Background Report 9

Overview of cloud seeding

Northern Region
Sustainable Water Strategy

Our **Water** Our **Future**

Victoria
The Place To Be

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Background Report 9

An overview of cloud seeding

What is cloud seeding?

Cloud seeding is a weather modification technique which involves the introduction of material into a cloud (using aircraft or ground-based generators) with a view to encouraging the formation and growth of ice crystals or raindrops and, in turn, enhancing the precipitation (snow and/or rain) falling from the cloud.

Types of cloud seeding

There are two basic types of cloud seeding – cold and warm:

- Cold cloud seeding (glaciogenic seeding) involves adding particles such as silver iodide crystals or dry ice pellets to the supercooled (ie below freezing point) water already present in clouds to promote the formation of ice crystals. The ice crystals grow, fall and melt to below the freezing level to become raindrops.

- Warm cloud seeding (hygroscopic seeding) involves adding salt particles (sodium, magnesium and calcium chlorides), which attract water into or just below the base of suitable clouds to enhance the growth of cloud droplets by coalescence.

Historically, most cloud seeding experiments and operational programs have involved cold cloud seeding. Warm cloud seeding is a more recent development, which has extended the range of potentially seedable clouds as it can be used on warmer clouds than those suitable for seeding with silver iodide.

Efficacy of cloud seeding

Cloud seeding experiments in Victoria and elsewhere in Australia and overseas have produced mixed and often disputed results. As a consequence, cloud seeding has been and continues to be, a fairly controversial issue.

It is generally accepted by experts that, under suitable circumstances, cloud seeding can enhance precipitation-forming processes in clouds and result in an increase in precipitation at ground level. The level of success however, is critically dependant on local conditions including the geography, topography, cloud origin and type, wind direction and the nature of background aerosols.

It is also accepted that it is very difficult to prove results “on the ground”, largely due to the need to detect a change in rainfall due to seeding (know as a seeding signal) against already high level of spatial and temporal variability of rainfall.

Many experiments claim success on the basis of the measured changes in individual cloud physical properties and changes in precipitation at the base of individual clouds. In particular, this is the case for many recent warm cloud seeding experiments, which have relied on the radar analysis of the amount of rain falling out of the base of a cloud. However, a very robust experimental design is required to demonstrate enhanced precipitation at ground level on a broad aerial basis.

In addition to the debate around the efficacy of cloud seeding in producing results on the ground, there is a range of associated issues that have, in the past, generated considerable community concern in Australia and elsewhere about weather modification activities. These include the possibility of flooding, the creation of rain-shadow areas downwind, and the potential toxic effects of seeding agents such as silver iodide.

Cloud seeding is often promoted as a solution for drought, but seeding opportunities are typically very limited in drought times because of the absence of suitable clouds to seed. Rather, the potential benefits of cloud seeding for water supplies are best realised through enhancing precipitation in moderate rainfall years and in the wetter seasons; in situations where the additional water can be stored to provide an additional buffer for drought times.

A recent statement by the World Meteorological Organisation on the status of weather modification activities is summarised in Attachment 1. Some of the key findings from a recent Australian Cloud Seeding Research Symposium held in Melbourne in May 2007 are also summarised in Attachment 1.

In summary, it is acknowledged that:

- there is real potential for precipitation enhancement in suitable circumstances;
- although there have been significant advances in the understanding of cloud physics and in cloud seeding technology over the past decades, the demonstration of statistically significant (and reproducible) results from cloud seeding operations 'on the ground' has been limited.

Cloud seeding in Australia

The history of cloud seeding in Australia pre- and post-2000 is outlined in Attachment 2.

It is accepted that, under certain Australian conditions (in particular where there is orographic uplift of air over mountain ranges, such as in the Snowy Mountains), that seeding of clouds can potentially enhance rainfall. Under the right conditions, increases in rainfall of the order of 10% might typically be expected in seeded events/seasons.

However, as noted above, there has been considerable controversy about the success of experiments in producing results "on the ground". Even in situations where the proponents of cloud seeding experiments claim a success, independent analyses subsequently often raise issues about the experimental design and the magnitude/significance of the cited results.

The most successful cloud seeding experiments to date are considered to be the Tasmanian experiments, and Hydro Tasmania still conducts routine cloud seeding operations in autumn and winter to enhance rainfall into its storages.

The most recent cloud seeding experiment in Victoria was the Melbourne Water experiment in the Thomson catchment in 1988-1992 which produced inconclusive results.

While advances in cloud seeding technology have taken place over recent years, covering a variety of cloud situations and producing good results from individual clouds, there is still limited information available about the potential of the techniques to increase rainfall on the ground over economically significant areas. However, in addition to the ongoing seeding program by Hydro Tasmania, there are now two major cloud seeding trials underway in Australia that will allow further evaluation of the efficacy of current cold and warm cloud seeding techniques. These are the Snowy Mountains Precipitation Enhancement Trial (2004-2009 and subsequently extended to 2014) and the South East Queensland trial (2007-2011) (see Attachment 2).

The Snowy Precipitation Trial (SPET) provides the opportunity for a full evaluation of the effectiveness of state-of-the-art seeding and monitoring technology in an environment that is acknowledged as being suitable for cold cloud seeding. Because it is aimed at enhancing snowfall, it provides a unique opportunity for monitoring impacts on the ground via the use of tracers which allow the identification of the components of snow pack that are directly attributable to the seeding operations.

The SPET will also provide increased understanding of the physical processes involved in the chain-of-events between seeding and the arrival of precipitation at ground level. All this will facilitate the evaluation of the potential for effective seeding operations in other similar areas (eg Victoria's Great Dividing Range). The SPET will also provide detailed information about related impacts (eg impacts on ecosystems, possible downwind impacts on rainfall etc) which will inform subsequent debate about these issues.

Similarly, the South East Queensland trials will facilitate an evaluation of the potential for warm cloud seeding.

Attachment 3 provides details of the ‘consensus position’ on cloud seeding coming out of a January 2007 Workshop on Cloud Seeding hosted by the NSW Department of Environment and Conservation and the Sydney Catchment Authority. This is a good summary of the current ‘state-of-the-art’ from an Australian viewpoint.

The Victorian position

Given existing uncertainties about the efficacy of cloud seeding, and the prevailing low rainfall conditions that have been experienced over the last 11 years, the Victorian Government has chosen not to become involved in cloud seeding research or operations at this time.

Any decision to undertake cloud seeding activities to augment water supplies is a commercial decision of water corporations/hydropower authorities based on their assessment of the associated costs and benefits.

The Victorian Government is, however, committed to keeping up-to-date with developments in cloud seeding research and operations in Australia and will maintain links with the National Task Group on Precipitation Enhancement that was formed after the Cloud Seeding Research Symposium held in Melbourne in May 2007. This group is best placed to provide consolidated advice on cloud seeding in Australia.

References

1) Australian Cloud Seeding Research Symposium – Bureau of Meteorology Research Centre, Melbourne (7-9 May 2007) (http://www.bom.gov.au/bmrc/basic/events/cloudseeding)

2) Dept of Environment and Conservation (NSW) and Sydney Catchment Authority (2007) Workshop on Cloud Seeding, Final Draft Report (http://www.bom.gov.au/bmrc/basic/events/cloudseeding/NSW_DEC_SCA_cloudseeding_report31Jan2007.pdf)

3) Ryan B and King W (1997) "A Critical Review of the Australian Experience in Cloud Seeding", Bulletin Amer. Met. Soc., Feb. 1997

4) Ryan B and Sadler B (1995) "Guidelines for the Utilisation of Cloud Seeding as a Tool for Water Management in Australia", Agriculture and Resource Management Council of Australia and New Zealand.

5) WMO (2007) "WMO Statement on Weather Modification" (http://www.wmo.ch/pages/prog/arep/wmp/documents/WM_statement_guidelines_approved.pdf)

Attachment 1:

Key findings from reviews of the status of cloud seeding research and operations

World Meteorological Organisation (2007) "Statement on Weather Modification"

The 'Executive Summary' of the above report summarises the status of precipitation enhancement technology and the underlying physical concepts as follows:

- *There is considerable evidence that cloud microstructure can be modified by seeding with glaciogenic or hygroscopic materials under appropriate conditions. The criteria for those conditions vary widely with cloud type. Evidence for significant and beneficial changes in precipitation on the ground as a result of seeding is controversial and in many cases cannot be established with confidence.*
- *In our present state of knowledge, it is considered that the glaciogenic seeding of clouds formed by air flowing over mountains offers the best prospects for increasing precipitation in an economically viable manner. These types of clouds attracted great interest in their modification because of their potential in terms of water management (i.e. the possibility of storing water in reservoirs or in the snowpack at higher elevations). There is statistical evidence that under certain conditions precipitation from supercooled orographic clouds can be increased with existing techniques. Statistical analyses of streamflow records from some long-term projects indicate the cost-effective increases have been realised.*
- *The use of glaciogenic agents such as silver iodide to seed supercooled clouds has produced few results of general validity. Observed responses of clouds vary widely. There are competing explanations and the questions are not yet resolved.*
- *Seeding of convective clouds with hydroscopic materials has been shown to be adaptable to different cloud types and has produced encouraging results but is not yet an established technology*.

Other points made in the main body of the report include:

- Expected effects of seeding are almost always within the range of natural variability (low signal-to-noise ratio) and our ability to predict the natural behaviour is still limited.
- It should not be ignored that, under certain conditions, seeding may cause more hail or reduce precipitation. However, properly designed and conducted operational projects seek to detect such adverse effects.
- Much work remains to be done to strengthen the results from cloud seeding experiments and produce stronger statistical and physical evidence that increases in precipitation occurred over the target areas and over a prolonged period of time, as well as to search for the existence of extra-area effects.
- Advances in observational and computational tools over recent years are supporting an improved understanding of cloud physics and an improved ability to evaluate the impacts of weather modification techniques.

(http://www.wmo.ch/pages/prog/arep/wmp/documents/WM_statement_guidelines_approved.pdf)

Australian cloud seeding research symposium (7-9 May 2007)

In May 2007, the Bureau of Meteorology convened a Cloud Seeding Research Symposium in Melbourne aimed at examining the potential benefits of cloud seeding, particularly in the light of the drought conditions affecting large parts of Australia. The scope of considerations included:

- reviewing the scientific basis for seeding and methods for testing the effectiveness of various cloud seeding approaches, taking into account recent technological advances;
- understanding international cloud seeding research/operational programs; and
- identifying areas of future research, and mechanisms that might be used to support such research.

A range of overseas experts gave keynote presentations at this Symposium, as well as representatives from a range of Australian organisations including Snowy Hydro, Hydro Tasmania, the Bureau of Meteorology, CSIRO and Monash University.

The material presented at the Symposium highlighted key understandings as follows:

- under specific conditions, cloud seeding can enhance precipitation;
- it is necessary to have a detailed understanding of weather systems and cloud physics to determine whether there are suitable seeding opportunities to make an operational program worthwhile;
- it is difficult to 'translate' measured changes in cloud physical properties as a result of seeding operations into verifiable changes in precipitation on the ground, or to employ methods that produce scientifically credible, and repeatable changes in precipitation;
- more than 37 countries do have operational cloud seeding programs aimed at enhancing precipitation or mitigating hail. However, many of these programs operate without any scientific quantitative assessment or evaluation of the seeding programs. There are even examples of ongoing operational cloud seeding programs in areas where it was previously found through scientific experimentations that seeding would not work;
- although there is strong evidence that cloud seeding can enhance precipitation under certain conditions in certain areas, there is also strong evidence that current seeding technologies will not work in other atmospheric conditions and areas (there is even evidence that in some situations glaciogenic seeding may reduce precipitation);
- scientific understanding has progressed on many fronts over the past two decades with the use of satellite imagery, improved techniques for monitoring the physical and chemical properties of clouds, and significant advances in observational, computational and statistical technologies; and
- cloud seeding is not a 'silver bullet' to provide relief from drought (there are typically limited seeding opportunities during drought times). However, it may be part of the solution in that cloud seeding benefits are usually best realised by seeding suitable rain-bearing clouds in wetter seasons and storing the additional water to provide a larger buffer for drought times.

A key outcome from the Symposium was the formation of a National Task Group on Precipitation Enhancement, chaired by Prof. Roger Stone (Director of the Australian Centre for Sustainable Catchments (ACSC) at the University of South Queensland), which is aimed at better coordinating cloud seeding research in Australia.

(http://www.bom.gov.au/bmrc/basic/events/cloudseeding)

Attachment 2:

History of cloud seeding in Australia

Australia has a long history of cloud seeding experiments. Details are provided below in terms of the history to 2000 and more recently.

1947-2000

Cloud seeding operations commenced in the CSIRO Division of Radiophysics in 1947. The Division was subsequently divided in two and a new Division of Cloud Physics continued the work. From about 1965, State governments also became active in operational cloud seeding programs during the severe drought of the mid-1960s. The CSIRO Division of Cloud Physics was amalgamated with the Melbourne-based Division of Atmospheric Research in 1983. CSIRO has not had an operational cloud seeding unit for some time, but scientists have been directly involved in some cloud seeding experiments and have continued to provide advice on cloud seeding matters.

Most of the Australian experiments have involved the injection of silver iodide into clouds as a means for promoting the formation and growth of ice crystals, with a view to having the ice crystals subsequently grow big enough to fall out as precipitation.

In 1995, Ryan and Sadler (under the auspices of the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ)) published a report titled “Guidelines for the Utilisation of Cloud Seeding as a Tool for Water Management in Australia.” This report summarised the Australian experience with cloud seeding (the various experiments are listed in Table 1), and set out guidelines for water managers to assist them (in consultation with atmospheric scientists and commercial operators) in the development and planning of cloud seeding experiments.

The most successful of the Australian experiments are considered to be the Tasmanian experiments which ran over three different periods (1964-1971; 1979-1983; and 1992-1994). Hydro Tasmania still undertakes routine operational cloud seeding programs in many years to augment their supplies (at a cost of a little over $1 million per year). It was originally estimated that rainfall increases of around 20% in autumn and winter can be attributed to the seeding.

Results of one of the early experiments conducted in the Snowy Mountains were also promising (suggesting a 19% increase in rainfall), but these results were subsequently disputed and the results finally reported as “encouraging” but “inconclusive”.

The Melbourne Water experiments over the Thomson catchment over the period 1988-1992 are the most recent in Victoria. They cost around $6 million and results were inconclusive - no increase in rainfall in the target area, but some suggestion of an increase in the buffer zone between the target and control area and in the downwind area.

Economic analyses based on the Tasmanian experiments, Melbourne Water experiments and the proposed Snowy Mountains experiment, suggest that for water management purposes, an increase in precipitation of the order of 5-10% in rainfall makes a cloud seeding operation economically viable. However, it is extremely difficult to prove impacts "on the ground".
An extensive Environmental Impacts Statement was prepared on a proposed cloud seeding experiment in the Snowy Mountains in 1993. Apart from the debate about the technical feasibility of such a project, other associated issues proved to be even more contentious, and the project did not proceed at that time.

These issues included:

- erosion and water quality in target and downwind areas;
- changed flow patterns and related environmental issues;
- potential additional flooding;
- some farmers not wanting more precipitation;
- presence of scientific equipment/raingauges (an issue in the case of national parks in particular);
- chemical 'pollution' from seeding agents (again an issue in the case of national parks in particular, even though concentrations of seeding agents reaching the ground are very small);
- upwind (target) areas seen as taking rainfall that would have otherwise fallen further downwind; and
- who owns the extra water produced (and whether this can this be accurately quantified).

Table 1: Summary of the history of cloud seeding experiments in Australia

- 1947-1952 CSIRO Single Cloud Experiments - using dry ice dropped into top of cumulus clouds near Sydney.
- 1953-1956 CSIRO Single Cloud Experiments - using silver iodide from ground-based and airborne generators, in locations from SA to QLD.
- 1953-1963 Early CSIRO Experiments in South Australia, Warragamba Dam, Snowy Mountains, and New England - using silver iodide and ammonium iodide dissolved in acetone. Of the four experiments, only that conducted in the Snowy from 1955-1959 showed what was initially thought to be statistically significant evidence for rainfall increase (+19%). However, there were subsequent disputes over the experimental methodology and analysis, and the final report described the results of this experiment as ‘encouraging’ but ‘inconclusive’.
- 1965-1971 Seeding by State Governments in Victoria, NSW, Qld, and WA - CSIRO acted in an advisory capacity. In all cases, results were inconclusive or controversial. For example, there was considerable debate about the results from a 1966 seeding project in the Wimmera-Mallee region of Victoria.
- 1964-1971 Tasmania I - using silver iodide. Results suggested increases in precipitation as high as 30% in autumn. HEC adopted operational seeding from 1972.
- 1979-1983 Tasmania II - using silver iodide; conducted by HEC and analysed by CSIRO. Results showed a 37% increase in rainfall on suitable days. Total increases calculated were about half that calculated in the previous experiment but were accomplished using a tenth of the seeding time.
- 1992-1994 Tasmania III - using dry ice. Detailed analysis underway at time of the writing of the paper.
- 1972-1975 CSIRO Emerald Experiment (Qld) - using both silver iodide and dry ice. Experiment abandoned, as it was evident that a controlled experiment would need many years to yield a reliable result.
- 1979-1980 CSIRO Western Victoria Experiment - using silver iodide and ammonium iodide in acetone. Found fewer seeding opportunities than expected and economic analysis showed that by 1983 B/C ratio had dropped due to falling wheat prices and the experiment was discontinued.
- 1980-1982 WA northern wheatbelt cloud study 1980-1982 - concluded that there was potential for operational cloud seeding but needed to commit resources on a 20 year time scale to demonstrate results.
- MMBW/CSIRO Experiment 1988-1992 - using silver iodide in acetone for stratiform or cumulus clouds, and dry ice for orographic cap clouds and cumulus clouds with tops warmer than -5°C. Results showed postfrontal and interfrontal clouds offered the best opportunities. Results were inconclusive.

Source of Information: "A Critical Review of the Australian Experience in Cloud Seeding" by B Ryan and W King, Bulletin Amer. Met. Soc., Feb. 1997

2000+

The Snowy Mountain Precipitation Enhancement Trial (2004-2009 with a recent extension to 2014)

Snowy Hydro are currently undertaking an experimental cloud seeding trial with the aim of increasing snowfall by seeding winter storms to enhance late spring and summer runoff from the Snowy Mountains. The trial commenced in the winter of 2004 and was scheduled to end after the winter of 2009, but it has recently been extended until 2014 and the size of the project area has been increased.

This trial is similar to the proposal that was considered and rejected in the early 1990s (see above) except that it has been revised to:

- exclude the Jujungal Wilderness area; and
- allow for the interruption of the seeding regime by the ski industry if the freezing level is too high above the ground at specific resort locations (to minimise the risk of enhanced precipitation falling as rain rather than as snow).

In addition, it is using the latest seeding technology and experimental design.

The operation targets the alpine area above 1,400 m elevation in Kosciuszko National Park. The seeding of suitable clouds is occurring via the introduction of silver iodide into suitable clouds from ground based generators. The seeding material includes an inert tracer agent (indium sesquioxide), which assists in the evaluation of the impact of the seeding operations.

The expected average annual increase in snowfall is of the order of 10%. This is within the range of natural variability. However, the tracer will enable the determination of which snow is a direct result of the seeding operations. The expected annual increase in water yield for the Murray River system is 70 GL.

Initial results from this trial are reportedly promising, with samples from the target area during the first snow season showing an average increase in snow precipitation of 25% - this still has to be translated into an estimate of the water generated in spring when the snow melts.

Snowy Hydro and Hydro Tasmania Alliance 2007

In early 2007, Snowy Hydro and Hydro Tasmania announced a joint venture to provide services to support interest in cloud seeding around Australia.

SE Queensland Cloud Seeding Trials 2007-2011

The Queensland Government is undertaking a four-year cloud-seeding project in South East Queensland which commenced in November 2007.

The aim of the project is to find out if cloud seeding is a viable way of enhancing the rainfall over South East Queensland's dam catchments. The intention is to determine whether it is worthwhile investing in cloud seeding in the long term to increase water storage. It is recognised that cloud seeding is not a means for breaking the drought.

The project has two components. The first is to understand local weather patterns and associated cloud physics to determine whether suitable opportunities exist (during South East Queensland's wetter spring and summer seasons) in which seeding is likely to be effective; the second is to carry out cloud-seeding trials. The initial focus will be on the Wivenhoe and Somerset dam catchments.

The project is being managed by the Queensland Climate Change Centre of Excellence and is being overseen by a Scientific Advisory Group, which is chaired by Professor Roger Stone (Director of the Australian Centre for Sustainable Catchments (ACSC) at the University of South Queensland), and includes experts on cloud seeding from the Australian Bureau of Meteorology, the Bureau of Meteorology Research Centre, CSIRO, and Monash University.

Attachment 3: Final Report – workshop on cloud seeding

Department of Environment and Conservation (NSW)

SYDNEY CATCHMENT AUTHORITY

- F I N A L D R A F T R E P O R T -

Workshop on Cloud Seeding

Hosted by the NSW Department of Environment and Conservation (DEC) and the Sydney Catchment Authority (SCA)

Wednesday 31st January 2007
Department of Environment and Conservation
59-61 Goulburn St Sydney

Introduction

A one-day workshop was held to review the current state of knowledge on cloud seeding for rainfall enhancement, and the role of aerosols and air pollution on precipitation. The workshop was jointly hosted by the NSW Department of Environment and Conservation (DEC) and the Sydney Catchment Authority (SCA), and independently facilitated by Professor Gary Jones, CEO of the eWater Cooperative Research Centre. Nineteen scientists and senior managers (see appendix) participated in the workshop, with formal presentations given by Neville Fletcher (Australian National University), Michael Manton (Monash University), Roger Stone (Queensland Climate Centre), Greg Ayers (CSIRO Marine and Atmospheric Research) and Keith Bigg (The Rainmaker Team).

Participants discussed key issues relating to the scientific evidence for the effectiveness of cloud seeding. Participants briefly reviewed the experience of cloud seeding activities in Australia, current and planned cloud seeding projects and the effect of pollutants on precipitation. The following summary presents a consensus position of attendees at the workshop, expressed as Q&A.

Consensus position

1. **Are scientists convinced that cloud seeding works**? It is generally agreed that targeted cloud seeding can modify precipitation from individual clouds under specific local conditions. The characteristics of clouds that will respond to seeding are well documented. In favourable circumstances cloud seeding has been demonstrated to increase precipitation from individual clouds, but it can also decrease precipitation from individual clouds if applied haphazardly. The extent to which the seeding of individual clouds can be scaled up to enhance precipitation over a large area is unclear. To provide reasonable scientific certainty, scientists require a viable physical model based on cloud physics and direct observational evidence as well as robust statistical validation of the results.

2. **What are the main difficulties?** One major problem is that is it difficult, if not impossible, to quantify the impact of a cloud seeding operation over a wider area, without expensive, time-

consuming and detailed experimentation and evaluation. Natural variability in rainfall is high, both in spatial and temporal terms, and it is difficult to predict what would have happened in an area had cloud seeding not taken place, despite the use of controlled experiments. It is difficult to design a practical cloud seeding campaign that has sufficient statistical rigour to prove or disprove the effectiveness of the seeding. Experiments using appropriate statistical design criteria may need to run for many years in order to detect with reasonable certainty a rainfall enhancement signal against the 'noise' of the natural variability of rainfall. Many cloud seeding trials have suffered because of the inability of the design to produce unequivocal signals of the effect of cloud seeding. In addition, clouds amenable to seeding may not be present for a significant fraction of the time - for example the 1979-1980 Victorian experiment was abandoned due to a lack of suitable clouds.

3. **What has previous experience in Australia shown?** Cloud seeding experiments have been conducted by CSIRO in Australia since 1947, with experiments in the 1950s and 1960s in South Australia, Queensland, the Snowy Mountains, Central Plateau of Tasmania, the New England district of NSW and the Warragamba catchment west of Sydney. Of these experiments, only the Snowy Mountains and Tasmanian studies produced statistically significant increases in rainfall, although the apparently positive result of the Snowy Mountains experiment was disputed by some of the parties involved. Other experiments, conducted by various State Governments in the late 1950s and 1960s, were inconclusive because the experimental design was not robust enough to provide certainty on cause and effect. Further studies of the potential for cloud seeding to increase agricultural productivity conducted in the 1970s and early 1980s did not demonstrate that seeding would be economical or reliable for this purpose.

   The most promising results have been obtained where clouds are formed by air forced up over mountain systems such as Central Tasmania, where results show with reasonable statistical significance that cloud seeding had increased precipitation over target areas (albeit with some anecdotal evidence for decreases downwind – there is not sufficient data to assess this possibility definitively). Cloud seeding is also being conducted by Snowy Mountains Hydro for snow pack enhancement, with the NSW Natural Resources Commission charged with supervision of the trial and reporting on the environmental impact of the trial[1]. The success or otherwise of the Snowy experiment will not be known until sufficient statistical data have been obtained several years hence at the end of the experiment. A 4-year, $7.5m cloud seeding investigative project in south-east Queensland has recently been announced. This will have a rigorous statistical design to test the effectiveness of the seeding in increasing precipitation. It should be noted that different types of clouds form at different latitudes and the Queensland experimental technique may differ from that used elsewhere.

4. **Can findings from one area be transported to another?** Not readily – each area has different topographic and climatological features that respond differently to cloud seeding. Detailed studies

[1] Snowy Mountains Cloud Seeding Trial Act 2004.

are required in specific areas to identify and assess cloud types in different seasons that may be amenable to seeding. Carefully designed experiments are required to separate signal (additional precipitation attributed to seeding) from noise (natural variability and sampling errors), test and verify models and predictions, and then iteratively improve the experimental design before progressing to operational design. Numerical modelling and prediction, in association with advanced measurement techniques, are also integral to the design and testing of specific hypotheses in modern cloud seeding.

5. **What are the types of cloud seeding?** There are two basic types of cloud seeding – warm and cold. *Warm* cloud or hygroscopic seeding involves the introduction of small droplets such as salt spray or large hygroscopic[2] aerosols into the base of continental convective clouds which cause raindrops to form and may cause the cloud to grow due to release of latent heat and/or due to enhanced coalescence of drops. *Cold* cloud seeding creates additional ice crystals that grow at the expense of supercooled liquid water using nucleating agents such as dry ice pellets or crystalline silver iodide nuclei released from ground burners or aircraft. The ice crystals then grow, fall and become raindrops below the freezing level. Currently much of the cloud seeding worldwide is operational hygroscopic seeding in warm cumulus clouds in sub-tropical and tropical areas, carried out without rigorous scientific validation.

6. **How do you tell if a cloud is suitable?** Modern direct and remote sensing techniques can give detailed information on cloud structure and physical quantities such phase (water-vapour-ice) and wind speed and direction. Doppler and polarisation radar can be used to study non-precipitating clouds and evolving cloud cells, microwave radiometer profilers measure liquid water content, and satellite data can be used to interpolate between detailed measurement points. These data can be fed into detailed cloud models for prediction and verification of seeding impacts.

7. **Can cloud seeding be used to break a drought?** No - cloud seeding cannot make clouds where none exist, nor can cloud seeding increase precipitation from clouds that do not have the relevant characteristics. Drying trends cannot be managed or offset by cloud seeding. If effective at all, seeding is most applicable in years of moderate rainfall.

8. **Are there any long-term impacts from cloud seeding?** Some studies have suggested the existence of “persistence effects”. A recent hypothesis is that the silver iodide used to seed clouds affects the microflora in soils and causes microorganisms to be released from soils. These are hypothesised to be carried into clouds and form nuclei that will lead to precipitation. This effect may last for a long period following the end of actual cloud seeding activities. If such effects are real, they will confound quantitative studies of cloud seeding effectiveness, but the overall effect could be a further increase in rainfall. Persistence effects have to date received narrow coverage in the peer-reviewed scientific literature.

[2] Hygroscopic particles attract moisture from the atmosphere

9. **Are there any downsides to cloud seeding?** The main disadvantage with cloud seeding is the high operational cost without commensurate assurance of success or economic return. Other issues include the possibility of downwind effects (decreased rainfall downwind from the target area), possible ecological impact of minute traces of seeding chemicals on sensitive terrestrial ecosystems, legal challenges, and overselling the technology without supporting scientific understanding and robust evidence. Experience has shown the importance of community engagement and consultation.

10. **Does pollution influence rainfall?** There is abundant physical evidence that aerosols (fine particles) emanating from human activity from industry, transport, landuse or fire does affect cloud physics, i.e. the characteristics of clouds are altered by introduction of these particles. Human activity is known to increase the concentration of airborne aerosols, particularly of smaller size. However there is limited, conflicting evidence on the impact of pollution on rainfall – increases, decreases and nil impact have been reported. The level of natural variability due to other causes is probably much higher than possible changes attributed to pollution. Importantly, low clouds that are particularly susceptible to microphysical changes due to aerosols emanating from the ground are generally not the main sources of annual rainfall in mid-latitude regions. If pollution effects were to be demonstrated in a particular region, then the preferred approach would be to reduce pollution at its source.

10 April, 2007

Appendix 1 – Workshop participants

Facilitator: Professor Gary Jones, Chief Executive of eWater Cooperative Research Centre

Participants

Dr Brian Spies, Manager Science, Sydney Catchment Authority (co-convenor)
Dr Klaus Koop, Director of Environment & Conservation Science and Chief Scientist, NSW EPA (co-convenor)
Dr Greg Ayers, Chief of Marine and Atmospheric Research, CSIRO
Dr Doug Shaw, Mathematics and Information Sciences, CSIRO
Prof Roger Stone, Director, Australian Centre for Sustainable Catchments, Queensland
Prof Neville Fletcher, Research School of Physical Sciences & Engineering, Australian National University
Prof Michael Manton, School of Mathematical Sciences, Monash University
Dr E Keith Bigg, Rainmaker Team
Prof Andy Pitman, Professor and Network Convenor & ARC Earth System Science Network, Macquarie University
Ms Jane Gibbs, Manager Policy, Metropolitan Water Directorate, NSW Cabinet Office
Mr Derek Elmes, Manager Strategic Science Section, DEC
Dr Henk Heijnis, Scientific Program Manager, Sydney Catchment Authority
Mr Mahes Maheswaran, Strategic Supply Planning Manager, Sydney Catchment Authority
Mr Jason Martin, Strategic Supply Planning Manager, Sydney Catchment Authority
Mr Barrie Turner, General Manager Environment & Planning, Sydney Catchment Authority
Ms Katrina van Lint, Natural Resource Analyst, Natural Resource Commission
Dr David Rissik, Natural Resource Analyst, Natural Resource Commission

Presentations

- Neville Fletcher (Australian National University) – Clouds, rain and rainmaking
- Michael Manton (Monash University) – Statistical design and evaluation of cloud seeding experiments in Australia
- Roger Stone (Queensland Climate Centre) – initial investigation of the potential application of scientific systems for cloud seeding in Queensland
- Greg Ayers (CSIRO Marine and Atmospheric Research) – Pollution and precipitation: evidence for Australia
- Keith Bigg (The Rainmaker Team) – A new look at cloud seeding suggests better and cheaper methods