RECEIVED
FILED
2005 OCT 28 PM 6:08
IDAHO PUBLIC
UTILITIES COMMISSION

BEFORE THE IDAHO PUBLIC UTILITIES COMMISSION

IN THE MATTER OF THE APPLICATION OF IDAHO POWER COMPANY TO DEFER EXPENSES ASSOCIATED WITH ITS CLOUD SEEDING PROGRAM FOR INCLUSION IN THE COMPANY'S PCA ON AN ONGOING BASIS.	CASE NO. IPC-E-05-36

IDAHO POWER COMPANY

DIRECT TESTIMONY

OF

GARY RILEY

October 2005

Q. Please state your name and business address.

A. My name is Gary Riley and my business address is 1221 West Idaho Street, Boise, Idaho.

Q. By whom are you employed and in what capacity?

A. I am employed by Idaho Power Company as Senior Meteorologist in the Water Management department.

Q. Please describe your educational background.

A. I attended the USAF Weather Observers School in 1965 and the Weather Forecasters School in 1970-71, graduating from both with honors. I received a Bachelor of Science Degree from Longwood College (now Longwood University) in 1981, graduating *Summa Cum Laude* with a major in physics and a minor in mathematics. I received a Master of Science degree in Atmospheric Science from the State University of New York at Albany in 1984.

Q. Please describe your work experience with Idaho Power Company.

A. I was hired by Idaho Power Company in June 2002 to implement and run the Company's cloud seeding project on the Payette River Basin and to provide weather forecasting support tailored to the Company's needs and interests.

The cloud seeding project is designed to augment the wintertime snowpack in the Payette River Basin and thereby increase spring and summer runoff through the Company's Hells Canyon Complex. The project became operational in late January of 2003, with the first seeding on February 1, 2003. Operations ended for the season on April 15, 2003 and resumed between November 1, 2003 and April 21, 2004. The third season of seeding was operational between November 1, 2004 and April 21, 2005.

Q. Please describe your experience in the field of weather modification.

A. Prior to joining Idaho Power, I was Vice President and Chief Scientist for Atmospherics Incorporated in Fresno, CA. Founded in the mid 1960s, Atmospherics is one of the oldest and most respected weather modification companies in the world. I first began working for Atmospherics in December 1991, and while there I supported, operated, and/or managed weather modification projects in California, Nevada, Colorado, and Texas. Internationally, projects were conducted in Spain, India, Indonesia, and Costa Rica.

From 1987 through early 1991, I was employed by Intera Technologies of Calgary, Alberta, Canada as a Senior Meteorologist and I was the Assistant Manager of the Greek National Hail Suppression Project.

Q. What is the purpose of your testimony in this proceeding?

A. I will describe the scientific basis supporting the effectiveness of cloud seeding. I will also describe the mechanics of how Idaho Power accomplishes its cloud seeding program and the steps the Company has taken to measure the effectiveness of its cloud seeding program.

Q. Based on the testing and measurement steps the Company has taken to date, do you have an opinion as to whether the Company's cloud seeding program will be cost-effective on a long-term basis?

A. Yes. Based on Idaho Power's experience to date and the sophisticated testing and measurement analysis described in my testimony, I conclude that the Company's cloud seeding program presents positive benefits to the Company and its customers and would be cost-effective on a long-term basis.

Q. Please briefly describe the theory behind cloud seeding as it applies to Idaho Power's project to augment snowfall.

A. The natural precipitation processes is fundamentally inefficient in the majority of cases. That is to say that more water is available *for* precipitation than actually falls *as* precipitation. The air in a storm system usually contains plenty of water, but it does not contain enough of the types of particles capable of acting as ice nuclei. These particles start the process of converting the available water into ice and finally, into snowfall. Cloud seeding to augment wintertime snowfall works by partially reducing the deficit by introducing more of these particles into the storm system.

Q. What factors are necessary for cloud seeding to be effective and provide the benefit of additional snowfall?

A. To be effective, three fundamental and necessary conditions need to exist in the airmass passing over the target area - in our case, the Payette River Basin.

First, the air must already be producing, or be about to produce, precipitation (this is snow *enhancement*, not snow *making*). Such a winter storm can produce a thermodynamic environment favorable for activation and transport of the seeding material into the part of the storm where the precipitation forms.

Second, the air must contain an appreciable amount of supercooled liquid water. Supercooled liquid water is simply water suspended in the air at temperatures below freezing, that is below 32 °F or 0 °C. Pure water can exist in the liquid state to temperatures as cold as -40 °C (or °F - they are the same at that temperature). This liquid water is converted, first to ice, and then to snow, by contact with a nucleating particle by processes called contact and condensation nucleation.

Third, and as is usually the case, there must be an insufficient number of naturally occurring ice nucleating particles to efficiently convert the available supercooled liquid water first into ice crystals and ultimately, into snowfall. These particles typically consist of dust, pollens, salts, and clays that have been picked up and transported into the cloud by the wind.

Q. Given an environment where snow is falling and surplus supercooled liquid water exists, but there are insufficient ice nucleating particles, what can be done to produce additional snowfall?

A. When there is more supercooled liquid water present than can be converted to ice by the available ice nucleating particles, the introduction of additional nucleating particles can convert some of the surplus moisture into ice crystals. These subsequently grow into snowflakes and fall to the ground.

Q. What does Idaho Power Company utilize as ice nucleating material?

A. The primary seeding material used by Idaho Power Company is silver iodide. It has been known since the later part of the 1940s that silver iodide acts as a very effective ice-nucleating particle at temperatures between about -4 °C and -15 °C. One gram of the material creates from 10^{10} to 10^{15} ice nuclei, depending on the temperature and composition of the seeding agent. Our network of ground-based generators each release 20 grams per hour. Depending on the configuration and other constraints, the project aircraft can release from 151 to as much as 1500 grams per hour.

Q. Are you able to target where the additional snow will fall?

A. To place this additional snowfall in the proper place, the target area, requires a clear understanding of how, and how fast, the process works. For effective cloud seeding, accurate information about the temperature and moisture structure and about the wind flow into and across the target area is needed. The seeding material must be released so that there is the correct amount of time available for it to be transported into the portion of the storm having the proper temperature and humidity structure and where the factors mentioned earlier exist.

Q. How long does it take to form snow once the silver iodide has been introduced into the storm?

A. The typical timeframe required for the additional particles to be transported into a suitable environment, induce freezing and grow into snowflakes is on the order of twenty to forty minutes, but it can be as long as 100 minutes. The amount of time required can be controlled to some extent by adjusting the formula of the seeding material. For the material IPCo uses, the silver iodide needs to be introduced into the storm system in a wind regime that will carry it into a zone of favorable temperatures and moisture and transport it into and across the target area in a time "window" of fifteen to forty minutes.

Q. How do you know that the snow on the ground is the result of cloud seeding efforts rather than snow that would have been present without cloud seeding?

A. Cloud seeding projects have, until recently, relied on statistical analysis of Target - Control, or seeded area vs. non-seeded area, data sets. Because the yield from any particular cloud seeding season lies well within the natural range of variability of precipitation, it can take many years to obtain statistically significant results and determine a reliable measure of success or failure. For that reason, many scientists and statisticians were reluctant to accept the results indicative of success. Nevertheless, this procedure is still commonly used.

In the last ten to fifteen years however, significant advances have been made in both our understanding of the physics involved and in our ability to confirm and evaluate results through trace chemistry investigations.

Because the materials used for cloud seeding are known, as is the time of their release, analysis of the snowpack itself provides information about where the seeding material fell, how much of the material went towards additional snowfall, and how much was simply scavenged, or swept out of the air, by precipitation already occurring.

The presence of enhanced silver in the target area snowpack indicates accurate targeting, but it says nothing about whether it was deposited in the form of additional snow or scavenged. Releasing an inert, non-nucleating tracer simultaneously with the active seeding agent makes it possible to determine if the source was additional precipitation or scavenging. That information, when combined with density variations within the snow samples, allows quantification of the amount of additional snow falling on the area.

Q. Did Idaho Power Company take steps to measure the effect of its cloud seeding program using this new, sophisticated approach?

A. Yes. Idaho Power contracted Desert Research Institute (DRI), an extension of the Community College of Nevada, to perform an analysis of snowpack samples from the Payette River Basin the past two winters. The tracer used was indium sesquioxide (In_2O_3), whose particles are similar in size and dispersion characteristics to the nucleating silver iodide (AgI). However, unlike the active material, the tracer is non-nucleating and is removed from the air only by scavenging. Therefore, *any* change in the ratio of silver to indium from what it was at the point and time of release gives a measure of how many of the silver particles went into making additional snow and how many were scavenged.

Q. Did Idaho Power measure the success of its cloud seeding efforts in the winter of 2002-2003?

A. Yes. The original project plan did not include an evaluation of benefit for the first season. The combination of start-up operations and a short operational season, only 2 ½ months, severely limited the amount of data available. However, two direct, and one indirect, analyses were conducted, and all produced similar results. All three of the analyses were independent. No Idaho Power Company personnel involved in seeding decisions took part in the evaluation.

Q. Please describe the two direct analyses of the cloud seeding effort during the winter of 2002 - 2003.

A. The first was by an Idaho Power employee not otherwise involved in the project. The second evaluation was done by an independent consultant (RHS Consulting of Reno, NV). A traditional Target - Control analysis, consisting of a linear regression of precipitation at sites inside and outside of the target area indicated a 17% increase in precipitation during the 2 ½ month period between February 1 and April 15, 2003. That translates to 2.4 inches of additional water when averaged over the Payette River Basin. Given a target area of approximately 938 square miles, that works out to 120,000 acre-ft of water.

The precipitation data was also provided to RHS Consulting who determined that the project would likely have produced a 9% increase had it been operational for the entire winter. Using the quality controlled data available now that number rises to 11%

Q. Please describe the indirect evaluation of the cloud seeding effort during the winter of 2003 - 2003.

A. An indirect evaluation was provided by North American Weather Consultants of Sandy, UT. North American operates a snow enhancement project on the adjacent Boise River Basin for the Boise Project Board of Control. Their initial analysis of the Boise Basin 2002 - 2003 season data indicated a "no effect" result until it was realized that the "non-seeded" Control sites being used for the Boise project were seeded Target sites for Idaho Powers' Payette project. After developing a new set of unseeded Control sites, North American arrived at a 13% increase for the Boise project, and by inference, for Idaho Power's project as well.

Q. Did Idaho Power measure the success of its cloud seeding efforts in the winter of 2003 - 2004?

A. Yes. Similar to the analysis done on the 2002 - 2003 season, a Target - Control analysis indicated a 6% increase in precipitation in the Payette River Basin for that season. This reduced yield - 6%, down from 17% - was expected because it was a dryer than normal year and the inclusion of the trace chemistry analysis mentioned earlier placed several constraints on operations. Still, even with only 80% of normal precipitation, the yield represents an additional 85,000 acre-ft of water.

Snow samples collected by DRI and analyzed in their ultra-clean laboratory in Reno showed very high levels of silver present and very little indium. Further, comparison of the depth at which the silver was found with data from nearby SNOTEL sites shows it to be consistent with seeded events. Degradation of the snowpack prior to sample collection prevented the laboratory from quantifying the yield in augmented precipitation, but the 2002 - 2003 data indicate scavenging was not a significant factor and Idaho Power has an effective project.

That conclusion is substantiated by the results of measurements made by an aircraft especially modified for airborne cloud physics data collection. Measurements were made prior to, during, and after a seeding flight on March 26, 2005. The data indicate water production from the aircraft alone to have been in excess of 600 acre feet per hour.

Q. What were the results of the cloud seeding program undertaken during the winter of 2004 - 2005?

A. This last season's SNOTEL data indicate a 26% increase in precipitation for the Payette River basin. While a percentage increase of that magnitude is possible, the number seems very high and should be viewed in the context of an ongoing effort to obtain a statistically significant evaluation of the cloud seeding project. However, the results from the second year of trace chemistry evaluation performed during the 2004-2005 season are very positive and similar to those of the preceding years and they are consistent with results obtained by other successful programs.

Samples collected by both DRI and RHS Consulting found positive evidence of an effective project. Using newly developed procedures and sampling equipment, DRI was able to correlate the silver, indium, and cesium in the snow with density gradients, allowing a quantitative estimate of augmentation. This makes it possible to distinguish between the seeding material released by the ground-based and airborne equipment and mathematically determine how much additional snow fell on the sampling site. The data provide clear evidence of an effective program.

Q. Can you provide examples from this analysis to help the Commission understand how the silver and indium relate to each other and how they relate to seeded snowfall?

A. Yes. As an example, I would like to offer Exhibit 1. These figures were provided by Dr. Ross Edwards of DRI. The first shows the concentrations of silver and indium detected in a snow sample from the east side of the Payette River Basin target area. The sample was collected on Mount Zumwalt at an elevation of 8,225 feet. Note the different scales for silver (left side) and indium (right side). Three seeding events are depicted and the silver to indium ratios show that for every silver iodide particle scavenged, between 6 and 19 other silver iodide particles contributed to additional snowfall.

The second figure graphically shows enhanced levels of both cesium and silver in a sample collected in December of 2004. Recall that ground-based units release only silver iodide while the airborne generators released a solution that included the cesium tag. Superimposing these diagrams (third figure, prepared by IPCo for purposes of demonstration) allows one to distinguish between silver released by the aircraft and that released at ground level.

The fourth figure shows how the presence of enhanced silver content that coincide with a layer of anomalous density can be evaluated for the amount of augmented snow in the sample. In the example shown, there is a 13% increase due to seeding. DRI found augmentation values ranging from 13 to 34%, with a mean of 22%. Consequently, this is a conservative example. DRI concluded that the overall augmentation in the target area for this past season was between 7 and 9%.

Finally, the fifth figure shows where the samples were taken and gives an indication of how the degree of silver content departs from what would be expected in pristine snow. As noted by Dr. Edwards, this provides evidence of effective targeting of the watershed.

Q. Is DRI preparing a final report containing the analysis that supports your testimony?

A. Yes. The report is in the final stages of completion and will be filed with the Commission as Exhibit 4 to my testimony as soon as it is received from DRI.

Q. Were the results of your measurement of cloud seeding success consistent with those for other projects and entities?

A. Yes. The yields I have indicated, 6 to 17%, are within the range of expectations from wintertime orographic cloud seeding contained in statements from the

World Meteorological Organization, the American Meteorological Society, the American Society of Civil Engineers, the Weather Modification Association, and even the Idaho Department of Water Resources. All of these indicate cloud seeding to augment wintertime snowpack can produce increases of from 5 to 20% when done correctly. Both RHS Consulting and DRI have said the results of their trace chemistry evaluations are consistent with and similar to those from investigations of this type in California and Nevada and elsewhere. Two of the comparable projects in California are operated by power companies (Pacific Gas and Electric and Southern California Edison) for the same purpose as Idaho Power's program. The results of trace chemistry evaluations of the Lake Almanor project run by Pacific Gas and Electric and those from Southern California Edison's project on the San Joaquin River have appeared in peer reviewed publications of the American Meteorology Society and the North American Hydroelectric Industry.

Q. Can you provide one of these articles that is written in non-technical language that is easier to understand by someone not familiar with weather and cloud seeding?

A. Yes. I have here a copy of an article by Brian McGurty reporting on the results of the study on the San Joaquin River project that appeared in *Hydro Review*. I think the Commission will find it very readable, and I offer it as Exhibit 2.

Q. Given a quantification of additional snow resulting from the Company's cloud seeding efforts, have you quantified how the additional snow translated into additional stream flows at the Company's hydro facilities over the past three winters?

A. Yes. The process is complex and requires a review of what was done in each of the three individual years to fully describe the process. First, the preliminary data from the 2002 - 2003 Target - Control evaluation was fed into the CHEOPS hydrological model to determine the generation potential of the augmented water when it passed through the Hells Canyon Complex. That allowed the determination of the benefit gained from the augmented water to be evaluated under several scenarios of seeding effectiveness and varying losses of the augmented water prior to reaching the Hells Canyon Complex. The model indicated increased generation capacities ranging from approximately 14,000 MWh if only 25% of the additional water reached the power plants to as much as 56,000 MWh if all of the water passed through the complex. These numbers would be expected to increase if the model was re-run with the quality controlled numbers available now.

The preliminary SNOTEL data from the 2003 - 2004 season was entered into the National Weather Service River Forecast System Model, and the inflow into the reservoirs on the Payette River was calculated for Seed and No-seed scenarios. The computer simulation determined that an additional 67,700 acre-ft of water flowed through the Payette drainage in the seeded scenario. That is in very good agreement with the 68,000 acre-ft determined from the Target - Control regression that was also based on the preliminary data. The difference is easily accounted for, in that the model takes losses to soil moisture and evaporation into effect and these factors are not included in the simpler regression analysis. Also, software limitations caused the input data to be cut off near the end of March. Consequently, precipitation after that was not included.

Q. Did you quantify the financial benefit of the additional stream flow at the Company's hydro facilities?

A. Yes. Along with the calculation of additional generation capacity, the CHEOPS data for the 2002 - 2003 season places the dollar value of the water at $ 1.5 million if only 50% of the augmented water reaches Hells Canyon Complex. However, the Payette River Basin was chosen for the cloud seeding project in part, because the river's reservoirs have a high probability of refill. Hence, the actual value would be closer to the 100% expectation with a value of $2.1 million.

Using the yield from the quality controlled Target - Control data, 120,000 acre-ft of water, and the in-house rule that for every hour one acre foot of water passes through Hells Canyon Complex, 0.5 MW can be generated, the value can be readily estimated. Taking the average high ($32.13/MWh), the average low ($29.47/MWh), and the average average ($30.47/MWh) price of power for the period May through August 2003 gives a comparable value between $1.77 and 1.93 million. For example, using the average price: 120,000 acre-ft times 0.5 MWh/acre-ft times $30.47/MWh indicates the water to be worth $1.83 million for hydropower generation alone. This number does not consider any monetary value of ancillary benefits to the region in the form of improved water conditions for fish and wildlife, recreation and navigation, irrigation, or additional drinking water, although these benefits also exist.

With the above-described results in hand, the value of the 2003 - 2004 yield was estimated by taking the yield, 85,000 acre-ft, and using the approach identified above. The generation potential from last season would be $1.78 million at an average price of $41.76/MWh. (85,000 acre-ft times 0.5 MWh/acre-ft times $41.76/MWh = $1.77 million.) That value is obtained by using the average of the On Peak and Off Peak Mid-C prices for the period from 1 May through

31 August 2004. The value is closer to $ 1.95 million if the higher Border prices are used.

Similarly, using the 7 to 9% yield determined by DRI for the 2004 - 2005 season and applying this same procedure at an average price of $36.71: the yield for 2004-2005 is between 85,000 and 105,000 acre-ft of water, or between 43,000 and 53,000 MWh of additional production. That would be worth $1.5 to 1.9 million.

Both of the computer simulations reveal one additional benefit from cloud seeding. The flow in the Payette River is not only increased, the peak flow is shifted later into the year and higher flows are maintained longer. This means that more water will be available to the Hells Canyon Complex as heavier summertime loads begin to become a significant factor for operations.

Q. Can you provide an example of the computer model output that illustrates this later peak in streamflow and the enhanced flow duration?

A. Yes. Exhibit 3 was prepared using the model output and shows the peak flow is shifted from late May into June and that higher flow levels are maintained into early July. Note that the figure does not include data for all of July and August.

Q. Over the past three years, how have the financial benefits of cloud seeding compared to the costs of cloud seeding?

A. The answer to this question will depend to some extent on the accounting period chosen. Because most of the activity associated with the project is based on the water year (October through the following September) rather than the calendar year, the accounting period was defined as July 1 through June 30.

The project expenses between July 1, 2002 and June 30, 2003 were:

Capital:	$ 23,723 and
O & M:	$ 802,348
Total:	$ 826,071.

The project yield, based on the average results already discussed was $1.83 million. That gives a benefit to cost ratio of 2.2 to 1.

For the twelve month period of July 1, 2003 through June 30, 2004, the project incurred significant additional expenses in association with the trace chemistry evaluation. These included not only the direct costs of the evaluation in payments to DRI, but the added burden of building and maintaining seven additional ground-based generator units to release the tracer. Consequently, the expenses during this timeframe were:

Capital:	$ 237,067 and
O & M:	$1,066,408

Total: $1,303,475.

Using the Mid-C power costs and the estimated yield value, $ 1.78 million stated earlier, the benefit to cost ratio for the 2003 - 2004 season, even with the high costs and reduced efficiency associated with the trace chemistry evaluation, is 1.4 : 1.

Finally, the total expenditure for the twelve months from July 1, 2004 through June 30, 2005 was $1,008,487. With the yield of augmented snow and power production worth $1.54 to 1.91 million as presented above, the benefit cost ratio is between 1.5 and 1.9 : 1.

Q. What is the cumulative benefit to cost ratio for the Idaho Power cloud seeding program?

A. For the Idaho Power cloud seeding project to date, considering the cumulative outlay of $3.14 million and the cumulative return of $5.43 million, the current benefit to cost ratio is 1.7 : to 1, even with the high costs of the trace chemistry evaluation.

Q. Does this conclude your testimony?

A. Yes, it does.

RECEIVED ☒
FILED ☐
2005 OCT 28 PM 6:08
IDAHO PUBLIC
UTILITIES COMMISSION

BEFORE THE

IDAHO PUBLIC UTILITIES COMMISSION

CASE NO. IPC-E-05-36

IDAHO POWER COMPANY

EXHIBIT NO. 1

G. RILEY

Exhibit 1.

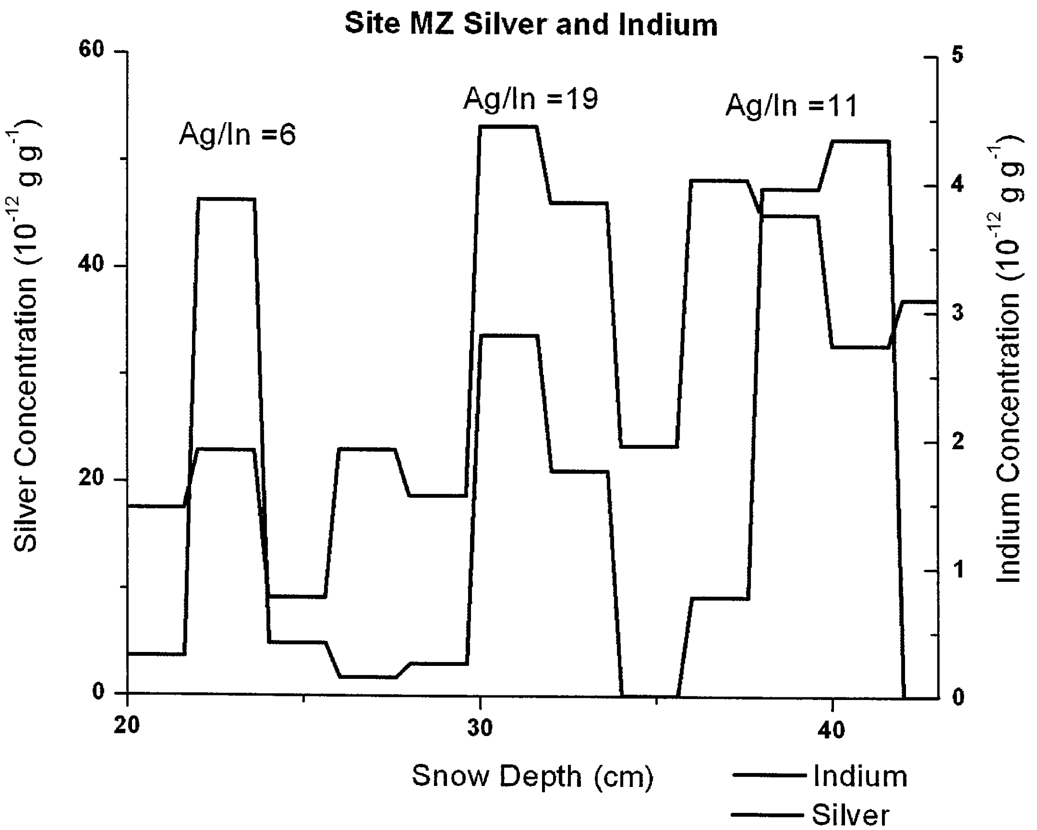


Figure 1.1. This diagram shows the concentrations of silver and indium detected in a snow sample from the east side of the Payette River Basin target area. The sample was collected on Mount Zumwalt at an elevation of 8,225 feet during March 2004. Note the different scales for silver (left side) and Indium (right side); the scales differ by a factor of 12. Three seeding events are depicted and the silver to indium ratios show that for every silver iodide particle scavenged, between 6 and 19 other silver iodide particles contributed to additional snow. The figure was prepared by Dr. Ross Edwards of Desert Research Institute, Reno, NV.

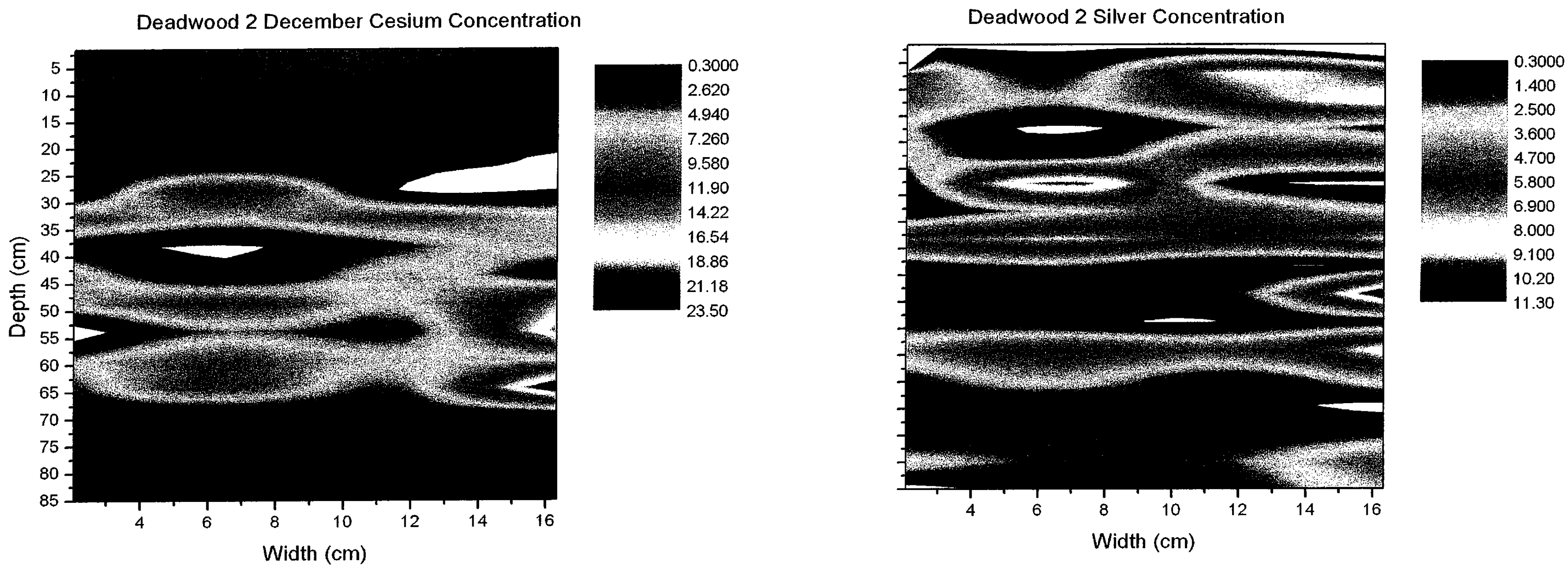


Figure 1.2. From the Desert Research Institute's 2005 preliminary report: The seeding material released from the aircraft was "tagged" with cesium (left diagram). The ground-based generators released only silver iodide seeding material. Figure 3.4 (right diagram) shows the silver concentration, but cannot distinguish the source. See Figure 1.3 on the next page.

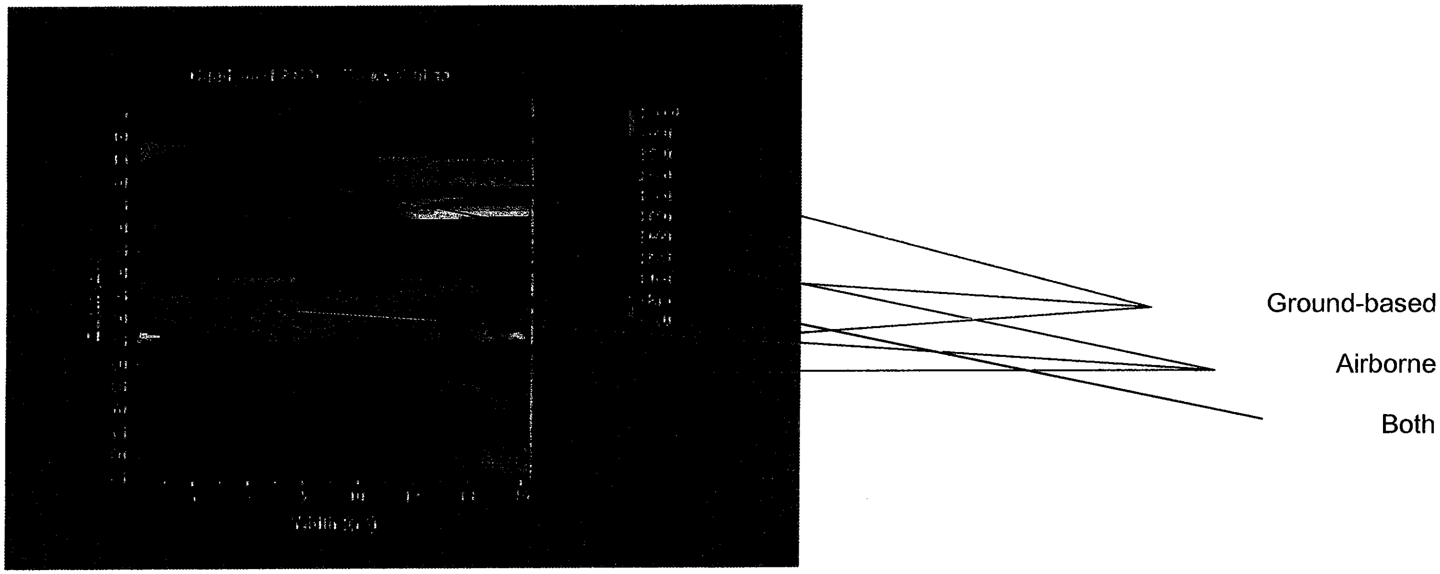


Figure 1.3. High resolution analysis of the data from both allows identification of the source. Layers containing both cesium and silver indicate seeding by the aircraft or by both the aircraft and ground-based generators. Layers containing only the silver result from ground-based seeding.

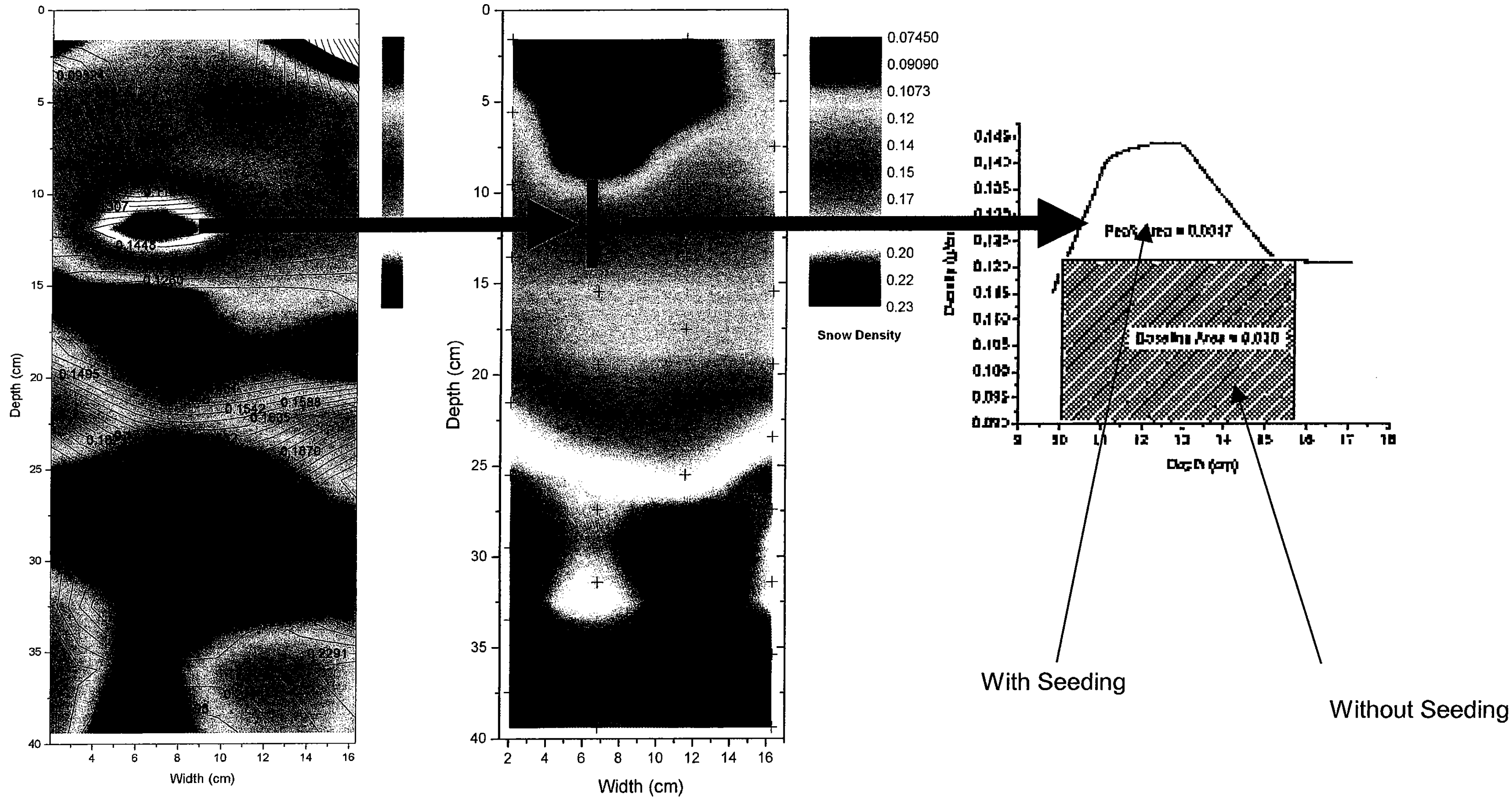


Figure 1.4. From the Desert Research Institute's 2005 preliminary report: Layers containing enhanced amounts of silver along with higher density allow the determination of how much additional snow fell during a seeded storm. This example shows a 13% increase in snowfall.

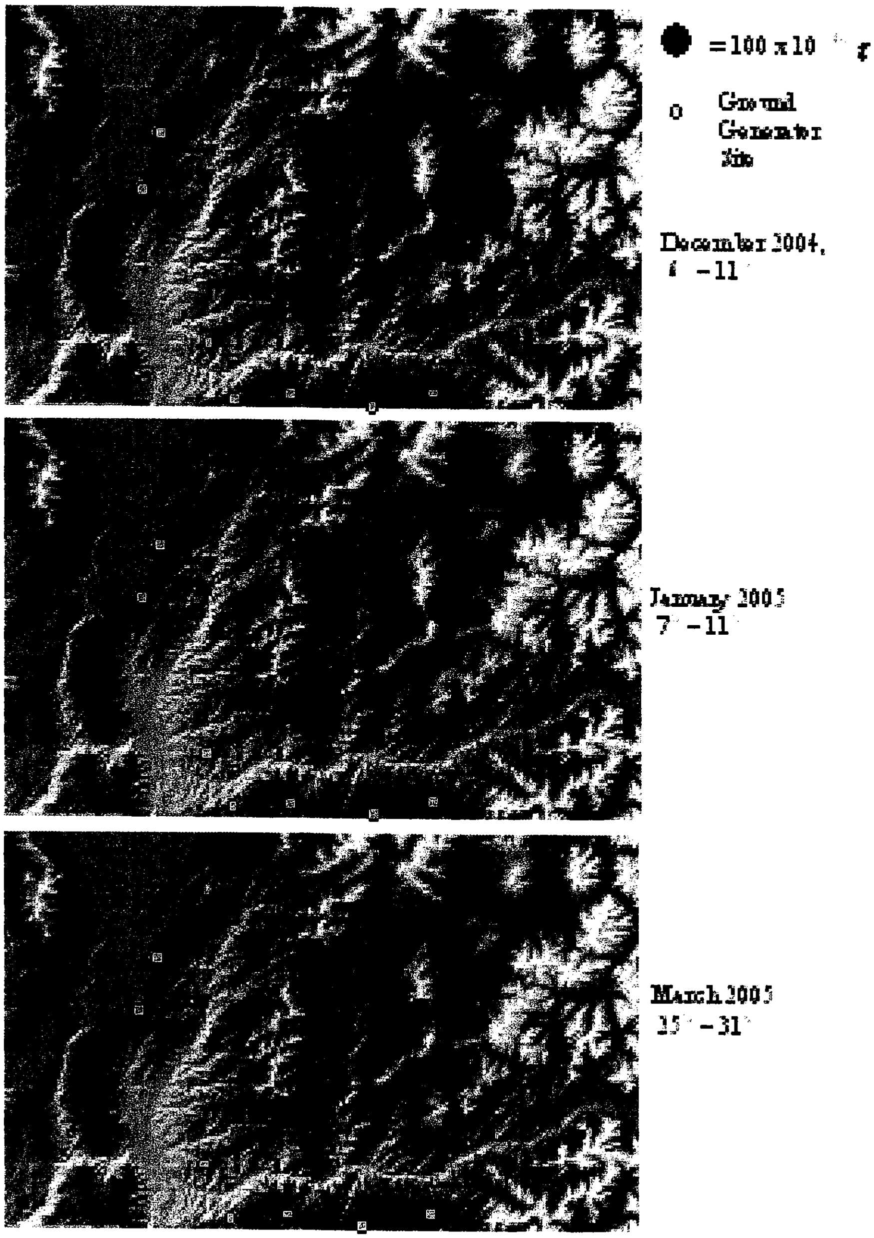


Figure 3-2. From the Desert Research Institute's 2005 preliminary report: Payette River Basin Targeting Maps. Red circles represent Snow silver masses integrated over a given time period.

RECEIVED
FILED
2005 OCT 28 PM 6:08
IDAHO PUBLIC
UTILITIES COMMISSION

BEFORE THE

IDAHO PUBLIC UTILITIES COMMISSION

CASE NO. IPC-E-05-36

IDAHO POWER COMPANY

EXHIBIT NO. 2

G. RILEY

Exhibit 2

Exhibit 2 is a copy of an article appearing in the April 1999 issue of *Hydro•Review* entitled Turning Silver into Gold: Measuring the Benefits of Cloud Seeding. The article has been peer reviewed, and was written by Brian McGurty.

Mr. McGurty is Chief Hydrographer and Technical Specialist/Scientist for Southern California Edison. In that capacity, he oversees that company's year round cloud seeding program to augment water supplies for hydropower generation on the San Joaquin River in the central Sierra Nevada of California.

This project, along with five others sponsored by Pacific Gas and Electric and the Los Angeles Department of Water and Power, are all in place to augment water for hydropower generation. Other projects exist for both hydropower generation and for public water supplies. Some of the California projects have been active for 50 years or longer.

The Exhibit consists of seven (7) pages, including this one.

Reprinted from

HYDRO·REVIEW

The Magazine of the North American Hydroelectric Industry

Volume 18, Number 2, April 1999

Turning Silver into Gold: Measuring the Benefits of Cloud Seeding

By Brian M. McGurty

Turning Silver to Gold: Measuring the Benefits of Cloud Seeding

Although it is a widely used technology, cloud seeding still is regarded with skepticism by many who are unfamiliar with its application. A recent research program in California is helping the practice gain the respect it deserves.

By Brian M. McGurty

Meteorologists estimate that about six times more water passes over the U.S. each year as vapor and cloud droplets than runs down all of its streams and rivers combined. Only a small portion of the available water in the clouds actually falls to the ground as precipitation. In a water-starved, populous region such as California, any improvement in the efficiency of the precipitation process would yield widespread benefits. These benefits would include an increase in clean, renewable electricity from hydropower; increased reservoir storage for recreation; increased water supplies for domestic and agricultural consumption; groundwater recharge; and various environmental enhancements for fish, wildlife, and botanical resources.

Many California water managers, seeking to extract additional water from the atmosphere, use cloud seeding to enhance mountain snowpacks. Numerous comparisons of seeded and unseeded watersheds, dating back to the 1950s, have indicated that the technique does produce a significant increase in watershed runoff. A 1997 study by Atmospherics, Inc., of Fresno, California, highlighted the economic importance of even moderate increases in runoff.[1] Using data from ten cloud seeding programs and site-specific watershed and hydro project information, the study's author showed that a reported 2 to 9 percent increase in supplemental runoff from the seeding programs had an annual value of between $25 million and $115 million. This value resulted from increased hydroelectric generation and increased water supply for agricultural, municipal, and environmental uses.

In 1992, Southern California Edison commissioned the Desert Research Institute of Reno, Nevada, and Atmospherics Inc. to conduct a five-year field and laboratory research program to verify and document the effects of cloud seeding over Edison's 1,000-MW Big Creek project. The study, the most comprehensive research of its kind yet conducted, corroborated previous indirect estimates of gains in snowpack caused by cloud seeding. It also indicated that, from the perspective of benefit-cost ratio, the program is remarkably successful.

Gaging Success through Comparisons

In the past, Edison and others have indirectly inferred the success of cloud seeding efforts through "target versus control" statistical comparisons of streamflow data, snow survey data, rain gages, and radar data in seeded and unseeded watersheds. For example, since the 1950s comparisons of runoff in the San Joaquin River (seeded by Edison) to the nearby Merced River (not seeded) have consistently suggested that Edison's cloud seeding program increases the water supply of the San Joaquin River by about 9 percent on average. Other industry estimates of the increase in other watersheds, based on the same analytical methods, range from about 5 to 15 percent.

Unfortunately, the large range of natural variability associated with these methods can limit the statistical significance of the results. In addition, traditional streamflow measurements often are only accurate to within about 10 percent and are particularly uncertain in wet years, and an unknown amount of water is lost to evaporation and percolation. Also, it is becoming increasingly difficult to obtain "control" data because virtually every available watershed is either directly or indirectly seeded.

Unlike many previous indirect estimates of seeding's effects, the Big Creek research was based on field and laboratory studies of seeded snow. The research team was able to use physical and chemical methods to make direct measurements of the snowpack affected by seeding and to compare the water content of the seeded snowpack to natural snow.

Understanding Cloud Seeding

Water vapor is continuously present to some degree throughout the atmosphere. If some mechanism, such as an advancing front, causes air to cool sufficiently, the water in the air is condensed from vapor to cloud droplets that form around microscopic particles called cloud condensation nuclei. On average, about one

Brian McGurty is chief hydrographer and technical specialist/scientist in the hydropower generation division of Southern California Edison. He has been responsible for Edison's cloud seeding program for more than ten years.

☑ **Peer Reviewed**
This article has been evaluated and edited in accordance with reviews conducted by two or more professionals who have relevant expertise. These peer reviewers judge manuscripts for technical accuracy, usefulness, and overall importance within the hydroelectric industry.

million cloud droplets are needed to produce a single raindrop, and a typical cloud condensation nucleus is only about one-one-hundredth the size of a cloud droplet.

Among the various condensation particles present in the atmosphere, a few have just the right size and shape to become ice nuclei. The water vapor phase is converted to a solid precipitation phase when cloud droplets freeze around ice nuclei and become ice crystals. However, the vast majority of the available water in the clouds remains in a vapor and cloud droplet phase. This creates an opportunity to artificially assist the precipitation process by adding more ice-forming nuclei (such as silver iodide) to the atmosphere.

In addition to providing additional nuclei, cloud seeding increases updrafts in the cloud through a secondary latent heat of fusion effect. This makes the cloud larger, more buoyant, and able to process a greater amount of water over a longer period of time. Radar images of seeded clouds indicate increased cloud top height, increased precipitation area, and longer precipitation times than in adjacent unseeded clouds.

From the Laboratory to the Watershed

In 1946, Dr. Vincent Schaefer of the General Electric Research Laboratory in Schenectady, New York, was conducting experiments on supercooled clouds in a refrigerated "cold box." Anxious to quickly cool the box to the temperature needed for his experiments, he placed some pieces of dry ice in the box. Much to his surprise, in the presence of the extremely cold dry ice, aerosol particles began to act as condensation nuclei, and the vapor around the nuclei froze into crystals. Some ice crystals grew large enough to fall and coat the inside of the box, fortuitously pointing to a new way to artificially glaciate super-cooled clouds. Dr. Schaefer then repeated the effect in the free atmosphere by dispensing crushed dry ice from an airplane. In this way he was able to create snow crystals in a cloud, verifying the earlier cold box laboratory experiments and calculations.[2]

Once the ice-forming properties of dry ice were demonstrated, researchers recognized that other solid substances with crystalline structures similar to that of ice could function much the same. In 1947, Drs. Bernard Vonnegut and Irving Langmuir (also of the G.E. Lab) found that the atoms in silver iodide in a hexagonal crystal form assume an arrangement identical to the positioning of the oxygen atoms in ice. Silver iodide crystals act as ideal ice nuclei at temperatures below -5 degrees Centigrade.

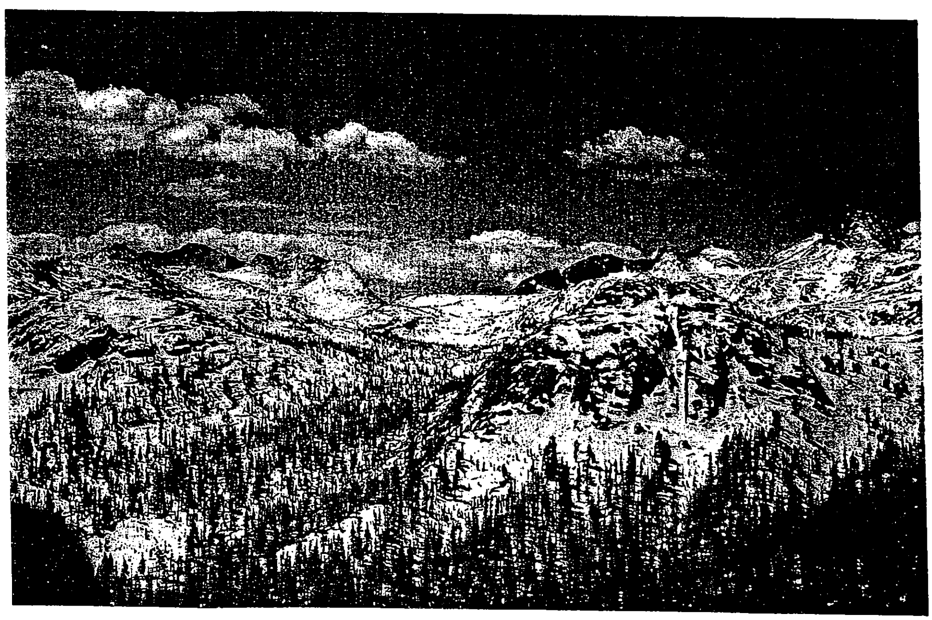
After Vonnegut's findings, enthusiasm ran so high among the experimenters that they initially talked about the possibility of modifying the weather over the entire U.S. using only a small amount of silver iodide. By 1950, about 10 percent of the land surface of the U.S. was being seeded by farmers, ranchers, utilities, lumber companies, irrigation districts, and municipalities. In the past, as many as 20 programs have been in operation at the same time in California alone. In an average year, there are 13 seeding programs in California, targeting virtually every major watershed in the state.

Edison's Cloud Seeding Program

For nearly 50 years, Edison has seeded the clouds over its Big Creek hydroelectric project in order to increase the water supply to the reservoirs of the project. The Big Creek program is the oldest continuously operated cloud-seeding program in the world. The hydroelectric project, located on the San Joaquin River in central California, includes six major reservoirs with a combined storage capacity of over 500,000 acre-feet and nine hydroelectric powerhouses with a total generation capacity of approximately 1,000 MW. The watershed above the Big Creek hydroelectric facilities consists of about 1,600 square miles of rugged mountainous terrain, with elevations ranging from less than 2,000 feet to over 13,000 feet.

Edison's program is currently run by Atmospherics, Inc. The program is staffed by experienced pilots, meteorologist-forecasters, and various support personnel. Major equipment includes a computerized ground-based radar surveillance system with digitized outputs, specially equipped turbocharged twin engine aircraft, a network of aircraft and ground-based silver iodide dispensing systems, a computerized satellite weather data acquisition system, a combined dual-channel radio and satellite communication system, and a computerized targeting model. The personnel and equipment are available 24 hours per day, seven days a week, year-round. Edison's use of both ground and airborne dispense mechanisms is unique; other programs typically use only one of the two methods.

Seventeen fixed-location manual and remote-controlled ice nuclei generators are located on the ground throughout t' watershed. Mobile dispensing syst' include the aircraft-mounted nucle' .i-erators and a mobile ground-bas' ,enerator. The fixed ground gene' rs are strategically placed throu ,ut the watershed at elevations m about 1,800 feet to nearly 10,0' ,et to allow seeding of cloud syster .noving from



Southern California Edison operates a cloud seeding program to enhance snowpacks in the Sierra Nevada headwaters of the San Joaquin River. There is much evidence that the program does produce an increase in runoff, with benefits for hydroelectric generation, agriculture, and domestic water supplies.

EXHIBIT NO. 2
CASE NO. IPC-E-05-____
G. RILEY, IPC
Page 4 of 7

southerly to northwesterly directions.

The locations of the fixed ground generators are based on a variety of factors, including the effects of low-level boundary layer windflows over complex terrain. Activation of the generators is based upon a theoretical 17-minute interval from ice nucleation to crystal fall-out along a path perpendicular to the prevailing wind direction. The generators produce silver iodide smoke particles by burning a 2 percent solution of silver iodide in acetone, injected into a propane flame.

Through the years there has been substantial indirect evidence that the seeding program enhances the snowpack and results in increased water supply to the project reservoirs. However, until recently the technology to make direct measurements of seeding's contribution to the snowpack did not exist.

Sampling, Testing Seeded Snow

The Big Creek research team was able to take advantage of several recently-developed techniques, which included:

— State-of-the-art vertical snow profiling to measure the concentration of silver (the seeding agent) in the snowpack;
— Innovative trace (source-receptor) chemistry tagging techniques;
— Measurement of supercooled liquid water using dual channel microwave radiometers;
— Upper air sounding measurements;
— Mountaintop icing and other meteorological measurements; and
— New seeding solution formulations for improved ice nucleating performance.

Cesium and indium, inert trace chemicals, were used as source-receptor tags on the seeding agent, silver iodide. Cesium was used with the ground generators and indium with the aircraft generators. This was the first research effort in which trace chemistry was used to determine the relative contributions of seeding using both ground-based and airborne sources.

After seeding with the tagged nuclei, the investigators sampled the snow in vertical profiles to detect the presence of silver iodide and the tracer chemicals. Eleven sites were sampled following storm events from January to April 1994.

The snow profiles were set up to determine the chemical and water content of the snowpack as a function of depth and time. Precipitation data were concurrently collected to establish the timing of the snow profile samples.

To collect the samples, the investigators pushed the vertical snow profiler downward into the snowpack, then dug a pit next to the profiler so that partition plates could be inserted into the profiler. Each partitioned layer, 2 centimeters high and with a 200-square-centimeter cross section, became one sample for chemical and water content analysis, yielding well over 600 samples. The samples were rapidly carried by helicopter to a staging area and transported in a refrigerated truck to the lab. After each sampling visit, the investigators moved a snowboard and a snow pole onto the surface of the snow to establish the level at which the next round of sampling would begin.

Accurate detection of the tracers depended on careful handling of the samples during and after extraction. Prior to use, each profiler was cleaned with detergent, rinsed with distilled, deionized water, and then sealed in polyethylene bags. The samples were collected with gloves and baggies to prevent contamination and were kept frozen to prevent adsorption by the container walls while in route to the lab.

In the laboratory, the project team used flameless atomic absorption spectrophotometer techniques to detect the tracers in the snow samples. Metal concentrations were determined from the absorption peak height measurements by compari-

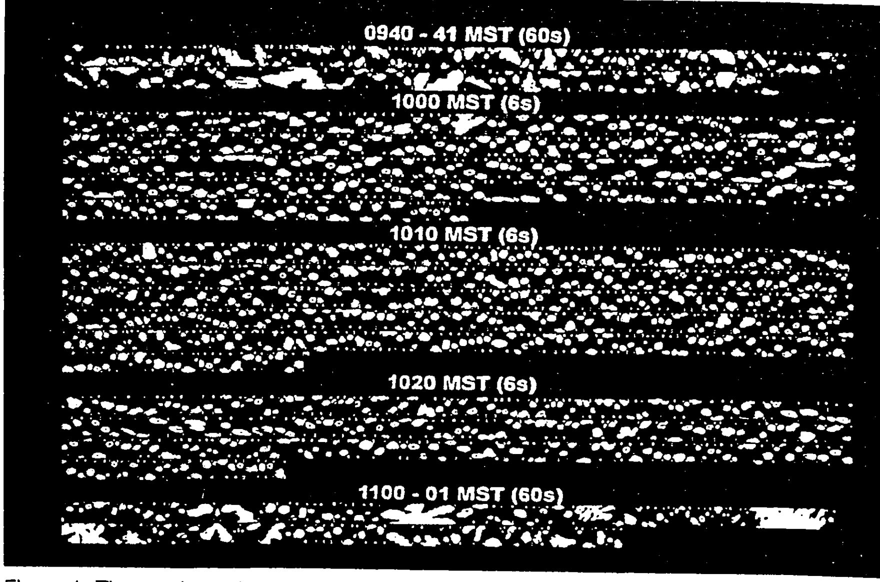


Figure 1: These micro-photographic images of ice crystals before, during, and after a pulse of cloud seeding show the effects of introducing silver iodide nuclei to the cloud. The silver iodide promotes the formation of the smaller, more densely packed crystals shown in the middle periods of the time sequence. (From Volume 29 of the *Journal of Weather Modification*—see Note 5)

Table 1: Concentrations of Silver Iodide (AgI) at Sample Sites in 1994

Seeding Target Area	*Sampling Location*	*Elevation (feet)*	*Number of Samples*	*Percent of All Samples Containing AgI Above Background*	*Concentration of AgI (ppt)*
Primary	Pioneer Basin	10,400	58	79	117.8
	Rosemarie Meadow	10,000	49	39	22.0
	Colby Meadow	9,700	43	88	66.1
	Mammoth Pass	9,500	79	87	21.6
	Dutch Lake	9,100	48	50	13.9
	Edison Lake	7,800	23	100	121.0
	Florence Lake	7,200	22	73	29.3
	Mean			73	60.8
Secondary	Strawberry Mine	7,800	68	32	14.1
	Huntington Lake	7,000	47	28	9.8
	Cow Meadow	6,200	17	47	14.1
	Shaver Lake	5,370	12	67	11.5
	Mean			36	12.4

Table 2: Calculated Increase in Precipitation Due to Cloud Seeding, in 1994

Seeding Target Area	Sampling Location	Density Ratio (Seeded/Unseeded)	Calculated Increase in Precipitation Percent	Calculated Increase in Precipitation Inches
Primary	Pioneer Basin	1.22	21.99	1.24
	Rosemarie Meadow	1.02	1.29	0.02
	Colby Meadow	1.27	22.93	0.93
	Mammoth Pass	1.09	5.35	0.59
	Dutch Lake	1.02	1.22	0.13
	Florence Lake	0.96	-2.63	-0.10
	Mean	1.09	8.23	0.50
Secondary	Strawberry Mine	1.13	4.99	0.14
	Huntington Lake	0.98	-1.47	-0.03
	Cow Meadow	1.05	1.46	-0.02
	Shaver Lake	1.15	9.68	0.32
	Mean	1.07	2.82	0.08

son with a second degree polynomial regression fitted to standard peak height data for the tracers and silver iodide. Modified analysis of variance techniques were used to determine the sample errors, which included component contributions from both standard calibration and from individual sample runs.

Measuring the Presence of Seeded Silver

The 11 sample sites included seven inside the primary target area for seeding and four representing a secondary target area. Table 1 lists the results of vertical snow profiling for the presence of silver at each of the 11 sites.

In the primary target area, seeded silver was detected above the background level of 6 parts per trillion (ppt) in more than 70 percent of the samples. The measured concentrations of 13.9 to 121.0 ppt, 2.3 to 20 times the background level, indicated very effective seeding results. By comparison, in other programs silver has been found in only 10 to 20 percent of the samples and at concentrations of only 10 to 40 ppt.[3] As expected and hoped, both the frequency and concentration of silver detected in the samples were greater in the primary target area than in the secondary area. In addition, seeding from ground generators was most effective for target sites, such as Pioneer Basin, that are located in canyons where stable southwesterly flow is frequently channeled. It was least effective for sites, such as Rosemarie Meadow, that are sheltered by ridges from the predominant southwesterly flow.

Detecting the Source of Seeded Silver

The project team used two of the sampling sites, Pioneer Basin and Rosemarie Meadow, to study the sources of the seeded silver in detail. The use of different tracers for the aircraft and ground-based seeding solutions—cesium for the ground generators and indium for the aircraft—made this analysis possible. Although Pioneer Basin and Rosemarie Meadow are at similarly high elevations, Pioneer Basin is exposed to southwesterly windflows while Rosemarie Meadow is not.

At Pioneer Basin, both tracers were present in the snowpack, but indium showed the lowest frequency and concentration, indicating that the majority of the silver at Pioneer Basin originated from ground-based generators. Based on loading estimates and the composition of the ground-based tracer solution, 72 percent of the silver detected at Pioneer Basin was released from the ground generators. In contrast, no cesium was detected at Rosemarie Meadow, indicating that all of the silver detected at that site originated from the aircraft. These results showed the value of trace chemistry as a way to differentiate between seeded snow from different sources, and thus to study the relationship between the prevailing windflow patterns at a site and seeding effectiveness.

Analyzing the Density of Seeded Snow

Ice particles produced by seeding are smaller than those that would occur naturally. Therefore, measurements of snow density can be used to infer whether the snow crystals were formed naturally or by seeding with silver iodide. In particular, when seeding is conducted from the ground, a substantial portion of the seeded ice crystals would be expected to be smaller than natural snow crystals, which form and fall from greater heights and colder temperatures. Additionally, crystals falling from a seeding plume would be expected to be more uniform than natural crystals and primarily of needle, column, and plate forms.

Researchers working in the Wasatch Mountains of Utah in 1993 and 1994 documented ice crystal images before, during, and after a pulsed seeding experiment.[4] (See Figure 1.) During the seeding portion of the experiment, the ice crystals increased in number and uniformity compared to the unseeded crystals, which were much more variable in size and habit. In addition, during the seeding pulse ice crystal concentration, ice nuclei concentration, and precipitable water increased, and the percent of ice crystals of larger size dropped significantly. These experimental measurements suggest a conceptual model, which is that seeding would produce an increase in snowpack density due to the increased packing of smaller, denser seeded crystals among the larger natural crystals.

From this conceptual model, seed/no-seed density ratios can be compared to silver concentrations. Previous experiments, in which the relative frequency distributions of silver were related to snow density, have documented that higher-density snow is correlated with higher concentrations of seeded silver. Therefore, an equation can be developed that relates the estimated increase in precipitation due to seeding to the total amount of precipitation containing silver (above the background level) and the average seed/no-seed sample density ratio. The Big Creek investigators applied such an equation to snow samples taken in March and April 1994 at the 11 sample sites, with results as shown in Table 2.

Snow samples unaffected by seeding would be expected to have density ratios, on average, around 1.0. The data in Tables 1 and 2 show that, as more silver is contained in a sample, the density ratio rises higher above the threshold of 1.0. This increase indicates that the seeding process is directly associated with changes in sample density.

Adding Up the Benefits

The Big Creek researchers, using direct measurements of snowpack density, calculated that the seeding program produced a minimum increase in precipitation of more than 8 percent in the primary target area during the months studied. This figure corroborates Edison's previous indirect statistical calculations and observations for the Big Creek project.

Edison estimates that the additional volume of water produced from cloud seeding in 1994 alone (a dry year), even accounting for little or no benefit of cloud seeding in the secondary target area, has a value of over $10 million in additional hydroelectric generation. The associated benefit:cost ratio for hydro generation alone is more than 30 to 1. Adding nearly $20 million for the total value of the additional water supply, including domestic and agricultural uses, gives a total benefit:cost ratio of more than 60 to 1. The equivalent value of cloud seeding in average or wet years would be expected to be even greater.

Although considered preliminary, these results have important and encouraging implications for Edison's cloud seeding program. ■

Brian McGurty may be contacted at Southern California Edison, 300 North Lone Hill Avenue, San Dimas, CA 91773; (909) 394-8718.

Notes:

[1]Henderson, T.J., "New Assessment of the Economic Impacts from Ten Winter Snowpack Augmentation Projects," *Journal of Weather Modification*, Volume 29, pages 42-48, 1997.

[2]General Electric Co., "First Man-Made Snow," State University of New York, GE Research & Development Center, 1978.

[3]Stone, R.H., *SCE Hydro Resources Management Project: Phase 1: Data Collection and Preliminary Analysis*, Preliminary Report for Southern California Edison Co., Contract No. C4103905, Atmospheric Sciences Center, Desert Research Institute, Reno, Nevada, 1997.

[4]Super, A.B., "Two Case Studies Showing Physical Effects of Both AgI and Liquid Propane Seeding on Utah's Wasatch Plateau," *Proceedings*, 13th Conference on Planned and Inadvertent Weather Modification, Atlanta, Georgia, American Meteorological Society, 1996.

[5]Super, Arlin B., and Edmond W. Holroyd III, "Some Physical Evidence of AgI and Liquid Propane Seeding Effects on Utah's Wasatch Plateau," (Figure 7), *Journal of Weather Modification*, Vol. 29, 1997, pages 8-32.

References:

Dennis, A.S., *Weather Modification by Cloud Seeding*, Academic Press, 1980.

Griffith, Donald A., "Planting the 'Seeds' for Increased Water Availability for Hydro," *Hydro Review*, Volume 12, No. 5, August, 1993.

Henderson, T.J., "A Summary of Cloud Seeding Activities Conducted Over the San Joaquin River During the Period 1 October 1996 to 30 September 1997," Report for Southern California Edison Co., Contract No. P2095902, Atmospherics Inc., Fresno, California, 1997.

Riley, G.T. and Henderson, T.J., "Findings from the Atmospherics Incorporated Component of the Southern California Edison Hydro Resources Management Research Program, 1993-94," Report to Southern California Edison Company, Atmospherics, Inc., Fresno, California, 1995.

EXHIBIT NO. 2
CASE NO. IPC-E-05-___
G. RILEY, IPC
Page 7 of 7

RECEIVED ☒
FILED ☐
2005 OCT 28 PM 6:08
IDAHO PUBLIC
UTILITIES COMMISSION

BEFORE THE

IDAHO PUBLIC UTILITIES COMMISSION

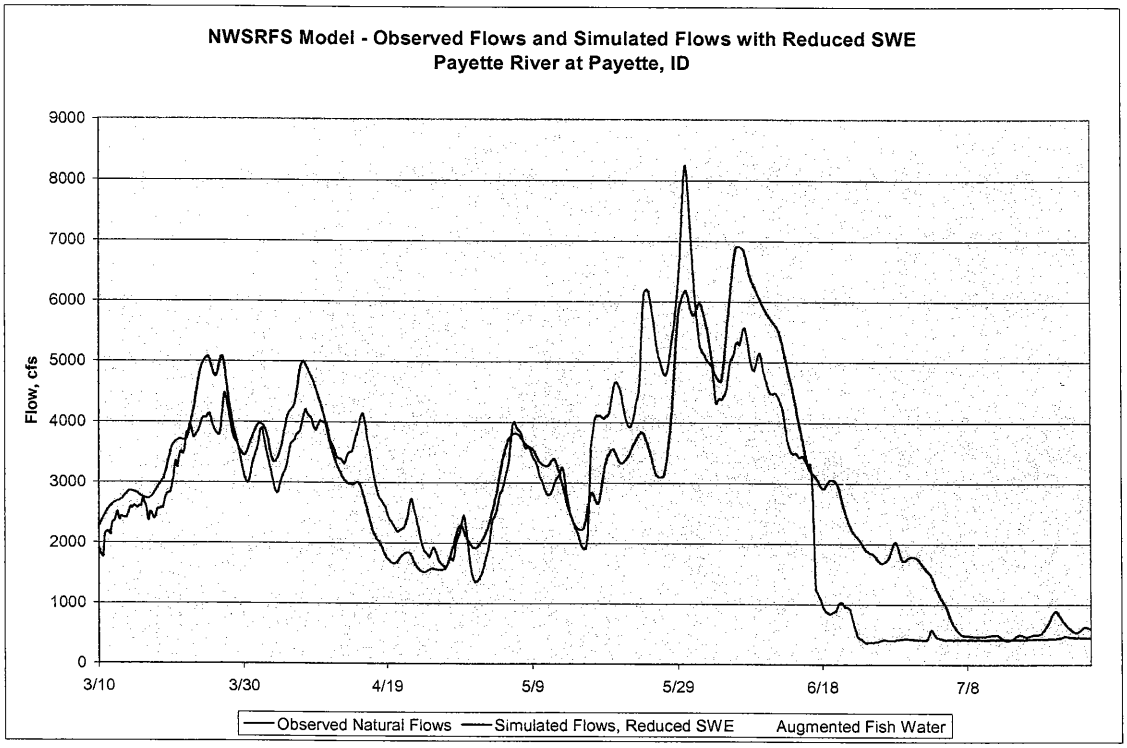
CASE NO. IPC-E-05-36

IDAHO POWER COMPANY

EXHIBIT NO. 3

G. RILEY

Exhibit 3



Hydrograph produced from the National Weather Service River Forecast System Model output showing the effect on flow in the Payette River with and without snow augmentation by cloud seeding. Note that not only is the total flow increased, but also that the peak flow occurs later and higher flows are maintained longer into the year in the seeded case.