Potential Economic and Social Value of Short-Range Forecasts of Boulder Windstorms

Abstract
Severe downslope windstorms are an outstanding feature of the winter weather in Boulder, Colo., and property damage associated with these storms averages about $1 million each year. Recently, efforts to develop a numerical model capable of forecasting downslope windstorms have yielded encouraging results. The possibility that short-term forecasts of these storms might become available on an operational basis led to a study of the societal impact of improved windstorm forecasts in the Boulder area, and this paper describes the results of that study.

Surveys were conducted of selected samples of Boulder residents and businesses concerning the potential economic and social benefits and disbenefits of improvements in downslope windstorm forecasts. The survey questions concerned five basic topics: 1) perception of the windstorm hazard; 2) the desire for improved windstorm forecasts; 3) the use of windstorm forecasts; 4) the value of improved forecasts; and 5) possible forecast dissemination techniques. Personal interviews were conducted with local businesses and public service agencies to supplement and extend the results of the surveys.

All segments of the community were found to be concerned about the windstorms because of the possibility of serious injury and/or major property damage. The responses also revealed a strong desire for improved windstorm forecasts, although the level of desire was found to depend upon the accuracy of the forecasts. Moreover, significant increases in the use of a variety of protective actions would occur if accurate (i.e., 80% accurate) windstorm forecasts were available.

The results of the surveys and interviews indicated that accurate forecasts could reduce residential property damage by approximately $200,000 annually, and the potential savings to local businesses were estimated to be an additional $150,000. These benefits appear to greatly exceed any incremental costs associated with formulating and disseminating the forecasts and any economic losses suffered by local businesses due to decreased windstorm damage. In addition, the residents expressed a willingness to support a local windstorm forecasting system if governmental funding was not available. Finally, while a completely effective procedure for alerting a significant fraction of the community to an approaching windstorm was identified, it was recognized that this problem is not unique to forecasts of downslope windstorms and requires further study.

1. Introduction
Strong downslope winds are observed in many mountainous regions of the world, including the areas of

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North America adjacent to the Rocky Mountains. In Boulder, Colo., for example, severe downslope windstorms are an outstanding feature of the winter weather (Julian and Julian, 1969; Lilly and Zipser, 1972; Brinkmann, 1973, 1974; Miller et al., 1974; Whiteman and Whiteman, 1974). These windstorms, which occur on the average of once every 2 or 3 years, are often accompanied by gusts >45 m s⁻¹. Property damage associated with such windstorms, and less intense storms that occur more frequently, averages about $1 million (in 1975 dollars) each year in the Boulder area alone. Moreover, the available evidence suggests that the amount of damage has increased in recent years, probably as a result of Boulder’s rapid growth (Brinkmann, 1974). Loss of life and injury, while surprisingly small, also occur in connection with these storms—3 people have been killed and more than 50 injured since the winter of 1964–65.

Until recently, Boulder’s windstorms have generally been considered to be chinook winds, which occur in the lee of the Rocky Mountains from Alberta to New Mexico. However, a recent study by Brinkmann (1973) has shown that these storms may be accompanied by temperature decreases as well as increases of as much as 15°C. Historically, downslope windstorms have been attributed to either rather short, quasi-periodic lee waves (e.g., Scorer and Klieforth, 1959) or hydraulic jumps (e.g., Houghton and Isaacs, 1968). However, models based upon lee wave and hydraulic jump theories have met with only limited success in reproducing the essential features of these storms. In addition, attempts have been made by the National Weather Service (NWS) to forecast Boulder’s high winds using “objective” statistical methods (Sangster, 1970, 1972, 1977). These efforts, however, have not as yet been very successful.

Recently, Klump and Lilly (1975) at NCAR formulated a theory in which downslope winds appear as surface manifestations of large-amplitude standing mountain waves. Moreover, they have extended this theory, which is closely related to the analysis of Eliassen and Palm (1960), to the development of a numerical model that simulates the significant features of these waves and the associated surface winds. The results of initial tests of this model, using real data from atmospheric soundings upwind of the Boulder area, are in good agreement with observations, and, as a result, the model appears to have at least a short-term predictive capability, with
2. Nature and design of the study

a. Economic and social value of weather forecasts: Assessment techniques

Studies of the economic and social value of weather forecasts (and, more generally, of weather information) have usually employed one or more of the following assessment techniques:

1) “back-of-the-envelope” type calculations;
2) surveys of actual and/or potential users;
3) decision-making models of user activities.

All of these techniques suffer from certain inherent deficiencies. Obviously, back-of-the-envelope type calculations can, at best, provide only very crude estimates of the benefits and costs associated with the use of weather forecasts. The other two techniques, although capable of providing more precise estimates of these impacts, have frequently been employed in a less than “optimal” manner. For example, many of the surveys have not been well designed or carefully conducted, and little effort has generally been made to select representative samples of users. Moreover, this technique necessarily depends upon the ability of individuals to assess, in an essentially intuitive manner, the impacts of weather and weather forecasts on their activities. Decision-making models ultimately offer the most promise of providing reasonably precise estimates of the relevant costs and benefits. However, the models used to date have generally been very simple and, as a result, have frequently failed to include essential features of the decision-making situations (including the fact that the users generally do not behave in a completely rational manner). Moreover, this technique is difficult to apply in contexts that involve many different decision-making situations, since each situation may require a different decision-making model.

These assessment techniques have been applied at a variety of “levels,” including:

1) the level of national and international meteorological services (e.g., WMO, 1968; Commission of the European Communities, 1972; Thompson, 1972);
2) the level of specific sectors of a national economy, such as the agricultural sector in South Africa (Theron et al., 1973) and the construction industry in the United States (Russo et al., 1965);
3) the level of particular user groups or “representative” individual users, such as the raisin industry (Kolb and Rapp, 1962; Lave, 1963);
4) the level of specific meteorological phenomena, such as hurricanes (e.g., Anderson and Burnham, 1973) and snowstorms (Howe and Cochrane, 1976).

The authors of such studies have almost invariably concluded that the benefits associated with the forecasts of concern far exceed the costs of producing them. However, as indicated previously, the available techniques can at best provide only crude estimates of the actual value of the relevant forecasts. In this regard, the above-mentioned studies have been almost exclusively concerned with the economic benefits of forecasts, and little (if any) effort has been made to quantify, or in most cases even to identify, the social impacts of such information or to evaluate the economic and social costs associated with providing and using it.

A study of the economic and social value of Boulder windstorm forecasts clearly involves many different users, both actual and potential, each of whom is faced with many different decision-making situations. In this study, then, it simply was not possible to formulate and evaluate the performance of decision-making models for the relevant set of users or even a representative subset thereof. Instead, we adopted the survey approach, which involved the formulation of a detailed questionnaire for each major user group. These questionnaires were carefully designed, representative samples of actual and/or potential users were selected at random from each group whenever possible, and the responses to the questions were obtained with the assistance of an “interviewer” in most cases.

b. The surveys: Construction of questionnaires and selection of samples

The questionnaires used in this study were designed to elicit information from selected samples of Boulder resi-
Home residents, mobile home residents, commercial establishments, and construction companies. The questionnaire for the permanent home residents is reproduced on the next four pages. The four questionnaires had the same general structure, but several questions in each questionnaire were modified, as appropriate, for that group (e.g., residents were asked to estimate their property damage during a previous windstorm season, whereas businesses were asked to estimate both property and sales losses during that period). The questionnaires were designed by the authors (with the assistance of other NCAR staff members) and were carefully reviewed by sociologists experienced in constructing questionnaires and conducting surveys.

The survey questions concerned five basic topics: 1) perception of the windstorm hazard; 2) the desire for improved windstorm forecasts; 3) the use of windstorm forecasts; 4) the value of improved forecasts; and 5) possible forecast dissemination techniques. Previous studies (e.g., Howe and Cochrane, 1976) have indicated that the value and use of weather forecasts are highly dependent upon the accuracy of the forecasts, and survey participants in this study were asked to respond to several questions at three different levels of forecast accuracy, namely, 80%, 50%, and 80%. These values were selected by the authors as reasonable estimates of the current level of windstorm forecast accuracy (30%) and of the potential levels of accuracy (50% and 80%) of the new forecasting technique being developed by NCAR scientists. The intent of requesting responses at different levels of accuracy was to measure potential benefits and costs as a function of changes in this attribute of the forecasts.  

In the traditional two-by-two contingency table frequently used to describe the performance of a set of dichotomous forecasts, accuracy is generally defined as the percentage of correct forecasts. For example, in the windstorm/no-windstorm situation, the accuracy of the forecasts would be equal to the sum of the number of windstorms and no-windstorms correctly forecast, divided by the total number of forecasts (this ratio would then be multiplied by 100). However, this definition involves an understanding of contingency tables, and it was felt that such a definition was impractical for inclusion in the questionnaires used in this study. Thus, the authors chose to present an abbreviated definition of accuracy in the questionnaires—a definition that the survey participants could easily understand and evaluate. According to this definition, accuracy was defined simply as the percentage of windstorm forecasts that subsequently verified. That is, if windstorms were forecast on 10 occasions and storms actually occurred on 3 of these occasions, then the accuracy of the forecasts would be 30% (using this definition, accuracy is equivalent to "post agreement"). However, it should be pointed out that when the participants asked questions related to the term "accuracy," the interviewer present would carefully explain its "full" and proper definition. Thus, the authors do not believe that the use of this "simplified" definition of forecast accuracy (instead of the full definition) had any appreciable impact on the responses of the participants.

Different procedures were used to select samples from the four user groups. A sample of 202 permanent homes was selected at random from the city directory (Polk, 1974), which lists the names and addresses of Boulder residents. This sample represents ~1% of the Boulder residences. A sample of 96 mobile homes was randomly chosen from local mobile home parks (the parks contained ~2500 homes). The sample of 153 commercial enterprises was randomly chosen from area listings, whereas all of the local construction companies were included in the study.

The questionnaires for the samples of residents were designed to permit completion without assistance and therefore they could have been mailed directly to the participants. However, it was recognized that surveys conducted by mail might yield biased samples, and, as a result, personal contact with each participant was considered desirable. A three-step approach was used to obtain a representative sample of responses and to assure survey participants of NCAR's sincere interest in their opinions. First, a letter of introduction was mailed or delivered to each residence explaining the purpose of the study, the importance of the resident's cooperation to the success of the project, and the confidential nature of all responses. This letter was personally addressed to the resident and signed by the director of NCAR. Second, each residence was contacted either by telephone or in person to arrange an appointment for questionnaire completion.

The third step involved the completion of the questionnaire in the presence of an "interview assistant." The participant was requested to use the cover letter attached to the questionnaire as the instructions for completing the form. At that point, the assistant would answer specific questions if so requested but would otherwise remain silent. Each assistant was well versed in the goals of the project, the basic windstorm climatology, and the purpose of each survey question. He (or she) was then capable of explaining any misunderstanding with regard to the questionnaire. As a result of these procedures, participant confusion and assistant-induced bias are believed to have been negligible. Moreover, by using this approach, return rates of 84.3% for the

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6 Hereafter, we shall frequently use the term "accurate" to refer to 80%, accurate forecasts.

7 Surveys conducted by mail may elicit a higher percentage of responses from individuals who are particularly interested in the topic of concern (in either a favorable or unfavorable sense), and these respondents may not be representative of the relevant population.
Questionnaire For Permanent Home Residents

1. Do you live within five miles of the Foothills? □ Yes □ No

2. Type of residence: □ Condominium
   □ Apartment
   □ Single family
   □ Mobile Home
   □ Other (specify) ____________________________

3. Do you own or rent your home? ____________________________

4. Location of residence: (You may check more than one area if appropriate)
   □ North of Alpine Avenue or Valmont Road
   □ East of 55th Street
   □ South of Baseline Road
   □ Near the center of town
   □ Boulder Valley Village
   □ Table Mesa area (west of Broadway)

5. Do you believe that the Boulder-area windstorms should be predicted?
   □ Yes □ No

6. What is your opinion of the accuracy of the current windstorm forecasts?
   □ Good □ Fair □ Poor

7. Please indicate your reaction to the Boulder area windstorms.
   □ Enjoy □ Indifferent □ Concerned □ Frightened

8. Do you have school age children? □ Yes □ No

9. Do you believe that public school classes should be cancelled or dis-
   missed early when a severe windstorm is forecast? Please answer for
   each level of accuracy. ("Accuracy" means that if windstorms are forecast
   on ten occasions but actually occur on eight of these occasions, the accu-
   racy of the forecasts is 80%.)

   Accuracy     Yes  No
   30%          —    —
   50%          —    —
   80%          —    —

10. Please indicate your opinion about receiving windstorm forecasts two to
    four hours in advance of the onset of a windstorm (for each indicated
    level of accuracy).

    Accuracy    Would like them    Don't care if I receive them    Don't want them
    30%          —                —                        —
    50%          —                —                        —
    80%          —                —                        —

permanent home residents and 87.8% for the mobile
home residents were obtained.

The surveys of local businesses and construction com-
panies were conducted somewhat differently. Each par-
ticipant received a mailed questionnaire that was per-
sonally addressed to the president of the company. En-
closed with the questionnaire was a letter of introduction
similar to that used in the surveys of residents. Approxi-
mately one week after the questionnaires were mailed,
the participants were contacted by telephone to en-
courage completion of the questionnaire. For these
samples, return rates of 44.5% for the commercial enter-
prises and 47.3% for the area construction companies
were obtained.

c. The interviews

To supplement and extend the results of the surveys of
local businesses, personal interviews were conducted with
the president or general manager of selected firms that
seemed particularly subject to windstorm damage. One
purpose of these interviews was to investigate, on an
informal basis, whether or not the responses to the
mailed questionnaires contained significant bias. These
results proved to be quite interesting and are presented
in Section 4.

Additional and more formal interviews were con-
ducted with various public service agencies (e.g., utilities,
mass transit) and local government entities (e.g.,
police, fire, school) to qualitatively estimate poten-
11. Would you favor being awakened at night to permit you to take protective actions against windstorm damage? (Answer for each indicated level of accuracy).

<table>
<thead>
<tr>
<th>Accuracy</th>
<th>Yes</th>
<th>No</th>
</tr>
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<tbody>
<tr>
<td>30%</td>
<td></td>
<td></td>
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<tr>
<td>50%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80%</td>
<td></td>
<td></td>
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</tbody>
</table>

12. If you answered yes to 80% accuracy in Question No. 11, please rank (i.e., 1st, 2nd, 3rd, etc.) the following potential windstorm warning methods as to how you would prefer to be awakened at night. (1 is the most desirable method; 2 is less desirable; etc.) Assume that all windstorm forecasts will be 80% accurate. Please additionally indicate any method that would be highly unacceptable to you.

<table>
<thead>
<tr>
<th>Method</th>
<th>Preference</th>
<th>Unacceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>A public address system such as police or fire department loud speakers</td>
<td></td>
<td></td>
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<tr>
<td>A prolonged telephone ring</td>
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<tr>
<td>Air raid (civil defense) sirens</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A radio or television message from a local governmental agency that you will receive at any time (even when your set is turned off)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

13. Please describe any other potential method of warning citizens at night of severe windstorms.

14. Would you make use of a telephone service that you would call to obtain the expected wind velocities for the next four hours? Answer for each of the stated levels of forecast accuracies.

<table>
<thead>
<tr>
<th>Accuracy</th>
<th>Yes</th>
<th>No</th>
</tr>
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<tbody>
<tr>
<td>30%</td>
<td></td>
<td></td>
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<tr>
<td>50%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80%</td>
<td></td>
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</tbody>
</table>

15. Please estimate how much windstorm damage to your property you received in the winter of 1972. $  

16. Please estimate the amount of windstorm damage (if any) to your property that you could have prevented in the winter of 1972 with a dependable and accurate (80%) windstorm warning period of two to four hours. $  

3. Results: Surveys of area residents

In this section, we first present the results of the surveys of the permanent and mobile home residents and then briefly compare the responses of the two groups. The discussion of these results will follow a format similar to that used to classify the questionnaire topics (see Section 2.b). In this regard, it is important to note that the responses to a particular question may provide information related to several topics. For example, the amount of money that citizens are willing to contribute toward improved forecasts (see Questionnaire, Question 20) provides both a quantitative estimate of the local funding potential and a qualitative indication of forecast desirability.

a. Permanent home residents

1) Windstorm hazard perception and desirability of improved forecasts

A majority (58.4%) of the sample of permanent home residents was concerned about the windstorms and an
17. From the following list of potential protective actions, indicate those actions you currently take as a result of windstorm forecasts only; and secondly, those actions you would take with an accurate (80%) severe windstorm forecast.

<table>
<thead>
<tr>
<th>Do you have the underlined objects: Yes</th>
<th>No</th>
<th>Action</th>
<th>Actions you currently take with existing forecasts</th>
<th>Actions you would take with an accurate forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Close draperies</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Secure loose objects in yard</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Close shutters</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Move <em>car</em> to protected area</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Tape windows</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Cover car with tarpaulin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cancel planned shopping trips or visits</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brace fences</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Reinforce incompleted construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leave work early</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Not go to work</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Not send children to school</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pick up children from school early</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leave area for short period</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leave area and go to motel</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Secure or remove awnings</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Cover windows with temporary protection</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase tiedowns on mobile homes</td>
<td></td>
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</table>

18. Please list any additional protective actions you would take with improved windstorm forecasts.

19. If the severe windstorm forecasts were 80% accurate, list any protective actions that you currently take on a routine basis and would no longer take except when windstorms are forecast.

additional 12.1% of the respondents was frightened by the storms (Question 7). Moreover, the latter figure may be conservative, since a study of the human perception of the windstorm hazard by Miller (1972) suggests that Boulder residents may attempt to minimize the perceived hazard in order to reduce their anxiety. Somewhat surprisingly, a small but significant portion of the sample (6.6%) indicated that it actually enjoys the windstorms, while the remainder (22.9%) was indifferent. With regard to forecasting the windstorms, 95.3% of the sample wanted to have the storms predicted (Question 5). Of the 4.7% who did not believe that windstorms should be predicted, most felt that they were not affected by the storms and that forecasting efforts involve an unnecessary expenditure of public funds. Others in this latter group expressed concern about heightened levels of anxiety that would result from the receipt of such forecasts.

To investigate the desirability of windstorm forecasts, the participants were asked to express their opinions about receiving such forecasts 2-4 h in advance of the onset of windstorms (Question 10). The responses indicated that desirability is strongly dependent upon the potential accuracy of the forecasts. For example, >90% of the respondents would like to receive the forecasts if they were 80% accurate, whereas <40% would like to receive them if they were only 30% accurate. The percentages of the sample that did not want to receive the forecasts were quite small (1.2% for 80% accuracy and 8.4% for 30% accuracy), and these figures were similar to the percentage of the sample that did not want to have the storms predicted.

The desirability of improved windstorm forecasts can also be assessed by examining the responses to a “willingness-to-pay” question (Question 20). Each participant was asked to indicate the annual amount in dollars that...
20. If a new forecasting system could NOT be financed from federal taxes, please indicate, for each level of forecast accuracy, the yearly amount you would be willing to contribute by means of local public financing to receive such a service.

<table>
<thead>
<tr>
<th></th>
<th>Nothing</th>
<th>$1.00</th>
<th>$2.00</th>
<th>$5.00</th>
<th>Other (please specify)</th>
</tr>
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<tbody>
<tr>
<td>30% accuracy</td>
<td></td>
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<tr>
<td>50% accuracy</td>
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<tr>
<td>80% accuracy</td>
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</table>

21. Did you move to the Boulder area before the severe windstorm of January, 1972?

☐ Yes  ☐ No

22. Comments:

he (or she) would be willing to contribute in order to receive the forecasts. The responses to this question, which are discussed in greater detail below, indicated that large voluntary contributions could be expected if significant improvements in forecast accuracy could be realized. For example, while only $0.49 (±$0.20) was offered per residence for forecasts that were 50% accurate, this amount increased dramatically to $3.77 (±$1.00) per residence for 80% accurate forecasts. If this latter figure is extrapolated to the entire city, approximately $87,500 (±$23,000) could be expected in voluntary contributions to support a forecast system. It is important to note that this amount exceeds the expected marginal costs of such a forecast system by at least a factor of two. In any case, the responses of the permanent home residents to this question indicated a strong desire for improved windstorm forecasts.

2) USE OF WINDSTORM FORECASTS

The use of windstorm forecasts ultimately determines their value. To investigate the use of improved forecasts, each participant in the survey was presented with a list of 18 potential protective actions or adjustments that could be adopted to reduce windstorm damage and/or mental anxiety (Question 17). The participants were asked to indicate which actions they currently take with existing high-wind forecasts and which actions they would take with accurate (80%) short-range forecasts. The responses to this question are summarized in Table 1, in terms of the percentages of participants taking each action for both existing and accurate forecasts. The statistical significance of the differences between these percentages was determined using a chi-square test for the differences between two correlated proportions (e.g., Wadsworth and Bryan, 1960).

The results presented in Table 1 indicate that the differences in percentages were significant at the 0.05 level (or higher) for all but 1 of the 18 proposed actions; 11 of these 17 differences were significant at the 0.001 level. Actions related to the cancellation of planned shopping trips or visits when high-winds are forecast, if taken more frequently, would presumably reduce the number of injuries and the level of anxiety, as well as prevent a significant amount of automobile damage. Moreover, it would not result in any appreciable net loss of sales or business; purchases would, for the most part, simply be delayed. In a study conducted by the City of Boulder (1970), it was found that window breakage and damage due to flying glass occurred almost as often as roof damage, the most frequent form of windstorm damage. In this regard, the results of the authors’ survey indicate that an increase of 24.7% would occur in the number of respondents who would cover their windows with temporary protective material such as

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8 The figures in parentheses represent 95% confidence intervals.

9 It is believed that the forecasting model currently being developed by NCAR scientists could be operated within the framework of the existing NWS observation and communication system. Computational resources necessary to produce model forecasts would be negligible. One version of the NCAR model would require special rawinsonde observations that would cost approximately $40,000 per year to obtain.
4.8% of the community's residents close their shutters during two severe windstorms that occurred since 1969 and by increased residential development in exposed, high-wind areas. It should be noted that these figures may underestimate the actual percentage of homes that have shutters, since it is frequently difficult and often unsafe to attempt to close them after a windstorm has begun.

With regard to other seldom used actions, only 1 person in the sample covers his automobile with a tarpaulin when high winds are forecast. However, with accurate forecasts, 11 respondents indicated that they would take this action.

The anxiety produced by the windstorms has been mentioned previously in this paper, but its existence may not be as widespread as has been suggested by other authors (e.g., Miller, 1972). Only 2 respondents admitted that they leave the area when high winds are forecast. This small number may be due in part to the perceived accuracy of current forecasts, since 11 respondents indicated that they would either leave the area for a short period or go to a motel until the high winds have subsided if accurate forecasts were available.

The survey participants were also asked to express their opinions regarding the closing of schools when a severe windstorm is forecast (Question 9). The responses indicate that 15.7%, 42.2%, and 80.7% of the sample believed that schools should close at the 30%, 50%, and 80% levels of forecast accuracy, respectively. Thus, if an 80% accurate forecast were issued, more than four-fifths of the respondents would want schools cancelled or dismissed early. For accurate forecasts, we have stratified the responses to this question according to whether the individuals live in single family units or in apartments and according to whether they do or do not have school age children. None of the differences among these stratifications was found to be statistically significant.

Finally, the participants were asked to describe any action(s) that they currently take on a routine basis that they would no longer take except when an 80% accurate windstorm forecast was issued (Question 19). These actions might include not taping windows or not closing shutters until the forecasts were actually received. Although the results of the survey did not indicate that any of these actions would be terminated, it is believed that some adjustments of this type would indeed occur after the improved forecast accuracy was demonstrated.

3) Economic value of improved windstorm forecasts

Estimating the economic value of improved windstorm forecasts to the community of Boulder is especially difficult because of the many possible protective actions that could be taken. Moreover, even after the relevant actions have been identified and an estimate of the fraction of the community that can be expected to take each action has been obtained, the reduction in windstorm damage associated with the various actions must still be determined. For example, it is necessary to decide whether, by protecting the windows of a house, the loss of the roof could have been prevented, or whether, by leaving work early, damage to an automobile could have been reduced or avoided entirely. Thus, estimates of the economic value of improved windstorm forecasts necessarily involve considerable uncertainty.

During the winter of 1971-72, Boulder experienced six damaging windstorms, one of which caused an estimated $2.5 million in insured property damage. A study of insurance company records (by the authors) revealed that approximately $1.9 million in claims was paid for damages to private property during that winter. This latter figure does not include deductibles, which amount to at least $250 000 according to the authors' estimate, or damage to business and commercial property. Moreover, if unreported and uninsured damages are also considered, property damage for the winter of 1971-72 could approach, or even exceed, $3 million.

The homeowners were first asked to estimate the amount of windstorm damage that they incurred during the winter of 1971-72 (Question 15). The sample reported a total windstorm damage for that winter of $18 694, or approximately $113 per residence. This dollar amount per residence, if extrapolated to the entire community, would yield approximately $2.6 million in total property damage for this particular winter. Since this figure includes only residential property damage and...
the $2.5 million in insured damage does not include deductible, uninsured, or unreported losses, these two estimates appear to be in reasonable agreement.

The homeowners estimated that 17.1% of the $18,694 in property damage could have been prevented with accurate 2–4 h forecasts of the windstorms (Question 16). When the community of Boulder as a whole is considered, this figure (17.1%) would amount to a $450,000 reduction in windstorm damage to private property during this period. Since severe windstorms occur, on average, approximately once every 2 years, an estimate of the expected annual savings that could result from such forecasts would be approximately $225,000. This value is undoubtedly a conservative estimate of the potential benefits, since it does not include the reductions in damage that could be realized by business and commercial enterprises. Moreover, this estimate does not take into account the fact that the amount of property damage has been increasing in recent years (see Section 1).

With regard to the reductions in damage associated with specific protective actions, we have investigated losses due to and associated with window breakage. Insurance company records suggest that approximately $45,000 in preventable glass breakage occurs each year. When this figure is adjusted to take account of the fact that only a percentage of the community would actually take the appropriate protective actions, a reduction in damage of approximately $11,000 is obtained. It should be pointed out that this figure is a conservative estimate because uninsured glass breakage was not considered and because window breakage associated with significant structural damage was considered unavoidable even with accurate short-range forecasts. A related analysis led to an estimated reduction of $9000 in interior damage resulting directly from window breakage. This approach could not be extended to include all of the possible protective actions and types of damage, but even these estimates indicate that substantial economic benefits could result from improved windstorm forecasts in the Boulder area.

Although the costs of implementing the protective actions that would yield these reductions in damage have not been quantitatively estimated, they have been identified and examined in a qualitative manner. The greatest costs to the Boulder community would arise from the additional time that the area’s citizens might devote to the implementation of these actions. This time would involve mainly the preparation of the residents’ personal property to withstand high winds (e.g., securing potential missiles, closing shutters). Although such actions require a significant number of man hours, most of these activities are already taken by residents of the community (many on a daily basis during the winter months). Consequently, the total time spent by the community in preparing for a windstorm would not be expected to increase substantially and might actually decrease after the increased accuracy of the forecasts had been demonstrated. Other costs related to improved forecasts include the purchase of materials that would be used in the implementation of the protective actions (e.g., tape for windows, plywood). Once again, the amounts of these materials used might actually decrease if the current tendency to overforecast windstorms was reduced or eliminated in the future.

4) Dissemination of windstorm forecasts

The design and implementation of an effective system for the dissemination of windstorm forecasts is, of course, a vital element in any effort to reduce property damage and personal injuries. However, since a substantial number of windstorms occur at night (Brinkmann, 1974; Whiteman and Whiteman, 1974), short-range forecasts of these windstorms would frequently first become available when a majority of the population was asleep. In this regard, the sample of Boulder residents was asked if it would favor, at least in principle, being awakened at night in order to be alerted about a possible windstorm (Question 11). The responses to this question indicated that 13.9%, 36.8%, and 63.9% favored being awakened with 50%, 50%, and 80% accurate forecasts, respectively. It is of interest to note that an appreciable number of residents (13.9%) would like to be awakened even at the present level of forecast accuracy and that this percentage increased to almost two-thirds of the sample with accurate forecasts. When the responses to this question were stratified according to the type of unit (i.e., single family or apartment) and/or according to whether or not the respondents had school age children, no significant differences were found.

It was possible for an individual to state that he/she favors being awakened at night in principle even though such an individual may find it difficult to specify a preferred method of being awakened. In this regard, the portion of the sample that favored being awakened with accurate forecasts (63.9% of the sample) was asked to rank order four possible methods of being awakened and, in addition, to indicate whether any or all of these methods were unacceptable (Question 12). Using a standard chi-square test (Wadsworth and Bryan, 1960), the prolonged telephone ring was the only method judged favorably by the sample of residents (significant at the 0.10 level). Unfortunately, this method is not technically feasible at present for the entire community, but it could be made available on a limited basis if only a relatively small number of residents participated.

Approximately 16% of the sample that wanted to be awakened at night (with accurate forecasts) objected to one or more of the proposed methods. Specifically, 18% objected to civil defense sirens and to public address systems, 16% objected to radio and television messages, and 12% objected to prolonged telephone rings. In response to a request for other possible methods (Question 13), only one suggestion was received—a neighborhood door-to-door or telephone-to-telephone alerting system.
Table 2. Sample response from mobile home residents to specific protective actions if 80% accurate windstorm forecasts were available.

<table>
<thead>
<tr>
<th>Protective Action</th>
<th>% of Sample Currently Taking Action with Existing Forecasts</th>
<th>% of Sample Who Would Take Action with Accurate Forecasts</th>
<th>Level of Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Close draperies</td>
<td>59.3</td>
<td>65.8</td>
<td>0.05</td>
</tr>
<tr>
<td>Secure loose objects in yard</td>
<td>65.8</td>
<td>72.3</td>
<td>0.05</td>
</tr>
<tr>
<td>Close shutters</td>
<td>83.7</td>
<td>100.</td>
<td>ns</td>
</tr>
<tr>
<td>Move car to protected area</td>
<td>32.0</td>
<td>41.3</td>
<td>0.01</td>
</tr>
<tr>
<td>Tape windows</td>
<td>10.0</td>
<td>21.5</td>
<td>0.05</td>
</tr>
<tr>
<td>Cover car with tarpaulin</td>
<td>6.3</td>
<td>21.5</td>
<td>0.001</td>
</tr>
<tr>
<td>Cancel planned shopping trips or visits</td>
<td>55.7</td>
<td>72.2</td>
<td>0.001</td>
</tr>
<tr>
<td>brace fences</td>
<td>4.8</td>
<td>14.3</td>
<td>ns</td>
</tr>
<tr>
<td>Leave work early</td>
<td>21.5</td>
<td>29.2</td>
<td>0.05</td>
</tr>
<tr>
<td>Not go to work</td>
<td>17.7</td>
<td>27.9</td>
<td>0.001</td>
</tr>
<tr>
<td>Not send children to school</td>
<td>77.0</td>
<td>77.0</td>
<td>ns</td>
</tr>
<tr>
<td>Pick up children from school early</td>
<td>84.6</td>
<td>92.3</td>
<td>ns</td>
</tr>
<tr>
<td>Leave area for short period</td>
<td>17.7</td>
<td>29.1</td>
<td>0.001</td>
</tr>
<tr>
<td>Leave area and go to motel</td>
<td>2.5</td>
<td>6.3</td>
<td>0.10</td>
</tr>
<tr>
<td>Secure or remove awnings</td>
<td>15.3</td>
<td>20.0</td>
<td>ns</td>
</tr>
<tr>
<td>Cover windows with temporary protection</td>
<td>11.4</td>
<td>22.8</td>
<td>0.001</td>
</tr>
<tr>
<td>Disconnect gas lines</td>
<td>3.1</td>
<td>9.2</td>
<td>0.05</td>
</tr>
<tr>
<td>Check tie-downs</td>
<td>14.5</td>
<td>23.2</td>
<td>0.05</td>
</tr>
<tr>
<td>Increase tie-downs on mobile homes</td>
<td>3.8</td>
<td>10.0</td>
<td>0.05</td>
</tr>
<tr>
<td>Secure steps to mobile homes</td>
<td>13.9</td>
<td>27.9</td>
<td>0.001</td>
</tr>
<tr>
<td>Place rocks or tires on top of your home</td>
<td>8.9</td>
<td>12.7</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Sample is defined as the number of respondents who have the item, when applicable; ns means not significant.

b. Mobile home residents

1) Windstorm hazard perception and desirability of improved forecasts

Historically, mobile homes have been particularly susceptible to windstorm damage (see footnote 5). As a result of this susceptibility, a sample of mobile home residents was surveyed separately to determine if their perception of the hazard and desire for improved forecasts were different than those of the permanent home residents. Most (55.7%) of these residents were concerned about the winds, while 32.9% expressed fear of the storms and 6.3% enjoyed the storms (5.1% were indifferent). Although more than half (55.7%) of the sample would want to receive short-term windstorm forecasts if such forecasts were 30% accurate, 88.6% would like to receive them if they were 80% accurate. It was also found that these residents perceived the current windstorm alerts to be ~40% accurate.

The mobile home residents were asked to state how much money they would be willing to contribute on an annual basis to support a windstorm forecasting system. With 30% accurate forecasts, $0.92 (+$0.35) per residence was offered, whereas if 80% accurate forecasts were available, $2.66 (+$0.54) per residence could be expected. These results indicated a strong desire for, and a high perceived value of, improved windstorm forecasts on the part of mobile home residents.

2) Use of windstorm forecasts

The mobile home residents were also presented with a list of potential protective actions against windstorm damage and asked to indicate which actions they currently take with existing forecasts and which actions they would take with accurate forecasts. Table 2 indicates that 14 protective actions would be used significantly more often with accurate forecasts (significance level 0.05). It is interesting to note that over half of the mobile home residents currently cancel their planned visits and shopping trips when a windstorm is forecast.

With regard to the closing of public schools when a severe windstorm is forecast, 35.4%, 53.2%, and 76.9% of the sample favored such closing with 30%, 50%, and 80% accurate forecasts, respectively. When the results for the 80% accurate forecasts were stratified with respect to the presence or absence of school age children, it was found that 80.3% of the nonparents favored school closing under the threat of a windstorm, whereas 53.8% of the parents favored this action.

3) Economic value of improved windstorm forecasts

During the winter of 1971–72, the sample of mobile home residents reported a total of $7211 ($91.28 per residence) in damage, of which an estimated $1500 (20.8% of the total damage) could have been prevented with improved (i.e., 80% accurate) forecasts. It should be noted that one respondent reported $3000 in damage, none of which he believed could have been prevented with accurate forecasts. Assuming ~2500 mobile homes in Boulder County in 1972 (U.S. Census, 1971), an estimated $240000 in total mobile home damage occurred during that winter. Reduction of this damage by ~20% (or by $24000 per year considering the biennial occurrence of severe windstorms) by using accurate forecasts would be a significant economic savings.

Mobile home insurance claims for windstorm damage were not available. As a result, we were unable to determine the types or total dollar amount of past windstorm damage, which in turn precluded obtaining direct estimates of damage reduction due to an increase in the use of protective actions. However, this reduction is expected to be significant and similar in proportion to that estimated for the permanent home residents.

4) Dissemination of windstorm forecasts

To investigate possible forecast dissemination techniques, the mobile home residents were asked if they would favor being awakened at night to permit them to take protective actions against approaching windstorms. Over three-fourths of the sample (77.3%) would want to be awakened if the forecasts were 80% accurate. When the responses to this question were stratified with respect to parents versus nonparents, it was found that with accurate forecasts, 74.2% of the nonparents want to be awakened as compared with 92.3% of the parents. This difference could also be due in part to some economic or other disparity between the two groups.
As in the case of the permanent home sample, the mobile home residents who wanted to be awakened at the 80% level of forecast accuracy were asked what means should be employed. None of the four proposed methods was found to be significantly favored or disfavored. Given the close proximity and relatively small number of neighbors in mobile home developments, it is somewhat surprising that a neighborhood door-to-door alerting system was not suggested.

c. Comparison of responses of permanent home and mobile home residents

The two samples of residents were found to be very similar with respect to their concern for and enjoyment of the windstorms. However, a higher proportion of the mobile home residents was frightened by the storms (32.9% versus 12.1%). They also had a stronger desire for the current short-term forecasts than did the permanent home residents. These results are indicative of the heightened anxiety of the mobile home residents and of the greater vulnerability of their homes to major windstorm damage.

Overall, the mobile and permanent home residents appeared to have similar views on the dismissal of public schools when accurate windstorm forecasts are issued. On closer examination, however, it was found that although the nonparents in both groups have similar opinions, the parents' opinions were quite different. The percentages of parents living in mobile and permanent homes that favor school dismissal are 53.8% and 78.6%, respectively. This difference may be due to the fact that mobile home parents believe that public school buildings are generally safer than their homes. Perhaps public school officials should consider allowing these students to remain in school during windstorm episodes.

The mobile home residents have a greater desire to be awakened at night in the event of an approaching windstorm than the permanent home residents. The largest difference occurs with 30% forecast accuracy, for which 13.9% of the permanent home sample and 34.2% of the mobile home sample wanted to be alerted. When the responses to this question at the 80% level of forecast accuracy were stratified with respect to parents and nonparents, no significant differences were found in the permanent home sample. However, with the mobile home residents, 74.2% of the nonparents and 92.3% of the parents were in favor of being awakened. It should be noted that this relationship may be due to factors other than the presence of school age children (e.g., property ownership).

The damage per residence reported during the winter of 1971–72 for the two groups was quite similar (i.e., $112.61 per permanent home versus $91.28 per mobile home). This similarity resulted in part from the fact that the mobile homes that were destroyed by the severe windstorm on 11 January 1972 (see Section 1) were not included in the sample. Of the damage reported, both groups believed that approximately the same amount could have been prevented with accurate short-term forecasts. A comparison of the protective actions taken by the two groups is of interest. Generally, the residents of mobile homes seem to be more concerned with implementing protective measures than the permanent home residents. For example, whereas 57.2% of the permanent home sample currently closes its shutters when a windstorm is forecast, 83.3% of the mobile home sample takes this action. With regard to leaving the area for a short time and leaving the area to go to a motel, the mobile home residents currently take these actions much more frequently than the permanent home residents and, as forecast accuracy increases, this difference becomes even greater.

4. Results: Surveys of business community

a. Commercial enterprises

1) Survey results

A sample of 153 local businesses was selected to receive a mailed questionnaire similar to those administered to area residents. By following the procedure described in Section 2, a return rate of 44.5% (68 questionnaires) was obtained. First of all, the companies were asked to indicate the number of years that they had been located in the Boulder area to determine their level of windstorm experience. It was found that only 3 had been in the area for <2 years and that 40 had operated in the area for >10 years.

Of the respondents, 64.8% believed that the windstorms directly affect the operation of their company. In addition, 19.1% felt that accurate forecasts of the severe windstorms would reduce the amount of their business by encouraging residents to stay at home. This matter is a valid concern and, in the case of certain activities (e.g., evening theater), total sales could be affected. However, in general, high-wind alerts would only involve

<table>
<thead>
<tr>
<th>Winter</th>
<th>Losses, $</th>
<th>Preventable Losses, $</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sales</td>
<td>Materials</td>
</tr>
<tr>
<td>1971–72</td>
<td>57 305</td>
<td>78 100</td>
</tr>
<tr>
<td>1972–73</td>
<td>27 455</td>
<td>63 325</td>
</tr>
<tr>
<td>1973–74</td>
<td>22 305</td>
<td>74 150</td>
</tr>
</tbody>
</table>

* Assuming 80% accurate forecasts with 2–4 h lead times were available.
postponing activities or purchases and would not significantly alter the weekly or monthly volume of business. It is also of interest to note that local businesses perceived the current forecasts to be 45% accurate, a percentage similar to that for the area's mobile home residents (see Section 3).

The sample was asked whether short-term windstorm forecasts, if disseminated by radio and television during normal working hours, would effectively reach their company. A large majority (78.5%) believed that the forecasts would or probably would be received. In this regard, only 19.1% of this sample would be willing to contribute financially to a special telephone system that would alert the subscribers to an approaching windstorm.

The willingness of company management to be awakened at night in the event of an approaching windstorm differed from that of the permanent home sample. With 80% accurate forecasts, 53.2% of the businessmen favored being awakened as compared with 63.9% of the permanent home residents. This difference, which may indicate a greater willingness on the part of business to absorb moderate amounts of windstorm damage, is consistent with the relationship between the concern for the windstorm hazard among members of the business community than was present in the mobile and permanent home communities.

2) Interviews with selected businesses

The managers (or owners) of 7 major automobile dealerships were interviewed to determine their past windstorm losses, their current protective actions, and their potential modifications to these actions as a result of improved forecasts. Based on these interviews, it was estimated that approximately $100,000 in damage per year is sustained by Boulder area automobile dealers and that ∼19% of that amount could be prevented with accurate, short-term forecasts of strong winds. Of the dealerships contacted, only 3 indicated an interest in improved windstorm forecasts. The remaining 4 dealers stated that complete insurance coverage was sufficient windstorm protection. In fact, one of these dealers considered wind damage to be beneficial. By selling the damaged automobiles at a reduced price while collecting insurance coverage for the loss, he was able to maintain his profit and substantially increase his volume of sales and service department business.

Managers of several mobile home parks were interviewed to investigate their reaction to improved windstorm forecasts. As a result of recent tie-down regulations, the managers felt that the extensive destruction that occurred in 1971–72 was unlikely to be repeated in the future. They were still concerned, however, with the less major but significant damage that results from flying debris. Accurate short-term forecasts could provide the time necessary to secure potential missiles (e.g., trash cans, children’s toys). Although the managers were unable to estimate the dollar benefit resulting from this can be more easily prevented than the damage due to extreme wind loading on structures.

Each participant was presented with a list of potential protective actions and asked to indicate which actions he currently takes on the basis of windstorm alerts and which actions he would take if 80% accurate short-term forecasts were available. Table 4 indicates that all eight protective actions would show a marked increase in use as a result of improved forecasts (significant at the 0.05 level), but the level of use of such actions would still be quite low compared to that found in the surveys of residents. In this regard, insurance coverage is often used to explain the rather modest use of protective actions. It was found that 70.6% of the commercial business sample, and 81.8% of the companies that experienced windstorm damage in 1971–72, had insurance coverage for windstorm-related damage.

The responses of the sample indicated little support for a locally funded forecasting system. Of the 68 questionnaires returned, only 7 respondents indicated a willingness to contribute (if necessary) for 80% accurate windstorm forecasts, and none was willing to contribute at the lower levels of forecast accuracy. This result and the other results of this survey seem to indicate less concern for the windstorm hazard among members of the business community than was present in the mobile and permanent home communities.

### Table 4. Sample response from local businesses to specific protective actions if 80% accurate windstorm forecasts were available.

<table>
<thead>
<tr>
<th>Protective Action</th>
<th>% of Sample</th>
<th>% of Sample</th>
<th>Level of Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tape windows</td>
<td>10.3%</td>
<td>20.6%</td>
<td>0.01</td>
</tr>
<tr>
<td>Cover windows</td>
<td>10.3%</td>
<td>16.2%</td>
<td>0.05</td>
</tr>
<tr>
<td>temporary protection</td>
<td>47.1%</td>
<td>58.8%</td>
<td>0.05</td>
</tr>
<tr>
<td>Lock west-facing doors</td>
<td>26.5%</td>
<td>33.8%</td>
<td>0.05</td>
</tr>
<tr>
<td>Secure outside materials</td>
<td>53.8%</td>
<td>82.1%</td>
<td>0.001</td>
</tr>
<tr>
<td>Move vehicles to protected area</td>
<td>20.6%</td>
<td>27.9%</td>
<td>0.05</td>
</tr>
<tr>
<td>Dismiss employees early</td>
<td>16.2%</td>
<td>25.0%</td>
<td>0.05</td>
</tr>
<tr>
<td>Not open business</td>
<td>4.4%</td>
<td>10.3%</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Sample is defined as the number of respondents who have the item, when applicable.
action, they felt that the amount involved was appreciable.

b. Construction companies

1) Survey results

In recent years and especially after the severe windstorms of 1969 and 1972, much of the residential damage has been attributed to flying missiles that reportedly originated from nearby construction sites. Moreover, partially completed construction projects are themselves highly vulnerable to the high winds. Consequently, local construction companies were surveyed to determine the nature and extent of this vulnerability, as well as the industry's desire for and potential benefit from improved forecasts. Of the 55 firms surveyed, 26 returned the questionnaire. More than half of these firms (14) employed fewer than 5 people. All have been located in the Boulder area for >2 years and, as a result, they were acutely aware of past windstorm damage. In fact, 23 of the respondents believed that the windstorms directly affect their company, and, consequently, they carried some form of windstorm insurance.

The amount of windstorm damage sustained by this group during recent windstorm seasons has been quite substantial. As can be seen in Table 5, the winter windstorms of 1971–72 were the most destructive. It should be noted, however, that building activity in the Boulder area has decreased since that time. Of the reported damage during the 1971–72 season, the sample estimated that 20.2% could have been prevented with accurate short-term forecasts. Increases in the use of protective actions that could account for this reduction in windstorm damage are indicated in Table 6. With regard to the current use of these actions, it is encouraging to note the high percentage of respondents who secure loose building materials and reinforce incomplete construction when a windstorm is forecast.

It was found that 73.1% of the company presidents favored being awakened at night if accurate forecasts were available. Additionally, even though the majority of the respondents believed that they would receive windstorm forecasts if such warnings were broadcast over radio and television, 46.2% would provide financial support for a specialized telephone alerting system that would warn them of an approaching windstorm. In response to a question concerning a locally funded windstorm forecasting system, only $121.00 was offered at the 50% level of forecast accuracy, but $1935.00 was offered at the 80% level. It is clearly evident that perceived forecast value was highly dependent upon forecast accuracy for the construction industry in the Boulder area.

2) Supplemental interviews

In addition to the survey of area construction companies, several of these firms were interviewed to investigate possible survey biases. Although the results of the informal interviews were in general agreement with the survey results, several interesting points emerged from these interviews. The survey indicated that all but 3 of the firms believed that their businesses were directly affected by the windstorms, and all respondents considered the windstorms to be a potentially dangerous and destructive phenomenon. However, during the interviews, disregard of high-wind alerts and lack of use of protective actions were found to exist. These companies stressed insurance coverage as the primary solution to the windstorm problem. Interestingly, one major contractor retains a private meteorologist to alert the company of expected high winds. Surprisingly, however, this service was apparently intended to provide a defense against damage-related lawsuits rather than a means of minimizing damage. Considering the results of the interviews and the marginal rate of return of the questionnaires, considerable bias in favor of improved windstorm forecasts may be present in the results of the survey of construction companies.

5. Results: Interviews with public service agencies and local government entities

The surveys of area residents and selected organizations in the business community were intended to quantify the economic and social impact of improved windstorm forecasts on their activities. Of course, other organizations such as public service companies and local government entities could also be affected by improved forecasts. However, a quantitative impact analysis based on the use of surveys was not appropriate for such groups. As a result, interviews were conducted with representatives of these two groups and the results of the interviews are summarized below.

The various public service companies (water, gas, electric, telephone, and bus service) expressed varying degrees of enthusiasm about the prospect of improved
Table 6. Sample response from local construction companies to specific protective actions if 80% accurate windstorm forecasts were available.

<table>
<thead>
<tr>
<th>Protective Action</th>
<th>% of Sample Currently Taking Action with Existing Forecasts</th>
<th>% of Sample Who Would Take Action with Accurate Forecasts</th>
<th>Level of Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secure loose building materials</td>
<td>88.5</td>
<td>88.5</td>
<td>ns</td>
</tr>
<tr>
<td>Move vehicles to protected area</td>
<td>50.0</td>
<td>65.4</td>
<td>0.05</td>
</tr>
<tr>
<td>Cover windows with temporary protection</td>
<td>73.0</td>
<td>65.4</td>
<td>0.001</td>
</tr>
<tr>
<td>Stop construction</td>
<td>26.9</td>
<td>50</td>
<td>0.001</td>
</tr>
<tr>
<td>Dismiss employees early</td>
<td>15.4</td>
<td>42.3</td>
<td>0.01</td>
</tr>
<tr>
<td>Reschedule daily work assignments</td>
<td>15.4</td>
<td>42.3</td>
<td>0.01</td>
</tr>
<tr>
<td>Reinforce incomplete construction</td>
<td>77.0</td>
<td>84.6</td>
<td>ns</td>
</tr>
<tr>
<td>Dismantle incomplete construction</td>
<td>3.8</td>
<td>15.4</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Sample is defined as the number of respondents who have the item, when applicable; ns means not significant.

forecasts. As might be expected, the utilities with above ground facilities would evidently experience the greatest benefit. With accurate forecasts of severe winds, work crews could be scheduled to be in areas where damage was expected (e.g., near the foothills instead of in the mountains), extra work crews could be called in, and vehicles could be moved to protected areas. All of the public service representatives wanted to receive the windstorm warnings at any hour if they were at least 80% accurate. However, some felt that these forecasts would be of only limited benefit. They all indicated a reluctance to implement emergency procedures based upon forecasts until the forecast accuracy was demonstrated over a period of years. In addition, they could not state specifically what actions would be adopted or estimate the resultant dollar benefit.

Local government offices and municipal departments that should be concerned with the windstorms (e.g., police department, fire department, municipal airport, City Manager’s Office, Office of Emergency Preparedness) were interviewed to determine their reaction to and reluctance to implement emergency procedures based on forecasts. As might be expected, the utilities with above ground facilities would evidently experience the greatest benefit. With accurate forecasts of severe winds, work crews could be scheduled to be in areas where damage was expected (e.g., near the foothills instead of in the mountains), extra work crews could be called in, and vehicles could be moved to protected areas. All of the public service representatives wanted to receive the windstorm warnings at any hour if they were at least 80% accurate. However, some felt that these forecasts would be of only limited benefit. They all indicated a reluctance to implement emergency procedures based upon forecasts until the forecast accuracy was demonstrated over a period of years. In addition, they could not state specifically what actions would be adopted or estimate the resultant dollar benefit.

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were not available. In this regard, approximately $90,000 per year in contributions was offered by local residents, and local businesses could also be expected to contribute a significant amount. Moreover, the responses to the surveys indicated that accurate windstorm forecasts could reduce residential property damage by approximately $200,000 annually, and the potential savings to local businesses was estimated to be an additional $150,000. These benefits greatly exceed any incremental costs associated with formulating and disseminating the forecasts (see footnote 9) and any economic losses suffered by local businesses due to decreased windstorm damage.

The dissemination of severe weather forecasts in general, and forecasts of downslope windstorms in particular, is a vital component in any system designed to reduce personal injuries and property damage. The results of the surveys revealed that more than two-thirds of Boulder's residents wanted to be warned about approaching windstorms, even when the warnings involved being awakened at night. However, no effective procedure of alerting a significant fraction of the community was identified. The problem of effectively disseminating timely warnings of severe weather is, of course, not unique to forecasts of downslope windstorms and requires further study.

In conclusion, the results of this study indicate that improved windstorm forecasts would be of significant economic and social benefit to the Boulder community. In addition, other communities along the Front Range in Colorado could be expected to realize similar benefits from such forecasts. Efforts to develop procedures capable of formulating and disseminating these forecasts in an effective and timely manner should be given high priority.

Note added in proof: During the week of 30 November 1977, Boulder experienced three windstorms in which gusts near or above 45 m s⁻¹ were recorded. One particular storm caused widespread property damage, power outages, and multiple-car accidents on the Boulder-Denver Turnpike. Initial estimates of insured property losses exceeded $15 million. One death and serious injury to at least 14 individuals were attributed to these windstorms.

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Meetings of interest

13–16 March 1978: A Workshop on the GATE Convective Disturbances of 2 September 1974 will be held at the University of Wisconsin in Madison. This workshop will assemble and synthesize material for an NCAR Technical Report on the 2 September case study analysis. Contact: Dr. Catherine Gautier, Coordinator, Université du Quebec (INRS), Rimouski, Quebec.

20–22 March 1978: A Conference on Carbonaceous Particles in the Atmosphere will be held at the Lawrence Berkeley Laboratory, Berkeley, Calif. The purpose of the conference is to provide a forum for reviewing current research on atmospheric particulate carbonaceous matter. Topics to be discussed include three areas: chemistry and chemical properties; physical properties; and biological, physiological, and toxicological effects of particulate carbon. The conference is being sponsored by the National Science Foundation through its Research Applied to National Needs (RANN) program and the Lawrence Berkeley Lab. Contact: T. Novakov, Bldg. 73, Lawrence Berkeley Lab., University of California, Berkeley, Calif. 94720 (tel: 415-843-2740, ext. 5319).

May 1978: (no dates available) The 13th International Colloquium on Polluted Atmospheres will be held in Paris, sponsored by the National Institute for Applied Chemical Research. Contact: M. Benarie, National Institute for Applied Chemical Research, B. P. No. 1, 91710 Vert-le-Petit, France.

Deadlines Calendar

Requests for proposals

1 Mar. 1978 NCAR Field Observing Facility (October 1977 BULLETIN, p. 1076)

Fellowships grants, etc.

15 Mar. 1978 U.S./India exchange grants (December 1977 BULLETIN, p. 1296)

15 July 1978 Macelwane Annual Award (this issue, p. 73)

15 July 1978 Hanks and Orville Scholarships (this issue, p. 73)

Call for papers—Abstracts due

1 Mar. 1978 Solar-terrestrial prediction workshop (this issue, p. 17)