4.5 THE SNOWY PRECIPITATION ENHANCEMENT RESEARCH PROJECT

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1. INTRODUCTION

Investigations over the last 50 years have confirmed the significant precipitation enhancement potential of the Snowy Mountains region of Australia. During 2004, special legislation authorizing Cloud Seeding under very strict conditions was passed in New South Wales. Trial operations commenced during June 2004, preceding a five year experiment to determine the economic and environmental viability of precipitation in a significant national park estate. The project infrastructure was constructed and installed over a period of 14 weeks to satisfy time constraints set in the enabling legislation. Meteorological data and operational experience gained during 2004 has been formative in developing the experimental design and refining equipment and systems requirements for the five year experiment commencing in 2005.

2. BACKGROUND

The Snowy Mountains form the highest mountain range in Australia and are located near the border of New South Wales (NSW) and Victoria (Figure 1).

Figure 1. Map indicating the location of the Snowy Mountains.

Snowfall over this region is an important source of water for hydro-generation, irrigation and recreation; however historical data indicates that the annual snowpack has decreased by more than 50% over the last 50 years.

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The potential and opportunity for seeding winter orographic clouds over the area have been well documented by Long and Huggins (1992) and Warburton and Wetzel (1992). The mountain range provides essential lift, with the terrain ascending approximately 1800 m over a rather short horizontal distance of about 15 km. The atmosphere in the lowest 2 km is the source of vast quantities of condensate supply and associated production of supercooled liquid water.

Australia has been involved in cloud seeding for over 57 years with the first investigations occurring in 1947, shortly after the experiments of Schaefer (1946). An experiment was carried out in the Snowy Mountains using aircraft during the period 1955-1960, and results from this investigation were extremely encouraging with a measured increase of 19%.

There was an attempt to undertake a cloud seeding experiment in the Snowy Mountains in 1993, however that attempt did not proceed because of environmental and ski industry concerns and a lack of political direction at the time.

The Snowy Mountains Cloud Seeding Trial Act 2004 (NSW) authorizes Snowy Hydro Limited to undertake a six year cloud seeding trial in the Snowy Mountains region of NSW. The Act was proclaimed on 5 April 2004, and Snowy Hydro commenced cloud seeding operations on 18 June 2004. The enabling legislation imposes a number of significant conditions on Snowy Hydro including a requirement that:

- Operations must be ground based;
- Only silver iodide be used as the ice nucleating agent;
- No dispersal of seeding agent is to take place from within Wilderness Areas;
- Operations only take place when precipitation would be likely to fall as snow; and
- That cloud seeding operations and their effect must be monitored and reported annually.

In addition, the NSW Government required Snowy Hydro Limited to prepare and implement an environmental management plan prior to commencing operations. Approximately 40% of the annual cloud seeding budget is allocated to environmental monitoring and compliance.

This project covers a target area of approximately 1000 square kilometres of the main range of the Snowy Mountains, including a primary target area of approximately 340 square kilometres of snow covered area above 1400 m elevation.

The project is to be evaluated using two separate methods: conventional statistical comparisons between target and control areas, and comparisons in the snow chemistry between seeded and unseeded snow.

This paper describes the fabrication, deployment and operational challenges encountered during 2004, the lessons learnt, and how these have been used to develop the experimental design and plan for the operational aspects of the experiment commencing in 2005.

3. CLIMATOLOGY

The SPERP was initially designed on the basis of the "Expert Panel Assessment; Snowy Precipitation Enhancement Trial" (Environ, 2003), which drew on the work of two earlier investigations. The SIROMATH study was a climatological analysis undertaken by Shaw and King (1986). The second study incorporated observations from the Snowy Mountains Atmospheric Research Program over the period of 1988 and 1989, and reported on by Warburton and Wenzel (1992).

Additional studies were undertaken during 2004 to evaluate:

- The impact of the operating constraints and cessation criteria of the project on the number of expected experimental units (EUs); and
- If and when ground based silver iodide releases would be expected to reach the -5°C level, where silver iodide becomes active.

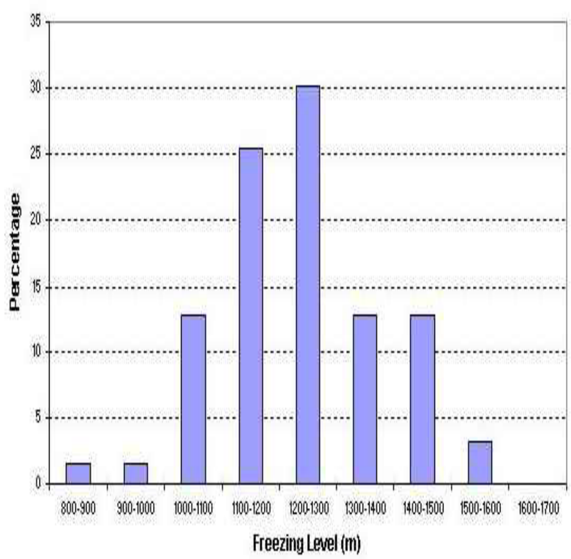

Figure 2. Frequency distribution of the height of the freezing level during cloud seeding operations in 2004.

Figures 2 and 3 show the results from 63 rawinsondes launched during storm conditions in 2004.

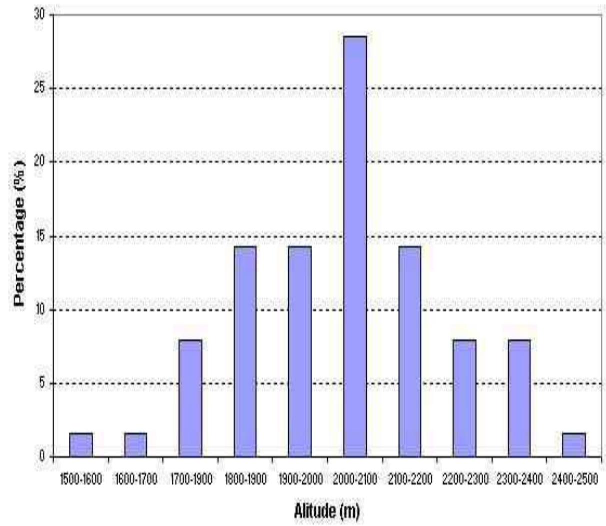

Figure 3. Frequency distribution of the height of the -5°C level during cloud seeding operations in 2004.

The critical isotherm analysis indicates that about 70% of the time during cloud seeding operations the 0°C isotherm was at or below 1300m and the -5°C isotherm was at or below 2100m. The altitude of the target area varies from 1400m to 2200m.

Establishing statistical significance of an experiment is dependent upon several parameters, including the number of EUs. An analysis was undertaken to determine the EU length required for the experiment, using precipitation and temperature records from Cabramurra (elevation 1544m), immediately to the north of the target area.

Cabramurra temperatures of ≤ 1.0°C and ≤ 0.5°C were analysed separately during periods of precipitation from May through September for the years of 1995 though 2004. This analysis provides a prediction of expected EUs based on 10 years of winter observations using a temperature closely approximating the free air 0°C isotherm at or below 1600 m.

Table 1 shows the expected number of EUs when Cabramurra temperatures were ≤ 1.0°C (Criteria 1) and ≤ 0.5°C (Criteria 2) when precipitation was measured within the hour. These calculations are based on a 1 hour purge time between EUs and precipitation was measured within the hour. Based on this analysis, a 5 hour EU length is being strongly considered for the project.

EU (hrs)	3		5		6		9		12	
Criteria	1	2	1	2	1	2	1	2	1	2
No. of hours criteria met	3	3	5	5	4	4	6	6	9	9
Avg EU/YR	40	33	19	15	29	24	18	15	10	8
Avg Precip. (mm)	4	4	7	7	7	7	10	10	14	13

Table 1. Summary of analysis of 1995 to 2004 precipitation and temperature data at Cabramurra as related to expected number of Experimental Units.

High resolution meteorological and plume dispersion modelling was performed for an operational period in early August 2004. The results of the modelling showed that:

- Simulated plumes from some fraction of the ground generator network passed over the target area during the entire operational period;
- The time required for the particles to clear the target area under varying winds, ranged from under 1 hour to over 5 hours; and
- Plumes from some of the generators did not appear to be effectively reaching the target area.

As a result of the odeling, the experiment will have a variable purge time between Eus to minimize the risk of contamination caused by highly variable wind conditions during storm events. In addition, three new generator sites are being established, involving relocation of two of the southern most generator sites.

3. PROJECT INFRASTRUCTURE

Over a period of 14 weeks following proclamation of the enabling legislation, Snowy Hydro Limited constructed and installed twelve pairs of ground generators, thirty high-resolution rain gauges, two weather stations and installed upwind and downwind rawinsonde stations, a dual-channel microwave radiometer and an X-band radar.

All of the equipment for the project is located within a significant National Park. Some of the most challenging aspects of the project instrumentation were associated with deployment of infrastructure. Road access throughout the park is limited, and a quarantine on clearing vegetation required innovative solutions to achieve the desired project outcomes. An example is shown in Figure 4, where it was necessary to raise the burner and shroud assembly above local vegetation so as to launch the aerosol plumes effectively and to avoid potential environmental impact.

4. TARGETING OF SEEDING OPERATIONS

A simplified dispersion and cloud physics model (GUIDE) was used to aid targeting during 2004 operations. The GUIDE model is further described by Rauber, *et al.* (1988). An example of the graphical output of the GUIDE model as applied to the project during 2004 is shown in Figure 5.

Figure 4. Elevated ground generator pair.

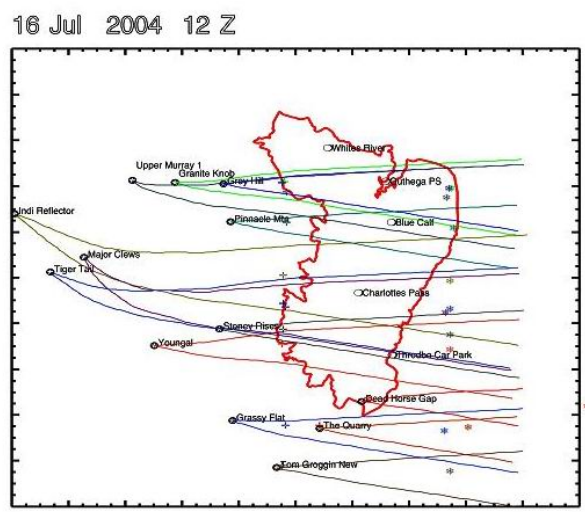

Figure 5. GUIDE model output.

The decision to start a generator pair during 2004 was made when all the seeding criteria were satisfied. Seeding criteria include the following elements:

- The GUIDE model indicated that temperature, wind direction and wind speed supports ice crystal nucleation and fallout over or immediately downwind of the target area (GUIDE output using latest upwind sounding);

- GUIDE plume trajectories indicated that the centerline of one or more plume(s) falls within the primary target area;
- Cloud top is -7^{o}C or colder (determined from the analysis of the upwind sounding);
- Cloud depth provides at least 400 m of cloud above the -5^{o}C level (Analysis of upwind sounding);
- The freezing level is ≤ 1600 m (on latest upwind sounding);

The results of the high resolution meteorological and plume dispersion modeling described in Section 2 above, indicates that a more sophisticated targeting model is required to account for local variations in wind conditions. Further work needs to be undertaken prior to 2005 operations to either refine GUIDE, or develop another targeting model.

5. GROUND GENERATOR OPERATION

Chai et al. (1993), Warburton et al. (1995a) and Warburton et al. (1995b) have proposed a method for measuring seeding effect by using an inert chemical tracer to differentiate between the processes of scavenging and nucleation in the removal of aerosol particles. The project will use silver iodide as an ice nucleating agent, and indium tri-oxide as the non-nucleating tracer. Silver to indium rations greater than that expected from the release ratio provide direct evidence of a seeding effect. Chai et al. (1993) showed that these ratios can be used to estimate changes in precipitation resulting from cloud seeding.

A critical issue in the use of trace chemistry in evaluating experiments is to establish and maintain the seeder and tracer particle size and concentrations emitted from the ground generators. Operation of a number of generators was aborted on several occasions earlier in the 2004 season because of wide variations in solution flow rates caused by temperature variations and degassing of the propellant in the solution lines. This problem was completely overcome by using computer-controlled valves, operating to maintain a set flow.

During the 2004 season, transmission electron microscope examination of seeder and tracer aerosols confirmed particle sizes and distributions smaller than that reported in the literature (see for example Warburton 1995a) required to produce optimal nucleation. Extensive monitoring under test-bed conditions has lead to the use of alternative solution atomiser nozzles that control the combustion process within the burner chambers.

6. SNOW CHEMISTRY

Snow samples were collected from 26 profiling sites during the 2004 season. Sampling sites were usually accessed by oversnow vehicle, as local conditions typically precluded the safe use of helicopters in post storm conditions. While the objective was to complete sampling within one day of operations, sampling campaigns extended to three days due to poor weather conditions. Consequently, data from samples collected after the first day were often of lower quality, as changes in the snowpack start to occur almost immediately.

Collection delays will be dealt with in future years by reducing the number of profiling sites to eleven, selected on the basis of their representative nature and reliable access during periods of inclement weather and low visibility. In addition, because it will be critical to the evaluation method, all snow profiling sites in 2005 will have collocated high-resolution precipitation gauges as shown in Figure 6.

Figure 6. Snow profiling adjacent to a high-resolution precipitation gauge.

The snow sampling equipment used in 2004 was based on the design of Warburton et al. (1995), being a hollow square section polycarbonate sampler, with provision for sampling the snowpack in 2 cm partitions. The equipment proved to be particularly difficult to use in Australian conditions, and as Warburton et al. (1995a, 1995b) and others report requires special attention and vigilance to maintain sample hygiene.

An alternative sampling methodology has been developed to minimize time in the field, and combining both the physical and chemical aspects into one operation. The new method employs a compact, single use sterile polycarbonate device to collect the sample directly, avoiding exposure and potential sample loss associated with transfer from the traditional profiler to the polyethylene sample bag.

This new method will be used from the 2005 season onwards, and is expected to deliver significantly improved levels of sample hygiene and data reliability.

Sample and data quality control was introduced to control the entire chain of custody process from field measurements, to consignment and shipping, through the laboratory, to the receipt and storage of data, and involved:

- converting field data into validated data files that prevent the entry of invalid data types and values;
- identification of each snow sample with a unique barcode number to track the sample throughout its

entire lifecycle from collection, through to analysis and reporting;

- database-level security and logging of all updates ensuring that only authorized users can access data, and that all such operations were recorded in an audit trail; and
- assigning quality codes during sample collection to all samples so that any observed contamination of the site (for example, animals, skiers, dust, positions of ice layers) can be recorded.

Results of the 2004 snow chemistry analysis, have confirmed that the primary target and upwind mountain ranges were being seeded effectively during most storm events, both in the concentrations of chemicals monitored and in the silver to indium ratio. Prevailing winds in seeded storms were predominately from northwest counter-clockwise through southwest. Recorded silver concentrations were as high as 180 ppt and silver-indium ratios of the order of 20:1, over the central part of the target area.

7. INFRASTRUCTURE DURING THE 5 YEAR EXPERIMENT

Operations during 2004 showed that the X-band radar and the downwind rawinsonde provided very little additional information. Conversely, three icing rate detectors are to be installed along the top of the main range to augment the radiometer, as large amounts of riming was experienced at mountain top level following most storms during 2004. A 2-D particle probe has also been included to provide a secondary seeding response variable.

The following equipment will be operational from 2005-2009:

- Thirteen pairs of ground generators (silver iodide/indium oxide) located around the western (upwind) perimeter of the study area;
- A dual-channel microwave radiometer located near the mountain crest;
- Three icing rate detectors on the main ridge of the target area;
- An upwind rawinsonde site located at Khancoban;
- Thirty four high-resolution precipitation gauges in the upwind, target, and downwind areas;
- Sixteen weather stations to monitor meteorological state parameters;
- Eleven snow profiling sites with co-located high resolution precipitation gauges; and
- 2-D particle measuring probe located near the mountain crest.

8. SUMMARY

Infrastructure for the Snowy Precipitation Enhancement Research Project was fabricated and operational within 14 weeks of enabling legislation being proclaimed by the NSW government in April 2004.

While the legislation enabled the project to proceed, it also imposed rigorous environmental performance obligations on Snowy Hydro, requiring annual surveillance monitoring and reporting to be undertaken. Approximately 40% of the annual operating budget is allocated to environmental compliance.

Experiences from the 2004 season have:

- confirmed earlier findings regarding meteorological conditions and seeding opportunities;
- permitted equipment, systems and processes to be thoroughly tested and improved for subsequent years;
- enabled an experimental design to be developed specifically for local conditions; and
- confirmed from snow chemistry results that the primary target and upwind mountain ranges are being effectively seeded.

9. REFERENCES

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