

Project Skywater

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Project Skywater

In 1961 Congress allocated funding for the creation of a weather modification program headed by the Bureau of Reclamation. Project Skywater came fifteen years after Irving Langmuir, Vincent Schaefer, and Bernard Vonnegut of the General Electric Laboratories in Schenectady, New York, successfully demonstrated that “seeding” clouds with nucleating agents like dry ice (carbon dioxide) and silver iodide produced rain. Skywater aimed to demonstrably prove that there was a practical basis for weather modification, as it was popularly called, in terms of cost-benefit and environmental sensibility. Nevertheless, the task was both daunting and singular. The science behind rainmaking was embryonic and not thoroughly tested against the complex variables that govern the weather. Moreover, never before had Reclamation embarked on such a project: a program of taking water management to the skies, of extensive coordination with government and non-government entities typically not involved in surface or ground water issues, of collecting data over a large area, and of understanding a system as large, unwieldy, and unpredictable as the weather.

In 1964 a report of the National Academy of Sciences produced by a panel of experts from the scientific community and government agencies gave a grim diagnosis of the changing of weather. The report critiqued “present efforts which emphasize the *a posteriori* evaluation of largely uncontrolled experiments,” and instead proposed “patient investigation of atmospheric processes coupled with exploration of the technological applications.” It predicted that even after a very costly and lengthy period of study and testing, not everything could possibly be known about the atmosphere. The program required “integrated large-scale studies” on

the structure and dynamics of convective clouds, the physics of precipitation, the initiation of convection in the boundary layer, the effects of cirrus and dust layers on the radiation balance, the dynamics of severe storms, such as thunder- and hailstorms, tornadoes, and hurricanes, and the role of convection therein.¹

Reclamation's Project Skywater was a cog in a larger wheel to address the need for an integrated program on artificial changes in the atmosphere. Reclamation concentrated studies and testing in the western states, principally in the upper Colorado River basin and along the Sierra Nevada in California, for the purposes of managing and mining water resources, as well as for national defense, public health, and technological development.² Never well funded, the program had a decidedly mixed cost-benefit, environmental, and operational record that never convincingly supported a sound basis for a national, extensively funded weather modification program.

The History of Rainmaking

If the scientific basis behind rainmaking is a modern phenomenon, people, for ages, have attempted to manipulate the weather. Primitive societies had rainmakers employing a number of techniques to produce rain, from hanging frogs on trees to blowing water from special pipes to other forms of homegrown weather magic. In some American Indian societies native peoples offered human sacrifice in return for rain; in China people used huge paper dragons to induce rain; in Italy rainmakers stripped statues of wings or banished the statues of saints until rain appeared. Dr. David Livingstone

¹ National Academy of Sciences, National Research Council, *Scientific Problems of Weather Modification; A Report of the Panel on Weather and Climate Modification*, Publication 1236 (Washington, D.C.: National Academy of Sciences, 1964), 1-4.

² United States Department of the Interior, Bureau of Reclamation, *Project Skywater: An Introduction to Rivers in the Sky*, December 1973, 1; the stated purpose of the program was "to explore, develop and determine the feasibility of applying the technology of weather modification to meet the Nation's increasing demand for clean water."

reported that, in Africa, natives burned charcoal and other local materials to make rain. Supplication to gods for rain has been with humans for centuries.

In time religious explanations for rain gave way to scientific or pseudo-scientific observations. Sometimes the modern notions built on earlier ones. The idea that firing artillery into the sky would induce rain, for instance, stemmed from the correlation noted since antiquity that rain followed the battle. Rain came not because the gods found the carnage offensive or because the blood, sweat, and tears from the slain produced the condensation for rain. Rather, some believed that the sound of the cannon induced the rain much as the crack of lightning produced the same result.

A common method of rainmaking was burning, but not until the nineteenth century did weather modification experiments take on the air of scientific authority. James Pollard Espy, considered by some to be the father of the U.S. Weather Bureau, devised a theory of explaining how clouds formed that put him well ahead of his time. Noting that hot air expanded as it rose, resulting in a drop in temperature and condensation of air vapor, he predicted that man could generate a cloud if he created hot air rising in a column. There he gave the scientific basis for the idea that burning/fire created rain—a phenomenon observed since antiquity. Espy proposed burning large areas of land—say, 40 acres of timber every twenty miles in a continuous line north to south spanning the length of the country—and assured

that the farmers and mariners would always know in advance when the rains would commence, or nearly so, and when they would terminate; that all epidemic diseases originating from floods and droughts, would cease; that the proceeds of agriculture would be greatly increased, and the health and happiness of the citizens much promoted.”

No such schemes were carried out. After one petition came before the U.S. Senate, John J. Crittenden of Kentucky urged his colleagues not to give Espy power to cause rain because “he may also possess the power of withholding it, and in his pleasure, instead of giving us a navigable river, may present us with rocks and shoals and sandbars.” It was probably a good thing that Congress never funded Espy’s schemes since burning requires a lot of fuel and energy for yielding, arguably, a scant inch of rain.³

Espy conducted and proposed his methods in the eastern states, where natural precipitation could support agriculture and water shortage was not acute. West of the hundredth meridian, however, water manipulation became a matter of survival. The usual method was to manipulate the water once it reached the ground. The Hohokam civilization, in central Arizona, is a remarkable yet cautionary tale of the creation of a complex hydraulic irrigation society in the Southwest that flourished until water scarcity led, as archeologists believe, to a complete collapse in the fifteenth century.

The first Euro-Americans to traverse the plains region and the far West mostly perceived the land as wind-swept and arid, largely unfit for settlement. In the plains region the lack of water and wood made the plains unfit for agriculture and even modest-sized populations. Although the explorer and map maker John C. Frémont suggested that cattle and farmers could subsist on the native grasses and soil on the plains, overland immigrants to the West famously passed over the plains with hardly a thought of lingering. Yet old notions of what the land could support shifted as the East’s populations moved westward following the call of boosters and agricultural enthusiasts claiming that “rain followed the plow”—meaning that planting trees and crops altered

³ Clark C. Spence, *The Rainmakers: American “Pluviculture” to World War II* (Lincoln: University of Nebraska Press, 1980), 9-11, 15.

climate conditions creating more moisture. Congress even encoded in law the notion that man could alter the western environment by passing the Timber Culture Act in 1873, which gave ranchers an extra 160 acres of land if they agreed to plant trees on at least 40 acres of it. Indeed, some believed that empirical evidence proved the theory right, by the fact that the late 1870s and early 1880s were wet years and hardly typical climatic behavior on the plains. As climate conditions returned to normal, water was in short supply, and farmers adapted to that reality by dry farming or using drought-resistant crops or pumping irrigation water from shallow underground aquifers.⁴

The idea to devise schemes to draw water from the sky stemmed from the age-old need to locate a reliable water supply. The alluring profit of entering into the rainmaking business brought people of varying background and knowledge to the task. Their methods ran the gamut from burning and releasing chemicals into the atmosphere to concussion and electricity. A common method was to release dirt, sulphuric acid, or salt that latched onto condensation nuclei in the atmosphere. One idea on the plains was to build a mammoth artificial ramp a mile high and miles across to lift air as it naturally rises horizontally across the mountains. The problem was that the rain produced by the artificial mount would leave other areas high and dry, to say nothing of the material and money needed to build such a ramp. A number of other schemes ran head-on into technical and financial improbabilities, such as ideas to use airplanes simultaneously to blow air from their propellers into the atmosphere, or to warm air on the ground which would then rise.

⁴ Howard R. Lamar, ed., *The New Encyclopedia of the American West* (New Haven, Connecticut: Yale University Press, 1998), 447-8, 1114-5.

Some rainmakers gained special notoriety. During the drought years of the late nineteenth century Frank Melbourne and Clayton B. Jewell made good money convincing farmers that their chemicals induced rain. Another avid proponent of rainmaking was Robert St. George Dyrenforth of the Department of Agriculture. No one was more infamous than Charles M. Hatfield, so successful at making rain that according to one historian “he was accused of washing out dams and credited with saving millions of dollars worth of crops and defying not only the U.S. Weather Bureau but the elements as well.”⁵ Even after supposedly inducing 20 inches of rain in San Diego in 1916 and escaping liability for resulting loss of life and property, Hatfield continued to collect upwards of \$4,000 for one inch of rain.⁶

Probably some sincerely believed they could call upon the elements at will even as they recognized the betting odds. The stories are rife with naivety, gullibility, deception, faith in progress and science. It might appear perplexing in hindsight why people would pay well for services of questionable validity, but water users facing shortage and a failed crop might have seen rainmaking as a legitimate risk to take. Moreover, although no one could prove the validity of rainmaking, neither could they disprove it. Who was to say that sulfuric acid or other particulate did not bring down the rain? How could a farmer desperate for water dismiss as fraud or luck the accurate predictions of a rainmaker?

A reason these questions could not be answered, people believed, was because no one had systematically studied the working of weather systems. Centuries of rainmakers wielding magic, religion, and pseudo-science to modify the elements had relatively little

⁵ Spence, *Rainmakers*, 80.

⁶ D. S. Halacy, Jr., *The Weather Changers* (New York: Harper & Row, Publishers, 1968), 55-78.

to show for these efforts. Unfamiliar with weather systems and how they worked, most rainmakers employed a healthy dose of guesswork, quackery, and fraud in their work. Still, there was not a clear or discernable break between what may be called amateur and professional rainmakers. Even as scientists gathered more data for understanding and predicting the weather, the modern science of rainmaking, according to one historian, owed a great deal to earlier inquiries into weather systems.⁷

In 1930 three European scientists pushed the experiments and science further than ever before. August Veraart of Holland triumphantly proclaimed that the dry ice he dispersed into the clouds caused it to rain, but his voice was so loud and his claims so extravagant that he was dismissed altogether. At the same time a duo from Scandinavia and Germany experimented with freezing vapor on ice crystals in clouds and claimed that “at comparatively slight expense, it will, in time, be possible to bring about rain artificially.”

None of these men garnered much credit for the first successful cloud seeding. That honor goes to Irving Langmuir, Vincent Schaefer, and Bernard Vonnegut of the General Electric Laboratories in Schenectady, New York, in 1946. Langmuir’s work on cloud seeding is a footnote in a long and storied career as a chemist and inventor. As a researcher, associate director, and consultant at General Electric, he advanced many fields and earned top honors for his work, including the Nobel Prize in 1932. Schaefer was Langmuir’s assistant who gained recognition for having serendipitously discovered how to form ice crystals in his home ice box—dry ice—which is solid carbon dioxide. In November 1946 he confirmed, in a four-mile long stratus cloud,—what he tested in his ice box—that ice crystals formed when clouds were cooled. Not long thereafter, the

⁷ Halacy, *Weather Changers*, 79.

younger Vonnegut found that silver iodide could be used to seed clouds to produce rain and snow.⁸

Postwar Science and Legislation

According to Secretary of the Interior Stewart Udall, in a speech delivered before the American Meteorological Society, the Bureau of Reclamation took interest in weather modification in 1947, a year after Schaefer's seeding demonstrations.⁹ It was not entirely surprising that Reclamation would jump into a new field of water management—not after several decades of broadening water operations to power generation, urban water supply, and recreation. After initial setbacks, the Great Depression and war era had remade Reclamation, perhaps most of all by planting a sense of supreme confidence in engineering and technology and human solutions. If Reclamation could construct the world's largest dams and power western cities with electricity, why could it not control the weather?

Even still, Reclamation did not immediately take part in the flurry of weather modification schemes in the wake of General Electric's cloud seeding tests. Rather, Langmuir coordinated with the Army Signal Corps, the Air Force, and the Navy to initiate Project Cirrus. The cloud seeding project reportedly produced numerous successful rainmaking demonstrations and gathered statistical information that other government and private entities later used. During the same period, a disparate community of enterprising meteorologists and privately funded individuals constituted what one critic called "a flock of quick-buck artists who traveled around the countryside

⁸ Halacy, *Weather Changers*, 80, 87-88.

⁹ "Water Resources in the Sky: an address by Secretary of the Interior Stewart Udall," *Congressional Record*, 112 (January 29, 1966): 1489.

convincing water-hungry farmers that they had the secret to the old Indian Rain Dance.”¹⁰ Farmers, public utility companies (Bonneville Power Administration paid \$59,000 for rainmaking services), the sugar industry, aluminum companies, and others spent millions hiring contractors to seed the skies with carbon dioxide and silver iodide. In 1951 one seeding company had under contract over 300,000,000 acres in the United States.¹¹

The rush to these rainmaking ventures seemingly reflected the confidence in the new cloud seeding technology and potential. The men advocating and profiting from the new era in weather modification tended to be meteorologists—men like Irving P. Krick, a member of the U.S. Army Weather Board that forecast the weather for the D-Day invasion, who after the war built a lucrative cloud seeding company and a name in statistical and long-range weather forecasting.¹² In those early years following the war, weather scientists and lay persons alike spoke of weather control enthusiastically and assuredly. Vannevar Bush, president of the Carnegie Institution, told a congressional subcommittee, “I have become convinced that it is possible under proper circumstances to make rain.... we are on the threshold of an exceedingly important matter, for man has begun for the first time to affect the weather in which he lives, and no man can tell where such a move will finally end.”¹³

Although experts came to believe that weather modification was possible, it was still unclear when and how often the proper conditions existed to make rain or whether rainmaking could be undertaken on a scale large enough to significantly impact the

¹⁰ “Drought in Western States and in Florida: Remarks by Senator Peter H. Dominick of Colorado,” *Congressional Record*, 117 (August 6, 1971): 30626.

¹¹ “Committee to Study and Evaluate Public and Private Experiments in Weather Modification,” *Congressional Record*, 97 (October 8, 1951): 12738; “Research and Experimentation in Weather Modification,” *Congressional Record*, 98 (June 21, 1952): 7777.

¹² Halacy, *Weather Changers*, 95-96.

¹³ *Congressional Record*, 98 (June 21, 1952): 7777.

economy. Also sketchy was the impact of cloud seeding agents in local areas or areas even as far as 3,000 miles away, as Langmuir believed. To answer these questions required no less than a massive data-driven program under auspices of a larger apparatus than private interests could provide. The need for a national, closely coordinated effort to develop the technology, test the methods, and evaluate the outcomes was acute.

In 1951 ten senators—eight from the Reclamation western states—sponsored a bill in Congress that called for creation of an independent committee to evaluate the enormous body of data generated by private and public weather modification experiments in the country. Initially, the act included a controversial amendment that gave government agencies authority to indemnify contractors for experiments conducted for the government. Fearing that the amendment “might expose the Government to substantial damage suits arising from the experimentation,” lawmakers removed section 10 from Senate Bill S. 2225 while considering the bill.¹⁴ However, law makers felt it essential for the government to take the lead in developing the science and technology to address the efficiency and feasibility of weather control. The government might help to protect farmers from kooks and scam artists, against fraudulent claims and promises, and against too much water derived from rainmaking. A significant step in a government role came in 1953 with creation of the Advisory Committee on Weather Control, patterned after the National Advisory Committee for Aeronautics.¹⁵

Like the nation’s vast groundwater stores, which by mid-century had increasingly become valued as sources of agricultural and domestic water, water resources in the atmosphere provided a common good. The question was how to regulate and manage a

¹⁴ *Congressional Record*, 98 (June 21, 1952): 7778; “Joint Resolution of Legislature of New Mexico,” *Congressional Record*, 101 (May 5, 1955) :714.

¹⁵ *Congressional Record*, 97 (October 8, 1951): 12738; *Congressional Record*, 98 (June 21, 1952): 7777.

resource that belonged collectively to the public. No legal, scientific, or physical means existed to control or regulate rainmaking. And no political mechanism to regulate weather manipulation could be created until more data existed on how various agents reacted to different atmospheric conditions, etc. Still, in the minds of some, the government could not hesitate any longer to intervene in the “uncontrolled and indiscriminate efforts of many groups and persons to modify climates.” In March 1955 the New Mexico Legislature passed a senate joint memorial urging the Congress to pass a law prohibiting cloud seeding or other methods of rain induction until there was enough information to regulate it. Reportedly, “a good many people in the Southwest” believed that rainmaking may be partly to blame for recent drought. Although there was no evidence to support this hypothesis, tinkering with the weather made some people nervous.¹⁶

The Advisory Committee on Weather Control, created by Congress in 1953, reported at the end of 1957 that the program of rainmaking required more basic information and practical experimentation. It recommended sponsoring a research program through grants and contracts to various federal agencies, universities, industries, and research institutions. Senator Francis H. Case of South Dakota subsequently supported a bill giving the National Science Foundation authority to build a research program, but it was a start and absorbed only a tiny fraction of the 1959 federal expenditure of \$7.4 billion for scientific research and development. Proponents of tapping the atmosphere for water commonly compared the miniscule public funding of rainmaking to the massive NASA program. As Admiral Luis de Florez of the U.S. Navy Reserve commented in 1961, “I do not imply that we should curtail our space programs

¹⁶ *Congressional Record*, 101 (May 5, 1955): 5714.

in any way, but I do mean that our atmospheric conditions constitute the greatest single factor controlling the existence of life on earth, and that reshaping the conditions of inner space to our own advantage should accompany the attempts to master outer space.”¹⁷

The Politics of Project Skywater

A long and varied history of rainmaking, then, preceded Project Skywater. Reclamation did not originate the idea of rainmaking or usher it into the modern era. Rather, it gradually assumed a leading role in determining how extensively rainmaking would be used in the future. In 1961 Congress appropriated \$100,000 out of the 1962 Public Works Appropriations Bill for research to increase rainfall through cloud seeding. The project was an experimental program designed to bring together the best minds in meteorology and the physical sciences in the public and private sectors. The initial and subsequent appropriations to Skywater went in large part to universities and private research organizations contracted out to perform the research. A team of physical scientists, meteorologists, electronic engineers, technicians, administrative personnel, and others based in the Engineering Research Center in Denver, Colorado, headed the program from Reclamation’s end.

Project Skywater complemented the general research program already initiated by the National Science Foundation as well as the specific weather programs studying hurricanes at the National Oceanographic and Atmospheric Administration and fog dispersal at the departments of Defense and Transportation. The difference was Skywater directed most of its attention to augmenting the nation’s water supply. In the early years the project did laboratory work to use previously acquired information to

¹⁷ “Weather—Take It or Make It,” An address by Adm. Luis de Florez of the U.S. Navy Reserve, *Congressional Record*, 107 (April 3, 1961): 5433-34.

develop cloud seeding techniques. Reclamation later tested this information when it developed larger field experiments and programs to test the practical application of seeding technology. Reclamation conducted tests in the West's mountains to increase winter snowpack and, later, on the high plains and other areas to develop cloud seeding techniques in the summer months. In addition, Reclamation performed theoretical and intellectual work on economic, environmental, and sociological aspects of weather-altering technology. Project Skywater was essentially a whirlpool of ideas, centrally directed by Reclamation across a broad area, with cooperation and coordination on the national, state, and local levels.

What Skywater needed to get up and running was a healthy infusion of cash, but no such expenditures were forthcoming. Project proponents pointed to the abysmal funding in the early years. In 1965 Reclamation received a mere \$1.1 million for weather modification, and the next year another \$3 million, largely for research in the Colorado River basin. The enormous expenditures on the space program and even ocean, land, and other atmospheric studies frustrated proponents of weather modification and Project Skywater in particular. Senator George McGovern spoke of the congressional funding for Skywater as “a pittance compared to the billions we are pouring into space exploration and, more recently, the development of a supersonic transport plane of questionable utility.”¹⁸

Weather modification received a boost in 1966 with Interior Secretary Stewart Udall's speech before the annual meeting of the American Meteorological Society in Denver. Udall cited the crisis of polluted air and water and the desperate need to clean

¹⁸ United States Senate, Committee on Appropriations, *Public Works Bill, 1962*, S.Rpt. 1097, 87th Cong., 1st sess., September 20, 1961, 28; “Rainfall increased over non-mountainous areas by South Dakota scientists,” Remarks by Senator George McGovern, *Congressional Record*, 114 (January 31, 1968): 1683.

the nation's skylines, rivers, and lakes. These, he argued, were common goods and essential resources which needed protection for future generations. Udall spoke in the tradition of conservationists who advocate environmental ethic not for protection's sake but for nature's utility to man. To that end he put faith in human solutions and technology.

The secretary reminded his audience that for decades the government had been at the forefront in damming, diverting, and powering water on the earth's surface, in taking water where it pools and channeling it to a field or a power generating plant or a city for drinking water. "Yet with all our planning and building and looking ahead to try to outguess the future," Udall claimed, "we find ourselves still at the mercy of the weather." The secretary pressed the point that society had not achieved total control over nature, particularly the elements. Udall continued,

[W]e must make progress in orders of magnitude greater than we are now making. Many ways of hastening this progress are open to us and we cannot afford to neglect any of them. But to my mind the most logical and challenging is the one which most stirs the imagination. This is worthwhile utilization of the water resources of the sky.

Then Udall waxed eloquent about "the idea of enormous rivers of water flowing over us in the atmosphere; of huge pools of moisture poised above our heads; of enormous reservoirs in vaporous state sailing majestically over mountains, or pumping into them and dropping their precious burdens too soon." What might it take to tap into and manipulate that enormous water supply? No less than total control over the knowledge of water in the atmosphere by bringing together the best minds, the latest technologies, and mapping out weather patterns. The secretary urged Congress to recognize the national importance for this research claiming, "We have no alternative but

to be knowledgeable of the water budget of the atmosphere, day-in and day-out, over any part of the United States, over the Nation as a whole, over this entire continent and the oceans which bound it.” Then, in issuing the challenge he evoked the spirit of Reclamation emphasizing that it was not a question of “‘Can we do it?’ but rather, ‘How soon can we do it?’”¹⁹

Udall was not the lone voice of support in the early years of Project Skywater. Politicians, Reclamation’s commissioner, and others spoke of the good and necessary step to fund fully the nation’s weather modification programs. Floyd Dominy, in a speech given in 1967, spoke of “[t]he wealth of water in both ocean and atmosphere, evident to all, [that] has, through history, just evaded mankind’s eager grasp.” “We have been like the legendary Tantalus, who was doomed to stand neck deep in water which flowed away as he bent his head to drink it, and to reach everlastingly for luscious fruit hanging just before his mouth, only to have it swung away out of reach by the breeze,” he said. Dominy emphasized the great strides researchers had made, “Now we are near to breaking the spell and winning the prizes both from the limitless sea and from brackish inland waters and from the atmosphere that carries moisture above our heads.”²⁰ Many were sure that the day was not far distant before humankind tapped these waters. Utah’s senator Frank E. Moss spoke of the need for the largest proposed distribution system in the world—the North American Water and Power Alliance (NAWPA)—because he took it for granted that water would be artificially engineered from the oceans.²¹

¹⁹ Udall speech, *Congressional Record*, 112 (January 29, 1966): 1488-90.

²⁰ Floyd Dominy, An address before the annual Rivers and Harbors Congress Convention in Washington, D.C., June 1967, *Congressional Record*, 113 (June 21, 1967): 16708-09.

²¹ Senator Frank Moss, An address at the Conservation Congress for the Pacific Northwest, Wenatchee, Washington, March 7, 1967, *Congressional Record*, 113 (March 21, 1967): 7487.

In its early years, Project Skywater gave some reason for optimism such as when, in 1968, the South Dakota School of Mines Institute of Atmospheric Science generated evidence that increasing precipitation over a non-mountainous area was possible.²² Nevertheless, for all the talk of the future of rainmaking, the data to support claims or provide irrefutable proof was not there. At first Reclamation engineers said, vaguely and quite imprecisely, little more than that weather modification might augment water supply in drought ridden areas or, conversely, prevent rainfall in flood-prone zones. Directly correlating rainmaking efforts in the sky to water storage and distribution on the ground was essential to winning support and situating rainmaking in the context of Reclamation's mission, but no one could say for certain how that correlation worked and what the benefits were. Reclamation's best guess was that weather modification in some areas had the potential to increase surface water by 10-20 percent. In the Colorado River basin alone they claimed cloud seeding could add two million acre feet to the Colorado River.²³

Even after several years into the project, all this seemed a long way off. Nevertheless, a number of supporters of Project Skywater remained convinced that the problem lay in the lack of government funding. But the project, like Johnson's Great Society, became a casualty of the Vietnam War and shrinking government budgets. Even still, expert coordination and liberal funding was unable to solve every problem. A Skywater press release on March 17, 1968, reported the challenges the project faced.

Progress, while quite substantial, has served also to identify many problem areas which must be solved before operational capability can be achieved.

²² McGovern speech, *Congressional Record*, 114 (January 31, 1968): 1683.

²³ Dominy speech, *Congressional Record*, 113 (June 21, 1967): 16709; McGovern speech, *Congressional Record*, 114 (January 31, 1968): 1683.

These areas include knowledge of—what atmospheric conditions are best suited for seeding, the amount of artificial nuclei required to achieve best results for given conditions. The behavior of nuclei inside real clouds, measuring and evaluating the effects of seeding, determining meteorological side effects, and the legal, social, biological, and other implications of precipitation management.²⁴

Thus, by the late 1960s a shift occurred in the rhetoric praising the potential of tapping the “rivers in the sky.” In the late 1950s *Science Newsletter* reported that in a poll of meteorologists nearly half believed humans could prevent hail and lightning within ten years and steer tornados and hurricanes within 50 years.²⁵ They predicted no less than total lordship over the elements in less than two generations. Years later the scientists who held that view revised their thinking as they confronted studies and data pointing to the highly unstable, unpredictable, and complex nature of weather. Moreover, a sea of change in the basic assumptions of how water management operated washed over the Reclamation’s operations. It was becoming clear that the best places to dam and distribute water were running low; that the quest to control every western water system alone was ineffective in solving the water crunch; that water managers must consider the impact of their operations on ecosystems and the health of water systems and living organisms. These new realities and societal assumptions began to chip away at the traditional enthusiasm for technology’s capacity to control nature. Not that the notion of rainmaking was necessarily wrongheaded or technically impossible. Evidence suggested that making rain or dispersing fog clouds was possible, but others schemes like steering hurricanes were less probable. The disappointment and disillusionment of total control

²⁴ Colorado River Basin Project Act, Remarks by Senator Frank Moss, *Congressional Record*, 114 (September 9, 1968): 26153.

²⁵ de Florez speech, *Congressional Record*, 107 (April 3, 1961): 5434.

formed the basis of a new weather modification plan, more tempered and down-to-earth than originally conceived.²⁶

Even as scientists and policy makers acknowledged all that they did not know, weather modification remained big business in the private sector and a preferred strategy to confront the nation's growing water crisis in public government. Reportedly, in 1965 seventy-nine weather modification projects operated in the United States and other countries of the western hemisphere—sixty for rainmaking, the others for fog dispersal and hail reduction. Private commercial firms seeded clouds for farmers, increased snowpack above dams for power companies, abated hail for ranchers, and dissipated fog for airlines.²⁷

In 1967 when Senator Peter H. Dominick of Colorado introduced legislation to fund weather modification efforts in the upper Colorado River basin, he acknowledged that “we have much to learn about the effect of weather modification upon ecology and we must be equally aware of the legal ramifications.” Accordingly, he proposed twice as much funding to study the results and effects of the program than for the practical experimentation of weather modification. His plan attempted to complement Project Skywater by enlarging the scope of research and direct application of increasing rainfall and snowfall in the upper basin. Dominick and other politicians sympathetic to the idea of increasing the nation's water supply by cloud seeding frequently argued their case by stating enough information existed to verify that weather modification was possible and

²⁶ See *Scientific Problems of Weather Modification*, 3-4.

²⁷ Halacy, *Weather Changers*, 4-5.

potentially beneficial, but the project required sufficient funding to come to a satisfying conclusion.²⁸

Technology, Testing, and Implementation

Project Skywater had been designed to develop weather modification technology and methods and to assist other entities working in the field. The project did not, however, have the congressional charter to extend beyond research and development to operation and implementation. If state or county entities hoped to implement weather modification in their locales, they had to fund it from state or county sources. Since none of the research projects could extend indefinitely, and the fact that Reclamation had no authority or funding to implement programs put the project on life support. Within three decades of its first congressional appropriation, it had been discontinued.

The criticism that federally sponsored weather modifications never made it past the drawing board was directed to, in Senator Dominick's words, "a persuasive bureaucratic attitude—in segments of both the government and academia—that it must remain in the category of a research project—perhaps ad infinitum." In the senator's 1971 speech to his colleagues, he pointed out that twenty-five years of study produced ample evidence that cloud seeding was feasible on a large scale. Instead, he claimed, scientists "sit on cloud seeding as if it were some kind of illegitimate egg." The senator derisively referred to an "expert" from Reclamation who stated that "maybe by 1974" the time was ripe to transition to actively using weather modification technology to fight drought and other water problems.

²⁸ "Colorado River Basin Legislation," Remarks by Senator Peter H. Dominick of Colorado, *Congressional Record*, 113 (June 29, 1967): 18010; "S. 2826—Introduction of Bill Relating to Weather Modification," Remarks by Senator Peter H. Dominick of Colorado, *Congressional Record*, 115 (August 12, 1969): 23526-27.

Dominick noted the rest of the world had taken weather modification seriously. Russia annually spent millions to reduce hail and increase rain. Using the services of a U.S. firm, in 1967 Iran ran an intense cloud seeding project and consequently broke a six-year drought. The same firm also aided Newfoundland's chief forester to fight raging forest fires and Cyprus to end a drought over a large portion of the island. All this occurred at a time when the United States government sat on its hands. Dominick blamed Congress for allotting only a small portion of the hundreds of millions of dollars earmarked to atmospheric research in the last quarter century to development of cloud seeding technology. For instance, in fiscal 1971 eight agencies working on research and development of cloud seeding shared only about \$10 million. The senator urged Congress to act on this issue to predict and prevent drought crises in the future.²⁹

Skywater never provided the kind of national umbrella advocated by Dominick, who in fact did not believe the program ought to be run by the Bureau of Reclamation anyway. Rather, he saw the project was highly regional and local. When interested parties convened at the Skywater Conference VII in Denver on March 2-3, 1972, the unanimous decision was to keep it local and especially to divest as much local control of individual projects as possible.³⁰ Even still, Skywater was part of a national attempt to collect in a systematic manner atmospheric data by testing cloud seeding technology on a local scale and evaluating it against broader patterns in weather behavior. To do this required a sweeping program that drew on the latest technology and techniques developed over the years.

²⁹ Dominick speech, *Congressional Record*, 117 (August 6, 1971): 30626-28.

³⁰ Archie M. Kahan, "Project Skywater – A Progress Report," 11, <http://wrri.nmsu.edu/publish/watcon/proc17/Kahan.pdf>.

Reclamation's Project Skywater was just such a program, and although modestly funded in its first years it had become poised to lead the national effort. Project planners used the latest technology such as a computer-drafted cloud model that by inputting the dimensions and characteristics of cloud formations was able to predict the behavior of the cloud to modification stimuli. The model used atmospheric pressure, cloud height, air temperature, and other variables to predict outcomes. Take for instance a cloud with a radius of one kilometer in Amarillo, Texas. Given all the variables, the computer model projected 0.138 inches more rainfall if seeded than would ordinarily fall under natural conditions.³¹

Skywater featured a series of pilot projects across the western states to study seeding in different environments at different times of the year. The earliest push in cloud seeding was in winter cloud research. The Desert Research Institute in Nevada headed Skywater's first winter storm studies in the Sierra Nevada. The Institute used a specially fitted plane, mountain-top radar, precipitation gauges, snow towers, and other instruments and technology to understand the convective cloud system over the Sierra Nevada and determine when and under what conditions it rained. Part of the program was to test silver concentrations to show how dispersal of silver iodide makes its way into the weather system in the air and the snow. The program lasted four seasons. The Institute's research at Pyramid Lake demonstrated, according to a Skywater report, that "under optimum conditions—cloud seeding could add up to 129,000 acre-feet of new water to the Truckee [River] annually."³²

³¹ Reclamation, *Project Skywater: An Introduction to Rivers in the Sky*, 3-4.

³² Desert Research Institute, University of Nevada System, *Project Skywater: Final Report of the Desert Research Institute*, July 1, 1968 to June 30, 1972, under contract for the Division of Atmospheric Water Resources Management of the Bureau of Reclamation, U.S. Department of the Interior, Reno, Nevada,

The largest winter cloud-seeding program was the Colorado River Basin Pilot Project (CRBPP), beginning in the winter of 1970-71. In implementing this research pilot project Reclamation was sensitive to state laws governing the use of weather modification in Colorado. Back in 1951 the Colorado state legislature passed the Weather Control Act, granting the state the right to claim increased snowfall from weather modification activities. The Colorado Weather Modification Act of 1972 clarified the powers of the Department of Natural Resources, established an advisory board, and required a permit and license for cloud seeding. Later, during the droughts of the 1970s the state legislature appropriated funds to the Department of Natural Resources for winter seeding programs to alleviate water scarcity in the state. Reclamation worked with the state and relied on the expertise of other agencies and organizations in carrying out the work. The Geological Survey supplied stream flow data; the National Oceanographic and Atmospheric Administration and National Center for Atmospheric Research provided special aircraft for studies; the Department of Transportation, Colorado State Highway Department, and the Colorado Highway Patrol shared information with avalanche researchers; and the Soil Conservation Service collected and measured snow samples.³³

The pilot program worked something like this. From field headquarters in Durango, Colorado, project meteorologists determined the right conditions to fire up the cloud seeding generators located at the base of the mountain slopes. Scientists in Denver, using models, determined how wind currents lifted particulates from generators on the

1973, iv, 1; Gilbert Stamm, speech at the 27th Annual Nevada Water Conference held in Carson City, "Reclamation—1973 and in the Future," *Congressional Record*, 119 (November 15, 1973): 37430-31.

³³ U.S. Department of the Interior, Bureau of Reclamation, Division of Atmospheric Water Resources Management, *Final Environmental Statement for Project Skywater*, Denver, Colorado, 1977, 1-22-1-34.

ground into the storm clouds above. After the seeding, contractors hired by Reclamation then collected data at over 200 monitoring sites to determine how much snowpack accumulated as a result of seeding and whether increased snowpack might have an impact on the ecology of the area and on avalanches. Scientists also examined how cloud seeding affected natural processes and species, testing, for instance, soil samples to determine concentration of silver from the cloud-seeding silver iodide.³⁴

In general, Project Skywater had the blessing of locals. Some, however, worried about impacts on snow levels and avalanches, damages from heavy snowfall, costs of snow removal, and other related issues. Residents from Telluride and Ouray and other communities on the western slope worried about avalanche danger and other problems associated with excess snow. They were concerned about the effects of snow and runoff on hunting, fishing, jeeping, agriculture, and ranching. The anxiety was so high that one miner even threatened sabotage, saying, “If those weathermen screw up life around here they may suddenly discover their equipment blown to bits.” A man from Silverton, Colorado, commented that regardless of the actual results of Skywater, Reclamation may shoulder the blame for weather accidents. Reclamation officials like Archie Kahan, chief of Reclamation’s office of atmospheric water resources in Denver, countered these criticisms by attempting to assure locals that the bureau was making every effort to study the ecological, social, and economic impacts of cloud seeding before implementing a long-term project.³⁵

³⁴ Colorado Department of Natural Resources, *Snowpack Augmentation Research Needs: A History of Weather Modification in Colorado*, Bureau of Reclamation Cooperative Agreement No. 9-07-85-V0027, Denver, Colorado, June 1982, 1-3; U.S. Department of the Interior, Bureau of Reclamation, *Mountain Skywater: The Story of the Colorado River Basin Pilot Project in the San Juan Mountains of Southwestern Colorado*, VHS, Reclamation, [no date].

³⁵ Roger Rapoport, “Some Tough Westerners Say: ‘No Snow Job for Us!’” *Sports Illustrated*, (June 29, 1970), online.

In the end, no long-term weather project was established in the Colorado River basin, despite the generally positive conclusion that seeding from 20 to 40 percent of the winter storms and that over half of those yielded higher precipitation.³⁶ The pilot project in the Colorado River basin was one piece of a puzzle spread across the western states. Project engineers and researchers developed or planned to develop technology and smaller winter cloud seeding projects in Montana’s Bridger Range, Utah’s Uinta Mountains, New Mexico’s Jemez Mountains, California’s Sierra Nevada, and Wyoming’s Medicine Bow Mountains.³⁷

Reclamation had high hopes that the Sierra Cooperative Pilot Project in the American River basin would bring together the latest technology to direct the possibilities of atmospheric water management in the Sierra Nevada. Armed with the mission to find a safe and clean way to enrich the area’s natural precipitation, Reclamation began by collecting environmental data. The Center for Regional Environmental Studies at California State University in San Diego received the contract to review the environmental effects of the project. Together with the Forest Service the project eventually produced a report situating weather management into the larger ecological picture: soil water, plant growth, stream and lake biota, and animal migration.³⁸ The project aimed to develop technology to predict the nature and cloud-seeding potential of winter clouds; evaluate when to seed, potentially to avoid contributing to avalanche or flooding danger; uncover potential legal, economic, and social consequences of cloud seeding. However, the project never made it past planning and was never carried out.³⁹

³⁶ Kahan, “Project Skywater,” 8.

³⁷ Reclamation, *Final Environmental Statement for Project Skywater*, 1-19; Kahan, “Project Skywater,” 13.

³⁸ Reclamation, *Final Environmental Statement for Project Skywater*, 1-18–1-19, 1-20 –1-21.

³⁹ Reclamation, *Final Environmental Statement for Project Skywater*, 1-20–1-21.

As winter cloud seeding research progressed, Project Skywater initiated a few summer cumulus seeding research projects. Archie Kahan stated that summer projects came “because many key problems remain in summer cumulus seeding and there is an apparent rapid increase in public interest in summer seeding.” The summer cloud seeding projects spread across the country. Research programs at the Institute of Atmospheric Sciences at South Dakota School of Mines and Technology examined salt and silver iodide in summer convective clouds. Skywater’s San Angelo Cumulus Project near San Antonio, Texas, developed use of hygroscopic seeding to increase precipitation in warm climates. In Illinois the state water survey teamed up with Skywater to develop technology on frontal and squall-line storms. Skywater also worked with the governors of Arizona, Texas, and Oklahoma and with the President’s Office of Emergency Preparedness for drought-relief cloud seeding operations. Cloud seeding reportedly produced increases in rainfall of 10-15 percent in Texas and Arizona and of 95,000 acre feet in Oklahoma—strong evidence that further developments and research in the field could result in large-scale benefits.⁴⁰

The largest summer seeding program was the High Plains Cooperative Program, a research-driven field program designed to develop rainmaking technology for use on the high plains. Reclamation established three field sites near Miles City, Montana, Colby-Goodland, Kansas, and Big Spring-Snyder, Texas, where testing began in May 1975. The program used some ground generators, like the CRBPP, and also airplanes to seed the cumulus clouds with silver iodide and urea-ammonium nitrate. The planes were specially equipped to monitor temperature, winds, humidity, and cloud updrafts. Although the planes seeded areas no larger than a radius of 65 miles from the radar

⁴⁰ Kahan, “Project Skywater,” 8, 11-12.

control station at each field location, the effects of that seeding might extend across a broad geographical area. This was one of the challenges of analyzing and evaluating weather data.⁴¹

The program collected as much data as possible. Field teams monitored clouds suitable for seeding, examined when and under what conditions seeding was applicable using complex numerical models and hypotheses, and developed seeding techniques appropriate to atmospheric conditions. Then, scientists evaluated the data. Just a few years into the program scientists had collected essential atmospheric data on convective rain cells and the percentage of cells acceptable for seeding. To be more precise, of the 20,000 convective cells expected to accumulate in the atmosphere during the five-month summer season, 800 appeared suitable for seeding.⁴²

From the beginning of Project Skywater the concern was how cloud seeding might affect “the balance of biological communities,” in the words of the National Science Foundation.⁴³ Reclamation initiated ecological studies such as the Uinta Ecology Project in Utah and the San Juan Ecology Project in Colorado and in some cases produced environmental impact statements for its Skywater projects. The challenge, of course, was that impacts to land, water, and air were not site specific. The size and complexity of weather systems made the task of determining environmental consequences highly difficult and imprecise.

There were also questions about a dark side of cloud seeding. Some wondered if cloud seeding caused, or at least contribute to, the torrential flood that ripped through

⁴¹ Reclamation, *Final Environmental Statement for Project Skywater*, 1-6-1-14.

⁴² Reclamation, *Final Environmental Statement for Project Skywater*, 1-12-1-14.

⁴³ U.S. Department of the Interior, Bureau of Reclamation, *An Overview of the Skywater IX Conference on Precipitation Management and the Environment: Discussion and Summary Reports*, Denver, Colorado, September 1977, 1.

South Dakota's Rapid City in the summer of 1972. During the evening of June 9, Rapid City residents thought little of the rising waters. Near midnight, however, the river tore up Canyon Lake dam—the last defense—and the waters that had been building strength all day laid waste to the city, claiming 250 lives and \$100 million in property damage. What was to blame for this catastrophe? Was it an act of nature or, as one writer called it, an “‘Act of God’—with a Few Grains of Salt?” Could the Institute of Atmospheric Sciences at the South Dakota School of Mines and Technology's Project Cloud Catcher, funded by a contract awarded by Reclamation, have been responsible for producing rain “at an unusually heavy pace?” The director at the Institute of Atmospheric Sciences denied any wrongdoing, and even a board of inquiry established by the governor concluded that cloud seeding did not contribute to the disaster. One article called into question conclusions weather modification scientists that there was no connection. Ironically, they simultaneously acknowledged not knowing enough about the weather system to definitely say how and when rainmaking works. James Crutchfield, an economist at the University of Washington, stated, “When it gets to the point where there is a possibility of really catastrophic side effects, and when these catastrophic side effects are occurring close enough to the weather modification as to raise the possibility of a cause-and-effect relationship, there is serious questions in my mind as to whether we ought to be fooling around with it at all.”⁴⁴

Another problem with cloud seeding is the chemical, silver iodide, an inorganic compound that can be toxic when ingested. According to one report, even at low concentrations dispersed over a large area the agent might have negative consequences to

⁴⁴ For details on the debate over the causes of the Rapid City flood, see “The Effects of Weather Modification,” *Congressional Record*, 119 (May 31, 1973): 17628-34; quote by Crutchfield, *Ibid.*, 17633.

freshwater microorganisms. Moreover, there was always a question of silver accumulating in the atmosphere, plants, or the groundwater if cloud seeding became widely practiced. A law professor in Arizona reportedly warned of the legal ramifications stemming from pumping silver into the atmosphere—in however small amounts. However, the workshop uncovered nothing incriminating. “There appears to be no real threat from silver iodide as a cloud seeding agent.... Public concern is probably based on misunderstanding, not on actual damages.” Despite the assurance, it recommended monitoring concentrations and left room for revision based on future studies.⁴⁵

Reclamation’s environmental statement noted adverse effects in tentative terms. Avalanches might occur, elk ranges could diminish, cropland may become subject to erosion, but concluded nothing was certain to warrant immediate concern. It was this tentativeness, this inconclusiveness, that had defined the project—not just the impact to the environment but the very efficacy of the project itself.

To be sure, Skywater brought complex technical and technological issues to bear on the question of altering the weather. The project required sophisticated statistical designs, data collection, measurement, communications, field support and equipment, analysis, and cooperative agreement between state and government agencies and the public. It required adjusting variables in each area and considering the nature of the atmosphere and other site-specific conditions over a broad geographic canvas. Skywater consisted of many parts, seemingly disparate, spread across the western states. Project Skywater designers hoped to integrate technologies and methods developed across the

⁴⁵ Reclamation, *Overview of Skywater IX Conference*, 1-2, 13, 15.

region into a national effort, but this was not to be. Moreover, Skywater never received the funding or congressional blessing that some supporters had hoped.⁴⁶

Conclusions

After 1940 some scientists and lay persons used the word “control” when speaking of the possibility of changing the weather. Some optimistically believed that it was possible to tinker with the weather system—to increase precipitation, disperse fog, steer hurricanes, etc. The idea of Project Skywater derives from the human impulse to modify the natural world to its own liking. When the technology and means became available to tinker with the weather system, it was as though an infusion of adrenaline shot into the scientific and meteorological communities. At long last the primal urge to harness and control rain, snow, hail, fog and even hurricanes seemed within reach. Skywater was an ambitious program that if seemingly fantastical today evoked in the Age of Engineering a certain inevitable and climatic drama.

If Project Skywater and other like projects teach us anything it is that human control of the atmosphere—nature, for that matter—is not as total as we sometimes think possible. No sooner had meteorologists, policymakers, and agriculturalists set out on the course of weather control than they confronted the immensity of the situation. The weather system was just too large. U.S. scientists in Project Stormfury tested methods to steer or disperse the energy in hurricanes, but by 1980 they had given up the quest. Dropping a bomb in the ocean to break up the storm would “be like trying to stop a freight train by placing a feather on the tracks,” according to one observer. Layering the

⁴⁶ James V. Lunsford, “Water Potentials of Weather Modification,” Paper delivered at the New Mexico Water Conference, March 27-28, 1969, 77, <http://wrri.nmsu.edu/publish/watcon/proc14/Lunsford.pdf>. Reportedly, in 1990 the project received a small infusion of funds \$3.2 million, but by that late date the project had already nearly expired, see *Congressional Record*, 136 (June 19, 1990): 14621.

ocean with a film to prevent moist air from rising and forming storms might work if the ocean were not so big and were it possible to predict where storm clouds developed.⁴⁷ Simply, nature is too big and too complex to control. Modified, perhaps, or managed, but even then not entirely to our liking. In fact, about the only method proven successful, at least to some extent, is cloud seeding to increase precipitation.

Project Skywater's history overlapped an important transitional period in Reclamation's history. It came as Reclamation entered an era of huge construction programs and built dams on many major river systems in the West and, when under Floyd Dominy, Reclamation enjoyed a reputation and elevated position within the pantheon of the federal bureaucracy. That the bureau took the next step in its institutional progression and turned to domination over the "rivers in the sky" should come as no surprise. By the late 1960s, the consensus that supported big dam construction had waned, and scientists tempered their optimism in weather modification possibilities. The United States was entering a new era of resource management, and that had a tremendous impact on Reclamation's operations. By the time it had thoroughly transitioned from dam builder to water manager, in the late 1980s, Reclamation no longer entertained notions of total domination over the West's water resources—not on ground nor in the air.

While scientists have faced the fact that the processes involved in rain formation are complex, not all have given up the quest to alter the weather. Recently, Roelof Brintjes, of the National Center for Atmospheric Research in Colorado, commented that better monitoring and measuring technology may lead to developments in rainmaking.

⁴⁷ Jack Williams, "Project Stormfury Attempted to Weaken Hurricanes in the 1960s and 70s," *USA Today*, April 18, 2006, online.

Even now, according to one account, there are more than 150 cloud seeding projects in forty countries. In China the China Meteorological Administration (CMA) oversees a major ongoing effort using anti-aircraft cannons to bombard the skies with silver-iodide particles. The Chinese government claims the \$100 million per year project created 250 billion metric tons of artificial rain over a seven-year period, but these figure cannot be verified. China is one of many countries that use weather modification, however scientifically suspect, to alleviate challenges related to crop damage from hail or from severe water shortages.⁴⁸

All this continues to be met with skepticism by some in the scientific community who insist that however far we have come in altering the weather, the dream is still a long ways off. Would-be weather changers must confront scientific, ethical, cost-benefit, and various questions if they are to make progress where Project Skywater and other early projects began. Project Skywater played no small role in the ongoing effort by producing a large body of experimental data for the field of meteorology and inching us closer to the possibilities and limitations of altering the weather.

⁴⁸ Rob Sharp, "Weather Modification: The Rain Makers," *The Independent*, April 30, 2008.

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