CLOUD SEEDING AND THE RAPID CITY FLOOD OF 1972

Arnett Dennis[1]
Rapid City SD 57702

1. Introduction

Rapid City, South Dakota is built along the banks of Rapid Creek, where it emerges from the eastern side of the Black Hills. In 1972 its population was approximately 60,000. On the evening of June 9 of that year, torrential rain upstream of Rapid City caused the creek to overflow its banks and devastate adjacent areas of the city.

That summer the Institute of Atmospheric Sciences (IAS) of the South Dakota School of Mines and Technology (Mines) was conducting research into cloud seeding under a contract with the U.S. Bureau of Reclamation (Reclamation), as a part of Reclamation's Project Skywater.

As word got around that the IAS had conducted two experimental cloud seeding flights on the day of the flood, many persons raised the possibility that those flights might have contributed to the severity of the flood. Others disagreed, arguing that the seeding agent used, which was ordinary table salt, could never have produced such a devastating storm. The controversy was fanned by inflammatory columns in the popular press. An extreme example of such writing was an article in the *National Tattler* of December 24, 1972, titled "Govt. weather tampering is causing world floods." Because of the threat of law suits, IAS personnel were not free to rebut such misleading statements until all legal issues were resolved, which took until 1982. By that time most of the persons directly involved had moved on to other activities.

With the 40th anniversary of the flood approaching, 2010 appears to be a good time to present this account of how the controversy developed. I have written this memoir so that residents of Rapid City and other interested parties can see how the controversy was viewed by one person, who was employed by the IAS at the time. In doing so, I have not been supported by any sponsoring organization, so the views expressed in it do not represent an official position of any government agency or other organization.

Of course, it is impossible to recreate exactly the thinking of the persons involved in the seeding experiments. They know now that the seeding experiments were followed by flooding rains, but no one knew in advance that a flood would occur on that day. This account also presents other information that was not available to the participants at the time, in order to explain the sequence of events a little more clearly than could be done otherwise.

This memoir begins with a very simplified explanation of how particles of common salt might influence the formation of rain. It is not a scientific paper in the usual sense; persons interested in the details of how various cloud seeding agents are supposed to work can consult the web sites of the American Meteorological Society and the Weather Modification Association (WMA). The next section of the account summarizes the events of June 9, 1972. The later sections summarize the development of the controversy, and point out some weaknesses of the postulated links between cloud seeding and the flood.

[1] Dr. Dennis is a Fellow of the American Meteorological Society. Copyright © 2010 Arnett Dennis. Unless otherwise indicated, all material on these pages are copyrighted by Arnett Dennis. All rights reserved. No part of these pages, either text or image, may be used for any purpose other than personal use. Therefore, reproduction, modification, storage in a retrieval system or retransmission, in any form or by any means, electronic, mechanical or otherwise, for reasons other than personal use, is strictly prohibited without prior written permission. Contact information: Dr. Arnett Dennis, 3931 Ridgemoor Drive, Rapid City, SD 57702; e-mail: asdennis@rushmore.com.

2. Why Seed Clouds with Salt?

2.1 Black Hills convective clouds

The cloud seeding experiments on June 9 involved the release of finely powdered sodium chloride (table salt) below the bases of non-precipitating convective clouds. That was done to gain information on whether or not such seeding could hasten the onset of rain from such clouds. In order to explain why salt was being investigated as a possible cloud-seeding agent, it is necessary to describe how rain forms in some, but not all, of the convective clouds which form over the Black Hills in spring and early summer, and ignoring, for now, the effects of ice crystals on the formation of precipitation (rain, snow, or hail) within them.

Convective clouds are formed when currents of warm air, often propelled by solar heating of the air close to the ground, rise through relatively cool air aloft. They range in size from the familiar, small cumulus clouds of fair weather to large cumulonimbus clouds (thunderstorms) covering several square miles each and towering to more than 40,000 ft above sea level. A large convective cloud usually consists of several convective cells. A convective cell begins as an organized updraft, and usually contains downdrafts in its later, dissipating stage. The individual cells can sometimes be identified as cloud towers, but not always. They are identifiable on radar screens after precipitation forms in them. They typically have lifetimes of 15 to 30 minutes, while a succession of convective cells can keep a thunderstorm going for up to several hours.

2.2 Formation of raindrops by coalescence

Many small cumulus clouds, especially those consisting of a single convective cell, form and dissipate without ever producing precipitation. Atmospheric scientists define the precipitation efficiency of a cloud as the fraction of the water condensed in it that falls to the ground as rain, snow, or hail. The precipitation efficiency of small, non-precipitating clouds is obviously zero. Over the Black Hills in summer the smallest cumulus clouds that produce any precipitation at all have a depth (distance from cloud top to cloud base) of about 12,000 ft. Serious rainfall requires clouds at least 20,000 ft deep, and the precipitation efficiency of many convective clouds in that size range is only 10 or 20 percent. Tall convective clouds, with depths greater than 30,000 ft, always produce precipitation. If they rise into dry air, their precipitation efficiency may still be less than 50 percent. However, large clouds rising into air that is already saturated typically have precipitation efficiencies close to 100 percent.

The low precipitation efficiencies of small clouds become understandable when one considers how raindrops form. A drop falling from a typical convective cloud over the High Plains must have a diameter of at least 0.5 mm in order to reach the ground before it evaporates completely[2]. Most raindrops are larger than that; we can take 1 mm as the diameter of a typical raindrop just below cloud base. <u>No cloud droplet can grow into a raindrop through condensation alone.</u> As a typical cloud droplet has a diameter of 10 microns, it follows that the <u>formation of a raindrop requires the coalescence of roughly one million cloud droplets</u>.

Coalescence of two cloud droplets occurs as a result of a collision between them, usually because one of them is falling faster than the other. Because cloud droplets are so small, typically 5 to 15 microns in diameter, they have very small fall speeds, and collisions are rare. Cloud chamber experiments and numerical calculations both show that the coalescence process is slow to get started, but speeds up as soon as a few large droplets, called raindrop embryos, are produced. The whole process takes some 10 to 15 minutes. Therefore, rain formation in small clouds, which tend to last only 10 or 20 minutes, is often ended prematurely, as the cloud droplets and raindrop embryos are evaporated into dry, ambient air mixing with the cloudy air.

---

[2] This account contains a mixture of metric and English units. For each variable, I try to use the units most familiar to the reader. Distances are expressed in statute miles, called simply “miles.” Speeds are expressed in miles per hour, rather than meters per second. However, cloud physicists generally use metric units, so raindrop diameters are expressed in millimeters (mm), and cloud droplet diameters are expressed in micrometers (microns).

The precipitation efficiency of small clouds can be increased, in theory, by introducing artificial raindrop embryos, thereby skipping the initial stages of the coalescence process. Any hygroscopic compound can be used to produce artificial raindrop embryos, but some of them are corrosive, poisonous, or both. There are several relatively safe salts that could be used, such as calcium chloride and ammonium sulphate, but ordinary table salt (sodium chloride) is the least expensive and is readily available. However, to achieve any reasonable degree of efficiency, it must be ground into a fine powder with particle diameters in the range of 5 to 20 microns.

2.3 A chain reaction

If each artificial raindrop embryo produced only one raindrop at the ground, adding artificial embryos never could be economically feasible. In 1948 Dr. Irving Langmuir wrote a paper about chain reactions, in which each embryo leads to the formation of several raindrops. To appreciate this suggestion, it is necessary to think about what happens to raindrops as they grow.

Newly formed, and hence small, raindrops are spherical, restricted to that shape by surface tension. As a drop grows and its fall speed increases, dynamic forces become important, and begin to override the effects of surface tension. The drop is distorted, becoming first an oblate spheroid, and then a flat disk. Time-lapse movies of large drops in a vertical wind tunnel show that the largest drops become irregular, with oscillations that threaten to tear them apart. They remind one of a water-filled balloon, stretched to its limit, being held up by children playing with it. Finally, the drop shatters. For this reason, raindrops with diameters greater than 5 mm are very rare. Most drops break up well before reaching that size, as a result of collisions with other raindrops. The key point is that each breakup releases several droplets big enough to function as raindrop embryos, as well as some finer spray. The process is surprisingly fast. Computer simulations show that the new embryos themselves may grow and break up in only two or three minutes. The possibility of a chain reaction made hygroscopic seeding a promising possibility, but in 1972 many engineering problems remained to be solved. A serious limitation was the fact that 50 to 100 lb of salt are needed to make a detectable impact on one medium-sized convective cloud.

2.4 Comparison of salt and silver iodide as seeding agents

Silver iodide crystals have been shown to initiate precipitation by producing ice crystals in the colder parts of convective clouds, and can be produced in prodigious numbers at reasonable cost in a variety of generating devices. Salt seeding poses engineering problems not involved in the use of silver iodide, and does not produce the cloud growth that sometimes appears to follow releases of silver iodide. However, the relative inefficiency of salt seeding is desirable in some ways.

The growth of convective clouds that occurs sometimes after silver iodide seeding is a dynamic effect, due to the release of latent heat when supercooled cloud water is frozen.[3] Many experimenters have sought dynamic effects, because large convective clouds precipitate more efficiently than small ones, and also process larger quantities of water vapor. However, if one is anxious to restrict seeding effects to the target clouds, dynamic effects can be a problem. Dynamic effects conceivably could affect the behavior of clouds forming near the target clouds.

Silver iodide crystals not drawn into target clouds can drift with the wind, and eventually affect other clouds. This is because some silver iodide crystals retain their effectiveness as ice nuclei for several hours. Salt particles, on the other hand, dissolve as soon as they either take on water vapor or collide with a cloud droplet or raindrop.

In 1972 some persons were concerned that silver iodide could harm the environment. While this possibility had been studied at some length, with no evidence of actual harm being uncovered, critics of weather modification projects were still raising the issue. Silver is sometimes found in the atmosphere from sources other than cloud seeding,

[3] Supercooled water is water existing in liquid form at temperatures below 0C (32 F). Many cloud droplets remain in the liquid state at temperatures down to -20 or -30C.

but is generally regarded as a pollutant. Unlike silver iodide, sodium chloride (salt) is a natural constituent of the atmosphere, and is a normal component of all animals' bodies, so concerns about its environmental impacts should be minimal.

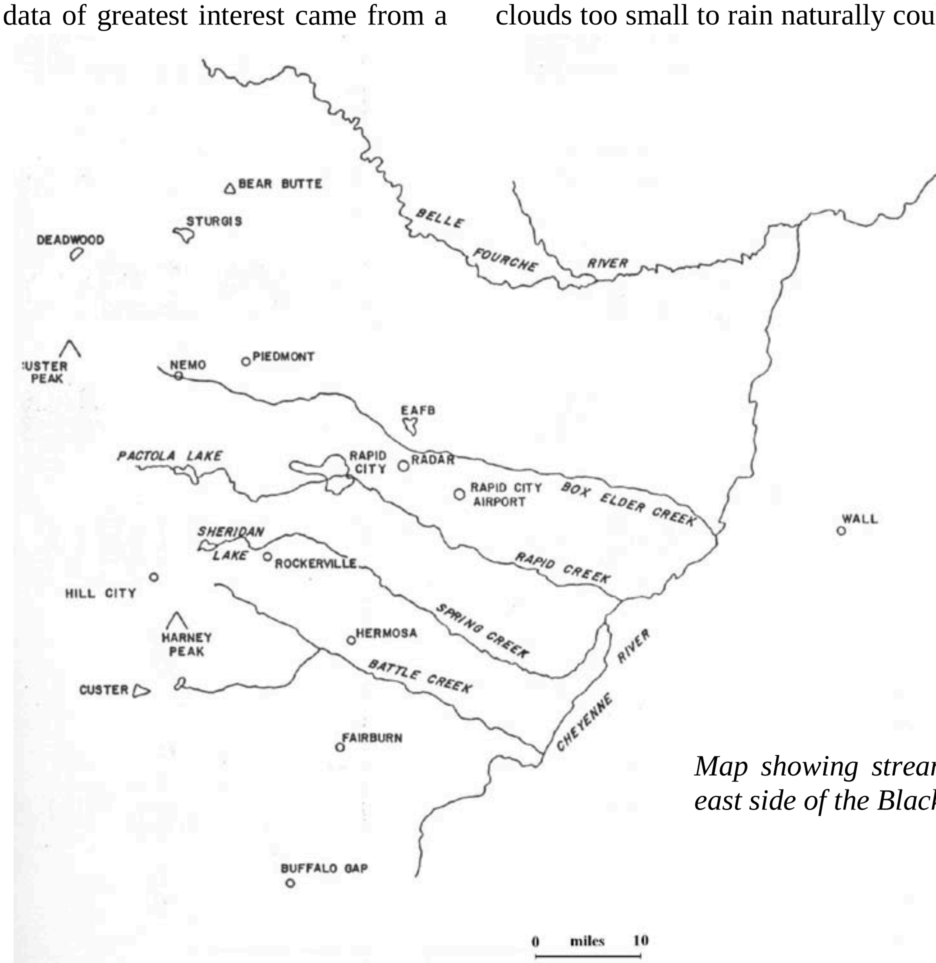
3. Events of June 9, 1972

3.1 Status of Project Cloud Catcher in the spring of 1972.

The IAS launched Project Cloud Catcher in 1969 to study the relative advantages of salt and silver iodide as seeding agents to increase rainfall from convective clouds. The project evolved from year to year as we gained experience, and our Engineering Group improved the radar system on which the IAS depended for the evaluation of the project. The effects of seeding were sought by comparing radar data from seeded and unseeded test clouds as they moved along, rather than by examining rainfall data from a fixed network of gauges. The data of greatest interest came from a computerized radar system, which was unique at that time. Radar data were fed to an on-line minicomputer, which calculated several important variables in real time, including an estimate of the rain falling from the clouds designated as test cases.

The seeding flights were directed from a radar station near the Rapid City Regional Airport by the Cloud Catcher operations director, Alexander Koscielski. Personnel involved in the project included members of the IAS Engineering group, led by Dr. Paul Smith, as well as members of the Meteorological Analysis group, which I led. My duties included preparation of the annual work plans for Cloud Catcher, and directing the analysis of the data collected.

Cloud Catcher results through 1971 had indicated that both salt and silver iodide could hasten the formation of rain in newly formed convective clouds, with salt appearing a little better at doing that. The radar data showed that some convective clouds too small to rain naturally could be made to

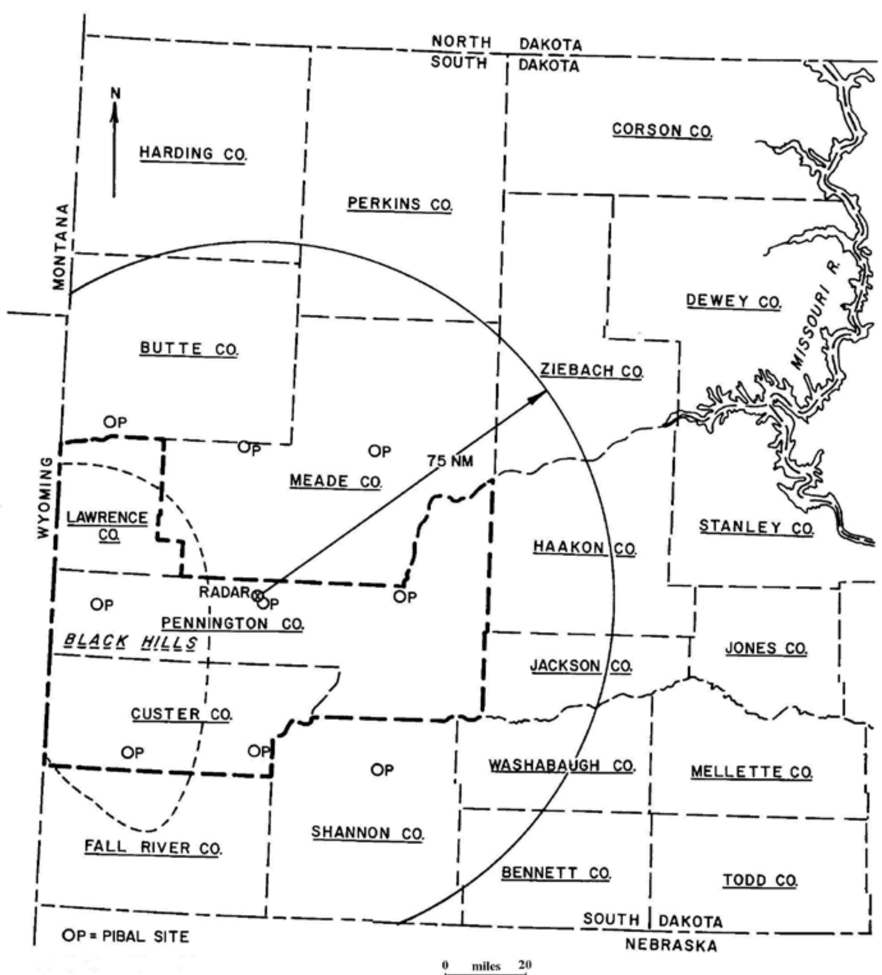


Map showing streams draining the east side of the Black Hills area.

rain, and that some clouds of moderate depth could be made to produce more rain than they would without seeding. However, seeding effects in large clouds were impossible to detect. That made sense to us. For small clouds with lifetimes of 20 or 30 minutes, speeding rain formation by 5 to 10 minutes would increase the precipitation efficiency considerably, while for large clouds, lasting an hour or more, the seeding effects would be swamped by the variability of the natural precipitation.

An addition to Cloud Catcher for 1972, which proved to be of great importance in analyzing the events of June 9, was a network of pibal stations. Pibal is short for "pilot balloon." At each station, a helium-filled balloon was released each 30 minutes and tracked with a single theodolite. Wind speeds aloft were calculated from the azimuth and elevation angles assuming a constant rate of rise for the balloon. The pibal stations were laid out on a 3 x 3 rectangular grid centered on the IAS radar site, with spacings of about 40 miles, so they bracketed the east side of the Black Hills and adjacent prairie to about 50 miles east of Rapid City. The pibal data were not available in real time. Instead, the operators brought their raw data to the Mines campus each evening, and entered them on punch cards for input to a main-frame computer.

In 1972 one third of the experimental days were selected at random as no-seed days. The random decision was provided to the pilot of the seeding aircraft in a sealed envelope to be opened after a flight was ordered. Participants in the exercise,



Area of operation of Project Cloud Catcher in 1972.

apart from the pilot and his on-board assistant, did not know until after the fact whether or not seeding actually took place.

In the spring of 1972 the State of South Dakota launched a weather modification program that covered many of the state's 67 counties. The program involved seeding clouds with silver iodide with the objectives of increasing rainfall and suppressing damaging hail. Three counties in the Black Hills area, Pennington, Custer, and Lawrence, elected to participate in the program. As a special concession to the long-standing experimental projects of the IAS near Rapid City, the managers of the state-sponsored program agreed to suspend their program for five days each week beginning June 1, so that Cloud Catcher could proceed for one more season. Thus it was that the IAS, rather than the state's Division of Weather Modification (DWM), happened to seed clouds on June 9.

3.2 The weather situation of June 9

On June 9 I went to work as usual, and sat in on the morning weather briefing, which was conducted on the Mines campus each day as part of Cloud Catcher. Dr. Richard Schleusener, director of the IAS, was away on IAS business. James Simmons, the assistant director, presented a summary of experiments conducted on the previous day, and then Koscielski briefed us on the current weather situation.

The general weather pattern showed a ridge of high pressure aloft over the Great Plains, and an upper low off the West Coast. The Rapid City radiosonde observation[4], taken at 6 am, showed a dry layer above a moist layer next to the ground. Winds were light southeasterly near the ground, veering to light southwesterly aloft. Use of a numerical cloud model showed that formation of showers was unlikely as long as the dry layer persisted. However, the upper-air prognostic charts indicated that a small disturbance approaching from the southwest would likely moisten the air mass enough to allow the formation of showers and thunderstorms by late afternoon.

As there were no problems with excessive ground moisture, Koscielski declared June 9 a "go day," which meant that one or more test cases would be declared if suitable convective clouds appeared. Our 1972 work plans called for silver iodide seeding of convective clouds where dynamic effects could be expected. However, the cloud model on June 9 indicated that any storms that developed would likely grow into thunderstorms without any assistance, so dynamic effects would be unimportant. The work plans called in that case for experimental salt seeding, provided that updrafts would exceed 10 meters per second (2,000 ft per minute), which is adequate for the initiation of rain through a Langmuir chain reaction. As the cloud model indicated that updrafts would exceed 10 meters per second, Koscielski announced that it would be a "salt" day.

With these decisions made, other Cloud Catcher participants moved into action. They included Melvin Flannagan, pilot of the seeding aircraft; his on-board assistant, Bill Shaw, who actually operated the seeding equipment; Smith and other members of the Engineering group including radar technicians; John Hirsch, the aircraft coordinator, who relayed seeding instructions to the pilot; radar operators; a photographer; and eight pibal operators.[5] I remained on campus, and worked on other matters.

Around 1 pm I checked the weather situation with Bob Riggio, a graduate student, who had meteorological experience with the U.S. Air Force. His job was to stay in the weather office on campus, monitor incoming weather data, and notify the operations director if anything unusual was happening or predicted to happen. One bulletin had appeared on the teletype mentioning the possibility of heavy rain in the Black Hills during the night. Meteorologists define "heavy rain" as rain falling at a rate exceeding 0.30 inches per hour. It occurs frequently in the Black Hills, where point rainfall totals for a thunderstorm often run to one or two inches. No flood watches or warnings had been issued.

[4] A radio sonde balloon carries aloft instruments to record pressure, temperature, and humidity, and transmit the data collected to a radio receiver on the ground. Tracking the balloon visually or by radar provides information on winds aloft.

[5] One pibal station was not manned on June 9.

3.3 The seeding missions

Later in the afternoon I drove to the radar site. There Koscielski told me that some showers had formed 15 to 20 miles northwest of the radar site, and he had declared a test case on one cluster of them. Flannagan and Shaw had taken off in the Beechcraft Baron seeding aircraft, which was loaded with about 350 lb of salt, at 2:54 pm. Koscielski declared the test case at 3:04 pm, and the first salt release followed immediately. They released the powdered salt on several seeding passes in updrafts below non-precipitating clouds close to the existing showers until 3:43 pm. The aircraft landed at 3:49 pm (all times MDT).

Later examination of time-lapse photographs of a surveillance radar scope showed that the convective cells were moving from the southeast at around 30 mph. However, the test case as defined by Koscielski did not move much; it was basically a circle of about 12 miles radius centered about 10 miles southeast of Sturgis. It appears that the individual convective cells were short-lived. The test case in its last stages consisted of new cells that had developed in the same general area, as the original ones dissipated while moving toward the northwest.

Our statistical evaluations were based on the rain that fell during a one-hour period beginning 10 minutes after the declaration of the test case, which in this case meant 3:14 pm. Therefore, the showers that continued to develop in and close to the original cluster up to 4:14 pm were considered as part of the test case. The radar-estimated rainfall for the entire test case was calculated at 1,300 acre feet, a relatively modest amount[6]. However, by that time heavy rain was spreading into the Black Hills to the southwest and west of Sturgis. Even before the test case ended, Koscielski had declared an area-seed day, which meant that data from the IAS rain gauge network would be examined for evidence of seeding effects.

About 75 minutes after landing from the first flight, Flannagan called from the airport to say the Baron was ready to go again.[7] Koscielski was studying the radar displays looking for a suitable cloud group for a second experiment. As there were precipitating clouds over the northern Black Hills, there was no point in seeding there. I suggested to him that he forgo a second test case because of the forecast of possibly heavy rain during the night. He agreed that we should not have a test case over the Black Hills. He suggested as an alternative seeding a new area of activity some 50 miles south southeast of Rapid City, and I concurred. The aircraft took off at 4:38 pm. As it climbed out, Koscielski told the crew to seed some cumulus clouds just west of the airport as part of the area-seed day. When he advised me of this fact, I repeated the suggestion that no seeding of any kind should be done over the Black Hills, and he agreed. The clouds seeded near the airport did not produce any rain. The Baron crew seeded non-precipitating clouds close to existing showers between 4:58 and 5:37 pm; the seeding runs began while the test case was centered about 25 miles southeast of Fairburn, and ended close to Fairburn itself. The aircraft landed at 5:53 pm.

The second test case did not behave at all like the first one. The cells within it were persistent, and moved very rapidly toward the north-northwest. Later analysis of time-lapse photos of a radar scope suggested speeds of 35 to 40 mph for the individual cells within it. New echoes, some of them just ahead of the target clouds, developed from time to time. Depending on their proximity to the echoes making up the test case, some of the new echoes were incorporated into it, which brought the speed of movement of the center of the test case up to roughly 55 mph.

The extremely rapid movement of the second test case became understandable later when the wind data collected by the pibal operators became available. Many of the pibal data for June 9 are missing due to low clouds hiding the balloons, and the dif-

[6] Radar estimation of rainfall depends on assumptions regarding raindrop size distributions, and can easily be off by 20 or 30 percent. The numbers quoted here differ slightly from the initial estimates derived by the on-line computer for June 9.

[7] In order that the operations director not know whether it was a seed or a no-seed day, the aircraft crew always waited an hour or so after landing before contacting him to see if another mission would be ordered.

ficulties experienced by a single operator trying to track a balloon being carried by a strong wind in a hazy atmosphere. Observations at the northern pibal stations were generally limited to the first 3000 ft above the ground by the persistent cloud cover there. As the clouds broke up during the afternoon to the south of Rapid City, operators at the southern stations were able to collect wind data up to 20,000 ft above sea level in some cases. These data reveal that a southeasterly jet stream existed there during the afternoon, and extended to around 15,000 ft above sea level. The strongest wind was recorded at the station in the southern Black Hills. There the SE flow peaked at 4 pm, when it reached 75 mph around 10,000 ft above sea level.

Low-level jets are a fairly common feature of the winds over the Great Plains. However, they usually blow from the south or southwest, and do not extend to such high levels as observed on June 9.

Aided by tremendous orographic lifting, the second test case grew into a tall thunderstorm as it approached the eastern foothills. At 5:45 pm, eight minutes after seeding ended, the computerized display showed that the strongest echo within the test case was in the vicinity of Fairburn, had an echo top just above 50,000 ft, and showed a maximum reflectivity factor of 68 dbZ, which suggested a rainfall rate of several inches per hour.[8] It was not possible to be more precise, because hail shafts can also produce very high reflectivity factors. As it turned out, the June 9 storms did not produce any large hail; the radar returns from the lower parts of the clouds were from raindrops.

Other showers and storms had formed by this time. One storm (unseeded) followed a track paralleling that of the second test case but about 20 miles further to the southwest. It passed over Custer around 5:30 pm, producing some street flooding.

3.4 <u>Flood warnings and the onset of flooding</u>

The radar data that the local National Weather Service (NWS) office at Rapid City Regional Airport normally got from Ellsworth Air Force Base (EAFB) were not available during the late afternoon of June 9, so several telephone conversations took place between NWS personnel and people at the IAS radar site. [The EAFB radar was operational, but the link to the local NWS office was not working.]

Koscielski called the NWS office around 5:30 pm to advise them of persistent heavy rain southwest of Sturgis. When the 68-dbZ reading from the storm passing over Fairburn appeared on our computer output at 5:45 pm, my attention turned from the quality of data being collected on the second test case to the need to alert the public to the threat of floods along the east side of the Black Hills. Koscielski and I never considered issuing a flood alert of any kind on our own, as we had no authority to do so. Instead, I called the NWS office to tell the forecasters there that the storm to the south was producing either very heavy rain or hail, or possibly both. While it was moving so fast that it could not produce excessive rainfall accumulations at any point, the indicated peak rainfall rate of several inches per hour was a cause for concern. In line with the rules for definition of a test case, the second test case officially lasted from 5:08 to 6:08 pm. When it ended, it was centered about 15 miles southwest of Rapid City. The computerized radar system showed the total rainfall from the second test case at 4500 acre feet. That was the largest amount recorded from any Cloud Catcher case, but not, in itself, enough to cause a flood. The final analysis of rainfall amounts on June 9, prepared by the U.S. Geological Survey (USGS) showed over an inch of rain between 5 and 6 pm in a small area just south of Keystone, which is in the Battle Creek basin. That was the largest amount shown along the path of the cloud cluster seeded on the second flight.

During that same hour (5-6 pm) over an inch of rain fell from unseeded clouds on upper Rapid Creek just above Pactola Dam. At 6 pm new convective cells were still appearing on the surveillance radar screen. Some of them covered the general area of Keystone and Pactola, and rainfall began to accumulate below the dam. However, Rapid City and the Rapid Creek basin for 10 miles or so west of Rapid City remained dry.

[8] If there had been a weather channel then, using the color codes used today, the echo would have been purple, that is, one level above the deepest shade of red.

An NWS meteorologist called Koscielski again about 6:15 pm. He relayed information about street flooding in Sturgis, and asked for information on the extent of the radar echoes. Koscielski described a large north-south band of rain extending from near Belle Fourche, north of the Black Hills, to near Buffalo Gap, which is about 45 miles south of Rapid City. Peak radar reflectivity factors indicated rainfall rates in spots exceeding one inch per hour. The meteorologist told Koscielski that the NWS planned to issue a flood warning for the northern Black Hills. Relieved by that news, I left the radar site around 6:45 pm. I assumed, incorrectly, that Rapid Creek would be included in the warned area, and did not realize that the required procedures for issuing a flash flood warning would take another 30 or 40 minutes.

Koscielski and the radar crew closed down the IAS radar station shortly after 7 pm. At that time the surveillance radar still showed a long band of rain extending from south to north near Pactola Dam. Subsequent radar coverage for the local NWS office came from the NWS radar at Huron, South Dakota and from telephone contacts with EAFB radar observers. The Huron data were useful, but lacked the horizontal and vertical resolution provided by the closer radar sets. If we had known what was in store, Koscielski might have kept the IAS radar crew on duty. As it was, they dispersed for the weekend.

The last pibal observations, taken at 6:30 pm, were very sparse, due to low clouds and poor visibility. The operator in the southern hills obtained data up to 12,000 ft above sea level. His data showed that the southeast winds aloft had eased off, but were still around 40 mph. The 6 pm radiosonde at Rapid City showed a similar situation with respect to the winds, and also indicated that the atmosphere was almost saturated from the surface to above 30,000 ft. Those data were not available at the IAS radar station.

The map of rainfall accumulations between 6 and 7 pm showed an area with over 2 inches over the high terrain north of Rapid Creek, extending about 15 miles to the northwest from Johnson Siding, but Rapid City and points several miles upstream received only a few sprinkles of rain up to 7 pm. However, the surface wind, which normally diminishes toward sunset, continued to increase at an alarming rate. This was an ominous development.

After clearing their decision with a hydrologic center in Sioux City, Iowa, the local NWS staff released the flood warning for the northern Black Hills to the media around 7:15 pm. Some actions had already been ordered by local authorities to cope with the threatening situation. The sheriff of Lawrence County in the northern Hills made the first call for help; he contacted the National Guard around 6:45 pm. Rainfall totals at some places in the northern Black Hills had already reached 7 inches by that time, and it was still raining hard. With the issuance of the flood warnings, the efforts of local authorities were intensified. The civil defense office in Rapid City was activated. Police, firefighters, National Guard personnel, other public servants, and volunteers began going door to door near Rapid Creek, alerting residents to the impending danger. Their efforts undoubtedly saved many lives.

3.5 Disaster along Rapid Creek

Throughout the evening, one thunderstorm after another moved into the Black Hills from the southeast. Shortly after 7 pm, a big one, moving northwestward, brushed the southwest side of Rapid City, dropping a heavy shower. Without local radar data, details of the subsequent storm development are unclear, but it appears that this storm brought the first serious flooding to the Rapid Creek basin. As it continued northwestward, and encountered the high ground just west of Rapid City, rainfall rates under it increased from heavy to phenomenal. Johnson Siding received 4 inches of rain between 7 and 8 pm, and at places just downstream of there the hourly totals exceeded 6 inches.

It appears that by 6:30 or 7 pm, the clouds west of Rapid City had merged into an almost stationary mesoscale[9] convective system (MCS), centered near Rapid Creek below Pactola Dam, and extending some miles both north and south from there. In

[9] The term "mesoscale" refers to weather systems in the intermediate size range, bigger than an isolated shower or thunderstorm, but smaller than the highs and lows that appear on weather maps of North America.

going over the data later, IAS personnel came to call this MCS the Pactola storm, but most of the rain it produced actually fell below the dam. Large cumulus clouds continued to move into the hills beneath the overhanging clouds spreading from the top of the storm, and merge with the MCS. Without this persistent influx of moist air and cloud water, the MCS would simply have rained itself out in less than an hour. As it was, water vapor that had been over south-central South Dakota and northern Nebraska during the afternoon was carried into the Black Hills on a sort of conveyor belt to keep the rainfall process going.

Because many of the low clouds passing over Rapid City dropped little or no rainfall until they had moved beyond the city, most people in town were unaware that places only a few miles to the west were being flooded. However, the reports of heavy rainfall along Rapid Creek prompted the NWS office to extend the flood warning to include the central Black Hills, with specific mention of flooding on Rapid and Box Elder creeks. The revised warning was released to the media about 8 pm, by which time a station only 5 miles upstream of Rapid City had accumulated around 8 inches of rain.

Koscielski called me from his home east of town on two occasions during the evening. From where I lived in west Rapid City one could see some of the train of menacing, cumuliform clouds racing northwestward toward the hills, but he had an unobstructed view of them. Around 8:30 pm he estimated that the easterly surface wind at his place had increased to a sustained 40 mph, and that the low clouds were moving into the hills at more than 50 mph. He said that he thought the flood which was getting under way would be the worst on Rapid Creek "since the white men came to this country."

Meanwhile, the city remained relatively dry. Schleusener got back from his business trip, and called me from the airport around 9 pm to inquire about the situation. I told him of reports of heavy rain in the Black Hills, but that no rain was falling on Arrowhead Drive. Minutes later a heavy rain began in west Rapid City; it lasted over an hour, and brought the storm total at our house to over 3 inches. The hourly rainfall charts suggest that the MCS (Pactola storm) spread slowly downstream during the evening, reaching west Rapid City by 9 pm. However, rain continued further upstream; in fact, the heaviest rain at Pactola Dam fell between 8:45 and 9:30 pm. The rain in Rapid City tapered off by 10 pm, but the Huron radar still showed patches of rain along the eastern edge of the Black Hills at midnight. Subsequent surveys by the U.S. Geological Survey indicated that total rainfall at some places was around 14 to 15 inches.

All evening the local TV stations showed the flood warning as a crawler at the bottom of the screen, and continued their regular programming. The 10 pm newscast on KOTA mentioned heavy rain in the Black Hills, but conveyed no sense of immediate alarm. Shortly afterward, regular programming was interrupted by an announcement that all persons near Rapid Creek should move at once to higher ground. Next came an appeal for volunteers to report to Canyon Lake Dam, a small dam on Rapid Creek in west Rapid City that impounded water for recreational purposes. Debris was beginning to block the spillway of the dam, and the authorities apparently hoped to clear some of it away to save the dam. In fact, the dam was about to be washed away by the approaching flood crest. The washout occurred at 10:45 pm.

The peak flow in west Rapid City occurred about midnight and in east Rapid City an hour or so later. The U.S. Geological Survey later estimated that it exceeded 50,000 cubic feet (1.2 acre-feet) per second, about 100 times the normal flow of the creek, and roughly four times the estimated peak flow of the second biggest flood recorded on Rapid Creek, the one of 1907.

Most IAS staff members spent June 10 taking care of family business and assisting flood victims. Schleusener called around 5 pm, asking me to help with a telephone tree designed to check on the status of all IAS staff, including our graduate research associates. That job was completed in less than an hour, and produced the gratifying news that all of them were alive and well. One of the graduate students, Mel Schroeder, and his family had abandoned their house trailer during the night as water began to flow into it.

On Sunday, June 11, I took time out from family business to type a memorandum entitled "Observations on the Rapid City Storm of June 9, 1972."[10] In the evening I telephoned Flannagan to ask him whether June 9 had been a seed or a no-seed day. He told me that salt had actually been released, disappointing news but not surprising, as there were two seed days for every no-seed day.

Haggerty's department store in west Rapid City a few days after the flood. Photo courtesy Arnett Dennis.

Maralee Dennis perched on a pile of debris along Spring Creek, July 1972. Photo courtesy Arnett Dennis.

A displaced house intruding on US Hwy. 16 in Rockerville, southwest of Rapid City, July 1972. Photo courtesy Arnett Dennis

Wrecked cars near the creek in Rapid City, June 1972. Photo courtesy Arnett Dennis.

[10] This memo was included as an appendix to a report on the flood by a state Board of Inquiry.

4. The Controversy Erupts

4.1 Monday morning (June 12)

When I got to the Mines campus on Monday morning, I found that Schleusener had left town again to keep a previous commitment. That was not a surprise, as the IAS had several contracts and grants with different government agencies, and he spent a lot of time on the road. Simmons was again in charge. Two IAS group heads, Dr. Harold Orville and Smith, joined in the effort to clean out the debris in the basement of the Mines' library, which had been filled with water. That effort took several days. By the time it was completed, nearly all of the School's technical and scientific journals had been buried in a landfill.

Simmons had agreed to some temporary rearrangements of office space to accommodate persons whose offices were not usable due to loss of telephone service. I was assigned temporarily to a room on the ground floor of a dormitory.

My first task after getting settled in my temporary office was to call Dr. Archie Kahan of Reclamation in the Denver Federal Center with the good news that all IAS staff and members of their immediate families had survived the flood without injury. He was greatly relieved by the news, and expressed sympathy for the trauma we had suffered.

My second task was to make sure things were still on track for the American Meteorological Society's (AMS) Third Conference on Weather Modification, which was scheduled to begin at the Alex Johnson hotel in Rapid City just two weeks later. After checking with the hotel, I placed a call to AMS headquarters in Boston. It was good that I did so, because the person I talked to said that AMS and National Science Foundation (NSF) officials had spoken on the previous day about a perceived need to move the conference out of Rapid City. They had gotten the impression that the city was totally devastated. I told him that the regional airport had not been affected, that airline service had not been interrupted, and that airport shuttles and taxis were functioning. Furthermore, the proposed site of the conference, the Alex Johnson hotel, had not been damaged, but losing the conference would be a serious financial and psychological blow to the hotel management and staff. The final decision on that matter was to go ahead with the plans already made.

4.2 Initial media contacts

IAS personnel were no strangers to media presentations. Schleusener was a firm believer in the need to keep the public informed as to what we were trying to do. Our relationships with the local newspaper and television reporters were friendly, and IAS staff members often presented talks to service clubs, conservation associations, and the like. Both Schleusener and I had been interviewed by reporters from TV stations around South Dakota and, occasionally, by stations outside the state.

The aftermath of the flood gave me my first experience with reporters who believed, or professed to believe, that I was trying to hide something. This was during the Viet Nam war, the time of the "Pentagon papers" controversy and other issues between the Federal government and the media. The fact that the June 9 cloud seeding flights were performed under a contract with an agency of the Federal government was enough to arouse suspicion in some quarters. The infamous Watergate break-in occurred just 8 days after the flood, and the Watergate revelations over the next two years further deepened the mutual distrust between government officials and the media.

On Monday afternoon Simmons asked me to take a call from a reporter. It was the first of several. One of the callers, Frank Santiago of the Omaha *World-Herald*, asked if there had been cloud seeding on the day of the flood. I told him that clouds had been seeded along the east edge of the Black Hills. He then asked me if cloud seeding had caused the flood. I assured him that it had not, saying that the flood-producing storm was too large to be modified or controlled. Pressed further, I said I would "stake my life on it."

Santiago thanked me for talking to him, but said that he needed to talk to other people before accepting my view of the matter. He called Prof. Lewis Grant at Colorado State University in Ft. Collins, and quizzed him on the matter for upwards of half an hour. As Grant wrote later, San-

tiago kept repeating his questions in slightly different form. The basic questions were, " Is there any possibility, even the slightest, that seeding contributed to the flooding rains?," and "Don't you think there should be an official investigation into that possibility?" In his article for the *World-Herald*, Santiago quoted Grant as saying the easterly winds on June 9 "might have signaled caution." He omitted Grant's opinion that salt seeding could not have caused or increased the flood. He did include my phrase about staking my life on my opinion that seeding had no effect on the flood.
Santiago's article was picked up by Associated Press. That exposure prompted more calls, some from newspaper reporters and some from TV personnel. James Kloss of the Chicago *Daily News* called me at 2:30 am of June 13 to read me Santiago's story, and ask for my reaction to Grant's alleged comment. I declined to say anything, as it appeared that his objective was to stir up controversy.

Early on the morning of June 13, a TV crew from CBS came to the IAS offices to seek an interview with me. Apparently, my comments to Santiago were considered newsworthy. We started the interview, but, in attempting to explain what had happened on June 9, I used the expression "convective cell." That brought everything to a halt. The interviewer, Mr. Pappas, said that nobody would understand that term, and asked me to simplify. Other IAS staff members got into the discussion. Is a convective cell the same thing as a cloud? Well, not exactly. Some small cumulus clouds consist essentially of a single cell, but a thundercloud may consist of several cells, and not all of them have to exist simultaneously. Eventually, after another false start, Pappas gave up, because there was no way I could explain what produced the flood in 30 seconds or less. In retrospect, I surmise that Pappas wanted me to say merely that cloud seeding did not cause the flood, and anybody who thought otherwise was badly mistaken.

Because of the possibility of law suits related to the flood, word came down very soon that IAS personnel should not discuss the flood with reporters. Most of us found that decision welcome.

4.3 <u>Schleusener's disclaimer</u>

With Schleusener back in his office on June 13, I briefed him on the initial media contacts and the questions reporters had raised about a possible connection between the IAS experiments and the flood. He prepared a statement denying that cloud seeding had caused or augmented the flood. He emphasized that the Pactola storm had not been seeded, and also stated that, ".. it is ridiculous to think that with a few hundred pounds of finely ground table salt disbursed from a single airplane we could cause twelve inches of rain in a few hours." This statement was forwarded through channels immediately to the Rapid City mayoral office and the office of South Dakota's Gov. Richard Kneip.

The governor then issued a statement of his own, saying that he had been assured that cloud seeding was not to blame for the flood, and asking the public not to spread rumors. That could have been the end of the matter, but of course it was not. Schleusener's statement was immediately denounced as self-serving.

4.4 <u>Intervention by Fred Decker</u>

I first heard of Dr. Fred Decker, an associate professor at Oregon State University, while I was working for a cloud seeding firm in California during the late 1950s. He was opposed to attempts by commercial cloud seeders to increase rainfall in Oregon, arguing that they were ineffective. He dismissed the rainfall analyses some of the cloud seeders used as evidence of positive results as lacking statistical significance. Now he reversed course. On June 14 he wrote to U.S. Sen. George McGovern (D, SD) as follows: "That Rapid City disaster could have resulted from irresponsible or uncontrolled cloud seeding, if one believes any fraction of the claims advanced by the cloud seeders and their university and Federal agency sponsors.....I urge appointment of a Presidential Commission to determine the facts in this case.....Human lives should not be snuffed out because scientists need the results of experiments.....I provide this suggestion in the spirit of one who believes you sincerely want to avoid having Fed eral funds provide the means for causing such homicide, if indeed the flood was possibly caused by cloud seeding."

Schleusener sent a copy of his June 13 disclaimer to Sen. McGovern, who responded with a note of thanks dated June 16. In it he noted that, "We have received a good deal of Mail (sic) from around the country - and from South Dakota - charging the heavy rain to 'cloud seeding.'"

Decker sent a letter to Gov. Kneip very similar to his letter to Sen. McGovern. His view of cloud seeders was expressed even more bluntly in a letter to the Omaha *World-Herald*, which was published in early July. "I (Decker) have for a long time been a skeptic of the cloud-seeders' tactics. I am not alone in my low esteem of these promotional and irresponsible operations, despite the fact that important agencies and officials of the federal establishment have underwritten financial support for these 'experiments' in weather modification..... In recent years the Bureau of Reclamation has sought control over the huge federal funding in this area and has sponsored various controversial projects, including one which was feared to be a critical avalanche producer in Colorado."

4.5 Krick weighs in

Most persons outside the cloud seeding fraternity in 1972 were not aware of the differences of opinion that existed within it. There was a controversy in Oklahoma, where the activities of the Water Resources Development Corporation (WRDC), a commercial cloud seeding firm controlled by Dr. Irving P. Krick, were hampered by the presence of experiments being conducted by state agencies as part of Reclamation's Project Skywater. Some of those experiments had involved the use of salt as a seeding agent.

Ferd Deering, the editor of the *Oklahoma Farmer* magazine, was a supporter of Krick. He thought that the presence of the state research program was depriving farmers of benefits they could have had from operational programs. After the June 9 flood, he wrote to Krick, asking if salt seeding could have contributed to the flood. Krick responded with a letter in which he stated that cloud seeding could well have contributed to the disaster. He emphasized that this was only a preliminary conclusion, and that the matter required further study.

The WMA met that fall in Ft. Collins, Colorado, with Krick in attendance. He did not present a formal paper, but entered into some of the discussions. He expressed concern that salt seeding might have contributed to the flood, but presented no plausible hypothesis as to how that could have happened. If I recall correctly, he mentioned the fact that the latent heat of condensation is greater than the latent heat of fusion for a given mass of water, and implied that this fact makes hygroscopic seeding more dangerous than seeding with ice nuclei, such as silver iodide. I found this fact irrelevant. Salt seeding does not increase the amount of condensate in a cloud, so it can not result in the release of additional latent heat. I wondered if I had misunderstood, or if Krick had misspoken, but found later that he had expressed the same opinion in a letter to Schleusener. I am baffled still over the fact that a leader in the field of commercial weather modification would raise such a misleading argument.

5. Reactions by Reclamation Scientists

Reclamation officials in Washington and officials of Reclamation's parent organization, the U.S. Dept of the Interior, were concerned with the possibility of legal complications arising from Reclamation's sponsorship of the June 9 cloud seeding flights, and directed Kahan to investigate the circumstances and make a report. He sent two members of his staff, the contract monitor, Raymond B. Girardo, and Dr. Wallace Howell,[11] to Rapid City to interview IAS staff about the events of June 9, and to look at the documentation that was available about them.

IAS personnel involved in the Cloud Catcher experiment met with Dr. Howell and Girardo to go over the available data. We looked at time-lapse radar data, logs from the seeding aircraft, and the general weather situation of June 9. Of particular interest were the radar-based estimates of the total

[11] Wallace Howell will be referred to as Dr. Howell to avoid confusion with a David Howell, who appears later in this story.

rainfall from the test cases, integrated over space and time. The first case of June 9 dropped about 1300 acre-feet of rain, and the second case dropped about 4500 acre-feet.

We had developed regression equations relating total rainfall from a shower to the cloud depth, that is, the distance between the cloud top as determined from radar and the height of the cloud base. The relationship is not linear, so data transformations were employed. A good correlation was found between the cube root of the total rainfall and cloud depth, so a regression line comparing those two variables was being used to estimate what the test cases might have yielded in the absence of seeding. One of the June 9 cases fell below the regression line, and one above it.

All of us were aware of the limitations of regression analyses. Statistical analyses of any type are useful in identifying trends in data, but can not lead to exact answers about individual events. In addition, the June 9 clouds were outliers. They were deeper than any others we had used as Cloud Catcher test cases, so the points representing them were at the right hand side of the scatter diagram. Confidence limits are weakest for points at the extreme left and right sides of a scatter diagram. All one can say is that the rainfall from the June 9 test cases was in line with expectations based on the observed cloud depths.

Our first meetings with Dr. Howell and Girardo involved only them and IAS staff. Schleusener organized a larger meeting, held on June 16, to expose the discussions to other interested parties. About 30 people were involved, including Pres. Harvey Fraser of Mines, Merlin Williams of DWM, Dr. Howell, and Girardo. IAS staff members presented an overview of the events of June 9, and answered questions about the possibility that seeding had contributed to the severity of the storms.

Preliminary estimates of the total rainfall in the Black Hills on June 9 were coming in between 400,000 and 500,000 acre-feet. Therefore Dr. Howell and Girardo agreed with us that the 6000 acre-feet measured in the two test cases combined did not contribute significantly to the rainfall totals for that day, and any possible increases in the test cases due to seeding would be even less important. They also concluded that the seeding did not cause the flooding rains that followed a short time later. Their findings were reported to Kahan and relayed to his superiors. The Reclamation office at Billings, Montana assembled a lot of material, including the Dr. Howell-Girardo findings, and distributed copies of it in September 1972.

Several coauthors at the IAS and I began work later that year on a more complete report to Reclamation. The first attempt, entitled “Precipitation mechanisms in the Black Hills flood of 1972,” was sent to Reclamation for review, and they sent it to some outside reviewers. In part because of the possibility of lawsuits related to the flood, a consensus was reached that the report should not discuss the seeding flights or speculate on details of the precipitation processes involved. The final version of the report was submitted to Reclamation under the title “Meteorology of the Black Hills flood of 1972” in September of 1973, and Schleusener presented a paper based on it at an AMS conference on severe local storms that same fall. The report is still a useful reference, as it pulled together a lot of information about the weather conditions over South Dakota on the day of the flood.

6. The State’s Board of Inquiry

State officials in the South Dakota Weather Control Commission (SDWCC), the DWM, and elsewhere decided soon after Gov. Kneip’s press release of June 13 that an outside review was needed. Acting in consultation with Williams of DWM, the chairman of the SDWCC, Burton Ode, therefore appointed a three-person Board of Inquiry (Board) to review the events of June 9, and submit a report. The governor gave his authorization to proceed on June 19, and the Board began work on June 21.

The Board was chaired by Dr. Pierre St. Amand, a geophysicist, who headed a research group at the Naval Weapons Center at China Lake, California. His group had investigated cloud seeding for military objectives, in particular, as a means of hindering the transport of war material into Viet Nam along the Ho Chi Minh trail. The other Board members were Robert Elliott, the long-time president of North American Weather Consultants, and Ray Jay Davis, a lawyer who was active in the WMA.

The Board members set to work with a will. They decided that they should have a report ready to present at the AMS Third Conference on Weather Modification, which, as already noted, was set for the last week of June. St. Amand and Davis arrived in Rapid City on June 21, accompanied by Williams and Jack Donnan of the state's DWM. Elliott arrived the next day. The Board members spent their time in Rapid City interviewing IAS staff members and others, amassing a large amount of data, and drafting a report. They worked through the weekend, and had their preliminary report ready in time to meet their ambitious objective.

The AMS conference got under way on schedule on the morning of June 26. As program chairman, I had arranged weeks earlier for Rapid City's mayor Don Barnett to deliver a welcoming address to open the proceedings. When I called his office to confirm that arrangement a few days before June 26, I feared he might beg off, pleading the multitude of things demanding his attention. It was a pleasant surprise to learn he had kept the date on his calendar. He did appear, and gave the attendees a quick summary of the many processes that had been set in motion to speed the city's recovery. It was an amazing performance for a 29-year-old man who had such great responsibilities thrust upon him.

The conference itself went off very well. Many interesting papers were presented and discussed. On the evening of June 28 the attendees enjoyed a buffalo barbecue at the State Game Lodge in Custer State Park, and were bussed to Mt. Rushmore to view the lighting ceremony. The official program ended at noon on June 29, but many people stayed in the meeting room to hear St. Amand present the preliminary Board report on the impact of cloud seeding on the flood.

St. Amand did quite a masterful job. The report was critical of the decision to launch a second seeding flight on June 9, but concluded that, "In the absence of seeding, the result would have been the same." Discussion of the report was surprisingly brief. One person noted that the Board members were not necessarily disinterested outsiders.

The printed "Report on Rapid City Flood of 9 June 1972" by the Board of Inquiry was dated June 27, 1972, and distributed incorporating an introductory letter from Williams dated July 5, 1972. My memo of June 11, "Observations on Rapid City Storm of June 9, 1972," was included as Appendix A.

Williams sent a copy of the report to the IAS with a request for comments. Schleusener and I went over it carefully. We were greatly impressed with the work that the Board had done, and agreed with its principal findings. However, as we studied it, we became aware of some shortcomings.

The report stated that many floods had occurred on Rapid Creek since the city was founded in 1878, and gave a list of the principal ones. It seemed as though the authors were trying to say that the June 9 event was not all that different from previous ones. It is only fair to note that Schleusener had made a similar point in his disclaimer of June 13. However, as already stated herein, the peak flow on Rapid Creek in 1972 exceeded anything recorded previously. Furthermore, most of the big floods mentioned in the Board's report occurred before Pactola Dam was built. Old newspaper accounts suggest that some of the historic floods were due to heavy rain in the upper reaches of the Rapid Creek drainage, and that the flood waters took 24 hours or more to reach the city. The June 9 flood crest reached west Rapid City less than four hours after the beginning of the heavy rain below Pactola Dam. The June 9 event was unique, as far as the historical record is concerned. Something similar may have happened centuries ago, but there is no way to know for sure if that is the case.

Another curious thing about the report was the inclusion of a calculation of the amount of water that could have condensed around the salt particles released on June 9. The apparent aim in presenting it was to show that the amount of water condensed on the salt was trivial compared to the rain that fell, thus supporting the assertion that, "…the result would have been the same." However, the calculation is irrelevant, and potentially misleading. There is **no** extra condensation due to salt seeding. The water that condensed on the salt particles released on June 9 would have condensed on the natural cloud condensation nuclei (CCN) as soon as the air carrying it rose above cloud base. The purpose of salt seeding was not to increase the amount of condensate, but to speed the appearance of the first droplets large enough to function as raindrop embryos, thus causing the clouds to rain sooner.

There were also some mildly disturbing comments to the effect that the operations director (Koscielski) was concentrating on the test cases and ignoring the larger picture, which was presented to him on the surveillance radar.

Our most serious reservation about the Board report was the statement that some of the salt released might have been carried into "the main storm." This statement was emphasized by a diagram, which purported to be a vertical cross-section of the atmosphere over the Black Hills at the time of seeding. It showed a single, tremendous thunderstorm centered squarely over the Black Hills, its dimensions distorted by the expanded vertical scale so that it looked almost as tall as the horizontal extent of the hills. It seems that by "main storm" the authors meant the MCS that settled over Rapid Creek between Pactola and Rapid City around 6:30 to 7 pm. No such storm existed when the seeding flights were made. Instead, there were several showers and thunderstorms scattered around the east side of the Black Hills. Furthermore, the large MCS that produced the flooding on Rapid Creek was not centered over the highest terrain, but over the eastern slopes of the Hills.
Schleusener wrote a letter to Williams on July 11 summarizing our concerns, but no revisions were made to the report. As it had already been made available to a wide audience, issuing a revised version might only have added to the confusion that already existed. The report was included as one of several appendices to the report issued by the Reclamation office in Billings in September, with the word "preliminary" crossed out on the title page.

The decision to rush the preparation of the Board's report probably was not the best way to go, but it did not matter much anyway. The Board's report did not settle the issue of causation any more than did the statements of Schleusener and Gov. Kneip on June 13. Those who regarded Schleusener's statement as self-serving thought the same about the Board's report, reasoning that it was a case of the cloud seeders sticking together to protect their own interests. They were not convinced by the Board's conclusion that cloud seeding did not contribute to the flood. Indeed, people who suspected that cloud seeding had done so could find sentences to bolster their thinking, e.g., "…seeded clouds marched into the main storm." Others noted that, contrary to what the report implied, the 1972 flood was not just a typical flood on Rapid Creek. On the whole, the report had negative impacts, not only on the IAS, but on all persons attempting to develop cloud seeding technology.

7. Further Elaboration in the Press

7.1 Background

Although IAS personnel stopped talking to media representatives, some writers continued to link cloud seeding to the flood, often using pejorative language. For example, the powdered salt, which was actually distributed in updrafts below developing, non-raining clouds, sometimes near existing showers, was described as being dumped, or "recklessly dumped," into clouds that were already raining. On the other hand, some meteorologists played down the possibility that cloud seeding augmented the flood.

The status of the literature on weather modification in 1972 was such that a person could find something in the literature to support almost any point of view about the effects of cloud seeding. Cloud seeding had been proposed as a way to disperse fog, to increase mountain snow packs, to increase rainfall, to suppress rainfall, to suppress hail, to suppress lightning, and to reduce winds associated with local thunderstorms and tropical hurricanes. Several groups had conducted experiments to see if one or another of these objectives could be realized, but conclusive results were hard to come by. Numerical cloud models to test some of the conceptual models were being developed, but the models were still primitive.

Scientists active in the field were generally able to distinguish between untested conceptual models, the output of numerical experiments run in computers, and those field experiments which had been run long enough and carefully enough to permit a meaningful statistical search for evidence of seeding effects. However, even among them, there were serious differences of opinion. Those that had a meteorological background tended to think that cloud characteristics were determined by the prevailing atmospheric conditions, notably the 3-dimensional wind field, static stability, and moisture supply. Others, including some cloud physicists and cloud modelers, paid more attention to the dynamics of cumuliform clouds, and how the dynamics might be affected by artificial freezing of supercooled cloud water. Their contributions to the literature tended to emphasize the possibility of seeding to increase cloud heights, promote cloud mergers, and prolong cloud lifetimes. Several articles in the popular press emphasized the possibility of such effects, without much consideration of the types of clouds existing on June 9, or the differences between the effects of salt seeding and those produced by seeding with silver iodide. Some of the letters, columns, and articles that came to our attention are described below.

7.2 Lewis Grant

The telephone call of Santiago to Grant has been mentioned above.

Grant was so dissatisfied with Santiago's rendition of their June 12 interview that he contacted a Ft. Collins newspaper, *The Coloradon*, to present a clarification of what he had said. *The Coloradon* carried the resultant story on June 15 under the headline, "CSU weather expert negates implied cause of heavy rains." The story under the headline included the following: "He (Grant) also pointed out that the experimenters used salt and not silver iodide to seed the clouds. Silver iodide 'can travel great distances' from the seeding point, but salt works only on the cloud to which it is applied, Grant explained."

Grant wrote a letter to Schleusener on June 21 with further explanation of how the interview had gone, and disowned the "might have signaled caution" quote.

7.3 H.J. Thompson

The first published description of the weather situation of June 9 to come to our attention was that by H. J. Thompson of the NWS Office of Hydrology.[12] It made no reference to the cloud seeding flights on that day, but concentrated on the features of the weather map that might give a clue to what happened. However, as he noted, "On the whole, there appeared to be no significant strong indicators in the broad-scale features of these charts suggesting that an exceptionally heavy rainfall was in the making." I do not think that he was aware of the existence of the pibal data collected that afternoon.

He noted that excessive rainfalls have occurred in non-orographic situations as well as in hilly terrain. "…[T]he thunderstorm mechanism itself, unaided by orography, is capable of producing the largest observed rains for durations of six hours or less."

Thompson took an interesting approach to the question of whether the 1972 flood was a 100-year flood, a 500-year flood, or whatever. Because the flow of Rapid Creek was altered by the construction of Pactola Dam, statistics of observed stream flows at Rapid City are useless for such a study. Therefore, he approached the problem by looking at the rainfall amounts on June 9, as virtually all the rain that fell ran off in just a few hours. He concluded that " …the rainfall amounts which caused this flooding are unlikely to occur more than once in several thousand years. The 100-year, six-hour rainfall expectancy varies from 3.0 to 3.5 inches throughout the Black Hills." Some IAS meteorologists expressed the view that the 100-year six-hour expectancy is more than 3.5 inches, but the approach seems reasonable. Leaving aside the fruitless exercise of arguing whether the 1972 flood was a 100-year or a 500-year event, it is safe to say that it was a rare event, the greatest "since the white men came to this country."

Thompson's article contains one apparent minor mistake, where he says, "….the gates of Pactola Dam were closed at the onset of heavy precipitation[13], runoff from above the dam was held in the reservoir and the flood producing runoff came from a drainage area of 51 square miles above the

[12] Thompson, H. J., 1972: The Black Hills flood, Weatherwise, Vol. 25, 162-167, 173.

[13] I repeated the mistake in a paper published in the *Journal of Weather Modification* in 1993.

Canyon Lake gage.…" An appendix to the catch-all Reclamation report released in September indicates that, due to disrupted communications, the gates were not actually closed until about midnight. However, Thompson's conclusion on this matter stands: Releases from Pactola were an insignificant part of the flood crest.

7.4 Peter Metzger

Dr. Peter Metzger, a free lance writer, called Schleusener on August 4 to gather information for a column about the flood. He told Schleusener that he was attempting to sell himself as a regular writer for the New York *Times*, and expected to include his comments on the Rapid City flood as a sample of his efforts. The column he wrote appeared in the Denver *Post* on September 24, 1972 under the heading, "Did cloud seeding swell Rapid City deluge?" The by-line stated that, "Metzger is a Boulder resident with a Ph.D. in biochemistry."

Metzger's column included a reproduction of a preliminary map of June 9 rainfall totals prepared by the USGS. It showed two broad maxima of rainfall, one northwest of Rapid City and one to the southwest. Metzger invited readers to draw the conclusion that the two maxima, of about 15 inches each, were the result of the two cloud seeding flights of June 9.

IAS personnel found Metzger's suggestion absurd. The number of apparent rainfall maxima on a chart depends on the spatial resolution of the data and the number of isohyets drawn. The final charts produced by the USGS showed not two, but eight or nine, rainfall maxima in the flood-stricken area.

Robert Yaw of Montana State University commented in a letter to the editor of the Denver *Post*, which was published on October 8, 1972, that the two broad rainfall maxima were most likely the result of orographic effects, one being over high ground well north of Rapid Creek and the other over high ground to the south of the creek. He also noted that Metzger might have missed that point, because he (Metzger) was not a meteorologist. The argument continued, as E.J. Ramaley of Denver, in a letter published in the *Post* in October, attacked Yaw for questioning Metzger's ability to discuss weather modification in an intelligent fashion.

Metzger's column contained other points which were troubling. He asserted that the purpose of the IAS experiment was to make rain, which was true in a way, but not exactly true. If we had wanted to make rain on that particular day, we would likely have seeded with a proven seeding agent, probably silver iodide. We were trying to find out if salt seeding could produce detectable effects on isolated cloud clusters. The technology of salt seeding was primitive. Metzger also questioned the accuracy and honesty of IAS statements about the flood. He quoted some damaging phrases from the Board of Inquiry report, such as, "The seeded clouds marched into the main cloud mass," while ignoring the main conclusion of the Board's report, which was, "Weather modification activities by the IAS did not contribute materially to the flood."

Schleusener summarized our reactions to Metzger's column in a memorandum for the record dated October 4. In a memorandum to Pres. Fraser on October 11 he emphasized again the disconnect in time between the seeding flights and the onset of heavy rains along Rapid Creek.

Schleusener could not go public with his memorandum because of the possibility of law suits. Therefore Metzger could publish anything he liked with no effective rebuttal, and his writings did shape public opinion. In a letter to the editor of the Rapid City *Journal* published on October 30, J.E. Story of Rapid City mentioned Metzger's column, and said, "I feel sure that the Institute of Atmospheric Sciences will deny any connection between the experiments in seeding and the flood."

Undeterred by Yaw's criticism, Metzger succeeded in getting his column published without major revisions in many newspapers besides the Denver *Post*, but not in the Rapid City *Journal*. It seemed that, as the column was recycled, the headlines became more ominous. The Los Angeles *Times* published it on November 26, 1972 under the headline "South Dakota flood ----Was it man-made?," and a subheading, "Seeding shows up on rainfall maps." The Kansas City *Star* followed on February 28, 1973 with a more positive headline, "Data indicates (sic) seeding contributed to big flood."

Metzger was also pictured and quoted extensively in the article published in *The National Tattler* of December 24, 1972, which reprinted rainfall maps for June 9. That article, headlined "Govt. weather tampering is causing world floods," portrayed Reclamation's Project Skywater as part of an ominous plot to control weather on a global scale. The article quoted an anonymous expert, "who asked that his name not be revealed."

One can only admire Metzger's persistence in spreading his views. I would estimate that for every person who ever read an IAS publication related to the flood, there were many thousands who read one of his columns.

7.5 Jack Reed

Considering how important the flood was to public perceptions of the potential benefits and risks of cloud seeding, it is amazing in retrospect how passive the AMS was in dealing with the allegations that cloud seeding contributed to the flood. The AMS issued no official statement covering the matter. Instead, the AMS allowed the issue to be debated in letters to the editor of its monthly *Bulletin of the AMS*.

Jack Reed of Albuquerque, a meteorologist employed by the Sandia Corporation, kicked off the discussion by sending to the *Bulletin* a draft paper entitled "Cloud seeding at Rapid City - A dissenting view." He was so anxious to put his views before the public that, without waiting for peer review, he sent the draft to 41 people in various walks of life, with a cover letter dated September 12, 1972.

I have looked at some of Reed's work on the Internet. Much of it deals with the effects of nuclear blasts and how those effects are influenced by atmospheric conditions. Perhaps that explains his tendency to view clouds as unpredictable and dangerous things, and his frequent resort to such concepts as "triggers" and cascading chains of undesirable effects due to cloud seeding.

The paper was a rambling sort of thing. Reed said he was not arguing that the clouds seeded on June 9 caused the flood, but hypothesized that they had "amplified progeny," and therefore augmented it. He invoked speculative ideas drawn from the literature on cloud seeding, including cloud mergers due to dynamic effects of seeding with silver iodide. It appears from the paper that he was at the Third Conference on Weather Modification, although I do not recall meeting him there. Speaking of rainfall maps shown at the conference, he wrote, "On review of these materials, however, it was NOT OBVIOUS that seeding operations could not have significantly affected the storm pattern." [Emphases as in original.] Actually, the maps were not intended to prove anything, pro or con; they were provided for information purposes only.

Reed's draft paper had some factual errors. For example, it said that the choice of seeding agent on June 9 was random, and that the salt seeding was intended to inhibit hailstorms. Reed noted the erratic nature of plumes of seeding agents under some weather conditions. That was not news to IAS staff, and was one reason why we seeded updrafts below target clouds instead of broadcasting seeding agents to drift with the wind. He also mentioned that some storms propagate at an angle to prevailing winds, which was also old news.

Reed summarized his opinion as follows: "Thus, there could have been a succession of increasing strength progeny of the seeded clouds, which propagated north and up the line of the Black Hills, and to the right of the mean wind direction. This could have caused the majority of the storm rain, or at least contributed substantially to the net rainfall that flooded areas outside Rapid City. This could have been the last straw, or 'trigger' that set off the Rapid City flood." Reed followed up this "conclusion" with a benefit-cost analysis, in which all 256 people reported to have died in the flood were counted as a cost of cloud seeding. This type of analysis would be familiar to anyone investigating the theoretical hazards associated with nuclear power plants.

Reed's draft article was sent out for review, and drew some very harsh comments. The response of the Board of Inquiry members included, "Reed has provided no data and has not provided a statistical test." Nevertheless, St. Amand thought that Reed should be allowed to have his say. Schleusener and I could not say what we really thought, namely, that the use of the term "progeny" was faintly ridiculous. "Progeny" means "offspring." Clouds are not alive. Those that appear in an area at a given time are not the children or grandchildren of the clouds that existed there previously. We could only say that Reed's "hypothesis" was not testable, because he had not offered any suggestion as to how a salt-seeded cloud could have amplified progeny. Several of the other reviewers also recommended against publication.

The editor suggested that Schleusener might help Reed in preparing a revised draft. Schleusener declined to do so, but Reed was undeterred. On October 25, 1972 he submitted a modified manuscript, which also was sent to reviewers. After receiving some additional comments recommending against publication, the Editor decided it should be cut down and submitted as a letter. Reed complied, and sent in his letter in December. It was published in the July 1973 issue of the *Bulletin*.

A letter by Schleusener and me, published at the same time, read in part: "These views expressed by Reed can never be refuted in a manner satisfactory to him. By postulating 'unknown and unsuspected effects of cloud seeding,' he moves away from scientific argument into a region of speculation beyond the reach of rational inquiry or scientific experimentation...We find the second part of Reed's letter a rather macabre and unnecessary exercise. If we believed that the cloud seeding experiments on 9 June 1972 killed over 200 people, we would cease field experimentation forthwith, rather than try to work out an 'acceptable' benefit-risk ratio."

The fact that Reed's letter was published in the *Bulletin* gave it a certain amount of credibility, and subsequent writers were able to quote it as providing a scientific link between cloud seeding and floods.

7.6 <u>David Howell</u>

David Howell's article about the flood appeared in the May 12, 1973 issue of *Environmental Action*, under the title, "It was an 'act of God' - with a few grains of salt."

In his article Howell argued that salt seeding could have increased the precipitation efficiency of the flood-producing clouds. He quoted from an article coauthored by Koscielski and me, in which we wrote that radar and gauge measurements "suggest that salt seeding produces substantial increases in rainfall." He failed to note that we were talking about results from a data base that was limited to small or medium sized clouds. He also noted that, once a cloud starts to rain, it "may remain efficient for the remainder of its life." That statement is true, but it applies to both seeded and unseeded clouds.

Howell also quoted Dr. Charles Hosler of Pennsylvania State University to the effect that an unstable atmosphere can be a delicately balanced thing. This quote is puzzling, because the atmosphere on June 9 was not "delicately balanced."

Howell went off track completely when he began to write about the release of heat when haze "condenses into raindrops." In reality, raindrops are formed, not by condensation, but by coalescence of cloud droplets. Furthermore, it is water vapor, not haze, that condenses to form the cloud droplets. Haze particles, if involved at all, function only as cloud condensation nuclei (CCN).

Following are some direct quotes from Howell's article: "If such minor 'perturbations' can induce such major changes, as Hosler contends, how can the Board of Inquiry (or anybody else) rule out the possibility that the 'perturbations' introduced by the cloud seeding - condensation of haze into drops of rain which in turn releases heat and causes other raindrops to form, which in turn affects cloud weight, altitude, velocity, etc. - might have had a significant effect on the outcome of the Rapid City storm?…Such a series of events 'is certainly possible' agreed Dr. Lewis Grant, meteorologist at Colorado State University in Boulder (sic)...The presence of the haze in itself, he noted, indicates that the condensation nuclei - minute specks of moisture not big enough to fall as rain - were not going to coalesce into raindrops on their own any time soon. 'This is the ideal condition under which you could promote [rainfall] artificially,' Dr. Grant contended. 'Because you couldn't get a coalescence process going naturally, artificial seeding is the only way you *could* get the process going.'"

This conclusion is completely opposed to the view of most cloud physicists, which holds that dense haze can indicate a supply of large, natural CCN, suited to the formation of large cloud droplets, which could grow into raindrop embryos in 10 or 15 minutes.

Howell questioned our definition of a test case as lasting for one hour. In late 1972 he telephoned Koscielski on this point. Koscielski pointed out that, in a sense, it would be a different cloud after an hour, because all the convective cells in it at the start would have completed their cycle of activity, and the water substance in the cloud, if it lasted that long, would all represent freshly condensed water vapor. Howell did not buy it. Instead of admitting that what Koscielski said might have some basis in reality, he dismissed Koscielski's explanation in his published paper as a "self-serving, facetious and misleading assertion." Some IAS staff members found that shocking. We were used to vigorous discussions at meetings, sometimes pointed out possible or perceived errors in speakers' presentations, but never accused them of deliberately withholding or falsifying data.

But Howell was not finished. He went on to talk about how rain "quickly intensified" after seeding runs, and came to the following conclusion: "The seeding seems to have turned the clouds to four heavy rain generators that came together over the Keystone/Sheridan Lake/Pactola Dam area where unique wind and weather conditions would keep them sitting for hours, pumping out the torrent that would roar down the mountains with death and horror riding at its crest."

After some further confusing discussion, Howell pronounced his conclusion: "Because of the almost infinite variables that go into the making of weather, there is no way it can be proved that the hypotheses put forward in this analysis actually account for the horror of Rapid City on June 9, 1972. What has been demonstrated is that they in fact could have. The steadfast denials on the part of those connected with the project and their self-serving twisting of facts and conclusions smacks of nothing less than a meteorological Watergate."

Howell's article was introduced into the *Congressional Record* by Sen. James Abourezk (D-SD) on May 31, 1973, along with a speech by Williams of the DWM. The inclusion of Howell's article in the *Congressional Record* was a source of profound embarrassment for Schleusener and Gov. Kneip, both of whom were on record as saying that cloud seeding had not contributed to the flood. Possibly because of its inclusion in the *Congressional Record*, Howell's inaccurate statements have been referenced in books released by prestigious publishers.

As noted above, Howell's article was confusing on the role of haze particles in cloud formation, and the quotes he attributed to Grant did not seem to make sense. Therefore Schleusener wrote to Grant for some clarification, and Grant replied in a letter dated July 12, 1973. In the letter Grant explained that Howell had telephoned him on January 22, February 8 and February 20. Howell wanted information on the Langmuir chain reaction, among other things. Quoting Grant, "I vaguely remember a very side conversation in which he made some outlandish comments to the effect that the salt seeding was the likely cause of the flood since there was a heavy haze on that day." Grant also wrote that in one of the later calls, Howell "called back and said that the 'experts' were all trying to protect weather modification and the School of Mines and thus wouldn't provide him with information." Howell wanted Grant to review his paper, and sent Grant a draft. Grant's reaction was, "After seeing the article it was obvious that it would be a major job to prepare comments since there were so many suppositions and assumptions, and in some cases obvious inaccuracies." Grant did not provide a review, but that did not prevent Howell from quoting (or misquoting) him.

Schleusener wrote to Gov. Kneip on July 27, reiterating his views of June 13, 1972 and sending several documents, including a copy of Grant's letter.

7.7 David Hacker

The tendency of writers to downgrade the capabilities of IAS personnel was not limited to our meteorologists. An article by David Hacker, entitled "A law suit grows from cloud seeds," appeared in *The National Observer* for the week ending June 7, 1975. Hacker had come to Mines to get information about the flood. When he asked about the pilot of the seeding aircraft, I told him that the pilot, Flannagan, was still on the IAS payroll, and happened to be in the building doing some drafting at that very moment. Hacker talked to him for a short time, and made him the central figure in the opening paragraphs of his story. However, he either neglected to ask about Flannagan's qualifications, or got things mixed up. Flannagan, a former pilot of the U.S. Marine Corps, who had retired with the rank of Major, and whose resume included piloting a helicopter carrying Pres. Eisenhower from Andrews AFB to the White House, was introduced to readers of the *National Observer* as a "draftsman who flies avocationally."

The rest of Hacker's article was quite well done. It included a brief description of the cloud seeding flights of June 9, 1972, with quotes from the Board's report. It also included quotations from Horace Jackson, a Rapid City lawyer, who represented plaintiffs in a law suit that had just been filed against the Government, and general comments about long-range prospects for the application of cloud seeding technology.

7.8 Summary

As the above items show, it was easier to get stories about the flood published if they pointed out the possibility that it was due to cloud seeding. The few items denying the connection did not sell as well, and were generally condemned as self-serving.

Many people in South Dakota saw a possible connection between cloud seeding and the June 9 flood. It is impossible to say how many of them were led to think that way because of the articles in the popular press. In any case, the general public in Rapid City kept its cool, and was very sympathetic to IAS personnel throughout the post-flood period. There were no threatening telephone calls that came to my attention. There were only two letters that qualified as hate mail, and they contained no threats. One of them was from the Chicago area, and was apparently triggered by an article in a Chicago newspaper. Instead of threats, we received many letters, some of them from atmospheric scientists in foreign countries, extending sympathy to us and the other residents of Rapid City.

8. Legal Actions

8.1 General considerations

From the day that the flood happened, Mines and Reclamation personnel were acutely aware of the possibility that legal actions, including lawsuits, might be initiated to compensate flood victims for the losses they had suffered. Rumors abounded, including one about a law firm in Sioux Falls that was supposedly looking for potential clients among flood victims and survivors.

Plaintiffs in a civil suit are supposed to prove the validity of their claims beyond any reasonable doubt. In view of the great variability of natural precipitation, it is impossible to determine the exact effect of cloud seeding on any particular day. It might seem, therefore, that the plaintiffs faced an impossible task. However, the fact that the U.S. Government was a potential defendant in the case could have changed that. Its supposedly limitless financial resources might cause sympathetic jurors to relax the scientific standards a bit, and find for the plaintiffs. The results of a public opinion poll taken in South Dakota in late 1972 were not reassuring to the defense team. About 30 percent of the people interviewed thought that there was some relationship between cloud seeding and the flood, while 4 percent saw seeding as the flood's sole or primary cause.

We were curious to know what expert witnesses the plaintiffs might secure who would say that cloud seeding augmented the flood. As early as 1972 Horace Jackson, a Rapid City attorney, had asked Grant if he would become a consultant on the case. Grant, who was already on record as saying that salt seeding could not have caused the flood, declined the offer. One other prominent atmospheric scientist told me years later that he had been contacted to see if he would testify for potential plaintiffs, but had also declined to do so.

I do not know if the plaintiffs ever contacted Krick, who was already on record as saying that cloud seeding might well have contributed to the disaster. While his reasoning was flawed, in my opinion, his air of complete self-confidence would have made him a convincing witness.

Mines had an insurance policy covering the effects of the IAS cloud seeding experiments up to a limit of $2,000,000. The insurance policy was obtained through a local insurance agency, and issued by Towers, Perrin, Forster and Crosby, Inc. of San Francisco. The certificate number for the basic policy was L-1472L. Policy was effected through E. W. Payne and Co. of London with underwriters at Lloyd's of London. The U.S. Government was a named additional insured.

The insurance policy was renewed effective May 15, 1972, and so was in force on June 9. Schleusener advised Towers, Perrin by telephone that the flood had happened, and might result in claims against the insurers. However, it was obvious that claims based on the events of June 9 could far exceed $2,000,000. There was some anxiety among IAS and Reclamation employees over the possibility that they might be named personally as additional defendants in any potential law suit, although their pockets were not deep enough to present an inviting target. It appeared more likely that any law suit filed would be against some government agency. Would it be the State of South Dakota, the U. S Government, or both? South Dakota law makes it very difficult to pursue a suit against the State, so the U.S. Government appeared to be a more promising target.

8.2 Administrative claims

The legal situation developed very slowly, and only a few persons ever sought compensation for their flood-related losses. The heirs of several persons who died in the flood filed six administrative claims with Reclamation's Project Manager at Huron, SD on June 7, 1974, seeking a total of almost $4,000,000 in damages. The claims were filed by Jeff Masten, who bore a letter of introduction from Sam Masten, an attorney at Canton, SD. Five of the claims were signed by attorneys, and one by Agnes Lunsford, Administratrix for the estates of T. and Alice Gall. The claims erroneously identified the June 9 cloud seeders as Reclamation employees. The claims were forwarded to Mr. Bielefeld, a field solicitor for the Dept. of Interior at Billings, MT.

Because the Government was an additional named insured under the Mines insurance policy, Bielefeld advised the insurance company (Tower and Perrins) that the claims had been filed. The insurance company engaged a New York City law firm, Condon and Forsyth, to represent it. Lawrence Mentz of that firm wrote to Bielefeld on July 29, 1974 accepting responsibility for the case, as the following quotes indicate: "We have been instructted by Underwriters to protect the interests of the assureds.... We assure you that the interests of the United States will be adequately protected in this matter…" Mentz immediately started collecting material related to cloud seeding and to the claims. Some lawyers raised the point that five of the claims were signed by attorneys rather than the claimants, without any signed power-of-attorney forms attached. However, the Interior solicitors accepted the claims as valid, and began to prepare a response. Mr. Desmul of the solicitor's office in Billings visited the IAS on August 2, 1974. Simmons and I briefed him on the principles of cloud seeding and the events related to the flood[14].

Obviously, the State of South Dakota also had a legitimate, powerful interest in the disposition of the claims. The Attorney General of South Dakota at the time was William Janklow. He assigned Asst. Atty. General Earl Mettler to keep track of the progress of the claims through the administrative process. Simmons kept him informed of the events that followed.

Reclamation denied all six claims related to the flood in a notice dated December 4, 1974. Bielefeld sent a certified letter to Sam Masten of Canton informing him that the claims were denied. The next move open to the plaintiffs was to file a suit in U.S. District Court; they had six months in which to do so.

8.3 The law suit

The suit, (Lunsford vs. United States), number CIV 75-5031, was filed under the Federal Tort Claims Act in the U. S. District Court for the District of South Dakota, Western Division, by Sam Masten and the law firm of Lynn, Jackson, Shultz, Ireland & Lebrun just before the deadline imposed by the applicable Federal laws. Horace Jackson

[14] I succeeded Schleusener as director of the IAS in July 1974. Simmons remained as assistant director.

had signed it on May 29, 1975. The plaintiffs were the heirs of five people who died in the flood, and for whom administrative claims had been filed in 1974, as follows: Agnes Lunsford and Carol O'Brien, heirs of their parents T. and Alice Gall, and of their brother Norvel Gall; and E. F. Lodmell, Jr., and Lee Ann Emme, heirs of E. F. Lodmell and Anna Lodmell. The suit asked for $250,000 for each of the five deaths, and $75,000 for personal property losses for each of the five. The suit also included an additional claim for $100,000 in property losses suffered by Lee Ann Emme, bringing the total amount requested to $1,725,000.

The suit alleged that the work carried out by the IAS on June 9, 1972 was "inherently dangerous in its very nature." It also alleged that the cloud seeding had been conducted in a careless and reckless manner, and had contributed to the flooding of Rapid Creek. Because the Federal Tort Claims Act allows suits against the Government for negligence on the part of its employees, but not for negligence on the part of contractor personnel, the plaintiffs alleged that Reclamation's employees had been negligent, in that they failed to supervise the experiments properly. Count V asked that the suit be declared a class action, and alleged that the claims denied by Reclamation on December 4, 1974 were filed on behalf of all members of the class. This move was a great threat to the Government, as it could have opened the door to claims for hundreds of millions of dollars in damages to persons not named in the suit. With the suit properly filed, the U. S. Court for the District of South Dakota, Western Division issued a summons to the Government on June 2, 1975.

IAS personnel learned of the suit in an article in the Rapid City *Journal* of June 3, 1975. We took immediate action to be sure that Kahan and others of the Skywater office in the Denver Federal Center were aware of the filing, but the Interior solicitors were already on the case. Bielefeld wrote to Kahan on June 6, 1975 to request his suggestions for responses to the various counts recited in the suit, and Kahan responded.

Government lawyers at some level then decided that the defense against the suit would be led by the Dept. of Justice, rather than the Interior solicitor's office. That made the U. S. Attorney for South Dakota, William F. Clayton, the on-site leader of the Government's team. Bielefeld wrote a letter to Clayton in July essentially handing the case over to him. Bielefeld provided 44 enclosures and attachments, including suggested responses to the plaintiffs' allegations, based in part on the input from Kahan. He also recommended investigating the possibility of joining South Dakota to the suit, either as a party defendant or by means of a cross complaint. People in the office of the Attorney General of South Dakota hoped that that would not happen, and it did not. Condon & Forsythe continued to defend the interests of the insurance company and the Government. A senior member of that firm, Thomas Whalen, now took a leading role, and Mentz remained on the case.

Clayton filed the Government's response to the suit on August 27, 1975. Among other things, the response noted that the work on June 9, 1972 was performed by contractor personnel rather than Government employees, and that some of the plaintiffs had failed to file administrative claims with Reclamation before going to court.

Whalen and Charles Kruse of the Dept. of Justice in Washington came to Rapid City at the end of September 1975 for a hearing on the class action aspect of the case. IAS staff briefed them on September 30 and October 1 on cloud seeding methods and the events of June 9, 1972.

Mentz was at IAS on November 3 and 4, 1975, and met with Simmons and me. Points discussed included whether or not IAS staff could ever be considered to be employees of the U. S. Government, and whether or not cloud seeding could be considered an ultra-hazardous activity. In a memo dated November 10 I wrote, "Mr. Mentz pointed out that, as of now, the interests of all parties (the state of South Dakota, the Federal government, and the insurance company) coincide..… However, if a class action is permitted, the total amount claimed by plaintiffs could rise above $2,000,000, in which case the interests of the various parties might diverge. Mr. Mentz said that we should not communicate to anyone, except as required by law, information concerning possible lines of defense against the suit."

On March 13, 1976 I met with Dr. Howell, Whalen, Clayton, and Kruse to review developments on the case to that point. We discussed the qualifications of some persons who might be called as expert witnesses for both sides. We met at Duke University in North Carolina, as several of us were there to attend a conference on the social aspects of weather modification projects.

8.4 Resolution of the case

Judge Fred Nichol presided over a hearing on the case in Rapid City in June 1976. Simmons attended the hearing for information purposes only. Lawyers for both sides made their case. The defense team invoked some legislation which granted the Government immunity in connection with flood control projects, although the work on June 9 could hardly qualify as flood control. Judge Nichol's decision, rendered on August 30, 1976, struck that line of defense. However, the important part of his decision was the rejection of the class action. One reason for dismissing it was that the unnamed members of the class had not filed administrative claims first, as required by the Federal Tort Claims Act. The claim for $100,000 compensation for property damage was dismissed for the same reason.

As expected, the plaintiffs' attorneys appealed the August 30 decision. The U. S. Court of Appeals for the 8th Circuit in St. Paul, MN heard their appeal on May 19, 1977. Whalen appeared to argue the Government's case. The decision by the Court of Appeals, rendered in 1978, upheld Judge Nichol's decision to throw out the class action suit. The end of the class action meant that the case would never become a bonanza for the plaintiffs' lawyers, but they kept the suit alive to protect the interests of the named plaintiffs.

Whalen met with Jackson and Jeff Masten in August of 1979, and told them that he proposed to introduce a motion to throw out the entire case against the U. S. Government, because the June 9 cloud seeders were not Government employees. Jackson said that in that case he would probably initiate a discovery proceeding concerning the contractual arrangements between Reclamation and Mines.

The motion for dismissal was duly submitted, and the discovery proceeding began. Kahan and Schleusener prepared affidavits regarding the contractual arrangements that governed the cloud seeding on June 9, 1972. The most important point to be considered was whether or not Reclamation personnel provided any advice to IAS regarding the conduct of seeding experiments on any particular day. The affidavits were reviewed carefully by the Condon & Forsythe team for accuracy and clarity, and slightly revised before the final copies were signed and submitted to the court. The whole process extended from late 1979 until late 1980.

The Government case as presented by Condon & Forsyth eventually prevailed. A stipulation for dismissal of the law suit with prejudice was prepared, dated May 28, 1982. The court order dismissing the action was entered at Sioux Falls on July 6, 1982.

9. Some Further Discussion

9.1 The null hypothesis

Because the law suit was thrown out on legal grounds, the issue of causation of the flood was never argued in court.

The differences of opinion regarding causation in the case of the flood can be traced to two opposed views of how one should interpret unusual events. In one view, unusual events require explanations, which one then proceeds to develop. However, most scientists, especially statisticians, favor starting from the null hypothesis, which is that there is no link between the event and the suggested explanation. One then applies statistical tests to find out if the null hypothesis should be rejected.

Using the null hypothesis as a starting point can cause one to fail to accept an actual effect as real. Nevertheless, it is the approach normally used by serious scientists. The alternative approach, of assuming at the outset that an effect is present, and demanding proof that it is not, puts an impossible burden of proof on those who say there is no effect. In particular, those who start from the point of view that cloud seeding caused the June 9 flood will never be proven wrong. Similarly, as pointed out in an editorial in the New York *Sun* of September 21, 1897, no one can prove that there is no Santa Claus.

However, the editorial writer's leap from that indisputable fact to the assertion that, "Yes, Virginia, there i**s** a Santa Claus," is not defensible logic.[15]

9.2 Microphysical mechanisms

As previously noted, Schleusener and I were both on record as saying that salt seeding could not have caused the flood. This section explains my basis for believing that to be the case.

If the flood had occurred one or two days later, the clouds preceding it would likely have been seeded with silver iodide as part of the DWM program. If the IAS had decided to seed with silver iodide on June 9, many clouds could have been seeded on a single flight. In either case the possibility of dynamic effects would have been significant, and it would be plausible to suggest that those effects intensified the rainfall experienced an hour or two later. However, as previously noted, the decision was made **not** to seed with silver iodide. That was a fortunate decision, for two reasons. First, because of operational limitations, it severely limited the number of clouds that could be seeded. Second, salt particles, unlike silver iodide crystals, are highly soluble in water.

Grant had explained to Santiago in their phone conversation of June 12 the distinction between silver iodide seeding and salt seeding, and made his views known in *The Coloradon.* However, as we have seen, Santiago did not include Grant's views on salt seeding in his article. This section expands upon the points made by Grant in his article of June 15, which also have a bearing on the later assertions made by David Howell.

The salt particles that were entrained into the clouds on June 9 ceased to exist as soon as they performed their function of nucleating unusually large cloud droplets, which would serve as artificial raindrop embryos. They simply dissolved. One can ask whether they produced unusually salty raindrops. Recalling that a typical raindrop is made up of 1,000,000 cloud droplets, each formed around a CCN, provides some perspective.

A salt particle of 25 microns diameter weighs about 0.02 micrograms. A raindrop formed around such a particle would also contain about one million cloud droplets, each formed around a CCN of about 0.2 microns diameter. The total weight of them would be near 0.005 micrograms, so the resulting raindrop would be about five times as salty as a natural raindrop. It could, in theory, evaporate to produce a giant salt nucleus larger than one resulting from the evaporation of a natural raindrop. However, as previously mentioned, raindrops constantly break up and reform during their fall, with the time constant of the process being less than 5 minutes. The salt contained in an artificial raindrop embryo would be redistributed several times before it could be entrained into another cloud. Therefore, in considering the physical contamination of successor clouds, the crucial factor is the total mass of salt involved, rather than the original size distribution.

The total influx of moist air to the storm system of June 9 over a 6-hour period has been estimated at 40,000 cubic kilometers, or almost 10,000 cubic miles. No aerosol samples were taken that day, but the air was of maritime origin and quite hazy. Such air typically contains from 1 to 5 micrograms per cubic meter of chlorides in the form of giant particles over 2 microns in diameter, and around 1 microgram per cubic meter of sulphate particles in the CCN size range. They would function as CCN, but would produce ordinary cloud droplets rather than raindrop embryos. Leaving them aside, and assuming a very conservative value of 1 microgram per cubic meter for the chlorides, we find that the storm brought into the Black Hills over 40,000 kilograms (90,000 lb) of natural salt, much of it sodium chloride from the sea surface, in the form of giant particles. Therefore, contamination by some tens of pounds of fugitive salt that might have avoided being drawn up into the seeded clouds could not have had any detectable effect on the total storm system.

We reiterate at this point that large convective clouds forming in moist air masses always precipitate, whether seeded or not. Sometimes the first

[15] Virginia O'Hanlon Douglas died in 1971, the year preceding the Rapid City flood.

rain forms by coalescence of cloud droplets, and sometimes by ice processes. In their later stages both processes are active, with the ice processes being of greater importance in the cold, upper parts of the clouds. Furthermore, if the large clouds are embedded in a preexisting cloud system so that entrainment of dry air is not a problem, they precipitate very efficiently. The clouds making up the Pactola storm fell into that category. They were large clouds forming in a very humid air mass, they were tall enough to have lots of ice particles in their upper parts, and the presence of haze indicated the presence of natural salt particles big enough to form raindrop embryos quite close to cloud base. Therefore it is not surprising that their precipitation efficiency has been calculated as close to 100 percent.

9.3 Possibility of dynamic effects

In his June 16 letter to Deering, Krick noted that the latent heat of condensation per unit mass of water is several times greater than the latent heat of fusion, and reasoned that the dynamic effects of hygroscopic seeding would therefore be greater than those associated with silver iodide seeding. He therefore argued that hygroscopic agents should not be released from aircraft in moist, tropical air masses. However, salt seeding does not change the total amount of water vapor condensed, and so could not have affected the total release of heat of condensation.

Any dynamic effects would be second-order effects related to precipitation loading. Raindrops in a cloud exert a downward drag on the air around them. Premature unloading of water by salt seeding conceivably could have a small effect on a treated cloud. Some cloud modeling studies have detected such effects. In some cases, premature rainout of a convective cell hastens the formation of subsequent cells. The later cells sometimes produce a bit more rain, and sometimes less rain. The outcomes are essentially random. In any case, the cells forming later do not become "amplified." Their growth remains subject to the limitations imposed by the availability of water vapor and the stability or instability of the air mass in which they form.

David Howell, quoting Dr. Howell, made much of the fact that a cloud can be viewed as a factory processing water vapor into rain. However, he did not carry the analogy far enough - without input, a factory can not continue to produce a product. The only way to increase (decrease) rainfall on the evening of June 9 would have been to increase (decrease) the speed of the easterly air flow into the Black Hills. No mechanism has been proposed by which hastening the formation of rain in several cloud towers close to existing showers could accomplish such a large-scale effect.

10. Forecasting of Flash Floods

The question posed by Metzger in 1972, "Did cloud seeding swell Rapid City flood?" distracted attention away from a far more important question, namely, "Why could not the worst flood in the history of Rapid City have been forecast before the rain started to fall?" The importance of the second question was brought home four years later by another disastrous flood, this time in Colorado. On the evening of July 31, 1976 a quasi-stationary MCS formed over the Big Thompson drainage basin on the east side of the Rocky Mts. in Colorado. A series of convective cells moving from southeast to northwest merged into the system, and made possible a heavy rainstorm lasting for several hours. The resultant flood crest rushed down the canyon during the night, destroying many homes and taking almost 150 lives. The flood warnings issued were less timely than those for the Rapid City flood.

In 1990 a flash flood killed 26 people in Shadyside, Ohio, which is on the Ohio River. The flood happened as a result of a quasi-stationary MCS dropping several inches of rain on steep slopes drained by a stream that joined the Ohio river at Shadyside. According to some news reports, no flood warning was ever issued. This tragedy showed once again that forecasting flash floods requires more than a few simple rules based on conventional weather maps.

Following the Big Thompson flood, scientists working for the National Oceanic and Atmospheric Administration (NOAA) wrote some reports and papers comparing it to the Rapid City flood. They noted that in each case there was an upslope flow of moist air from the southeast close to the ground and light winds aloft. However, the prevailing winds at Rapid City during the spring rainy season are from the southeast; little seeding would ever be done if such days were automatically declared no-seed days. Koscielski and I had discussed this point during my visit to the radar site on June 9. We recalled such a period in June of 1967, when moderate to heavy rain fell on the eastern Black Hills for several days in a row, but without anything more than very minor flooding.

There were other signs on June 9 that might have indicated a potential problem. The very dry and warm air aloft on that morning prevented an early onset of convective storms, which could have dissipated some of the available energy. As it was, the moisture near the ground was trapped until it was released late in the afternoon. The dry layer likely reflected the existence of a fairly strong short wave in the light southwesterly flow aloft. The subsidence ahead of the short wave would produce a dry layer aloft, while the rising air accompanying the short wave would lead to an increase in the depth of the moist layer next to the ground and, of equal or greater importance, an increase in the instability of the air mass. However, these possible effects were taken into account to some extent by Koscielski and the IAS cloud modelers, who asked themselves what would happen with the disappearance of the dry layer aloft.

Looking back at it from the year 2010, it appears to me that one key factor in the production of the phenomenal rainfall rates during the evening of June 9 was a mid-level jet stream flowing into the Black Hills from the southeast. This fine-scale feature of the weather situation may not have existed in the early morning. If it had, it could not have been detected by the NWS radiosonde network, as the nearest station to the south of Rapid City was, and is, at Scottsbluff, Nebraska. Furthermore, the radiosonde balloons went up only twice a day, at 6 am and 6 pm. The SE winds over Rapid City at 6 am were not alarming. The data collected by the IAS pibal operators beginning at 12:30 pm would have been cause for alarm, if they could have been analyzed and made available to the operations director in real time. Southeasterly winds of 50 to 75 mph at elevations of 10,000 to 15,000 ft above sea level are far out of the ordinary for the Black Hills during the summer. However, as previously noted, the pibal data were collected for their potential value in the evaluation of the Cloud Catcher test cases, and not as an operational tool.

The 6 pm rawinsonde at Rapid City showed the SE wind had increased to near 40 mph at the surface, but diminished from the surface upwards. There is no definite information available on winds aloft after 6 pm, but the extremely rapid east-to-west motion of the convective clouds noted by Koscielski around 8 pm would be consistent with a deep easterly flow of 50 mph or more. It appears that the mid-level jet stream edged northward during the evening, bringing increasingly moist air into the eastern Black Hills. Plots of the surface dew points after 6 pm show a moist tongue directed into the Rapid Creek basin from the southeast. As pointed out by Thompson, the role of topography was to keep the storms more or less in place, so that successive cells unloaded their rain in almost the same location time after time.

In order to forecast a flash flood, then, one should have data on winds up to 20,000 ft, taken at least once per hour at locations separated by no more than 10 miles, to catch the fine-scale features of the air flow. It is not feasible to do that with pibal operators, but the latest remote-sensing techniques could do it.

In addition to the data-collection system, one would need a 3-dimensional model of the atmosphere for the area of interest, and powerful computers to run the model in real time. Some work along these lines has already been done, using the Regional Atmospheric Modeling System (RAMS), which has been developed at CSU. A paper entitled “Numerical simulation of the 9-10 June 1972 Black Hills storm using CSU RAMS”, by U.S. Nair, M.R. Hjelmfelt, and R. A. Pielke, Sr. appeared in the August 1997 issue of *Monthly Weather Review*. The model results showed maximum rainfall amounts on the east side of the Black Hills, but not quite where the actual maxima occurred.

The ideal system described above does not exist yet, despite the best efforts of many experts in the modeling of atmospheric processes. If one were concerned about only one drainage basin, say Rapid Creek, the U.S. Government could easily afford the necessary system. However, when one considers the actual situation, cost becomes a serious problem. The trouble is that the United States has hundreds of drainage basins potentially subject to flash floods. The fact that a certain basin has never had a flood is no guarantee that it will not have one in the next 100 years, or even next year.

For the time being, flash-flood forecasts will be very short-range forecasts, rather than forecasts with several hours lead time. Hence, the emphasis today is on more advanced radar systems with Doppler and polarization capabilities. The nationwide lightning detection system, new since 1972, is being investigated as another forecast tool. Streamflow data from automated gaging stations are also valuable to flood forecasters. Even so, moving people out of flood plains looks like the only fool-proof way to avoid future tragedies.

11. A Sobering Conclusion

The history recounted above shows that some controversies over scientific matters are settled with scant regard for the facts. Despite the fact that no one ever came up with any serious, quantitative hypothesis linking cloud seeding to the abnormal easterly flow of moist air into the Black Hills on the evening of June 9, the possibility that cloud seeding caused or augmented the 1972 flood on Rapid Creek is well embedded in the minds of many lay persons. It has been promulgated in science textbooks and in books published by MIT Press and Oxford University Press. An essay linking cloud seeding to the flood, titled "The Morton salt disaster," appeared in the book *Writing on Water*, which was published by MIT Press in 2002. Irresponsible, or ill-informed, authors have spoken of an aircraft taking off at the height of the June 9 storm to try to increase the already excessive rainfall rates. While no one ever contemplated ordering such a mission, Ted Steinberg has written, "There is only one thing more incredible than all the rain and destruction: In the midst of the rainstorm, clouds were seeded as part of the Bureau of Reclamation's Cloud Catcher project."[16]

The controversy over cloud seeding and the flood of 1972 has been eclipsed in the media and the public mind by the much more important issue of global warming caused by human activities. It would be nice to think that rational discussion would lead to wise decisions regarding possible courses of action to counter the threat of global warming, should it prove real. However, the issue has become politicized. Many persons dismiss the possibility of global warming as a hoax, and some scientists studying the subject have become the victims of *ad hominem* attacks. My experiences in connection with the flood do not provide me with any confidence that the human race will make a rational response to the potential threat of global warming, compared to which the dangers associated with cloud seeding are scarcely worth mentioning.

Acknowledgments: The author thanks Dr. Patty Andersen and her staff at the Devereaux Library at the South Dakota School of Mines and Technology for access to the library's flood archive. Dr. Lilah Pengra provided highly useful reviews of two earlier versions of this memoir. Thanks to Connie Crandall of the Institute of Atmospheric Sciences for help in formatting and posting this to the websites.

[16] Steinberg, T., 2000: *Acts of God*, Oxford University Press, 318 pp.