should be the development of standard methods for data recording so information can be gathered at a central location for distribution to all those needing it. Once these procedures have been implemented, a wide variety of individuals can be involved to supplement data gathering.

The short-term approach, then, is to identify specific information needs, develop standard methods for obtaining and recording this information, and returning it to specific users through a central data bank. An example of how this might work involves developing better mortality data regarding bird collisions with powerlines. In this hypothetical example, a network of diagnostic laboratories specializing in wildlife are identified to assist in various mortality studies. Field investigators pick up dead birds in their areas and record a variety of data such as age of powerline, size of the line, and weather conditions during the preceding and current 24-hour periods prior to submitting this record to the appropriate diagnostic laboratory with the bird specimens. After necropsy and laboratory tests, the mortality findings are added to the form, a copy is kept by the diagnostic laboratory, a copy is returned to the field investigator, and the original is sent to a central data bank. Computer retrieval and sorting allow various approaches to the data.

3. *What long-term research needs to be initiated to evaluate the impact of transmission line corridors?*

Until information needs are more specifically defined, only general comments can be made in response to this question. A combination of field and laboratory studies will be required to evaluate why birds collide with wires, how serious the problem is, and what can be done to reduce the probability of these collisions. Field studies should focus on the highest predictable risk situations based on current knowledge. Intensive long-term (5 to 20 year) studies need to be developed to address the entire impact of powerlines on bird populations.

These studies should address successive changes in the habitat disturbed by construction of a powerline and the effects of these changes on the distribution of bird populations at a local, regional, and national level; identify changes in movement patterns as a result of powerline placement; identify differences in response patterns by different species at different times of the year; and identify differences in effects on resident and staging bird populations versus transients.

Laboratory studies should focus on providing information on why birds collide with objects. Studies of bird flight and vision are highly relevant since a greater understanding of these two basic areas will provide for potential mitigation through revised structural design of powerlines and supporting structures. Other laboratory studies need to focus on developing recording devices that will automatically record bird collisions so that better evaluations can be made relative to the seasonal and daily timing of these collisions and the number of collisions that are immediately fatal. Electromagnetic effects must be studied to determine if they result in altered physiological functions. The development of avoidance devices that can be used at high-risk locations on a continual or seasonal basis to repel birds from powerlines is another area of laboratory research needed.

4. *Who needs this knowledge, and who should fund the research?*

Private utility companies need a sound data base for selecting powerline corridors that have minimal environmental impacts and are still economically feasible. Resource agencies must have the data to prepare environmental assessments of proposed powerlines. Environmental groups and others must have access to these data to properly evaluate the environmental impact assessments and statements. Mitigation of predicted impacts also depends on this data base.

Despite the common need for these data, different orientations of these groups result in different priorities and, perhaps, different areas of responsibility. Utility companies should not expect resource agencies to provide funds or other resources for redesigning and engineering powerlines and supporting structures that may be less hazardous to birds. However, state and federal resource agencies should be primarily responsible for supporting research efforts involving bird populations, habitat changes, and bird migration. Both groups have an obligation to support research on the magnitude of bird collisions with powerlines. Basic studies on flight, vision, and avoidance mechanisms (to prevent bird strikes) have implications for many areas of science. Therefore, these studies appear appropriate for funding by the National Science Foundation and other such agencies.

5. *How should information be transmitted?*

Effective information exchange on a continuous basis is needed to reduce the costs and time involved in minimizing current information gaps. Information must be transmitted rapidly enough for investigators to take advantage of local field situations and current advances in technical knowledge. One means is the Center for Short-Lived Phenomena. Subscribers to this service are immediately sent an Event Notification Report that provides the date, location, and source of the report along with a brief description of the event. Issuance of a report is dependent upon the Center's being notified of the event. This notification system potentially provides interested investigators the opportunity for on-site data gathering.

The brevity of these Event Notification Reports dictates that other means of information exchange also be utilized. Establishment of a quarterly journal, a monthly newsletter, and an annual workshop are suitable forums for exchanging detailed information. Of the three, the workshop may be the most useful for the short-term.

Workshop Summary

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During the past 2½ days we have gathered to try to evaluate the impact of bird collisions with transmission lines on avian populations. The goals have been (1) to determine what we knew about the question, (2) to find out what results could be expected from known management techniques, and (3) to determine the areas of uncertainty and the means of understanding these areas. We have discussed many aspects of these questions and tried to resolve some of the difficulties. We have suggested short-term solutions and posed questions to establish long-term efforts to promote a more complete understanding of the subject.

Transmission lines are a source of mortality to bird populations as discussed in several papers presented at the conference. However, at this time we have not assimilated the data on the percentage of population mortality, the effects of scavengers on bird death counts, or the actual number of collisions with transmission lines.

Further studies of the effects on populations are needed if we are to understand the complete scope of this question on avian mortality. Rare or endangered species are of particular concern if any individual of such populations collides with transmission lines. The loss of a single Everglade kite or whooping crane can severely alter those populations. Most other populations produce more young than the habitat can maintain. In this case we must determine whether natural population controls are being partly taken over by transmission line collisions. These types of data are fairly easy to collect.

Every region has specific problems which require a particular type of evaluation for proposed transmission lines. Local habitat and bird behavior must be studied in each region. Planners must consider how changes in routing, tower design, and land use can reduce avian collisions in each region. Bird maneuverability, seasonal behavioral changes, flight patterns, and habitat use must be known in normal and adverse weather conditions.

It is apparent that the limited data currently synthesized is primarily on raptors and waterfowl because these are more conspicuous. Even so, their data bases are inadequate to make reliable decisions on line placement. Data on other species of birds are virtually nonexistent.

The utility companies are faced with many interest groups when proposing a transmission line. Private land owners, conservationists, and local and national governments must be satisfied in the planning and construction phases. While the aesthetics of the lines and towers dominate thinking once government regulations have been satisfied, the effect of the transmission lines on wildlife, particularly migratory birds, is not known. The initiation of studies to assist planners and engineers in placing transmission lines and designing structures that minimize the impact on migratory birds would benefit many of the interested groups that must be satisfied.

We have not yet assimilated all the data on the impact of transmission lines on avian populations. This should be our first order of business. Next, we should learn more about the techniques to evaluate flight patterns and use these techniques to provide planners with information on desirable and undesirable line locations. We should consider habitat type and suggest where habitat alteration due to transmission line siting might be managed to benefit wildlife and where critical habitat or habitat features exist that should be avoided in transmission line siting. Means of deterring birds in flight from lines and towers should be investigated. Noise, lights, and colors that are effective in different regions should be considered. Potential design changes in towers should be studied.

There is a great deal of interest in the powerline-avian mortality relationship as is indicated by the requests for attendance at this workshop. The concern, however, varies in different regions. As professionals, we have an obligation to bring together information and suggest forms of data to answer the questions. This does not mean we need to have a mass of different data collections, but we must answer basic questions to help designers and those evaluating the impact of transmission lines to make the best decisions. The question is, then, national in scope as far as data assimilation techniques and biological impact are concerned. We are not suggesting national regulations with additional steps of applications and approval when utility companies propose transmission lines. Each transmission line siting poses regional questions. Local engineers, planners, and biologists must evaluate the routing, the biological, and, ultimately, the social questions affecting local areas.

Data Base on Avian Mortality on Man-Made Structures

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A computerized data base concerning avian mortality on man-made structures is available for searching at the Ecological Sciences Information Center of the Information Center Complex, Information Division, Oak Ridge National Laboratory. It is one of four data bases sponsored by the U.S. Department of the Interior, Fish and Wildlife Service, National Power Plant Team, in Ann Arbor, Michigan.

This data base, which contains entries from the available literature, provides information on avian mortality from either collision into or electrocution on man-made structures. Primary emphasis has been placed on avian collision with obstacles such as television and radio towers, airport ceilometers, transmission lines, and cooling towers. Other structures included in the studies are fences, glass walls and windows, lighthouses, telegraph and telephone wires, buildings, monuments, smokestacks, and water towers. Collision studies involve field counts with identification of victims and field observations of both flight behavior near structures and avian attraction to lights. Studies which evaluate migration patterns by using collision data and which describe the impact of weather on migration and flight patterns have also been included. Other reports examine the causes of death and injury from impacts, report victim morphometry and physiology, evaluate species susceptibility to collision, and assess the impact of predation on study reliability. Related studies describe the impacts on birds from the siting of transmission facilities in wetlands or migratory flyways or provide recommendations for such sitings. Avian electrocution studies, which cover both electric transmission structures and electric fences, identify and assess bird fatalities, examine the activities resulting in death, identify problem locations and lethal structure designs, and recommend structural modifications to reduce fatalities. References from the data base which pertain solely to avian transmission wire strikes are found in the following paper.

Resources and services of the Ecological Sciences Information Center are available to all individuals. Searches are performed without charge to DOE staff members and to researchers working on directly related DOE-funded projects. Searches are also performed without charge at the request of the sponsor. For all others, a minimum fee of $30, which covers the charges for most searches, is assessed. Fees are billed through the National Technical Information Service, Springfield, Virginia.

Information searches may be initiated by contacting the Ecological Sciences Information Center and giving complete details of the request. Specific searches can be performed for authors, corporate author, keywords, subject categories, geographic location, taxon, and title. Mail written requests to Nancy S. Dailey or Helen Pfuderer, Ecological Sciences Information Center, Information Center Complex, Oak Ridge National Laboratory, P.O. Box X, Oak Ridge, Tennessee 37830, or telephone (615) 483-8611, Ext. 3-6173 (FTS: 850-6524). Additional assistance may be obtained by contacting Gerald Ulrikson, Information Center Complex, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830.

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A Selected Bibliography on Bird Mortality Involving Overhead Wires

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Reports on bird losses due to collisions with overhead wires date back to the 1870s; however, until recently, most of the reports were random observations containing little more than a list of the casualties. In the past several years, the body of literature on this topic has increased dramatically, perhaps partially due to an increased public awareness.

The following selected references, mostly from the 1970s, deal with bird mortality caused by overhead wires. Three papers (Fog 1970, Gunter 1956, and Hunt 1972) describe avian flight behavior in the vicinity of transmission lines, and a few reports discuss mitigative measures. The bibliographies compiled by Dailey (1978), Thompson (1977), and Weir (1976) contain numerous references on a spectrum of related topics. Several foreign reports are included to emphasize that the mortality problem is not restricted to the United States.

Copies of all references cited are available from the Ecological Sciences Information Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 37830. This list is part of an annotated bibliography, now in preparation, concerning bird mortality at all man-made structures.

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