MANAGEMENT OF SNOW PACK BY WEATHER MODIFICATION

By

Wallace E. Howell
E. Bollay Associates, Inc.
Subsidiary of EG&G, Inc.
Bedford, Massachusetts

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INTRODUCTION

The subject matter of this paper implies change. The management of snow pack by weather modification is not now an accepted practice. It is unimaginable that the power to augment the snow pack by cloud seeding, once it is broadly percieved, will lie unused. It is being used beneficially in some areas in the west, and the day will inevitably come when its use here in the east will be commonplace. Between now and that day lies the long and uncertain course of technological innovation. This course is by its nature one of aggression against the status quo.

In the dawn of civilization, the water resources engineer was junior partner to the magician in charge of weather, a subject much too important to leave to a mere engineer. It was the prerogative of the king, whose duty it was to produce precipitation by the proper propitiation of the powers of earth or heaven who governed the primeval sources of moisture and life. He had one infallible rule: it always rains at the end of every drought. If the drought persisted, this was taken as evidence that the priest had lost his powers, and the approved procedure was to sacrifice him to make way for a more favored practitioner. There was, perhaps, some advantage to being a mere engineer.

However, the effectiveness of the water engineer's professional services have multiplied and re-multiplied through thousands of years in direct ratio to his success at separating the delivery and use of water from its origin in the sky. It has been his task, and his victory, to take the highly capricious product of the priest's magic (read alternatively "the will of heaven" or "the climatological probability") and make of it the well-mannered and dependable servant that the modern citizen has come to take for granted. The path that led to the present ascendancy of water resources engineering turned resolutely away from tom-foolery in the sky and instead turned toward material means of impounding and channeling the water. Consequently, we now have a large, highly trained, highly competent professional body of men who know how to erect the largest man-made structures on earth but who know -- as a body -- nothing at all about precipitation control. This is what we might call a base line for measuring progress in the course of technological innovation toward artificial management of snow pack.

CHANGES IN ACCEPTANCE OF WEATHER MODIFICATION

The first stage of this innovation begins when weather modification is perceived as something useful enough to be worth trying; or, to turn the terms around a bit, a bet one cannot afford to pass up. A brief review will show some rapid changes here. In 1957, when the President's Advisory Committee on Weather Control found that cloud seeding had increased the snow pack on orographic watersheds in winter by about 15 percent, and recommended governmental programs in both basic and applied research, the scientific community was not ready to concede the validity of the increases nor the appropriateness of applied research. Alan Waterman, Director of the National Science Foundation, testified that "no large or important effects will be produced by present means until further basic research has led to great improvements in our understanding of this process. -- It would seem to us wise not to attempt to embark upon any program having as its aim the development of a means of weather modification with practical results ---." Francis Reichelderfer, Chief of the Weather Bureau, Stated "A new research approach to the problems of weather modification is necessary to determine what is fact and what is fancy." Paul Klopsteg, Associate Director of the National Science Foundation, wrote, "We must be under no illusions that modification of clouds to achieve specific, planned results, can be accomplished in our present state of knowledge. Even with every resource that we can intelligently apply to the problem, its solution is not in sight."

As a consequence, government sponsorship of applied research was set aside until the Department of the Interior, which had previously stood aside as having no institutional interest in meteorology, in 1963 initiated a program with the ultimate view of stimulating snow pack in the Colorado River Basin, and obtained funds from Congress for this purpose. Concern expressed in professional circles that such a move toward application was still premature and siphoned away funds needed for basic research culminated in publication of a report by a panel of the National Academy of Sciences (NAS Publication 1236, November 1964) which concluded that the techniques of weather modification then available were ineffectual for precipitation stimulation and compared the commercial application of them to the practice of astrology, inveighing against applied research until such time as basic research should have come up with entirely new bases for practice. This was essentially the way things stood just three years ago.

But there have been some changes. The NAS Panel was persuaded by the reaction to its 1964 report to re-study the matter and in particular to undertake its own evaluation of the results of a number of commercial weather mdofication operations. Two years ago, in January 1966, it released a greatly revised report that noted "increasing but still somewhat ambiguous statistical evidence that precipitation from some types of cloud and storm systems can be modestly increased or redistributed by seeding techniques" and recommended that planning be started immediately on a number of major field investigations, including establishment of several carefully designed, randomized seeding experiments, planned in such a way as to permit assessment of the seedability of a variety of storm types. Testifying on a Senate bill to implement these recommendations, Leland Haworth, who succeeded Waterman as Director of the National Science Foundation, said, "it is now time for enhanced Federal support of applied research and engineering development aimed toward economically beneficial operation in several areas of weather modification." In the same session of Congress, the Department of the Interior won greatly expanded support for its newly-established Office of Atmospheric Water Resources.

In its quadrennial report, published in 1967, the Cloud Physics Committee of the American Geophysical Union took cognizance of some dozen papers published subsequent to the preparation of the NAS report that tend to reinforce the conclusions of the latter, including a carefully randomized and controlled experiment coming out of the Weather Bureau-Navy Project Stormfury documenting unambiguously the growth of cumulus clouds due to seeding.

The wind has got kind of thick with straws. In October, 1967, the Israeli government announced that its program of precipitation stimulation, carried out for the past several years on an experimental basis, has now been placed on a regular operational status. Writing in the British publication Science J ournal in August 1967, E. G. Bowen stated, "Cloud seeding experiments carried out in the past ten years have shown conclusively that clouds can be induced to release their water. This technique is now being exploited in Australia, in some cases very profitably." Patrick Hurley, reporting the program plans of Project Skywater, the name given to the Department of the Interior's snow-pack augmentation program in the Colorado River Basin, told the American Society of Civil Engineers in October 1967 that this plan aims at obtaining a fifteen percent increase in snowpack over selected target areas situated generally at elevations above 9500 feet, yielding an average additional runoff of nearly 2 million acre feet annually, at an expected cost in the vicinity of $2.5 millions annually, with direct benefits estimated at $20 to $25 millions per year.

No longer are the West-Coast utilities that have been seeding the clouds for the past fifteen years and more regarded as such dupes; in fact, the prior rights they contend they have established in the atmosphere may prove to have some value. The perception is rapidly gaining strength that we are now possessed of a technology valid for useful application to snowpack augmentation, seasoned by nearly twenty years of real though belatedly-recognized success. To be sure, today's technology will look primitive in comparison with what we may expect to achieve in the future, but it is serviceable.

THE ROAD AHEAD

Despite this change in official attitudes, one cannot characterize the present situation as one when the use of weather modification for snow pack management is proliferating. Though we have reached the point where we can confidently predict that proliferation will occur, and that weather modification will in the course of time take its place along with other techniques of water resources management, it is not yet possible to say how soon the proliferation will begin nor how fast it will progress. At each stage we are reminded that change is aggression, and the way of the aggressor is not smooth. Three themes need to be brought into consonance: The validation of techniques for bringing about particular modifications; the validation of modifications for meeting particular needs; and the validation of the practice in the context of an open society.

In the validation of techniques, recent changes have brought us face to face with a new complex of problems. Behind us is the question, does precipitation stimulation work, yes or no. We are at work now on the questions when, where, how, and why it works, and what techniques are best suited to what weather situations and what specific modifications. And progress is being reported. From work near Climax, Colorado, Lewis Grant at Colorado State University has reported a significant

distinction between relatively cold storms, the ones where the temperature at precipitation-producing altitudes is colder than -25C, in which cloud seeding appears to diminish the already scanty precipitation, and the warmer and generally more productive storms characterized by temperatures between -12C and 120C, in which precipitation increases of fifty percent and more are indicated following seeding. Schleusener (South Dakota School of Mines) presented preliminary results of a Skywater-sponsored program of randomized seeding of summer cumulus near the Black Hills showing a significant effect on storms moving from the southwest but indeterminate results on those from a northwesterly direction. In another Skywater study, I and my co-workers have addressed the problem of evaluating the effect of seeding on individual storms, so that grounds may be found for investigating the "seedability" of given storms in terms of their synoptic characteristics, and in stochastic trials have been able to effect correct sorting between seedable and unseedable storms in three out of every four trials. The list is longer than the time available here for presenting it.

The second theme is validation of modifications for particular needs. Quite simply stated, is the augmentation of snow pack by cloud seeding an advantageous way of increasing the available water resources, or would the effort be better spent on an increase in storage capacity, development of additional watershed area, diversion from an adjacent watershed, or other of the traditional approaches that has regarded precipitation as beyond control? Here, a case-by-case study is implied, and the most favorable solution is in general a mix of techniques. To what extent snowfall stimulation may become a prominent element in that mix may be foreshadowed by the following example.

New York City's demand for water is relatively inflexible; the economic and social consequences of water shortage are not the less severe for being so thinly spread that they perhaps fall not too heavily on most individuals. It is therefore necessary to maintain the capability of furnishing adequate water in even an extraordinarily dry year, even though this may represent two or three times the capacity adequate for an average year and the difference represents a large investment that is unproductive most of the time. As demand grows, the capacity of the system must be increased. A ten percent increase in developed watershed area in the Catskills would cost in excess of $100 millions and would yield additional water at a marginal cost in the neighborhood of 15¢ per thousand cubic feet, according to estimates by the Department of Water Supply, Gas and Electricity. Yet a ten percent increase in precipitation achieved during the critically dry years would be the complete operational equivalent of a ten percent increase in developed watershed area; the cost would be in the vicinity of 1¢ for each thousand cubic feet of additional water, with virtually no additional capital expenditure and with operating expenses incurred only during critical periods.

There is a real question where the initiative for proliferation is going to come from. Traditionally, the role of exploring and exploiting new technologies has been the realm of private enterprise, with government furnishing encouragement and regulation where necessary. Weather modification in a fuller state of development will come to bear the same relationship to cloud physics as we know it today that the aviation industry bears to the science of aerodynamics. Except for a small minority of venturesome companies, however, the initiative for exploitation of weather modification has gone by default to the federal government. Will it remain there?

This brings up the third theme: validation: validation of the practice of weather modification in the context of an open society. Weather is a common resource; it cannot be sequestered for the use of any one interest. Its use for one purpose cannot disregard effects other than those intended. The problem looks complex but it is not without the possibilities for simplification. Consumptive use of the atmosphere is, after all, an established practice, as is the use of eminent domain to acquire facilities needed for public purposes; and the problems of weather modification may be looked upon as variants of these in both the private and the public sectors.

Likewise the problem of interference between weather modification and individual impacts on elements of the public becomes less intractible when viewed in the light of practical experience. Weather modification in its present form is capable only of effects smaller than normal day-to-day changes in the weather. We cope successfully on the whole, with these day-to-day changes and the strategies by which we cope with them are not strained in dealing with the modifications we can now accomplish or those contemplated in the foreseeable future. Also, in the practical sense, the purposeful use of weather modification will coincide with the mitigation of extreme conditions, those that present the greatest hazard to the public, and not with their aggravation. In principle, therefore, it seems likely to be recognized that there is nothing inherently wrong with modifying the weather for a particular purpose, even a private one, so long as aggravation of an extreme condition is not involved and so long as the right of individuals to recover for specific damages caused by the modification is preserved. Liability insurance appears quite capable of dealing with the latter problem.

Nevertheless, the fact remains that our technological progress is far more rapid at the present time than our progress toward incorporation of the actual use of weather modification into an accepted legal, economic, and social structuring. The most important problems now facing us in the task of technological innovation, of actually putting weather modification to work in the management of snow pack, lie outside the realm of the physical sciences, in the fascinating and kaleidoscopic field of human relationships.