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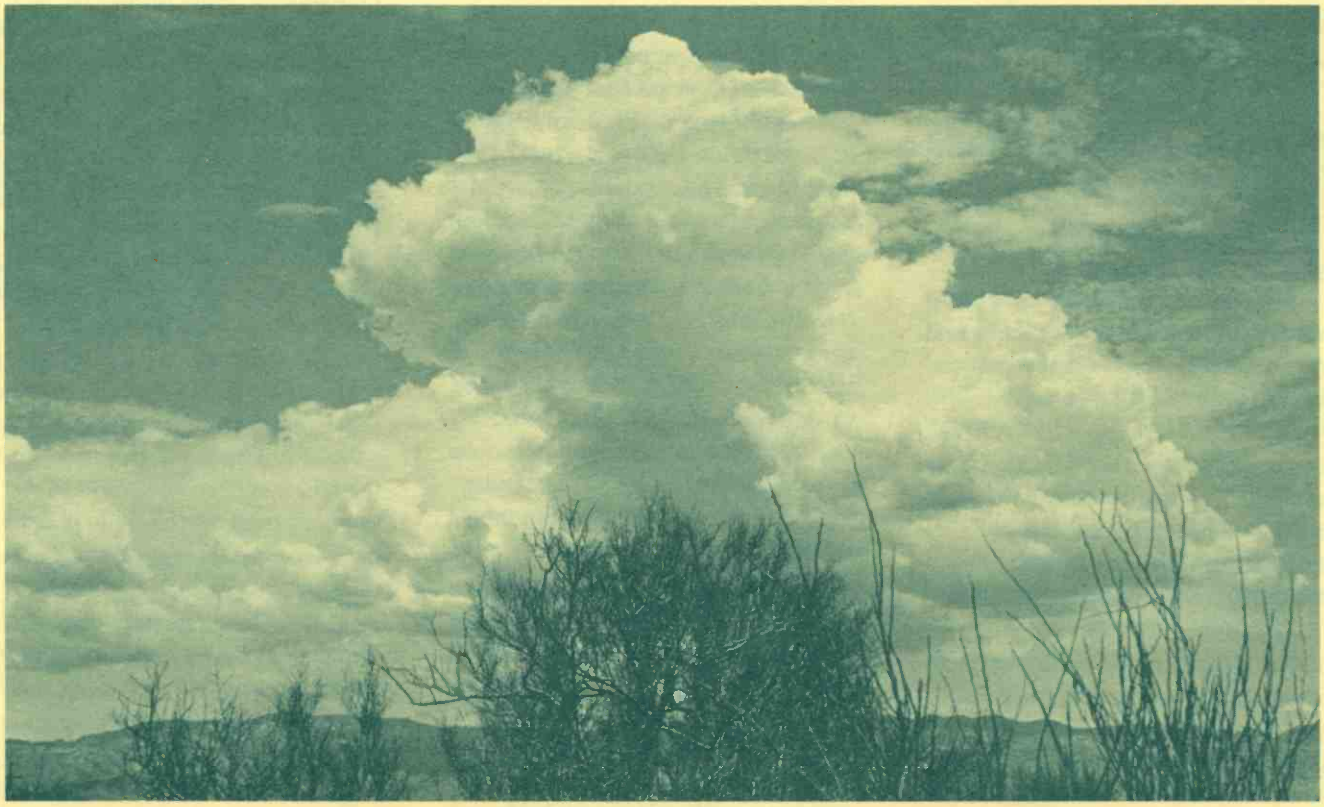

Beautiful and varied, clouds are seen as possible sources of additional water resources. (Photo: UA Graphics)

Weather Modification, a Water Resource Strategy to be Researched, Tested Before Tried

by Joe Gelt

When Loren McIntyre, South American traveler and explorer, asked a Mayoruna Indian where the source of the Amazon River was located, the Indian pointed skyward to the clouds. Advocates of weather modification likewise look to the clouds as a source of water to augment current supplies.

Weather modification has a rather unique status among water resource issues. Along with attracting attention as a potential water supply source, weather modification is of interest because of its varied and changing status in the scientific and public policy communities; it has an aura of controversy. Because of this, weather modification represents an interesting history of an idea in the study of water affairs.

Arizona's interest in weather modification evolved over time, from

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early cloud seeding experimentation to the adoption of sophisticated computer modelling techniques that simulate climatological phenomenon and test weather modification premises. The evolution reflects a change in attitudes, from an optimistic expectation of immediate results to a more cautious, even skeptical regard about the potential of weather modification. State officials today view weather modification as a research topic and have no plans for direct application of cloud seeding.

Mixed Responses to Weather Modification

In some ways, weather modification or precipitation enhancement remains an idea whose time has not yet come. It has always had its advocates, but widespread acceptance has not followed for a variety of reasons. Even its supporters generally agree that weather modification has a public image problem. When explaining this cautious, wary attitude, analysts point to various scientific, socio-economic, and political factors.

Some scientists and water resource managers are wary because they believe that weather modification research conducted thus far shows inconclusive results. They seek additional scientific investigations to demonstrate quantitatively the benefits of cloud seeding. These people represent the jury that is still out.

Others are wary of weather modification because it goes against the grain of a certain ecological ethic. It represents an interference with a natural process, with results possibly difficult to predict and control. Man as geologic force built dams and controlled the course of powerful rivers, upsetting along the way ecological balances and causing environmental harm. What then might man as an atmospheric force accomplish?

Some advocates claim that by failing to take a leadership role in weather modification, the federal government is partly responsible for its lack of recognition. For example, they point out that the federal government has not defined a national weather modification policy. Such a policy arguably might help interpret the societal benefits of weather modification and its role in promoting the national interest. Further, it is argued that an established national policy would help determine the research and development needs of weather modification and provide valuable support for funding efforts.

Possibly because it involves high-in-the-sky cloud work, weather modification has at times connoted an airy, unreal pursuit or quest. Not helping its image were the names given to early experiments, titles that conveyed fanciful, futuristic and high-tech images, more to do with the stuff of science fiction than serious scientific work. For example, a U.S. Forest Service 1950s research project to reduce forest fires by decreasing lightening was designated Project Skyfire, and a 1960s U.S. Weather Bureau effort to modify hurricane clouds to mitigate winds was called Project Stormfury.

But regardless of what the projects were called, early advocates of weather modification often promised more than could be delivered. During the early years of weather modification work in the 1950s and 1960s, the shift from research to actual application was too rapid. This premature action was not consistent with the careful evolution of a body of knowledge and the maturing of recognized scientific principles. This created weather modification credibility problems.

Others remain fully convinced that weather modification holds great promise to augment water resources. They believe its premise is sound and scientific findings promising. They believe its potential will be realized with more research and the eventual application of cloud seeding activities.

How Weather Modification Works

Seeds are generally planted in the ground. Cloud seeding therefore conveys an earthy, agricultural image of natural growth and development, a maturing toward a timely harvesting of precipitation. The process, of course, is more atmospheric than agricultural. Wind pushes moist air over rising terrain such as occurs in mountainous regions of the West. Rising, the moist air enters the colder, higher elevation temperatures. Water droplets are then formed through condensation, and orographic clouds result.

The clouds consist of small droplets that, despite below-freezing temperatures, remain liquid. The water's purity and the lack of foreign particles in the atmosphere prevent the droplets from freezing. They are called "supercooled droplets," and they form supercooled clouds. As temperatures decrease the droplets form ice crystals around small atmospheric particles such as dust.

Cloud seeding introduces additional particles or nuclei into the atmosphere, causing more ice crystals to form. Silver iodide compounds or dry ice are the usual cloud seeding agents. Aircraft or ground-based generators introduce the agents into the atmosphere. The ice particles grow and attract nearby water vapor and droplets. The enlarged ice particles eventually fall as snow.

Cloud seeding experiments originally involved mostly cumulus clouds, the most common, widely distributed cloud form and the world's most important precipitation source. The short life span and instability of such clouds complicate seeding operations. Orographic clouds, which form over mountainous areas, are better for seeding because they last longer, and weather modification experiments can be more readily arranged.

Orographic clouds are the source of both rain and snow. In the mid-latitudes nearly all precipitation begins as snow. If it is much warmer than freezing below the cloud base the snow melts and reaches the ground as rain. Freezing temperatures are required for crystallization to occur with the seeding material or agent. As a result, snow is the expected result of cloud seeding.

Arizona Conditions and Weather Modification

The West provides conditions favorable to weather modification efforts. Its mountainous terrain is generally conducive to the forming of orographic clouds. Also, the West is an area of water scarcity, with the dependable flows of its natural streams usually appropriated. Thus natural conditions and water supply needs suggest western suitability for weather modification activities.

The most obvious benefit that would derive from successful cloud seeding is increased water supplies. In its perennial search for water resources, the West has dammed, diverted, marketed, conserved, stored, managed, and reclaimed its water. Options are narrowing, especially in the face of government reluctance to appropriate large sums of money for extensive water projects. Almost all existing resources have been accounted for, except what may be available through such strategies as vegetative management and weather modification.

Arizona public policy acknowledges weather modification as a possible water augmentation method. Arizona's Groundwater Management Act (GMA) commits water managers to consider water augmentation options as part of a strategy to reduce groundwater use. In the GMA's Second Management Plan (SMP) specific augmentation methods are discussed that are considered suitable for achieving the management plan's goals. Weather modification is included as one of the methods.

The SMP acknowledges that "weather modification has been cited as one of the most promising water supply augmentation options for the future," but goes on to state, "yet it is the one option studied for the second management period which has the most uncertainty and the most need for further research." The SMP calls for additional study to determine the feasibility of weather modification as an augmentation method.

This is hardly official recognition and support for weather modification. Yet the document does express the Arizona Department of Water Resource's (DWR) guarded interest in the method and a willingness to support further research.

Arizona in some ways is geographically well suited to benefit from weather modification strategies, both at a regional and in-state level. Allocated a share of the Colorado River, Arizona would benefit if its flows were increased. The state was therefore interested in a U.S. Bureau of Reclamation study, Winter Orographic Snowpack Augmentation, that claimed an additional 2.3 million acre-feet per year could be added to the Colorado River with an extensive Rocky Mountains cloud seeding operation.

The Mogollon Rim area has been identified as offering the greatest potential for in-state weather modification efforts. A central geological feature of the state, the Mogollon Rim provides Arizona with a laboratory for weather modification experimentation and research. Stretching from northwest to southeast, the rim forms a barrier that forces flowing air upward to cool, a situation favorable to orographic cloud development. Not having such an advantage, other states are often limited to studying cumulus clouds such as those seen during Arizona's summer monsoon. Such clouds could form almost anywhere causing difficulties in locating and conducting studies.

The Mogollon Rim is a suitable location for weather modification research because about 40 percent of the water for central and northern Arizona falls as winter precipitation over this area. Spring snow melt seeps into local aquifers and drains into nearby streams and rivers. Snow melt drains north into the Little Colorado, and south to the Verde and Salt river systems.

Cochiti pueblo pottery design

Major Weather Modification Events in Arizona

With much to gain from successful weather modification efforts, the Salt River Project (SRP) conducted some of the earliest cloud seeding operations in the state. (The Salt and Verde watersheds are the source of about 1 million acre-feet of water per year. If runoff were increased by 15 percent, the annual water needs of 750,000 would be met.) During the 1950s, a time of drought in Arizona, SRP set up a series of ground-based seeders on its 13,000-square-mile watershed.

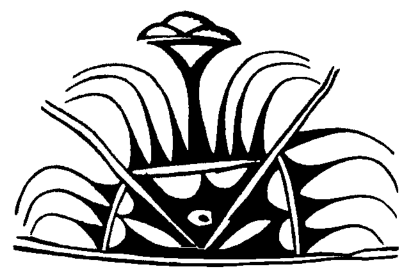
The plan of operations relied on air masses to lift propane-burned silver iodide for seeding. SRP's strategy also involved contracting for aerial seeding during the 1950s and 1960s. These early SRP efforts concluded when drought conditions lessened. No efforts at verification were made.

Weather modification work began in earnest after World War II. Its research and development has generally been a federal task, with states primarily in a supporting role. Initially, Arizona's principal federal collaborator in weather modification efforts was the U. S. Bureau of Reclamation (BuRec). Western senators, in an ongoing pursuit of water resources for their arid regions, were instrumental in establishing a BuRec weather modification program. Funding began in 1962, and by 1967 the Bureau was supporting research and development activities at universities and institutes in all 17 western states.

BuRec was no doubt very influential in encouraging interest in weather modification in Arizona. Those seeking to make a case for weather modification in the state readily found support from BuRec statistics and information. Thus, Bureau information is much in evidence in papers and presentations from the early eighties, a time when the role of weather modification in the state was actively debated.

An oft-quoted 1974 Bureau study described the great potential of weather modification to increase water resources in the region. The study declared that the average annual water augmentation potential in the Upper Colorado Basin is about 1.4 million acre-feet, with 300,000 acre-feet in the lower basin and 500,000 in adjacent basins. Most of the lower-basin 300,000 acre-feet would come from Arizona watersheds. An additional 300,000 acre-feet could be delivered to Arizona via the Central Arizona Project canal. Bureau statistics indicated that generating this new bountiful runoff would cost about $2 to $5 per acre foot (1974 dollars).

The Bureau went on to identify various benefits to be derived from the new supply of water. For example, an increased infusion of fresh runoff would decrease salinity concentrations in water supplies. BuRec studies showed that a salinity reduction of 90 milligrams per liter could result. Salinity reduction would mean more water available for new uses, with a value of about $48.5 million.



San Ildefonso pottery design showing cloud cluster and leaf motif

Further, greater flows would increase hydro-electric power. BuRec estimates project an additional annual 1.66 billion kilowatt-hours of hydroelectric energy from the increased flows resulting from cloud seeding. Increased hydro-electric capacity and energy production could mean an annual benefit of $136.6 million.

The above is worthy of note for several reasons. For one, the BuRec facts and figures stimulated Arizona's interest in weather modification. How could they not? But the information provoked another type of response among those who were suspicious of BuRec's motivations in promoting weather modification.

To them the BuRec is essentially a political organization needing to justify its weather modification funding. It is decidedly to the agency's advantage therefore to promote interest in weather modification. With increased interest more projects will be proposed, projects in need of BuRec financial and technical support. Agency studies, such as some of its work in Arizona, are sometimes criticized therefore as an exercise in self-promotion. The BuRec information however might only reflect the heady optimism that was shared by many in the early years of weather modification studies.

Regardless of motive BuRec has been a valuable weather modification resource to the state providing technical and financial support. In 1986 DWR worked out an intergovernmental agreement with BuRec to conduct a cloud seeding feasibility study using historical climatological data from the Mogollon Rim. State funding supported the work.

The final report issued in 1987 identified major storm-producing patterns during wet, normal, and dry years. Estimates of augmentation potential were figured using model studies and results from past winter programs. The report concluded that a moderate potential likely existed for snowfall augmentation in some storm situations.

Another DWR-BuRec cooperative venture involved two two-month intensive observation programs conducted over the Mogollon Rim. The first occurred mid-January to mid-March 1987, with the other taking place during the same months a year later. The studies examined winter cloud characteristics over the Mogollon Rim to assess future weather modification activities. A special focus of the studies was to determine the availability of supercooled liquid water. Its presence is essential for effective cloud seeding. BuRec, DWR and the SRP were the main contributors to the project.

Results demonstrated that supercooled liquid water generally concentrates in a few large storms and that their natural capability to produce snow is variously efficient during their passages. Thus, the timing and location of seeding would have to be carefully planned to occur when cloud conditions are most favorable for producing precipitation. Seeding clouds indiscriminately would not be a productive strategy. Future work was recommended to quantify expected precipitation and streamflow increases from cloud seeding.

From this preliminary work BuRec proposed in 1989 an eight-to-ten year weather modification program for the state at a cost of about $2 million per year. It was an ill-starred proposal. The prohibitive cost projected for the program prompted DWR to consider other agencies and options to support its weather modification work. BuRec did not receive funding for the program, and its weather modification authorization ran out.

In its quest for a weather modification collaborator, DWR contacted the University of Arizona. At that time the UA was not involved in weather modification studies. The university did have modelling expertise however to apply to research problems. This expertise was strengthened through subcontracts with the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. Arizona's unique weather modification strategy took form.

Arizona's Weather Modification Strategy

Two basic strategies are in general use to research and test weather modification. One approach relies on statistical analysis. Utah, a southwestern neighbor, is committed to this strategy. Utah's approach consists of establishing field programs for heavy seeding of clouds, with control and experimental watersheds identified. After clouds are seeded, researchers compare precipitation levels and chemically analyze snow samples on the control and experimental watersheds in an attempt to determine statistically the effectiveness of the cloud seeding operation.

Some researchers refer to this type of research as the classical method, in acknowledgement of its early and established status within the brief history of weather modification studies. Critics argue that a purely statistical approach is limited. They say a direct application of cloud seeding is taking place without a complete understanding of the atmospheric dynamics at work. They argue that seeding operations would be better understood and therefore more effectively administered with more studies of physical causes.

Another limitation of the statistical method is that one or two decades of continual seeding are needed in the same geographical area to accumulate sufficient statistical data to demonstrate successful cloud seeding. Also required are fairly large financial expenditures to be committed over this extensive time period.

Arizona currently follows a different strategy by relying on computer modelling for studying weather modification. Models or simulations enable scientists to study a phenomenon without directly observing its actual occurrence. Models are especially useful for reviewing a complex situation with many variables at work determining a particular course or outcome. Atmospheric studies and weather modification make up such a complex situation. With modelling, individual variables can be isolated and observed and their relationship to the whole studied.

This emphasis in weather modification research is the result of various scientific developments. For example, more information is available because of advances in such fields as statistics and cloud physics and because of developments in cloud-probing instrumentation. Most importantly computer system advances enable the rapid processing of vast quantities of information. As a result, highly sophisticated and detailed numerical models can be used to study atmospheric conditions.

Arizona's strategy involves delaying actual cloud seeding and relying instead on computer modelling to evaluate weather modification methodology. Work is under way with two interactive models that are to provide the data and information for modelling winter precipitation over the Mogollon Rim. A tool would thus be available for formulating seeding hypotheses, devising seeding experiments, as well as predicting potential consequences prior to cloud seeding. Arizona's modelling approach to studying winter clouds is unique in the nation and, indeed, in the world.

One of the models in use is Clarks's three-dimensional wind-flow model. Developed at NCAR, the use of this model is the result of collaboration between the UA and NCAR. BuRec research demonstrated the importance of topography and wind-flow patterns for cloud and precipitation formation over the rugged and complex terrain of the Mogollon Rim. The wind-flow model simulates wind-flow patterns and cloud formation over the Rim and is therefore useful for investigating the implications of the BuRec research findings. The wind flow model is programmed to respond to specific Rim country conditions.

The model has predicted the flow of atmospheric waves over Mingus Mountain and the Verde Valley, upwind of the Mogollon Rim. Winds striking Mingus Mountain are uplifted, with a severe downdraft occurring in the Verde Valley. Most likely of great importance to the development of clouds and precipitation in the area, this phenomenon probably will be a critical determinant when deciding the most suitable location for cloud seeding.

The accuracy of the wind-flow model has been tested and verified by field work. Much more work is needed to improve and verify the cloud microphysics model, a more complex and difficult modelling design. This model is to simulate the precipitation-forming process, from the uplift of humid air to the forming, aggregating, and falling of snow crystals.

The wind-flow and the cloud microphysics models are intended to be interactive. The wind-flow model will drive the cloud microphysics model which, in turn, will have input into the wind-flow model, thus simulating a natural process. As clouds form, temperature and humidity changes, and this influences wind-flow patterns.

When the modelling of cloud development over the rim is accomplished with sufficient accuracy, cloud seeding experiments then can be modelled. These experiments are expected to predict the possible consequences of seeding operations. The results of the modelled cloud seeding experiments will determine when, and if, actual cloud seeding takes place. Limited testing of cloud seeding is not expected for another three years.

Support for State Weather Modification Project

After BuRec's role lessened, the National Oceanic and Atmospheric Administration (NOAA), through its Federal-State Cooperative Atmospheric Modification Program (AMP), became Arizona's chief federal partner in weather modification studies. Arizona, which joined AMP in 1989, is one of five U.S. states participating in the program. The other current AMP states are North Dakota, Utah, Illinois, and Nevada.

AMP provides about $500,000 to DWR each year to support research. The funding goes to the University of Arizona's Department of Atmospheric Physics to do the scientific work for the project. The UA in turn subcontracts with NCAR for computer modelling services. NOAA scientists also contribute to Arizona's weather modification project.

NOAA funding enables states to conduct specialized research programs for their particular climatic regimes, with reference to their atmospheric modification needs and interests. A concern of special interest to Arizona is that cloud temperatures here are warmer than what occurs in other areas of the country. Preliminary work conducted by the BuRec found that at times some of the clouds over the rim may be too warm for the conventional silver iodide seeding. Other types of agents may need to be tested.

Plans are afoot for NOAA to expand its services to the state and region. A legislative proposal has been worked out to establish a Southwest Hydro-Meteorological Program. This regional program is to coordinate the activities of various agencies and bureaus involved in atmospheric work. This proposal, which was not submitted during this federal legislative session due to the economy, is expected to go to Congress next year.

The Army Corps of Engineers also contributes work to the state weather modification program. The Corps is developing a continuous flow model to determine the flow of the increased runoff that might result from cloud seeding. The model will indicate such matters as how much of the flow would remain in a watershed; its course through stream systems; and its effect on the terminal reservoir systems.

The financial contribution of various agencies and organizations to Arizona's weather modification project since the mid-1980s is significant. This time period marks the state's official involvement in weather modification research, a commitment prompted by the passage of the state's Groundwater Management Act and the establishment of the Department of Water Resources. Since 1986 the following financial support has been provided: DWR, $97,500; BuRec, $860,500; SRP, $125,000; Central Arizona Water Conservation District, $85,000; Maricopa Water District, $2,000; and NOAA, $481,200. The total amount is $1.7 million.

Law and Public Policy Implications

Oft-lamented is the fact that everybody talks about the weather but no one does anything about it. To do something about the weather however is to raise various complex legal and public policy questions. For example: Who is liable for damages from floods or other weather events resulting from weather modification? How are the rights of those who want rain to be reconciled with the rights of those who prefer sunshine? What if precipitation increases in a basin in which cloud seeding occurred but decreased during the same period in another basin? Has the latter basin been wrongfully deprived of its rightful precipitation?

And there are other questions: How is it determined that precipitation was in fact the result of weather modification? How is the amount of new water to be quantified for credit and distribution? On what basis is the new water induced by weather modification to be allocated among water users? How can those who pay for the weather modification be ensured that they will in fact receive their share of the new water?

Such issues are the stuff and drama of lengthy and interesting court proceedings and water policy debates.

Also not to be neglected are possible environmental problems resulting from weather modification. Local or regional manipulation of climate could impact present plant and animal populations. For example, increased precipitation might mean increased weed growth, and a heavier snowpack could disrupt the winter food habitat of large mammals. Concern has also been expressed about the effects of introducing artificial condensation nuclei (e.g. silver iodide, dry ice and liquid propane) into the atmosphere.

Ancient pueblo pottery design of bird-like figure

Some officials believe that some of the above issues are really non-issues if weather modification were truly understood. They stress that weather modification is not controlling the weather, but modifying the atmosphere. For example, they argue that no conflict exists between those who prefer sun and those favoring rain. Already formed clouds would be seeded to enhance precipitation, with no new clouds created to block the sun. Further, they argue that flooding is not a danger because seeding would not be done during years with a heavy snowpack. Criteria would be adopted to determine when to suspend cloud-seeding operations.

Is Weather Modification Scientifically Viable?

It is generally conceded that human activities can in fact modify and change the weather. The issue is complex though. One aspect of the issue is weather modification, an effort to affect intentionally atmospheric forces for beneficial purposes such as water supply augmentation. This is called planned weather modification.

Another side of the issue is inadvertent weather modification. This phenomenon occurs when various types of human activities such as industrialization, urbanization, irrigation, and changes in land-use patterns modify local and regional weather. The foremost example of inadvertent weather modification is of course the greenhouse effect, an occurrence some claim will become increasingly disruptive to global processes. The extent and, indeed, even the existence of the greenhouse phenomenon is much debated.

The issue at hand however is planned weather modification, and a pertinent question is: Is weather modification a scientifically feasible strategy of increasing precipitation and expanding water supplies? In other words, does it work? Responses to this question have varied over the years. Even now, after many years of weather modification research, the issue is undecided, even controversial.

In 1985 the American Meteorological Society (AMS) adopted a policy statement addressing planned and inadvertent weather modification. Still referred to by many in the scientific community, the statement acknowledges that under favorable conditions and with existing weather modification technology, the precipitation yield of cold orographic cloud systems apparently can be increased in the western United States. The statement notes seasonal increases of about 10 percent that have been indicated in some areas. The statement then goes on to note that under certain conditions decreases in orographic precipitation is also possible.

The statement expresses concern that much of the evidence in support of weather modification, both planned and inadvertent, relies on statistical indicators. More physical support therefore is needed to explain and verify the apparent effects. The policy statement concludes that the science of weather modification is mostly still in a research and experimentation stage, with more work to be done to establish a sound scientific basis. Arizona's approach to weather modification is compatible with the AMS policy statement.

Summary

Weather modification remains an unfinished business. Still a matter of scientific uncertainty, weather modification raises legal and public policy concerns in need of resolution. Although much is unsettled, the present is an interesting time to speculate about weather modification's potential role in water resource planning.

New and emerging technologies are needed for weather modification to become a reality. This prompts an interesting question. If achieved, will successful weather modification, a high-tech endeavor, prompt progressive public policy to benefit water users? What is the relationship between scientific and technical progress and the workings of the public policy process?

The questions are of interest in light of some discussion already under way. Various citizens of northern Arizona criticize cloud seeding because they believe its benefits will accrue mostly to the Phoenix metropolitan area, which they view as a black hole for water resources. Not so, claim various water officials. Satellite imagery of the Salt, Verde and Gila drainages show that 50 percent of the snowpack remains on the Rim or flows north. Some officials argue therefore that those on the rim will likely benefit more from increased precipitation from cloud seeding than southern residents. Others from the north offer guarded support of weather modification believing that, if it works, additional water resources may in fact flow their way. These waters then could be stored in reservoirs for recreational uses. Other northerners are resigned to supporting weather modification to fend off possible water transfers to the south. Weather modification is viewed as the lesser of the two evils.

The technology of weather modification may be new, but some aspects of the public policy debate sound very familiar.

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