emerging problems in the management of atmospheric resources: the role of social science research

W. R. Derrick Sewell
Department of Economics
University of Victoria
Victoria, British Columbia

Abstract

The emergence of three major problems has given rise to growing public concern about the atmosphere and an increasing desire to manage it like other natural resources. These problems relate to the mounting volume of air pollution, the rising toll of losses due to extreme weather events, and man's increasing ability to modify the weather. Such problems have brought into sharp focus the fact that our knowledge of the human impact of atmospheric variations is still quite limited, and has emphasized the need for a considerable acceleration in research relating to the economic, social, institutional, and ecological aspects of the management of atmospheric resources. This article outlines types of research that are most urgently required in this connection and offers suggestions as to possible means of stimulating an expansion in the present research effort in this field.

Introduction

One of the most conspicuous features of American life is the desire to ascend the ladder of social status. This phenomenon and the means by which it is attained have occupied the interest of many sociologists and writers.[1] Unfortunately, those who have studied the subject so far have totally ignored the fact that other elements of the environment are status seekers too. One of the best examples is natural resources. Today there is increasingly fierce competition between them for recognition, particularly because recognition brings with it substantial rewards. Those resources that stand at the top of the social totem pole get far more attention in public debate and much more money spent on them than those at the bottom. The ultimate goal of any self-respecting natural resource, therefore, is membership in the Society of Elite Resources. Resources such as forests, agricultural land, fish, and water resources have long been members of this select group. They monopolize debate about resources in the Congress and they carve out the major share of funds allocated for resource development.

Election to membership of this august body is not easily attained, and in fact it is becoming increasingly difficult to get in. At one time just about any resource that applied for membership was accepted. Today, however, some very rigorous tests must be passed.

The first requirement is that the resource be scarce relative to the demand for it: that is, it must have emerged from the status of being a free good and people must be willing to pay a price for its use. Second it must possess a considerable potential for conflict creation. The greater the number of conflicts and the greater the number of interests involved, the greater the prospects for entering the Society of Elite Resources.

The third criterion is that it must have a distinctive oedipus complex: that is, it must like to be mothered, particularly by a considerate federal government agency. A fourth is that it must provide opportunities for public investment, for without this the resource in question might remain merely a regulated resource rather than a publicly developed resource. The latter attract much more public attention than the former and are therefore more likely to be considered for membership of the elite group.

Finally the resource must offer opportunities for the application of technology, preferably on as large a scale as possible, for this is one of the ways in which attention can be drawn both to the importance of the resource and to those who manage it. Among the most popular symbols of social status among resources are concrete dams, complicated

[1] The best known of these, of course, is Vance Packard. See Vance Packard, *The Status Seekers*, New York, David MacKay Co. Inc., 1959.

electronic devices, and expensive mechanical equipment. Resources which are unable to provide a challenge for the technologist seem to be doomed to remain at the bottom of the social ladder!

Do atmospheric resources qualify for membership of the elite?

Thus far atmospheric resources have been amongst the most frustrated of all resources. While these resources have been said to be "one of the most vital assets available to man," they have yet to be admitted to the ranks of the elite natural resources. In many ways this is surprising, for they seem to conform to almost all of the criteria that are needed for membership.

1. Resource scarcity

Although atmospheric resources are in general very abundant, there are a growing number of instances where real scarcities are beginning to appear. One of the most obvious is the scarcity of clean air in cities. A revolt against pollution in North America shows that people are willing to pay a price for good quality air. Congress apparently approves of this revolt and has already agreed to the expenditure of at least 150 million dollars as an initial step in the campaign to deal with the revolting situation. In addition, in some instances the right kind of weather has become a scarce commodity. Lack of precipitation, or threat of hailstorms or lightning, has stimulated experimentation and development of techniques for modifying the weather. Farmers, electric power utilities, water utilities, forest companies and ski resorts have engaged commercial weather modification firms to alter natural weather patterns for them. They have backed their faith in the ability of such firms to produce the desired results by paying them many thousands of dollars in fees and retainers.

2. Conflict creation

The atmosphere also seems to qualify for membership under the second criterion, conflict creation. In fact there are probably few resources that have greater potentialities in this connection. It is a dynamic resource, changing constantly in composition and in geographical location. Because any given change in the weather may benefit some people at the expense of others, there are likely to be conflicts, either in the same area as the modification was made or further downwind. Court cases have already arisen in which claims for damages have been brought against those who have attempted to modify the weather. Some States have tried to minimize such conflicts by banning weather modification within their boundaries, or by laying claim to the atmospheric resources above their territory. Needless to say the various States try to help each other out in this connection. Already signs are being erected at the Virginia border which say "Let's keep Maryland dry!" [2]

Legal restrictions on weather modification in individual States, of course, can only be partially effective. If commercial firms wish to operate in Texas, for example, and are permitted to do so, there is nothing that Oklahoma can do about it.[3] Nor are there any restrictions on inadvertent weather modifications, such as through air pollution or jet contrails.

3. Oedipus complex

Atmospheric resources appear to meet the third criterion too. Like those resources already elected to membership of the Elite Society, they like to be managed and mothered. Already several federal government agencies have recognized this desire and have offered their services for baby-sitting and foster care. Currently the principal agency in charge of screening applications for adoption, the U. S. Congress, is still trying to decide which of the various applicants would make the best mother.[4] If the Weather Modification Act of 1967 becomes law the atmosphere is likely to have a large family looking after it, with its principal home being located in ESSA and with uncles and aunts in the De-

---

[2] In a more serious vein, Maryland has enacted legislation barring weather modification activities in that State for a two year period.

[3] Problems of regulating weather modification activity are discussed in Howard J. Taubenfeld, *Weather Modification: Law, Controls, Operations,* Washington, D. C., National Science Foundation, 1966.

[4] See, for example, U. S. Senate Committee on Commerce, *Hearings on Weather Modification,* Washington, D. C., U. S. Government Printing Office, 1966; and U. S. Senate Committee on Interior and Insular Affairs, Subcommittee on Irrigation and Reclamation, *Hearings on a Program for Increasing Precipitation in the Colorado River Basin by Artificial Means,* Washington, D. C., U. S. Government Printing Office, 1964. See also U. S. Senate Committee on Commerce, *Weather Modification and Control,* Washington, D. C., U. S. Government Printing Office, 1966.

partments of the Interior, Agriculture, HEW and Defense, as well as in the FAA and in NSF. Other interested relatives will be given an opportunity to offer advice on the nurturing of the resource through the Interdepartmental Committee on Atmospheric Sciences (ICAS), and other such family get-togethers as seem desirable.

Although the atmosphere should feel flattered at such a plethora of attention being foisted upon it, there are some inherent dangers in such diversity of management responsibility. One particular danger is that unless responsibilities are clearly defined, there will *either* a) be inaction because no one wants the responsibility or because the agency assumed to have the responsibility does not know how to handle it, *or* b) there will be endless squabbles between agencies because they *all* feel it is *their* responsibility!

4. Public investment

As a further qualification, the atmosphere appears to offer expanding opportunities for the investment of public funds. But these opportunities have hardly been tapped so far. The federal government currently spends only half a billion dollars a year on programs relating to the atmospheric sciences and meteorological devices.[5] This is a small sum compared with expenditures on other natural resources, such as agricultural lands, forests, fisheries, and water resources. Annual federal appropriations for land and water resources in the United States, for example, amount to over $2 billion. The amount of money spent on research in the atmospheric sciences is even more minute when compared with funds devoted to research on other resources, including those on which we are likely to have little or no dependence for many many years to come, such as those of outer space. The Space Program is allocated some $3 billion a year for research, but only $200 million is allocated to atmospheric science research.[6]

5. Changing views of man's command over the atmosphere

The small amount of money spent on developing atmospheric resources is partly a reflection of the traditional view that weather and climate must be taken as given, and that nothing can be done about them. Claims about augmentation of precipitation or about any kind of alteration in the atmosphere have always been regarded with considerable skepticism by scientists and by others as well. In recent years, however, some dramatic changes in viewpoint seem to have occurred. Advances in knowledge about the mechanism of the atmosphere, coupled with the development and application of more sophisticated techniques of statistical analysis, have made possible a more scientific approach to weather modification. Gradually the potentialities for the application of scientific technology to the management of atmospheric resources are beginning to be accepted by professionals and laymen alike.

Why hasn't the atmosphere joined the elite?

Although the atmosphere seems to have met most of the criteria for membership in the Society of Elite Resources, the Society does not yet appear to have opened its doors to this potential new member. What has been holding it back? The missing element seems to have been a *crisis*. The Society's Board of Directors seems to have been unaware of the fact that atmospheric problems have become important problems and that the public is beginning to demand that something be done about them. The storm clouds of crisis, however, seem to be gathering. First, as noted earlier, there is growing concern about the mounting volume of air pollution across the nation. People are beginning to demand purer air to breathe and a reduction in the health hazards and property losses which arise from such pollution.[7] The hunt is on for the culprits and the government now has a mandate to take corrective actions, which only ten years ago would have been opposed (or at least not supported) by the public at large, let alone the culprits, who of course were let alone! Second, there is concern about the huge losses of property and income which result from extreme weather events such as hurricanes, tornadoes, heavy snow, lightning, hail and heavy precipitation. Each year severe weather events in the United States cause an estimated $1.5 billion in property losses alone, as well as major losses of income, and sometimes large losses of life too.

---

[5] During fiscal year 1965 the federal government spent just over $431 million on atmospheric sciences and meteorological operations and services. See U. S. Committee on Government Operations, *Government Weather Programs*, Washington, D. C., U. S. Government Printing Office, 1965, p. 20.

[6] *Ibid.*

[7] The problems of pollution in the United States are outlined in National Academy of Sciences-National Research Council, *Waste Management and Control*, Washington, D. C., 1966.

A third cause of concern is man's increasing ability to manipulate the atmosphere. While it is clear that weather modification may bring substantial benefits to those who ordered the modification to be undertaken, it may also result in losses for others. Since atmospheric resources are common property resources, the question immediately arises as to the circumstances under which one man (or group of men) should be allowed to alter a jointly owned resource. It is a matter which involves not only legal considerations but also economic, social and political factors, and perhaps ethical ones as well. Decisions will need to be made as to whether alteration of the weather should be permitted, and if so when and where should it be done.

1. Should we do it, when should we do it, and how far should we go?

The question of whether we should do it has already been answered. Weather modification is becoming an established fact in North America. Attempts have been made to alter the weather in almost every State of the Union. The 1966 National Science Foundation Report on Weather Modification notes that some 46 commercial operators had projects covering over 100,000 square miles in the United States in that year.[8] There were many projects in Canada too. Commercial operations and various types of weather modification experiments were undertaken last year in 30 States of this country. In general those who have hired commercial weather modification firms seem to have been fairly well satisfied with the results and the indications are that such activity will continue to expand substantially in the years ahead.

It is also evident that several federal government agencies are convinced that there must be something to all this talk about successful weather modification, and they have decided to embark upon programs of research and development themselves. The Department of the Interior, appropriately enough is trying it in the interior,[9] while the Department of Commerce and the Department of Defense are said to be up to something elsewhere![10] For years people have been trying to find out what is going on in the Interior, but now the Interior has begun to be concerned with what's going on outside! The Department of Agriculture has been much slower in getting things off the ground but is now working with lightning in an effort to catch up.[11] Other federal agencies are accelerating their research programs too.[12]

2. When should we do it?

The enthusiasm for weather modification stems from several sources. First, it may provide a means of augmenting critical inputs into the productive process, such as rainfall in agriculture. This is perhaps the main rationale for the Bureau of Reclamation's program. Second, it may help to reduce losses in certain activities such as forestry, airline operations, or the construction industry. This accounts for the Department of Forestry program for reducing lightning-caused forest fires and for the United Airlines' program for dispersing cold fog at airports. Losses from certain types of storms are enormous, especially tornadoes and hurricanes.[13] Research on severe storm suppression would clearly have a very large payoff if it were successful. The Navy and ESSA are pursuing such studies with this in mind.

---

[8] National Science Foundation, *Weather Modification: 8th Annual Report,* Washington, D. C., U. S. Government Printing Office, 1967.

[9] The U. S. Bureau of Reclamation's programs of research and development relating to precipitation augmentation in the upper reaches of the Colorado River and in the northern Great Plains region. For a description of these programs see U. S. Senate Committee on Commerce, *Weather Modification and Control, op. cit.,* pp. 122–127.

[10] The ESSA-U. S. Navy project Stormfury is concerned with the investigation of mechanisms of hurricane formation and possibilities of controlling such storms. ESSA is also undertaking research relating to hail suppression. *Ibid.,* pp. 98–102.

[11] The U. S. Department of Agriculture, Forest Service has been experimenting with the control of lightning, a major cause of forest fires in the U. S. Most of the work in this connection has been undertaken through Project Skyfire. The Department is also conducting research relating to hail suppression, and the modification of atmospheric processes by alterations in vegetative cover. *Ibid.,* pp. 95–98.

[12] Programs of the U. S. Department of Defense (Army, Air Force, and Navy), NASA, and the National Science Foundation are concerned with a wide variety of types of weather modification, including precipitation augmentation, cold fog and warm fog dispersal, and modification of major storms. *Ibid.,* pp. 102–132.

[13] Losses in the United States from hurricanes have been estimated by ESSA at over $250 million a year. More than 15,000 people have been killed in this country since 1900 by such storms. Tornadoes are estimated to cause damages in excess of $200 million a year.

3. How far should we go?

There is clearly considerable enthusiasm for weather modification in the United States. But before we let this enthusiasm run away with us we should pause for a moment and ask ourselves the question: supposing the scientists and the technologists do succeed in developing highly efficient means for modifying the weather, what would the implications be? This question was one to which the National Science Foundation-sponsored Special Commission on Weather Modification gave considerable attention.[14] It was aided in its deliberations by a National Science Foundation-sponsored Symposium on the Economic and Social Aspects of Weather Modification, held in Boulder, Colo., in 1965.[15] It has also been explored by several Congressional Committees.[16] Each of these bodies has concluded that while the gains from weather modification may be large, it does not necessarily follow that everyone will benefit, and in certain cases it is possible that some individuals may suffer losses. There seems to be general agreement that weather modification should be controlled and that losers should be compensated. Debate continues, however, as to what mechanisms should be used for controlling weather modification and what principles should be applied in determining compensation. All the bodies that have studied the problems of the expansion of weather modification activity have stressed the need for an accelerated program of research on these matters.

Towards this end the National Center for Atmospheric Research established a Task Group on the Human Dimensions of the Atmosphere in April 1966, under a grant from the National Science Foundation. Composed of 13 members, it included representatives from economics, geography, sociology, political science, law, ecology, and meteorology.* Its assignment was to determine the areas of research most urgently required to answer the questions posed by the increasing use and modification of the atmosphere. The Task Group completed its work in June 1967 and its Final Report is due to be published shortly by the National Science Foundation.

Problems raised by man's increasing use and modification of the atmosphere

Seven major questions are raised by man's increasing use and modification of the atmosphere.

a) Do the benefits exceed the costs?
b) What is the potential impact on biological systems?
c) Does everyone favor weather modification?
d) Should the losers be compensated?
e) Are present legal theories adequate?
f) What types of control are required?
g) What role should the government play?

a) Benefits and costs

It is apparent from the rapid spread of weather modification in the United States during the past 20 years that those who wish to modify the weather perceive important benefits from this activity. It is also evident from the increasing number of Court cases that major losses are also perceived from certain types of modification.[17] Identifying the benefits and costs of the use of, or modification of, atmospheric resources, however, is not an easy matter.[18] It requires in the first place the identification of activities that are affected directly or indirectly by weather changes, and an analysis of the manner in which a given change results in gains or losses to such activities. It requires in the second place a comparison of the costs of supplying the benefits claimed for weather modification with the costs of achieving the same objective by some alternative means.

---

[14] National Science Foundation, Special Commission on Weather Modification. *Weather and Climate Modification*, Washington, D. C., 1966.

[15] Papers presented at the Symposium appear in W. R. Derrick Sewell (Ed.), *Human Dimensions of Weather Modification*. Chicago, University of Chicago Department of Geography Research Series No. 105, 1966.

[16] See, for example, U. S. Senate Committee on Commerce, *op. cit.*, and U. S. Senate Committee on Interior and Insular Affairs, *op. cit.*

* Members of the Task Group are listed on p. 331.

[17] See Howard J. Taubenfeld, *op. cit.*

[18] For discussions of problems of identifying and measuring benefits and costs of weather modification, see Ivars Gutmanis and Lester Goldner, "Evaluation of Benefit-Cost Analysis as Applied to Weather and Climate Modification," in W. R. Derrick Sewell, *op. cit.*, pp. 111–126; and Emery N. Castle and Herbert H. Stoevener, "The Economic Evaluation of Weather Modification with Particular Reference to Agriculture," in W. R. Derrick Sewell, *op. cit.*, pp. 141–158.

TABLE 1.

Task Group on Human Dimensions of the Atmosphere.

Prof. Charles F. Cooper School of Natural Resources University of Michigan Ann Arbor, Mich.	Prof. Fremont J. Lyden Graduate School of Public Affairs University of Washington Seattle, Wash.
Prof. James A. Crutchfield Department of Economics University of Washington Seattle, Wash.	Prof. Dean Mann Department of Political Science University of California Santa Barbara, Calif.
Prof. J. Eugene Haas Department of Sociology Ohio State University Columbus, Ohio	Prof. Vincent Ostrom Department of Political Science University of Indiana Bloomington, Ind.
Prof. Maynard Hufschmidt Dept. of City & Regional Planning University of North Carolina Chapel Hill, N. C.	Prof. W. R. D. Sewell (Chairman) Dept. of Economics & Political Science University of Victoria Victoria, B. C.
Prof. Ralph Johnson School of Law University of Washington Seattle, Wash.	Prof. Stephen C. Smith Department of Economics Colorado State University Fort Collins, Colo.
Dr. Paul Julian National Center for Atmospheric Research Boulder, Colo.	Prof. Howard Taubenfeld School of Law Southern Methodist University Dallas, Tex.
Prof. Robert W. Kates Department of Geography Clark University Worcester, Mass.	

Thus far, attempts to identify benefits and costs of weather modification have been very crude and have generally been confined to activities for which the modification was undertaken. Most of the estimates of impacts undertaken to date have been prepared by commercial cloud seeding firms usually in the form of a prospectus, attempting to assess the value of the weather change to the client. Seldom is any attempt made to identify and measure effects on other activities. Generally alternatives to weather modification are not examined. In the case of precipitation augmentation, for example, alternatives might be the development of drought resistant crops, crop insurance, or location of production in some other area. Studies of such alternatives are very seldom, if ever, undertaken.

b) Ecological impacts

A second problem is that of ecological impacts. Lack of moisture is the principal factor limiting the biological productivity of much of the Earth. Added precipitation in water-short regions will doubtless increase yields of food and fiber from forests, rangelands, and cultivated croplands. Some observers have suggested that precipitation augmentation may provide a solution to the world's number one problem—production of food for the world's burgeoning population. A major change in the weather, however, may also alter the balance among plant and animal species, with attendant sharp declines in the numbers of some plants and animals and growth in abundance of others. In particular it may result in the rapid spread of certain weeds and pests and vector-borne diseases.[19] Thus far very little attention has been paid to the long run ecological consequences in the formulation of schemes of weather modification. Several federal agencies now have major programs of research aiming to determine possibilities of alter-

[19] See Daniel A. Livingstone, "Biological Aspects of Weather Modification," *Bulletin of the Ecological Society of America,* March 1966.

ing the weather. Unfortunately, little or no money is allocated in these programs to determine the potential ecological consequences.

c) Public acceptance of weather modification

Weather modification is welcomed with great enthusiasm by some but bitterly opposed by others. In some areas of the country experimentation and commercial operations have gone on for years without opposition. Elsewhere such activity has aroused vocal and sometimes violent opposition. In many parts of the Great Plains weather modification is welcomed with open arms. In some parts of the eastern United States, however, weather modification has aroused major public outcries, notably in Pennsylvania. Differences in public acceptance of weather modification occurs in Canada too. In Quebec a couple of years ago the publicly owned electric power utility, Hydro Quebec, hired a firm of cloud seeders to increase precipitation over the utility's watersheds in eastern Quebec. The operations were so successful that it rained non-stop for three weeks! So irate did the local residents become that they threatened to assassinate the Cabinet Minister responsible for hiring the cloud seeders unless he saw to it that the rain was stopped. Happily it stopped the next day.[20]

The reasons for differential public acceptance of weather modification are not well understood, and little research has been done to discover them. Instead, attempts to modify the weather generally proceed on the assumption that most people will not know whether the weather has been modified, and even if they do, they will not care anyway. René Levesque, former Minister of Natural Resources in Quebec, would soon remind them that this assumption may be very naive!

Although public acceptance of weather modification is clearly a critical factor, present research programs of federal agencies do not concern themselves with it. This may be a reflection of the fact that such agencies feel that they know what the public wants and they believe they know how the public will react when they get it. Often this is a valid assumption, but sometimes it is not. Failure of farmers to adopt certain federally sponsored farm improvement programs, the continual growth of flood losses despite massive expenditures on flood control, and the expansion of pollution despite the enactment of regulations, indicate that our ability to predict human responses to public policies in resources management is still quite limited.[21] Research in this connection could have one of the highest payoffs of all research in the resources field.

d) Compensation of losers

The fact that there are gainers and losers from weather modification activity gives rise to a fourth question. What provisions are there for compensating those who lose? Thus far the approach has been for those who feel they have suffered a loss from the attempts of others to modify the weather to take the matter to the Courts. Inability to prove that a change in the weather had in fact taken place has resulted in no judgments being made about compensation. It seems, however, that as techniques of modification become more efficient, claims as to losses will be much more difficult to reject. The need for principles upon which to base compensation will therefore become even more urgent.

e) Adequacy of present legal theories

Questions have been raised also about the adequacy of traditional legal theories of liability to deal with problems raised by human use and modification of the atmosphere. Conclusions of the legal experts on the Task Group suggest that present legal theories may be inappropriate to handle such problems and that new principles are needed to deal with them, and in particular the problems that are likely to emerge from conflicts between individuals, between States, and between nations resulting from weather modification.

f) Types of control required

It is clear that as weather modification activity continues to expand an increasing degree of control over operations will be required. The question arises, however, as to what types of control are needed and which levels of government should impose them. Is licensing of operations sufficient or should there also be a requirement to furnish information as to results? Should control be located in the hands of local, state or federal

[20] See James Quig, 1965: René Levesque and the internal machines. *Weekend Magazine*, **15**, No. 32, 1–6.

[21] See Gilbert F. White, 1966: Formation and role of public attitudes. *Environmental Quality in a Growing Economy*, Baltimore, Md., Johns Hopkins Press, 105–127.

authorities? Should the federal government, for example, be responsible for controlling those attempts to modify the weather that might result in effects on more than one state or on other countries, and leave other attempts to be controlled by state, and/or local authorities? Who should decide whether or not an attempt should be made to alter the track of a major storm? A hurricane, for example, might be headed for a major urban area, with a population of perhaps 2 million people. It might be possible to divert this storm and so reduce potential losses of life and property in that area. But this might be accomplished only at the expense of turning the storm towards another area where losses might be smaller but nevertheless real.[22] Such decisions are too important to be left to any one individual or to even one agency. It may be that once we have found the technological capability for managing major storms we will have to make some really radical institutional innovations. Perhaps we will need to set up a Fifth Estate, composed of individuals who will be delegated responsibility to make decisions about technological changes that involve *any* chances of human disaster.

g) *The role of the government*

Another question relates to the role that the government might most appropriately play in the management of atmosphere resources. Should this role be confined to the collection and dissemination of information or should it be extended to the regulation of weather modification activity, or perhaps even further to actual participation in development? Are there peculiar characteristics of atmospheric resources and their management that call for government participation in development in the same way that certain characteristics of water resources call for such participation? In the case of water resources the existence of externalities and the demand for certain public goods (such as flood control, recreation facilities, and public water supplies) leads to public intervention and participation in development. Some of these features are also present in the case of atmospheric resources. It seems inevitable, therefore, that the government will be called upon to play an increasingly active role in managing and developing these resources.

Priorities for research

Given the problems that are emerging from the increasing use of the atmosphere as a means of waste disposal, from the mounting losses from severe weather events, and from man's growing capacity to modify the weather, what are the types of research that are most urgently needed to deal with these problems? And what must be done to ensure that the research is in fact undertaken?

It is beyond the scope of this paper to detail all the types of studies that should be undertaken in connection with these problem areas. This matter is dealt with at length in the forthcoming report of the Task Group on the Human Dimensions of the Atmosphere. However, some illustrations of needed studies are noted in Table 2. Even this list is a long one. Its length underlines the magnitude of the task on the one hand, and emphasizes how little has been done so far on the other. Research on the human dimensions of the use and modification of the atmosphere has been extremely limited. Expenditures in this connection have increased somewhat in the past few years but the overall total is probably still well below $100,000 a year. This contrasts with the $200 million or so spent annually on research on physical science aspects of atmospheric resources. It should be clear from the foregoing discussion that a major acceleration of investment in social science research on the use of modification of atmospheric resources is needed *now*. Unless this happens we can only expect the crisis-sponsored approach that has characterized the management of most of our other natural resources. And there is no need to emphasize how inefficient and costly that has sometimes been! Here is a rare opportunity in resources management to plan *before* the event rather than react *after* the crisis! Research is of course the essential ingredient in such planning.

Getting the research done

There is clearly a need to expand the present research effort relating to the human use and modification of the atmosphere. How much more money should be spent in the latter connection, however, is difficult to estimate. A useful guideline might be to allocate

[22] For discussions of various aspects of this problem see Robert L. Hendrick and Don G. Friedman, "Potential Impacts of Storm Modification on the Insurance Industry," in W. R. Derrick Sewell, *op. cit.*, pp. 227–248; and Edward A. Morris, "Institutional Adjustment to an Emerging Technology: Legal Aspects of Weather Modification," in W. R. Derrick Sewell, *op. cit.*, pp. 279–288.

TABLE 2. Selected problems of managing atmospheric resources, and related research.

Problem	Related research
A. What is the impact of weather on various economic activities?	1. Development of techniques to identify and measure impacts of weather on various economic activities. e.g. use of input-output analysis, simulation techniques, linear programming, etc. 2. Empirical studies of various economic activities to determine their sensitivity to changes in various weather elements. 3. Empirical studies of various regions to determine their sensitivity to changes in various weather elements. 4. Development of weather sensitivity indices for various activities and various regions. 5. Development of an "ideal weather" model to assess value or cost of given weather changes on the economy. 6. Studies to determine the relative importance of climate in locational decisions, as in the migration to the South, the Southwest, and the West of the U. S.
B. Which of the various possible responses to weather variations is the economically most efficient?	1. Development of techniques for weighing the gains and costs of various alternative responses to the weather—for example, accepting it as given and taking no action, insulating against weather changes, re-scheduling activities, moving away from or towards weather events, or trying to alter the weather—such as benefit cost analysis, or cost effectiveness techniques. 2. Comparisons of relative efficiency of various responses in given activities. e.g. is it more efficient to develop draught resistant crops than to establish crop insurance, or to grow the crops in less arid regions? 3. Comparisons of relative efficiency of various responses in given regions, taking into account the secondary gains and losses as well as the direct ones. e.g. is it more efficient for a region to concentrate on one combination of weather-sensitive activities than another, given the overall gains and losses involved?
C. What is the impact of changes in different weather elements on various biological systems?	1. Review of currently available data relating to the effects of weather on existing plant and animal communities, seeking to establish hypotheses to be tested in later studies. 2. In depth field and laboratory studies of effects on specific organisms of changes in moisture, temperature, and other environmental variables. 3. Field studies to monitor effects of weather modification projects on plant and animal communities in given regions.
D. What factors condition decisions relating to human response to weather and climate?	1. Studies to determine how people perceive the weather and the alternative adjustments to it. 2. Studies to determine the influence of attitudes on decisions relating to adjustment to the weather. e.g. differential responses to attempts to modify the weather. 3. Studies to determine how people use weather information. e.g.—how do people respond to forecasts of various probabilities of precipitation? —do managers of different types of activities respond in different ways to the same information? 4. Studies to determine the influence of various factors—such as habit, legal and administrative constraints, and economic considerations—in actual decisions relating to adjustment to the weather.
E. What is the appropriate mix of public and private enterprise in the management of atmospheric resource?	1. Studies of adaptability of existing agencies to undertake functions relating to the management of atmospheric resources. e.g. the potential effectiveness of present water resources agencies in managing atmospheric resources. 2. Studies of the probable effectiveness of each of the various levels of government in controlling human use, and modification of the atmosphere. 3. Studies of the problem of allocating the common property resource of the atmosphere among competing users.

TABLE 2.—(Continued)

Problem	Related Research
F. What mechanisms are available for compensating those who suffer losses from the use of modification of atmospheric resources?	1. Studies of alternative arrangements for compensating those who suffer losses from the use or modification of the weather, such as insurance schemes, compulsory fees or user charges.
G. Are the principles underlying present laws adequate to deal with problems emerging from increased use and modification of the atmosphere?	1. Studies to determine whether and the extent to which court centered common law system is appropriate to the management of atmospheric resources. 2. Studies to determine what types of laws and administrative arrangements are required to resolve conflicts between users of atmospheric resources such as interstate compacts and international treaties and agreements.

5% of all funds devoted to atmospheric research to the study of the human dimensions. If this were the case, then some $10 million would be available for research on the latter problems. In view of the present scarcity of researchers ready, willing, and able to undertake the needed studies, however, it would seem prudent to build up the funding gradually to the proposed level. If only 1% of the present funding for research in the atmospheric sciences was released for social science and natural science research, some $2 million would be made available. At the moment there are just not enough social scientists ready, willing, and able to undertake a research effort of that magnitude in the field of atmospheric resources!

Merely making the funds available, therefore, is not enough. Theoretically at least, funds have been available for research on human dimensions of the atmosphere for several years. Several factors, however, have accounted for the fact that they have not been used. First, very few social scientists have been interested in atmospheric problems. Problems relating to the management of other resources, such as forests, fisheries, agricultural lands, and water resources have appeared to be much more urgent and much more challenging. Second, there has been a somewhat more positive attitude in the participating agencies concerned with problems of agriculture and forests, and more recently, fisheries and water resources, that economic and social dimensions should be studied. Many of the agencies involved in managing these resources have actively sought social science research talent to get studies done either on an "in house" basis or by financing research programs at universities and elsewhere. Thus far, however, there has been a general reluctance on the part of those agencies concerned with the management of atmospheric resources to undertake, or sponsor, social science research. ESSA, for example, employs some 10,000 people. Of these, it seems, only about 10 are professional economists. It undertakes or sponsors research amounting to over $10 million a year, yet spends only a few thousand dollars on studies relating to economic, social, ecological, and institutional aspects of the management and use of the atmosphere. Similar comments could be made about most other federal agencies that have responsibilities for the management of atmospheric resources.

It is in the field of weather modification, however, that the need for research and the human dimensions of atmospheric resources is especially urgently required. One of the principal recommendations of the Orville Committee in 1957 was that the National Science Foundation be given the responsibility to "initiate and support research in the needed fields, and to coordinate research projects." So far the NSF has funded research relating to the physical possibilities of modifying the weather amounting to about $12 million. In contrast, funds spent on research relating to the human dimensions of the problem have amounted to little more than $300,000. Most of this incidentally has been spent on studies undertaken in conjunction with, or following from, the Special Commission on Weather Modification. Other federal agencies that have embarked upon weather modification investigations have generally neglected the human dimensions of the problem in their research programs.

Various explanations have been offered for this state of affairs. In the case of the National Science Foundation, for example, the responsibility to initiate research seemed to be alien to its traditional image. It has tried to "encourage" applications, therefore,

rather than to actively *solicit* them. In an era when research talent is so scarce and there are many other challenging topics, it is perhaps not surprising that so few applications have been made to the Foundation for funds for studies of the human dimensions of weather modification. Another problem may have been that because the weather modification program of the Foundation was located in the Atmospheric Sciences Section, few, if any, social scientists have been aware that funds were available for studies of human dimensions of such problems. Whatever the explanation, it is clear that a basic change in approach is needed if the studies noted earlier are to be done. The National Science Foundation must take a much more active role in encouraging social science research on weather modification and must make the necessary funds available for it.

The problem of communication is a very real one. Although the reports of the National Academy of Sciences Panel on Weather Modification and of the Special Commission on Weather Modification were widely distributed, very few social scientists have read them or know of the recommendations relating to economic and sociological research. It is evident that publishing of reports is not enough. Additional means must be found to make potential researchers aware of the importance of particular problems.

Not only should the National Science Foundation make a major effort to actively encourage research on atmospheric problems in the social sciences, but the various operating agencies should increase their efforts in this connection too. The latter might be urged, for example, to devote a much larger portion of their weather modification research budgets to studies of human and biological aspects of such modification. Some of these agencies have already begun to step up research on this latter dimension but the effort is still puny compared with what is needed.

Formation of a new group of elite resources

In summary it seems that atmospheric resources are ready to enter the society of Elite Resources. They have already met most of the criteria which other members of this group had to meet. A new group of elite resources, however, is just about to be formed and only those resources which can conform to the most rigorous criterion of all, cost effectiveness, will be allowed to enter. Some of those resources which have long enjoyed a position of high social standing will not be able to meet this criterion and will topple from the pinnacle of the totem pole. It behooves those who would like to see atmospheric resources in the elite group, therefore, to develop the technical capability to ensure that programs for managing these resources can meet the new criterion of membership. And it is only through vastly increased programs of social science research that the actual and potential effectiveness of atmospheric resource management policies can be determined.