natural resources commission

REPORT TO THE MINISTER FOR THE ENVIRONMENT AND MINISTER FOR PLANNING

REVIEW OF SNOWY PRECIPITATION ENHANCEMENT RESEARCH PROJECT ANNUAL REPORT (FEBRUARY 2005)

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Inquiries

Inquiries about this report should be directed to:

Alex McMillan

Phone (02) 8227 4300

E-mail alex.mcmillan@nrc.nsw.gov.au

Postal address GPO Box 4206, Sydney NSW 2001

List of acronyms

BACI	Before–After, Control–Intervention (a standard experimental design)
BAI	Before–After–Intervention (a simpler, less analytical experimental design)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEC	Department of Environment and Conservation
NRC	Natural Resources Commission
NSW	New South Wales
SPERP	Snowy Precipitation Enhancement Research Project

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1 Introduction

The Snowy Precipitation Enhancement Research Project (SPERP) and its monitoring program were established to answer the following questions:

- Will cloud seeding increase snowfall in the Snowy Mountains?
- Will cloud seeding have a significant adverse environmental impact?

In February 2005, Snowy Hydro Limited (Snowy Hydro) submitted the first annual report on its cloud seeding trial[1] to the NSW Government. The report covers the calendar year 2004, in which Snowy Hydro established and tested its cloud seeding equipment, and developed and tested the protocols it intends to use to monitor the effectiveness of its cloud seeding operations and their environmental impacts.

In March, the Minister for the Environment referred[2] this annual report to the Natural Resources Commission (NRC) for review and provision of advice on the progress of the trial, its environmental impact to date, and the validity of its environmental monitoring elements.

The NRC has now completed this review. It analysed and assessed the information provided in the annual report, and consulted with Snowy Hydro and the Department of Environment and Conservation (DEC). It also inspected some of the trial's generator and monitoring sites and obtained additional expert opinion from the Commonwealth Scientific and Industrial Research Organisation (CSIRO). This report presents and explains the NRC's findings and recommendations.

1.1 Compliance with legislation and environmental management plan

The *Snowy Mountains Cloud Seeding Trial Act 2004*[3] authorises Snowy Hydro to conduct cloud seeding operations in the Snowy Mountains subject to certain conditions. Snowy Hydro's annual report indicates that they are conducting the cloud seeding trial and associated environmental monitoring in accordance with the Act and their environmental management plan.

1.2 Will cloud seeding increase snowfall in the Snowy Mountains?

Snowy Hydro is generally using the best available technology and procedures, some of which are well established and others are 'cutting edge'. They are using innovative approaches to overcome some inherent limitations in the design of the trial.

However, the NRC believes the trial may have difficulty establishing statistically whether cloud seeding operations are increasing snowfall, as the planned trial duration (5 years) is quite short for a trial of this type, and as the trial has insufficient controls by which to judge the relative impact of cloud seeding and natural variability in snowfall.

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1 Snowy Hydro (2005). *Snowy Precipitation Enhancement Research Project Annual Report (February 2005)* (Snowy Hydro Limited: Sydney).

2 Pursuant to section 8 of the *Snowy Mountains Cloud Seeding Trial Act 2004.*

3 *Snowy Mountains Cloud Seeding Trial Act 2004 No. 19* (New South Wales), at s. 4 (1)

Snowy Hydro has developed an experimental design that includes randomised cloud seeding over a target area to assess the impact of cloud seeding on snowfall. This technique relies on replication in time rather than in space to statistically demonstrate the impact of cloud seeding. The longer the trial runs the greater would be the chance to reliably demonstrate if cloud seeding has increased snowfall.

Snowy Hydro is hopeful that it can overcome the constraint of a short trial (5 years) by sampling more frequently and intensively. However, given the small size of expected increase in snow pack depth relative to the natural variability, the NRC believes five years may prove to be too short to get statistically significant results.

Snowy Hydro consulted international experts in setting up a chemical marker study to strengthen the assessment of cloud seeding operations. This relatively new technique allows quicker assessment (on an event-by-event basis) of change in snow pack depth due to cloud seeding. However, in the absence of a conventional control and with only 11 snow monitoring sites in an area of more than 1000 km^2, there can be no guarantee that this technique will provide sufficient data to reliably demonstrate that cloud seeding has increased snowfall.

To be sure of delivering a reliable result, the trial may need to be extended to around 10 years and to have a conventional control area added which is biophysically comparable to the target area. A decision on whether or not the trial may need to be extended can be deferred until say Year 4 by which time the adequacy of the data acquired to that point should be evident.

1.3 Will cloud seeding have a significant adverse environmental impact?

The Act provides that the relevant Ministers may suspend or terminate the cloud seeding operations if they are having or will have a significant adverse environmental impact.[4] However, the Act is silent on how any 'significant adverse environmental impact' is to be assessed. The NRC considers that this assessment should be made by balancing any positive and negative environmental impacts that can be attributed to the cloud seeding.

In 2003, an expert panel of scientists assembled by Snowy Hydro found that the cloud seeding proposals were unlikely to have a significant adverse environmental impact over the 6 years of the trial. Nothing that has occurred subsequently would warrant a review of that assessment, and the NRC agrees that there is a very limited likelihood of any significant environmental impact from this trial over the next 5 years.

In making its assessment, the expert panel considered possible impacts on a broad range of environmental factors, including downwind precipitation, stream flow, health of montane streams, habitat of snow dwelling fauna and the health of alpine ecosystems.

4 *Snowy Mountains Cloud Seeding Trial Act 2004*, s.6.

However, the trial's current environmental monitoring plan is focused on ecotoxicity potential only. It is designed to detect whether the silver iodide and indium trioxide, dispersed in aerosol form across a 1000 km^2 area, have accumulated at one of the sites[5] being measured, such that they might become toxic to plant or animal life at that site. Given the very small amounts of these chemicals used in the trial and the randomness of their distribution across the target area[6], finding an accumulation at one of the very few sites being monitored is a very unlikely outcome. Indeed, Snowy Hydro's monitoring in 2004 did not detect any accumulation above trigger values. Nevertheless, ecotoxicity is probably worth monitoring at the end of the trial (rather than every year), provided that a sufficient number of sites are monitored to enable valid conclusions to be drawn about the whole target area.

Further, the NRC believes that the environmental monitoring plan should be modified to cover the other potential environmental impacts examined by the expert panel. This would lead to a more balanced impact assessment and potentially provide multiple lines and levels of evidence to better establish whether the cloud seeding caused any of the observed environmental impacts. Ultimately, if the monitoring program were extended, it would generate meaningful lessons on the likely long term environmental impacts of cloud seeding programs generally.

One way of doing this would be to broaden the trial's monitoring progam to incorporate monitoring data already being generated in the trial area (but not as part of the trial). This could be done with little or no increase in the overall cost of environmental monitoring in the Snowy Mountains.

1.4 Recommendations

The NRC recommends the following amendments to the trial to improve the scientific robustness of the results:

- establish a conventional control area which is biophysically comparable to the target area
- reprioritise the environmental monitoring to include the following additional parameters to assess potential environmental impacts and to provide data to allow the use of a Multiple Lines and Levels of Evidence approach to strengthen the inference of causal links between cloud seeding and its effects:
  - changes in snow pack density
  - changes in downwind precipitation
  - changes in water yield and river flows, particularly in montane streams, and
  - changes in terrestrial alpine ecology and montane stream ecology
- amend the ecotoxicity survey design to increase its statistical power and make it more representative of the intermediate, target and downwind areas, and additional baseline data should be collected
- refine the ecotoxicity protocols.

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5 Depending on the parameter being measured, samples are taken at between 2 and 16 sites, which is a very small number given the approximately 1000 km^2 of the target area.

6 20.1 kg of silver iodide and 11.3 kg indium trioxide were released during the pilot trial, dispersed as an aerosol across some 1000 km^2 of terrain, and probably beyond, before coming to ground at random as fine particles.

1.5 Structure of report

This report explains the NRC's findings and recommendations in more detail:

- Chapter 2 discusses Snowy Hydro's compliance with its legislative obligations
- Chapter 3 provides an understanding of the design of the trial
- Chapter 4 looks at the trial's capacity to demonstrate that cloud seeding increases snow fall
- Chapter 5 focuses on the trial's capacity to assess both positive and negative environmental impacts
- Chapter 6 reviews on-ground supervision of the trial, and
- Chapter 7 discusses Snowy Hydro's claims and conclusions about the effectiveness of the trial and its environmental impacts to date.

Attachments 1 to 5 contain a complete list of recommendations and additional analysis that informed the NRC's development of its recommendations.

2 Compliance with legislative obligations

Snowy Hydro sought authorisation to conduct a trial of cloud seeding in the Snowy Mountains in 2004. Its aim for the trial was to determine whether cloud seeding could increase the snowfall in this area, in response to a long-term downward trend in annual snow pack and a lengthy drought. If it did increase snowfall, Snowy Hydro expected that the trial would also result in additional water for irrigators in the Murray/Murrumbidgee system and improvements in the health of montane streams.[7]

This chapter outlines the authorisation granted to Snowy Hydro to conduct the trial and how Snowy Hydro's annual report demonstrates that it has complied with its legislative obligations.

2.1 Authorisation

Snowy Hydro was granted permission to conduct authorised cloud seeding operations through the *Snowy Mountains Cloud Seeding Trial Act 2004 No. 19* (New South Wales) (the Act). This Act conditionally authorises Snowy Hydro to carry out cloud seeding operations, designed to increase precipitation within a designated 'target area',[8] by discharging a seeding agent into passing clouds [s.4 (1)]. It provides that the:

- seeding agent is not to be discharged from within the Jagungal Wilderness Area and may be discharged only when precipitation in the target area is likely to fall as snow [s.4(1)(b) & (c)]
- seeding agent is to consist of silver iodide only, although indium sesquioxide may also be discharged as a control tracer, and both seeding agent and tracer are to be discharged only by land-based generators [s.4 (1) (d) & (e)]
- authorisation has effect for the period of 6 years, unless terminated sooner [s.5]
- authorised cloud seeding operations may be carried out despite any other Act or law [s.7 (1)].

The Act also provides that the cloud seeding operations and their effect must be monitored [s.4 (1) (f)], and that the 'relevant Ministers'[9] may suspend or terminate the authorisation if:

- the cloud seeding operations are having or will have a significant adverse environmental impact
- Snowy Hydro has not complied with any requirements that have been imposed by the relevant Ministers to minimise environmental impact, such as a requirement to prepare or implement an environment management plan, or
- Snowy Hydro has not provided the relevant Ministers with information relating to environmental impact that they have requested [s.6 (2)].

In addition, the Act provides that the NRC must supervise the cloud seeding operations [s.8 (1)].

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7 Verbal advice on 2 February 2005.

8 The 'target area' covers most of the main range area of the Snowy Mountains National Park.

9 The Act defines "relevant Ministers" as the Minister administering the *Environmental Planning and Assessment Act 1979* (currently the Hon. Frank Sartor, MP, Minister for Planning) and the Minister administering Part 4 of the *National Parks and Wildlife Act 1974* (currently the Hon. Bob Debus, MP, Minister for the Environment).

2.2 Compliance

The NRC has not conducted its own independent audit of Snowy Hydro's compliance. To do so would have exceeded the NRC's Ministerial remit. However, based on its review of the annual report, the NRC believes that Snowy Hydro is conducting its cloud seeding operations in compliance with the Act. The NRC also found that Snowy Hydro is generally using the best available technology and procedures, including some that are well established and others that are 'cutting edge'.

Snowy Hydro is using silver iodide as a seeding agent and indium (III) oxide as a chemical marker. It is discharging both chemicals from ground-based generators into clouds that pass over the target area. No generator is located within the Jagungal Wilderness Area. Protocols are in place to ensure that seeding only occurs when precipitation is likely to fall as snow. These protocols appear to be effective, e.g. seeding operations were temporarily suspended in 2004 whenever meteorological conditions became inappropriate.

Snowy Hydro has prepared an environment management plan in negotiation with DEC, which mandates the monitoring of ecotoxicity potential (the potential for chemicals to poison plants, animals and other biota). It has put in place arrangements to monitor concentrations of silver and indium in various environmental matrices[10] at the generator sites and in the intermediate, target and downwind areas. These metal concentration data may be used as an estimate of ecotoxicity potential. It has also put in place arrangements to monitor snow pack depth to assess if the cloud seeding is effective.

Chapter 3 outlines the design of the trial.

Observation

The annual report indicates that Snowy Hydro is conducting its cloud seeding operations in compliance with the Act.

[10] 'Matrices' is a generic term used in the annual report to cover water, soil, sediments, humus, peat and moss, the compartments of the environment in which Snowy Hydro has measured silver and indium concentrations.

3 Purpose of the trial

Snowy Hydro has advised that the trial has been designed as a 'business experiment' and not a 'scientific experiment'. Its purpose is to establish the business feasibility of using cloud seeding to increase snowfall in the target area, *not* to evaluate the environmental effects of cloud seeding, although it must be able to detect any significant adverse environmental impact.[11] This means that there are likely to be major constraints on the extent to which the results of the trial can be interpreted scientifically (particularly to infer causality between the cloud seeding and any environmental changes observed), and used to inform management decisions in relation to it and future cloud seeding proposals.

In addition, when the legislation was introduced to the NSW Parliament, the Government stated that it was seeking 'to encourage and facilitate a scientific experiment'.[12] Understandably, this has created an expectation in government and the community that the authorised cloud seeding operations would be undertaken as a trial that would provide scientifically reliable results.

To fully address the NRC's concerns, the trial would need to be redesigned as a scientific experiment. The NRC recognises that such a response may seem unwarranted, given that the Expert Panel[13] assembled by Snowy Hydro in 2003 found that Snowy Hydro's cloud seeding proposals are unlikely to have an adverse environmental impact over the 6 years of the trial, and that nothing has occurred since then to alter that view. Accordingly, the NRC will focus this report on measures that might be put in hand to improve effectiveness of the current trial.

The trial and its monitoring program were established to answer the following questions:

- Will cloud seeding increase snowfall in the Snowy Mountains?
- Will cloud seeding have a significant adverse environmental impact?

Chapter 4 and 5 assess the trial's capacity to answer the above questions.

11 Verbal advice on 2 February 2005.

12 Second Reading Speech , p.5, final paragraph,

13 Expert Panel (2003). *Expert Panel Assessment of Snowy Precipitation Enhancement Trial, Snowy Mountains Region, NSW* (Snowy Hydro Limited: Sydney)

4 Will cloud seeding increase snowfall in the Snowy Mountains?

After reviewing the trial's experimental design and its environmental monitoring elements, the NRC believes the trial will have difficulty establishing statistically whether cloud seeding operations are increasing snowfall, as the duration of the trial is too short and it has insufficient controls by which to judge the relative impact of cloud seeding and natural variability in snowfall.

If the trial were designed as a conventional scientific field experiment, it would have had at least two biophysically comparable target areas. One of these areas would have been selected at random as the 'treatment' or 'intervention' area (over which passing clouds would be seeded). The other would have been the 'control' area (over which passing clouds would be left unseeded). Ideally, the trial would have had more than two target areas, so that the treatment and control areas could be replicated several times. Alternatively, it would have been conducted over a longer timeframe so this replication could occur over time, rather than space, and with environmental monitoring commencing well before the cloud seeding 'intervention' was initiated to provide a temporal 'control'. Such 'Before–After, Control–Intervention' (BACI) designs are now generally accepted by scientists as being suitable for establishing causal links between an intervention and environmental responses.[14]

However, Snowy Hydro has not used this conventional approach, because of the technical and logistical difficulties and costs involved. The scientists advising Snowy Hydro are of the opinion that a conventional spatial control is not possible in this instance because they cannot confine the seeding agent, once it is released into the clouds, to the nominated target area. They believe that some of it would be likely to impact on the potentially suitable control areas to the north or south of the target area.[15]

Instead, Snowy Hydro has developed an experimental design for assessing snowfall that includes randomised cloud seeding over the target area, and the use of a chemical marker with the seeding agent to identify which snow has fallen in response to seeding (Attachment 2).

4.1 Randomised cloud seeding technique

The randomised cloud seeding technique uses replication and randomisation in time as a substitute for conventional spatial replication and randomisation. In the current trial, two-thirds of all suitable clouds will be seeded each season between 2005 and 2009, and the remaining third will be left unseeded. There will be a once-only statistical assessment covering the full five years of the trial at the conclusion of the trial.

The NRC has reservations about the duration of the trial. As this type of study relies on replication in time rather than in space, the longer the trial runs the greater would be the chance of reliably demonstrating that cloud seeding had produced a statistically significant increase in snow pack depth. Given the small size of the expected increase relative to the magnitude of the

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14 Downes B, Barmuta L, Fairweather P, Faith D, Keough M, Lake P S, Mapstone B and Quinn G (2002) *Monitoring Ecological Impacts: Concepts and Practice in Flowing Waters* (Cambridge University Press: Cambridge UK).

15 Verbal advice on 1 July 2005.

natural variability and the experience of previous studies of this type, the NRC anticipates that the trial may need to be conducted for at least a decade, and five years may be too short to get statistically significant results.

Initially, Snowy Hydro considered that the trial would need to be conducted for at least 6 years. Snowy Hydro informed the NRC on 1 July 2005 that the experience of the trial's first year has shown that their innovative methodology enables them to extract more experimental units from snow events than has been possible in previous cloud seeding studies, and they are hopeful they will have enough experimental units by the end of the trial to demonstrate significance.

Further, spatial controls can be used to 'speed up' randomised cloud seeding trials and Snowy Hydro plans to use an upwind control area for this trial. Such a technique has been applied successfully when total precipitation in two areas was similar. In the present instance, precipitation in the upwind control area is much lower than the target area and falls as rain, whereas in the target area it will be falling as snow during seeding events. While this does not prevent correlations and covariance being established, it adds additional natural variability with which the statistical analysis of the variability must cope.

4.2 Chemical marker technique

Snowy Hydro consulted international experts in setting up a study employing a chemical marker technique to strengthen the assessment of cloud seeding operations. This technique allows quicker assessment (on an event-by-event basis) of change in snow pack depth due to each seeding event. In the current trial, Snowy Hydro plans to make an annual assessment of seeding-induced change in snow pack depth.

However, this technique is relatively new, little peer-reviewed and is still regarded as developmental. To implement this technique, Snowy Hydro has 11 snow monitoring sites in an area of more than 1000 km^2. To work effectively, seeded snow will have to fall at some of these 11 sites and not at others, thereby allowing some of them to be taken as 'intervention' sites, while others can be used as 'control' sites for comparison. With no capacity to control where the snow from each event will actually come to ground, there can be no guarantee that this technique will provide adequate data to reliably demonstrate that cloud seeding has increased snowfall.

4.3 Conclusion

While Snowy Hydro is now confident that the trial may be drawn to a successful conclusion within 5 years, the NRC notes that this will be dependent on meteorological and other factors quite outside Snowy Hydro's control, and remains sceptical of such an outcome. To be sure of delivering a reliable result, the trial may need to be extended to around 10 years and to have a conventional control area added which is biophysically comparable to the target area. A decision on whether or not the trial may need to be extended can be deferred until say Year 4, by which time the adequacy of the data acquired to that point should be evident. The need for a conventional control is considered further in the next section.

Observation
In order to obtain statistically significant results, it may become necessary to extend the trial, possibly to 10 years, but such a decision may be deferred until Year 4.

5 Will cloud seeding have a significant adverse environmental impact?

The Act provides that the cloud seeding operations and their effects must be monitored, but does not specify what the monitoring should involve. However, the Act also provides that the relevant Ministers may suspend or terminate the operations if they 'are having or will have a significant adverse environmental impact',[16] which the NRC considers should be assessed by balancing all environmental impacts, both positive and negative, that can be attributed to cloud seeding.

For the Ministers to act upon this provision, the cloud seeding operations and monitoring protocols need to be established in such a way that it is possible to determine, in a scientifically reliable way, whether or not any significant adverse environmental impact can be attributed to the authorised cloud seeding . The current design will not permit this but could be improved to allow for a greater causal link to be developed.

The NRC has identified four specific issues about the design of the trial:

- The monitoring program design does not allow causality to be inferred between cloud seeding and any environmental response, positive or negative.
- The trial's environmental monitoring focuses solely on ecotoxicity potential, which means it will provide no information on other important potential environmental impacts.
- The ecotoxicity surveys being undertaken are not likely to generate data that are representative of the target area.
- The ecotoxicity survey protocols contain some deficiencies and could be amended to improve the capacity for meaningful interpretation of results.

5.1 Establishing causal links between cloud seeding and environmental responses

Snowy Hydro has adopted a separate design for the ecotoxicity potential assessment, which might be described, using the Before-After, Control-Intervention (BACI) analogy, as a 'Before-After-Intervention' (BAI) design.

The BAI design, sometimes referred to as 'standard intervention analysis', compares before versus after intervention. 'Before' data act as a baseline or 'temporal control' against which 'After' data can be compared. While a BAI analysis can demonstrate changes in the target area over time, it does not permit inferences as to whether these changes occurred because of the intervention (cloud seeding in this case) or independently of it. A BAI design is fine where an

[16] The Act does not define 'a significant adverse environmental impact'. The meaning ascribed to it by previous rulings of the Land and Environment Court presumably would serve as a guide to its meaning. In this Act, however, the legal test that applies to the term is that of proven significant environmental impact, or certainty that such impact will occur. This is a higher threshold than that which applies under the Environmental Planning and Assessment Act 1979 – merely the likelihood that such impact will occur.

inference as to cause and effect does not need to be made, but where one does (as in the present case), the conventional solution is to add a control, resulting in a BACI design.[17]

A BAI design is also difficult to use if an intervention is introduced progressively, as in this case, because the Before–After comparisons are difficult to define. A further difficulty in this case is that the ecotoxicity potential 'before' dataset is extremely limited, being based on a single small survey conducted immediately before the trial commenced (see also section 5.2).

Therefore, if a Before-After comparison revealed an increase in ecotoxicity or an improvement in river flow during the course of the cloud seeding trial, the current experimental design would not enable a distinction to be made between a cloud-seeding-induced effect and natural variability. In fact, Snowy Hydro will not be able to attribute to the cloud seeding operations any environmental effects noticed – whether they are improved flows in montane streams, additional water for irrigators or ecotoxic impacts on biota.

There is a technique under development that may partially address the inadequacies of Before-After-Intervention designs. It is referred to as 'Multiple Lines and Levels of Evidence (MLLE)'.[18] Where it is not possible to employ a BACI design, as Snowy Hydro believes in this instance, it may be possible to use other evidence to strengthen any inference of causal links between an intervention and a perceived environmental response. The general concept of using a range of different types of evidence, when drawing conclusions, is gaining acceptance in the scientific community. However, a consistent way of combining different forms of evidence in a formal, quantitative way has not yet been devised.[19]

The NRC notes that Snowy Hydro has incorporated what it considers to be a spatial control in its experimental design. However, this 'control' is not suitable as a conventional spatial control area as it is located in low ground, upwind of the target area, and is not biophysically comparable with the target area.[20]

Given the limitations of the Before–After-Intervention design, the NRC believes it would be worthwhile, even at this stage of the trial, and despite the difficulties identified by Snowy Hydro's scientists, to add a conventional biophysically-comparable control that is at an elevation similar to that of the target area. This would assist in determining whether the cloud seeding caused any assessed changes in both snow pack depth and ecotoxicity potential, or not.

Recommendation

1. ***The experimental design of the trial should be amended to incorporate a conventional control area that is comparable in elevation, geology and ecology to the target area and for which the same assessments are undertaken as in the target area.***

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17 Cottingham P, Quinn G, King A, Norris R, Chessman B and Marshall C (2005) *Environmental Flows Monitoring and Assessment Framework* (CRC for Freshwater Ecology: Canberra)

18 See Downes *et al.* (2002) at footnote 11.

19 See Cottingham et al. (2005) at footnote 14.

20 In relation to the upwind 'control' area, Snowy Hydro advised the NRC that it selected the site of this area because modelling had shown that, for precipitation, there was a much higher correlation between the upwind area and the target area than between a parallel area on comparable high ground in the vicinity of Tooma – Cabramurra and the target area. The NRC considers that this may have arisen because the analysis was based on a single parameter and data from a single season only. So the upwind site may not be more generally representative.

5.2 Environmental monitoring focuses solely on ecotoxicity potential

Snowy Hydro's environment management plan was prepared in negotiation with DEC, prior to pilot operations commencing in 2004. This plan provides for monitoring of and reporting on the effects of the trial on snow pack depth and ecotoxicity only. These indicators are important, but they are not a sufficient basis for making a well-informed assessment of the positive and negative effects of the cloud seeding operations on the environment. A balancing of these positive and negative effects is the key step in determining whether, overall, there has been a significant adverse environmental impact.

The Expert Panel[21] indicated that the cloud seeding trial should monitor a much wider range of environmental indicators/variables, including:

- increases in precipitation (including changes in snow pack depth and density)
- increases in water yield and river flows
- changes in stream hydrology and fluvial geomorphology
- positive or adverse impacts on alpine ecology
- increases in ecotoxicity due to silver iodide and indium (III) oxide
- changes in water quality.

Consistent with its remit from the Minister for the Environment, the NRC sought the views of both Snowy Hydro and DEC on this question. Snowy Hydro advised[22] that it was decided during its negotiations with DEC on the environment management plan that it would not be practicable to measure all the indicators discussed in the Expert Panel's report. DEC has confirmed this,[23] but its officers[24] remain concerned that the trial will neither provide information on broader environmental impacts, such as the potential impact of cloud seeding on threatened species, nor enable a broad assessment of whether or not there has been a significant environmental impact.[25]

Having considered the views of both Snowy Hydro and DEC, the NRC remains concerned about the limited number of environmental indicators being monitored. One of the consequences is that a decision about whether or not the cloud seeding operations 'are having or will have a significant adverse environmental impact', and hence should be suspended or terminated, will need to be made solely on the basis of surveys of silver and indium concentrations in the environment, conducted at the end of each season. As the Expert Panel pointed out, cloud seeding could impact on a range of environmental parameters without causing ecotoxicity, so an assessment confined to ecotoxicity potential is an inadequate basis on which to judge the effects of cloud seeding on the environment. Indeed, changes in other environmental indicators, such as alpine ecology, seem more likely during the course of this trial than the occurrence of ecotoxicity (which is a seemingly remote probability).

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21 Expert Panel (2003). *Expert Panel Assessment of Snowy Precipitation Enhancement Trial, Snowy Mountains Region, NSW* (Snowy Hydro Limited: Sydney)

22 Verbal advice on 5 April 2005.

23 Verbal advice on 21 April 2005.

24 In line with the Minister's request when referring the report to the NRC, the NRC has consulted with DEC officers directly concerned in the operation of the trial.

25 For example, if cloud seeding increased snow pack depth, it also might increase snow pack density, which, in turn, could adversely affect animals that live within the snow pack.

Another consequence is that an opportunity to establish empirically whether cloud seeding can increase water for irrigators or improve the health of montane streams or terrestrial alpine ecosystems, without causing adverse environmental impacts, is being passed up. For environmental attributes other than snow pack depth and ecotoxicity, it will now be possible, at best, only to estimate benefits and adverse impacts of cloud seeding using mathematical model projections.

In addition, the NRC notes that, while the environment management plan makes provision for measurement of the effect of the trial on downwind precipitation, this effect is to be assessed and reported only at the conclusion of the trial. As this is a sensitive issue in the community, Snowy Hydro will need empirical evidence to verify its theoretical projections that cloud seeding will not reduce rainfall downwind of the target area. Further, it will almost certainly need to compare precipitation downwind of the target area with precipitation in a parallel downwind control area if any such claim is to be sustained scientifically. The NRC is of the opinion that such data should be presented progressively in future annual reports, not simply at the conclusion of the trial. This would engender confidence that the appropriate data are being collected.

Taking all the foregoing factors into account, the NRC considers that the environmental monitoring program should be expanded. To establish the extent to which this should occur, one needs to first consider the questions that the trial must answer. The key question that the trial must answer is: Will cloud seeding increase snow pack? Then, if cloud seeding increases snow pack, will it also:

- increase ecotoxicity in the target area
- reduce downwind precipitation
- increase stream flow and water potentially available for irrigators in the Murray and Murrumbidgee systems
- improve the health of montane streams
- degrade the habitat of snow pack dwelling fauna
- improve the health of alpine ecosystems?

In order to answer the above questions, one or more scientific indicators (Table 5.1) need to be measured for each of the parameters of interest.

Table 5.1: Possible indicators to measure cloud seeding impact

Parameter	Indicator
Snow pack	Snow pack depth; snow pack chemistry (silver : indium ratio)
Ecotoxicity	Silver and indium concentrations in matrices of interest in the target area
Downwind precipitat'n	Rainfall downwind of target area
Stream flow	Stream flow in selected montane streams, particularly during snow melt
Montane stream health	Macroinvertebrate community in montane streams
Snow pack habitat	Snow pack density; subnivean space
Alpine ecosystem health	To be developed in consultation between Snowy Hydro and DEC

Of the above indicators, some are already being used in the trial (e.g. snow pack depth, density and chemistry; silver and indium concentrations in environmental matrices) and others are being used in the Snowy Mountains for other purposes (e.g. rainfall, stream flow, macroinvertebrate community composition) and their extension to the trial may be relatively simple. A couple, however, may require new protocols (e.g. subnivean space, alpine ecosystem health indicator).

Further, the monitoring of a wider range of environmental variables might also enable a MLLE approach to be used to strengthen the inference of any causal links which emerge between the cloud seeding and environmental responses (see section 5.1). While this concept cannot yet be used quantitatively, a means of doing this may well have been developed before this trial comes to an end in 5 years time.

Finally, the annual report makes no mention of local environmental impacts linked to the trial infrastructure. DEC advised the NRC that the installation of cloud seeding generators, monitoring equipment and related infrastructure within Kosciuszko National Park had resulted in local environmental impacts, including habitat loss and impaired visual amenity.[26] NRC staff saw some evidence of this when inspecting generator and monitoring installations on 8 June 2005. While impacts of this nature are to some extent unavoidable and acceptance of them is implicit in the decision to permit the trial, Snowy Hydro needs to demonstrate that it has acted rigorously to minimise them. Consequently, the NRC considers that such impacts should be monitored and that the findings should be included in future annual reports.

Recommendations

2. ***Additional parameters should be monitored to enable a balanced assessment of the potential environmental impacts of the trial and to provide multiple lines and levels of evidence that would strengthen any causal inferences, including:***
   - ***changes in snow pack density***
   - ***downwind precipitation***
   - ***changes in water yield and river flows, particularly in montane streams, and***
   - ***changes in terrestrial alpine ecology and montane stream ecology.***

3. ***Any relocation of existing cloud seeding generators, monitoring equipment and related infrastructure should be avoided to minimise local impacts on the landscape and ecology. Where relocation is necessary, compliance with current protocols should ensure environmental impacts are minimised. However, any impacts should be monitored and reported in the annual report.***

5.3 Ecotoxicity survey is not representative of the target area

To monitor the effects of the cloud seeding operations on the potential for ecotoxicity to develop, surveys of silver and indium concentrations will be conducted at the end of each snow season. So far, two surveys have been conducted – a pre-trial survey in autumn 2004 and a post-season survey following snow melt in summer 2004-05. The chemical data gathered in

[26] Verbal advice on 21 April 2005

these surveys will be assessed against ecotoxicological guideline trigger values (GTVs) derived by Snowy Hydro before the trial began and confirmed by it following the pre-trial survey.

The NRC is concerned that the surveys conducted to date have sampled very few sites in the intermediate, target and downwind areas. As Table 5.2 shows, for most environmental matrices in the intermediate, target and downwind areas, samples have been collected from only 2 to 4 locations. Unless the survey design is changed, an ongoing issue in interpreting the ecotoxicity survey data will be the extent to which they are representative of the zones and matrices they purport to represent. Clearly, inferences about ecotoxicity potential in a target area that exceeds 1000km^2 cannot be drawn from data derived from only a few locations. A target area-wide survey would be needed to enable such an inference to be made.

Table 5.2: Silver and indium ecotoxicity survey – sampling intensity in 2004

Zone	Matrix	Number of Sampling Locations	Samples per Location	Number of Depths	Number of Samples
1. Generator Sites	Soil	12	8	1	96
2. Intermediate Area	Water	4	3	1	12
	Soil	3	5	1	15
3. Target Area	Water	7	3	1	21
	Potable Water	8	3	1	24
	Alpine Humus	16	5	1	80
	Peat	4	5	1	20
	Sediments	2	4	1	8
	Moss	4	5	2	40
	Meadow Snow Patch	4	5	1	20
4. Downwind Area	Soil	4	5	1	20
Total		**68**			**376**

The NRC believes Snowy Hydro needs to reconsider the number of sites that it is sampling in the intermediate, target and downwind areas (i.e. the sampling intensity). In a survey of this type, if very few locations are sampled, the survey will have very little statistical power. It could lead to statistical type II errors (i.e. concluding that there has been no environmental impact when in fact one has occurred), particularly where there is insufficient power to distinguish between small changes in an observed indicator and large natural variability in that indicator.

Now that the GTVs have been established and the pre-trial survey has provided some indication of the extent of natural variability, a statistician should be able to advise Snowy Hydro about the sampling intensity needed. The NRC believes that this advice is most likely to be that many more locations need to be sampled.

The NRC recognises that Snowy Hydro has taken a 'critical site' approach in the intermediate, target and downwind areas in an attempt to contain analytical costs in particular. However, it

believes that its use of this approach is inappropriate (see Attachment 3). The NRC has identified a range of other ways that the survey design might be changed so as to increase its statistical power without increasing analytical costs (see Attachment 3). If these suggestions are implemented, it should be possible to sample at least 100 separate locations within the target area and still remain within the current analytical budget.

Recommendation

4. The ecotoxicity survey design should be amended to increase its statistical power and make it more representative of the intermediate, target and downwind areas; and additional baseline data should be collected.

5.4 Ecotoxicity protocols should be refined

To assess the ecotoxicity survey sampling, analysis and interpretation protocols, the NRC sought independent advice from Dr Michael Warne, Senior Research Scientist of CSIRO Land and Water, Adelaide. Dr Warne is an environmental chemist and ecotoxicologist, and is a past president of the Australasian Society for Ecotoxicology. He is widely respected internationally for his research on aquatic and terrestrial ecotoxicology and played a leading role in the derivation of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*[27] on which Snowy Hydro has based the GTVs for this study.

Dr Warne found that many aspects of the approach being taken and the protocols being used are sound. However, he identified a range of refinements that should be made, to improve the capacity for meaningful interpretation of the collected data.

The NRC believes that the ecotoxicity protocols should be adjusted to incorporate most of Dr Warne's refinements. A summary of these refinements and the NRC's recommendations in response to them is provided in Box 5.1, and Dr Warne's full report is at Attachment 5. Most particularly, the NRC endorses Dr Warne's proposal that future annual reports should present temporal trends in the concentrations of silver and indium in each matrix at each site to determine if concentrations are increasing over time. This information could be extremely useful, as it would provide an early warning of the probability of trigger values being exceeded, if current practices were to continue, and the timeframe within which this would happen. Further, this is the conventional way data are analysed under the 'Before-After-Intervention' experimental design that is being employed, and reporting in this way and would ensure that those data were fully utilised.

Recommendations

5. The ecotoxicity protocols should be refined (consistent with advice in Box 5.1).

[27] ANZECC and ARMCANZ (2000). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. National Water Quality Management Strategy Paper No. 4 (Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand: Canberra).

Box 5.1 Summary of Dr Warne's advice on ecotoxicity protocols and NRC's recommendations

1. **The current guideline trigger value (GTV) for silver in freshwater (27 µg In.L^{-1}) is too high and should be replaced with a more appropriate value.** The NRC believes the most conservative of Dr Warne's estimates for this value (0.55 µg In.L^{-1}) should be used. It notes that both the pre-trial and post-season surveys found that the measured concentration maxima of silver in freshwater were more than two orders of magnitude below the recommended value (see Table 7.1 in section 7).
2. **The bioavailability protocols are unsuitable for estimating bioavailability to organisms that ingest soils, sediments and plant material, and it is difficult to judge whether they are suitable for higher plants.** Bioavailability is not currently an issue in this trial. However, if future survey findings suggest it is becoming one, site and laboratory studies should be undertaken to clarify these uncertainties.
3. **The interpretation protocol for soils and sediments do not indicate how one should proceed at the end of step 3.** The NRC agrees it should be amended to clarify this.
4. **There is no interpretation protocol for moss,** probably because there is no suitable trigger value to compare the moss data with. However, the pre-trial data could be used as a baseline for this comparison. The NRC agrees and believes an interpretation protocol for moss should be established on this basis. A statistically significant ($P < 0.05$) increase should trigger a field investigation to establish whether there is evidence of toxicity.
5. **There is usually no need to measure the bioavailable silver and indium concentrations unless the total concentrations exceed the relevant trigger values**, because the bioavailable concentration can never exceed the total concentration. To offset increased costs in other areas, the NRC considers that the bioavailable concentrations should not be measured unless the total concentrations become elevated.
6. **There is little value in taking a one-off grab sample of water from rivers and lakes once a season,** particularly as there is likely to be temporal variation in concentration, with peaks during cloud seeding and snow melt. If concentration in water were important, there would either need to be several sampling events throughout the year or a passive sampler would need to be deployed to provide an integrated seasonal sample. The NRC believes there is little value in continued surface water sampling.
7. **The annual report did not address bioaccumulation of silver and indium.** The NRC agrees, but considers that it should not be necessary to address this issue unless some evidence emerges of elevated total concentrations in the matrices currently being surveyed.
8. **The annual report did not cover temporal trends.** Although comparisons with trigger values are useful, they are not an adequate basis for assessing environmental impact. Future annual reports should present temporal trends in the concentrations of silver and indium in each matrix at each site, to determine if concentrations are increasing over time. The NRC agrees. It considers that this information could be extremely useful, as it would provide an early warning of the probability of trigger values being exceeded, if current practices were to continue, and the timeframe within which this would happen.

6 On-ground supervision of the trial

The Act provides that the NRC is to supervise Snowy Hydro's authorised cloud seeding operations, and report on the environmental impact of those operations to the relevant Ministers.[28]

To date, the NRC's supervision has included undertaking a desktop review of the annual report at the end of the snow season and an occasional field inspection[29]. However, it has not directly supervised the on-ground aspects of the cloud seeding operations.

DEC has officers permanently located in the Kosciuszko National Park. Although the statutes administered by DEC do not apply to authorised cloud seeding operations undertaken under the *Snowy Mountains Cloud Seeding Trial Act 2004*, DEC officers have been informally overseeing the installation of cloud seeding and monitoring infrastructure in Kosciuszko National Park[30] and have advised the NRC about those activities when warranted.

The NRC will raise with Government the issue of the best arrangements for on-ground supervision of the operation and any relocation of the cloud seeding generators, monitoring equipment and related infrastructure.

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28 *Snowy Mountains Cloud Seeding Trial Act 2004*, s.8 (1).

29 Field inspections are considered necessary because the risk of a significant environmental impact from this trial over the next 5 years is primarily from infrastructure works associated with it, which could have local impacts on the landscape or ecology.

30 Verbal advice on 21 April 2005. A review of environmental factors for the infrastructure works is included in the environment management plan. DEC officers have inspected every installation and are keeping the installations under surveillance. However, this oversight has essentially been informal as it is not supported by statutory powers or a Ministerial direction.

7 Conclusions on impact of operations to date

The NRC reviewed the results of the pilot trial undertaken in 2004, as reported in the annual report. It also sought informal advice from CSIRO on one aspect of cloud seeding theory. As a result of these assessments, the NRC has several concerns about claims made in the annual report in relation to the impact of the pilot trial on both snow pack depth and ecotoxicity.

7.1 Impact on snow pack depth

During the pilot trial, there were 12 occasions on which meteorological conditions were suitable for cloud seeding. Each such occasion is referred to in the annual report as a seedable event. All 12 seedable events were seeded using both silver iodide and indium trioxide.[31]

The annual report contains data comparing snow pack depth in 2004 with the maximum, median and minimum depths for three snow courses over the past 50 years. These data indicate that snow coverage was significantly higher than average at the two snow courses in the central and northern sections of the main range, but was only slightly higher than average at a course in the southern section where the seeding operations were undertaken.[32]

Although the annual report does not link this effect to cloud seeding, it could seem to some readers of the report that the data indicate that the cloud seeding had suppressed snowfall. The NRC considers that it would be unsafe to draw a causal link between cloud seeding and snowfall suppression, as there is little reason on theoretical grounds to suspect that cloud seeding could have such an effect,[33] and the data are not replicated in either space or time. The NRC considers that it is more likely that the data merely reflect natural seasonal and spatial variability.

More significantly, the annual report contains no evidence that cloud seeding increased snow pack depth in 2004, despite the fact that 'key conclusion 1' in the report's executive summary claims that 'analysis of data from 2004 operations has confirmed that cloud seeding undertaken during the initial set-up year has increased snow pack'. The NRC understands that the preliminary chemical marker data indicated that cloud seeding had increased snow pack depth.[34] When subsequent analysis did not support this conclusion, the data were not included in the annual report. However, this change was not reflected in the executive summary.[35] Snowy Hydro informed the NRC on 22 June 2005 that it had provided an amended report to Ministers from which 'key conclusion 1' had been removed.[36]

Observation

The annual report contains no evidence to sustain a claim that cloud seeding increased snow pack in 2004.

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31 Randomised seeding – where only two-thirds of the events, chosen at random, will be seeded with silver iodide – will only commence with the trial proper in 2005.Annual Report p. 23.

32 Annual Report p. 23.

33 Personal communication with Dr Greg Ayers, Chief, CSIRO Division of Atmospheric Research on 24 May 2005.

34 Verbal advice on 2 February 2005.

35 Verbal advice on 5 April 2005.

36 The relevant Ministers have not asked the NRC to review this revised report.

7.2 Impact on ecotoxicity

Snowy Hydro undertook a pre-trial ecotoxicity survey in autumn 2004 and a post-season ecotoxicity survey in summer 2004-05. These surveys measured the background concentrations of silver and indium at a range of locations. The results of these surveys are summarised in Table 7.1 and explained in Attachment 4.

Table 7.1: Silver (Ag) and Indium (In) concentration maxima in various matrices in the pre-trial and post-season surveys

Location	Matrix	Units	Metal	GTV	Pre-trial survey	Post-season survey
Generator Sites	Soil	$mg.kg^{-1}$	Ag	1	0.266	0.468
			In	1	0.168	0.209
Intermediate Areas	Water	$\mu g.L^{-1}$	Ag	0.02	<0.001	0.00099
			In	27	<0.001	0.00007
	Soil	$mg.kg^{-1}$	Ag	1	0.215	0.217
			In	1	0.063	0.062
Target Areas	Water	$\mu g.L^{-1}$	Ag	0.02	<0.001	0.00130
			In	27	<0.001	0.00008
	Potable Water	$\mu g.L^{-1}$	Ag	0.1*	<0.001	0.0014
			In	0.1*	<0.001	0.0011
	Alpine Humus	$mg.kg^{-1}$	Ag	1	0.126	0.087
			In	1	0.065	0.062
	Peat	$mg.kg^{-1}$	Ag	1	0.074	0.101
			In	1	0.013	0.015
	Moss	$mg.kg^{-1}$	Ag	No GTV	0.016	0.062
			In	No GTV	0.006	0.012
	Sediments	$mg.kg^{-1}$	Ag	1	0.032	0.046
			In	1	0.032	0.043
Downwind Areas	Soil	$mg.kg^{-1}$	Ag	1	0.111	0.168
			In	1	0.056	0.049

* *Drinking water quality guideline value*

The results of the pre-trial survey indicate that background concentrations of silver and indium in the Snowy high country were very low, and were well below the concentrations at which toxicity might be expected to occur (the guideline trigger values or GTVs). However, the NRC wants to emphasise that the pre-trial survey was based on a relatively small number of samples. It considers that further sampling of comparable areas in the Snowy high country, that are not impacted by the trial, is warranted to refine the background estimates.

It was not expected that the relatively small amounts of silver (20.1 kg silver iodide) and indium (11.3 kg indium trioxide) released in the pilot trial would increase ambient concentrations of silver and indium appreciably – particularly as these amounts were released into the atmosphere and dispersed as an aerosol across some 1000 km^2 of terrain, and probably beyond, before coming to ground at random as fine particles. The results of the post-season survey are consistent with this expectation. Nevertheless, they are also based on sampling at a small number of locations (2–16, depending on matrix, in the target area) and cannot be considered representative of the target area.

For this reason, the NRC considers that 'key conclusion 2' in the executive summary of the annual report is unsound. This conclusion claims that 'extensive monitoring of silver and indium levels has confirmed no significant environmental impact, with monitored sites substantially below the relevant ANZECC (2000) trigger guideline levels'. While it is true that silver and indium concentrations at the monitored sites were substantially below the trigger values, it does not follow that there has been no significant environmental impact. Indeed, such a claim is an extrapolation well beyond the limits of the survey design. There have been far too few sites sampled in the target area to substantiate such a claim.

Observation

Silver and indium concentrations were well below trigger guideline levels at monitored sites. However, the ecotoxicity monitoring program was not designed to establish whether there has been a significant adverse environmental impact. Thus this evidence does not support the claim in the annual report that there was no significant environmental impact from the cloud seeding.

Attachment 1

LIST OF RECOMMENDATIONS

Attachment 1 List of recommendations and observations

Recommendations

1. The experimental design of the trial should be amended to incorporate a conventional control area that is comparable in elevation, geology and ecology to the target area and for which the same assessments are undertaken as in the target area.
2. Additional parameters should be monitored to enable a balanced assessment of the potential environmental impacts of the trial and to provide multiple lines and levels of evidence that would strengthen any causal inferences, including:
   - changes in snow pack density
   - downwind precipitation
   - changes in water yield and river flows, particularly in montane streams, and
   - changes in alpine and montane stream ecology.
3. Any relocation of existing cloud seeding generators, monitoring equipment and related infrastructure should be avoided to minimise local impacts on the landscape and ecology. Where relocation is necessary, compliance with current protocols should ensure environmental impacts are minimised. However, the impacts should be monitored and reported in the annual report.
4. The ecotoxicity survey design should be amended to increase its statistical power and make it more representative of the intermediate, target and downwind areas, and additional baseline data should be collected.
5. The ecotoxicity protocols should be refined (consistent with advice in Box 5.1).

Observations

- The annual report indicates that Snowy Hydro is conducting its cloud seeding operations in compliance with the Act.
- In order to obtain statistically significant results, it may become necessary to extend the trial, possibly to 10 years, but such a decision may be deferred until Year 4.
- The annual report contains no evidence to sustain a claim that cloud seeding increased snow pack in 2004.
- Silver and indium concentrations were well below trigger guideline levels at monitored sites. However, the ecotoxicity monitoring program was not designed to establish whether there has been a significant adverse environmental impact. Thus this evidence does not support the claim in the annual report that there was no significant environmental impact from the cloud seeding.

Attachment 2

REVIEW OF CLOUD SEEDING EXPERMIENTAL TECHNIQUES

Attachment 2 Review of cloud seeding experimental techniques

Snowy Hydro has not used a conventional scientific approach to experimental design such as including comparable control sites. The alternatives adopted by Snowy Hydro for the assessment of the efficacy of cloud seeding are outlined and reviewed below.

Randomised cloud seeding technique

Randomised cloud seeding is a long-established technique for assessing the impact of cloud seeding on precipitation, which uses replication and randomisation in time as a substitute for conventional spatial replication/randomisation. The technique involves seeding some suitable clouds and leaving others as unseeded controls. The decision to seed/not seed is made randomly to enable a statistical assessment of the efficacy of seeding in increasing precipitation.

In the current trial, two-thirds of all suitable clouds will be seeded each season between 2005 and 2009, and the remaining third will be left unseeded. There will be a once-only statistical assessment covering the full 5 years of the trial at the conclusion of the trial.

An independent peer reviewer appointed by Snowy Hydro[37] has conducted a desktop review of the randomised seeding approach being employed. This review found that the design and the statistical evaluation methods being employed are quite acceptable, and are commonly used in cloud seeding evaluations.[38]

The NRC notes that with time-series studies such as randomised cloud seeding, valid statistical questions often arise about the independence of various sequential observations. It is very important that a seed/not seed decision be made independently of any previous seed/not seed decision. The NRC understands that, in this trial, the cloud seeding events will be considered in groups of six, with four events seeded and two not seeded and with the four seeded and two unseeded treatments fully randomised among the six events *before* the set of six events commence. The NRC considers that this approach should avoid any seed/not seeded decision being dependent on a previous decision.

The NRC, however, has reservations about the duration of this trial. There is considerable natural inter-seasonal and spatial variability in snow pack depth in the target area and cloud seeding is not expected to increase snow pack depth by more than an average of 10 per cent. As this type of study relies on replication in time rather than in space, the longer the trial runs, the greater is the chance of demonstrating that seeding has produced a statistically significant increase in snow pack depth. Given the small size of the expected increase relative to the magnitude of the natural variability and results of previous studies of this type, the NRC anticipates that the trial may need to be conducted for at least a decade. Snowy Hydro's scientists originally considered that it would need to run for at least 6 years, but 5 years is all that is now available.

Despite this, Snowy Hydro's scientists advised, in a briefing for NRC officers on 1 July 2005, that they are now 'hopeful' they will have enough experimental units by the scheduled end of the study in 5 years' time to be able to demonstrate significance. They have found that their

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37 Mr Byron Marler, Supervising Meteorologist, Pacific Gas and Electric Company of California.

38 Annual Report Annexure G pp. 199 – 207.

methodology enables them to extract more experimental units from snow events than has been possible hitherto. Further, spatial controls also can be used to 'speed up' randomised cloud seeding trials and Snowy Hydro plans to use an upwind control for this purpose in the present study. Such a technique can be valid when used in rainfall enhancement studies, particularly when total precipitation in the two areas is similar. In the present instance, however, precipitation in the upwind control area is very much lower than that in the target area and falls as rain, whereas in the target area it will be falling as snow during seeding events. While this does not prevent correlations and covariance being established, it adds additional natural variability with which the statistical analysis of cloud seeding must cope.

Clearly, there is a significant element of luck in all this and only time will tell whether the current confidence of Snowy Hydro's scientists is justified. Should luck not go their way, they may have to base their assessment of the efficacy of cloud seeding solely on the findings of the chemical marker study.

Chemical marker technique

The chemical marker technique involves releasing a chemical marker (in this case, indium trioxide) with the seeding agent into the cloud being seeded, then measuring the ratio of seeding agent to marker found in any snow that falls from the seeded cloud. A ratio of 1:1 implies no response to seeding, while a ratio much greater than 1:1 implies a response.

The technique allows the effectiveness of seeding to be assessed on an event-by-event basis, thereby avoiding the need to wait many years before obtaining a result (as is common with more traditional statistical approaches, such as randomised cloud seeding). In the current trial, the chemical marker technique will be used to make an annual assessment of seeding-induced change in the depth of the snow pack.

The NRC notes that in setting up the chemical marker study, Snowy Hydro consulted international experts in this field and is employing personnel trained in the technique. It also appointed an independent peer reviewer[39] to conduct a desktop review of its approach. The reviewer found the approach to be sound, and described the chemical marker study as 'excellent'.[40]

Nevertheless, this technique is relatively new and is still regarded as developmental. Little peer-reviewed evidence of its reliability is available in international scientific literature.

The NRC also notes that such studies also need a control. In the absence of a separate conventional spatial control area, Snowy Hydro intends to rely on the fact that during any seeding event, not all clouds passing over the target area will be seeded. The depth of snow falling from the unseeded clouds within the target area hopefully can be compared with that from seeded clouds. The geographic location of the sites receiving unseeded snow (control sites) and sites receiving seeded snow (intervention sites) will change from event to event, depending on cloud availability and wind direction in relation to the fixed generator sites. As there will only be 11 fixed snow fall monitoring sites from now on, hopefully some of which will receive seeded snow and others unseeded snow, a substantial element of luck will be involved in whether adequate data are acquired to enable statistical significance to be demonstrated.

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39 Mr Byron Marler, Supervising Meteorologist, Pacific Gas and Electric Company of California.

40 Annual Report Annexure G pp. 199 – 207.

Attachment 3

REVIEW OF ECOTOXICITY SURVEY

Attachment 3 Review of ecotoxicity survey

Snowy Hydro has adopted a 'critical site' approach to its ecotoxicity survey design. The NRC considers that the 'critical site' approach is appropriate at generator sites, but that a broader spatial approach is necessary in the intermediate, target and downwind areas to allow assessment of variability between sites rather than variability within sites. This is outlined below along with suggestions for cost effective ways to modify the survey design to be consistent with the NRC's recommended approach.

Views of the survey designers

Based on discussions with Snowy Hydro's scientists on 1 July 2005, the NRC understands that they chose a critical site approach in the intermediate, target and downwind areas because of their concern that the geographic extent of the intermediate, target and downwind areas was simply too great to enable chemical characterisation of those areas by conventional survey. Accordingly, they decided to survey a few locations and matrices within those locations where silver and indium were likely to accumulate. The purpose of this survey, apparently, was to test the hypothesis that these locations and matrices would be places of accumulation; by establishing the variability in silver and indium concentrations within each chosen 'critical site'. The NRC's view is that this may have been appropriate as part of the preliminary study in Year 1 when methodology was being validated, but now that the study proper is underway, we have to accept that these sites and matrices, chosen on the basis of the best available scientific knowledge, are the sites and matrices where silver and indium are most likely to accumulate. We can use this knowledge to focus a more comprehensive survey.

A further insight into the thinking of the survey designers was provided in a letter dated 25 August 2005 to the NRC from Mr Allen Kearns, Deputy Chief, Sustainable Ecosystems, CSIRO. Mr Kearns advised that the preliminary assessment of the Expert Panel had been that there would be no significant negative impacts either from the increase in snow pack or the addition of silver iodide or indium sesquioxide to the environment. Consequently, the objective of the SPERP monitoring program is to test a hypothesis of no significant impact to alpine ecosystems; and monitoring is at the ecosystem-level rather than species-level of biodiversity, with the second order stream catchment as the monitoring unit. Alpine and sub-alpine catchment monitoring units, which contain likely zones of accumulation of silver and indium compounds (e.g. bog peat, snow patch soils and lake sediments), have been selected in the primary target area. Representative accumulation zones in each selected monitoring unit are being sampled. The routine monitoring can be adaptively extended should the hypothesis of no significant impact in the most likely zones of accumulation be challenged by any results that exceed the guideline trigger values for bioavailable levels of silver or indium.

The NRC has just two difficulties with this approach. Firstly, it is testing the hypothesis in relation to ecotoxicity only, ignoring the snow pack factor and other ecosystem components that may be affected; and, secondly, the number of monitoring units (4 – 16, depending on matrix) selected is inadequate to enable inferences to be drawn about the target area as a whole (which is >1000 km^2). One is not justified in concluding, just because the hypothesis has not been 'challenged' in the few locations surveyed, that it would not have been challenged in other, unsurveyed locations, especially given the variable meteorological conditions leading to a likely random distribution of seeding agent across the target area. Accordingly, the NRC considers that an annual survey of the target area as a whole will be necessary from now on to enable the Ministers to perform their statutory duty in relation to the trial's termination.

Peer review of ecotoxicity survey design

Snowy Hydro appointed an independent peer reviewer[41] to conduct a desktop review of the trial's ecotoxicity survey approach. This reviewer explained, from a statistical perspective, the different approaches to sampling for 'spatial description' of an area, and sampling of 'critical sites' to establish spatial variation within a site.[42] He noted that Snowy Hydro, having adopted the 'critical site' approach for the ecotoxicity survey, was undertaking it correctly from a statistical perspective. The peer reviewer, however, did not examine whether the hypothesis being tested was the appropriate hypothesis in terms of the management questions that needed to be answered, although he said he understood that the critical site approach had been chosen as it would be much cheaper than a conventional area survey.

The Survey Hypotheses

The NRC considers that the management question that needs to be answered at the generator sites is to what extent has each individual site become contaminated by silver and indium during the course of the trial and has a pattern of contamination developed across the site. So, we need to establish the distribution of the two metals within each site. Accordingly, the critical site approach is appropriate for the generator sites as we need detailed knowledge of each individual site.

The NRC considers that the management question that needs to be answered in the intermediate, target and downwind areas is to what extent has each of these areas become contaminated by silver and indium. We are principally concerned here with the distribution of contamination across each area, rather than the distribution of contamination within individual sites within the area. Accordingly, it is the conventional spatial description approach that should be used to design the survey of these areas. The NRC, however, does see the merit of choosing, as sampling sites for the survey, those landscapes, sites and matrices where silver and indium are most likely to accumulate. Sites for sampling should be chosen either at random or according to a systematic pattern and, at each site, each of the matrices of accumulation (soil, sediments, moss etc.) which occur at that site should be sampled.

Suggestions for increasing the statistical power of the ecotoxicity survey

The NRC recognises that cost constraints were a major factor in Snowy Hydro adopting the critical site approach. Nevertheless, the NRC considers that it should be possible to undertake a 'spatial description' survey of adequate statistical power without incurring a substantial increase in costs. While sample collection costs would increase, there is scope to save on analytical costs.

The NRC believes that the current ecotoxicity survey design should be retained for the generator sites, as it is appropriate to measure spatial variations and patterns within each site. It also believes that potable water sampling also should continue unchanged, as it is a matter of public health interest.

However, for the intermediate, target and downwind areas, where a 'spatial description' of each area (or of strategically selected sub-catchments within the area) at a given point in time is sought, the number of locations sampled needs to be increased. Snowy Hydro should seek

41 Dr C J Brien, Senior Lecturer in Statistics, University of South Australia.
42 Annual Report Annexure G pp 208-214

statistical advice on the number of samples needed to avoid the probability (at say $P<0.05$) of making a statistical type II error. It should be possible to calculate this sample number now that a baseline survey has been undertaken and guideline trigger values have been chosen.

There would also be value in sampling a control area generally comparable to the target area for the duration of the trial, to better establish background levels of silver and indium in the matrices of interest in alpine and sub-alpine country. The high country south to south-west of Cabramurra (generally including Three Mile Dam Snow Course and Deep Creek Snow Course) might be suitable for this purpose.

To compensate for additional costs associated with these increases, other sampling and/or analyses could be reduced. For example:

- Bioavailable silver and indium need not be analysed routinely. Rather they could be analysed only in samples in which total silver and indium concentrations exceed the relevant trigger values. This should substantially reduce analytical expenses.
- While it would be desirable to continue collecting several samples at each survey location in the intermediate, target and downwind areas, these samples could be bulked, mixed well, and then a single sub-sample taken for analysis to give a mean value for the location. This is feasible, as the variation between and among locations is of more interest than the variation within a location. It would substantially reduce analytical costs and would compensate for sampling additional locations
- There is little value in sampling surface water in either the intermediate or target areas. Looking for silver contamination in a single grab sample of water is analogous to looking for the proverbial needle in a haystack and serves little useful purpose. Water sampling could be made useful by deploying passive samplers (differentially permeable sampling bags containing a silver solvent into which silver would partition preferentially) in the water column, so as to integrate silver in the water column over a season. However, there is little need to do this.
- There is probably little point in sampling the intermediate and downwind areas every year. A detailed study of these areas following the final season of cloud seeding is probably all that is justified.

If these suggested changes were made, it would be possible to collect 280 samples in the target area each year, with 256 devoted to the critical matrices of alpine humus, peat, sediments, moss and meadow snow patch, an average of 51 samples per matrix. Assuming that concentrations of total silver and indium would remain well below the relevant GTVs, the average number of samples per matrix could more than double. On the basis of this broad estimate, it should be possible to sample at least 100 sites within the target area and still remain very comfortably within the current analytical budget.

Attachment 4

RESULTS OF ECOTOXICITY SURVEYS TO DATE

Attachment 4 Results of ecotoxicity surveys to date

Two ecotoxicity surveys have been conducted – a pre-trial survey in autumn 2004 and a post-season survey following snow melt in summer 2004-05. The results of these surveys are summarised in Table 5.1 and are described below.

For soils and sediments, the nominated guideline trigger value (GTV) for both silver and indium is 1.0 $mg.kg^{-1}$. In the pre-trial survey, the background concentration maxima for silver and indium were 0.27 $mg.kg^{-1}$ and 0.17 $mg.kg^{-1}$ respectively, and the majority of data were below 0.1 $mg.kg^{-1}$. Therefore it would seem that silver and indium concentrations in soils and sediments in the trial area are normally well below the nominated GTV. At the end of the season, soil and sediment maxima (0.47 mg Ag. kg^{-1}; 0.21 mg $In.kg^{-1}$) remained well below the GTV.

For water, the nominated GTVs are 0.02 µg $Ag.L^{-1,}$ and 27 µg $In.L^{-1}$ (although, as discussed in Box 5.1, the NRC recommends this should be changed to 0.55 µg $In.L^{-1}$). In the pre-trial survey, all data recorded for both silver and indium were <0.001 $\mu g.L^{-1}$. Thus it seems that silver and indium concentrations in surface waters in the trial area are normally less than 5 per cent of the GTV in the case of silver and at least two orders of magnitude less than the recommended GTV in the case of indium. At the end of the season, the silver and indium maxima remained of this order, confirming the NRC's view that the collection and analysis of grab samples of water is unlikely to serve a useful purpose in this trial.

For potable water, the nominated drinking water quality guideline value for both silver and indium is 0.1 $mg.L^{-1}$. In the pre-trial survey, the maxima for both silver and indium were <0.001 $\mu g.L^{-1}$, at least two orders of magnitude below the guideline. In the post-season survey, the maxima for both silver and indium were again of this order. However, given public health interest in the potable water supplies, the NRC supports continuation of the potable water surveys.

Attachment 5

WARNE REPORT

Attachment 5 Warne Report

Review of the 'Snowy Precipitation Enhancement Research Project – Annual Report February 2005'

Client Report

Prepared for the Natural Resources Commission, NSW

Michael Warne
Centre for Environmental Contaminants Research, CSIRO

May 2005

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Executive Summary

The Natural Resources Commission requested that I review the report 'Snowy Precipitation Enhancement Research Project: Annual Report February 2005' and provide my opinion on five issues. I have reached my opinion after reading the pages suggested by the NRC (ie. 14- 19, 35-143, 169-170, 178-198, 184-185, 192-198 and 215-226).

The guideline trigger values (TVs) for silver and indium have been derived appropriately in sediment and soil and for silver in freshwater. A more appropriate TV could be derived for indium in freshwater and a number of possible TVs for indium have been proposed in this report.

The sampling, analysis, interpretation protocols and the criteria for suspension used in the report are all appropriate.

The methods used to determine the bioavailability are appropriate to assess the bioavailable fraction in water. The methods are also appropriate to determine the bioavailability of indium and silver in soil, sediment, peat, humus or moss via water exposure. Alternative less conservative methods are described in this report. The current methods are not appropriate to determine the bioavailability of indium and silver in soil, sediment, peat, humus or moss once they have been ingested. It is difficult to determine whether the method would be appropriate to assess the bioavailability of silver and indium to higher plants. Site-specific approaches, particularly direct measurement in higher plants, would overcome many of the uncertainties involved with the current method.

There is little point in measuring the bioavailable concentration when the total concentrations do not exceed the trigger values. Such measurements could be ceased.

One – off grab samples will not necessarily reflect the variation observed at any site. It is recommended that several sampling events occur in a year in order to determine the suitability of the current sampling strategy.

Review of the 'Snowy Precipitation Enhancement Research Project: Annual Report February 2005'

Whether the guideline trigger values for silver and indium have been derived appropriately

Freshwater TVs - The trigger value for silver in freshwater that is stated in the report is correct (ie. the same as that provided in the Australian and New Zealand water quality guidelines (ANZECC & ARMCANZ, 2000)). The report correctly states that there is no Australian water quality guideline for indium.

Due to the limited availability of an appropriate freshwater TV for indium the authors of the report adopted the TV for aluminium, on the basis that indium (In) and aluminium (Al) belong to the same periodic group (ie. group 3A). This is a reasonable approach, but there are two problems with this. First, the toxicity of Al is highly dependent on pH and there are separate TVs for conditions where the pH is greater than 6.5 (ie. the PC99 is 27 µg/L) and less than or equal to 6.5 (ie. the TV is 0.8 µg/L). There are no reports in the literature that indium behaves in the same manner which brings into question the appropriateness of using the Al TV for In. Second, Group 3A also includes Boron, Gallium and Thallium and there are Australian freshwater TVs for all of these elements and it may be possible to use a more closely related group 3A element as the surrogate for indium or to estimate a TV for indium.

Gallium (Ga, atomic no. 31) and Thallium (Tl, atomic no. 81) are both closer to In (atomic no. 49) than Al (atomic no. 13). They may therefore, have chemical and toxicological properties more closely related to In than Al. As both of these elements differ from In it might be better to use either the mean or geometric mean of the two TVs rather than either the Ga or Tl TV as the surrogate for In. The mean and geometric mean of the Ga and Tl TVs are 9 and 0.73 µg/L, respectively.

It is well established that within classes of chemicals that the toxicity increases and aqueous solubility decreases with increasing size (e.g. atomic mass or molecular weight) until the concentration required to cause toxicity is greater than the aqueous solubility – the cut-off effect. As TVs reflect the toxicity of chemicals one might expect a relationship to exist between TVs and physicochemical properties of chemicals. A plot of the TVs for these group 3A chemicals and atomic mass is presented below (Figure 1). Given the above, it is not surprising that there is a relationship between TVs and atomic mass (Figure 1) and atomic number (not shown).

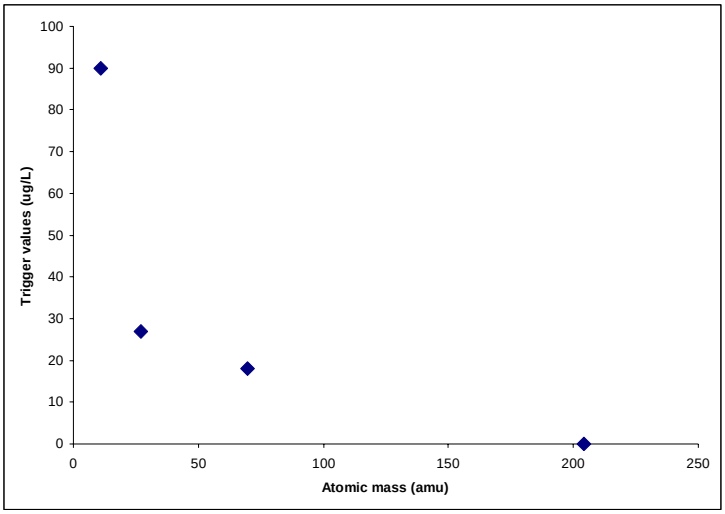

Figure 1. Variation of the Australian and New Zealand freshwater Trigger Values for the chemicals belonging to group 3A (B, Al, Ga, Tl) of the periodic table.

Unfortunately logarithmic, exponential, power and linear distributions do not fit these four data points particularly well. Boron, whilst it belongs to group 3a, is a metalloid whereas the others, including indium, are metals. When Boron is removed high quality linear relationships can be fitted to the remaining data:

TV = -0.1475 atomic mass + 29.818 $R^2 = 0.9898$ (1)

TV = -0.3886 atomic no. + 31.203 $R^2 = 0.9943$ (2)

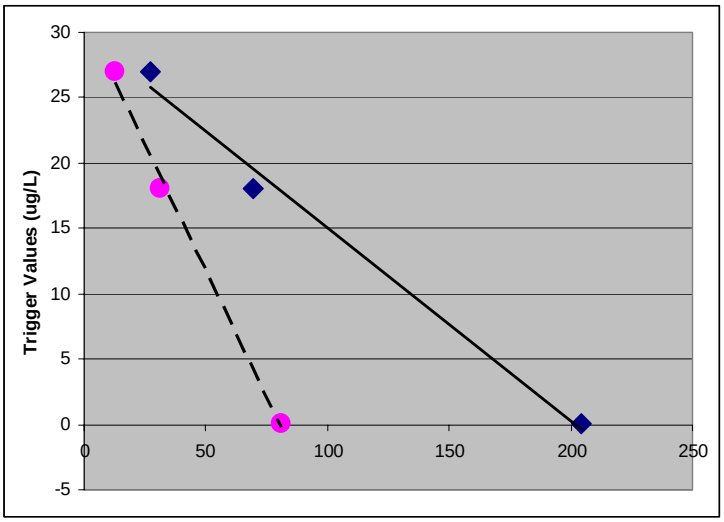

Figure 2 The variation in trigger values for Al, Ga and Tl based on atomic mass (diamonds) and atomic no. (circles) and their corresponding linear regressions.

Using the above equations two freshwater TVs can be estimated for indium. The resulting estimates are 12.9 and 12.2 µg/L based on equations 1 and 2 respectively.

When the log of the TVs for the three compounds in Figure 2 was regressed against the log of the atomic masses the resulting estimated TV for In was 0.55 µg/L.

One could argue about the scientific merit of all of the estimated TVs for In that have been derived above but it is clear that the TV for In should be less than the Al TV. Exactly which of the above estimates of an In TV should be adopted really depends on the degree of conservatism that is desired by the regulatory authority overseeing this project. To some degree the above argument about the In TV is academic, as even if the most conservative of the estimated TVs for In (ie. 0.55 µg/L) was adopted the measured concentrations post-season were all well below this.

Sediment TVs – The sediment quality TVs stated in the report for silver are the Australian and New Zealand TVs (ANZECC & ARMCANZ, 2000). The report correctly states that there are no Australian sediment guidelines for indium. I was not able to find any indium sediment quality guidelines for other countries. Due to the lack of a sediment TV for indium the authors of the report adopted the sediment TV for silver as the value for indium. From a scientific point of view it would have been better to adopt the Australian & NZ Cd sediment TV (atomic no. 48) for indium (atomic no. 49), rather than that for Ag (atomic no. 47). However, in practise this makes very little difference as the upper and lower levels are very similar for Ag and Cd: 1 – 3.7 µg/L for Ag and 1.5 – 10 µg/L for Cd. In fact by adopting the sediment TV for Ag a more conservative TV has been adopted and applied to the site. I therefore support the sediment TV for In adopted in the report.

Soil TVs - There are no Australian soil quality guidelines for either silver or indium in the National Environment Protection (Assessment of Site Contamination) Measure (NEPM) (NEPC, 1999). The authors of the report adopted the sediment TV for Ag for both the Ag and In soil TVs. Given the lack of suitable TVs I support this.

Whether the sampling, analysis and interpretation protocols for each of the environmental matrices [water, soil (including humus, peat and snow patch), sediment and moss] are sound;

I believe that the sampling strategy for soils at the generator sites is appropriate. I similarly, believe that the sampling strategies for all the matrices in the intermediate, target and downwind areas are also appropriate.

The chemical analyses used in the report are appropriate for the stated aims and sample matrices.

The interpretation protocols are all entirely consistent with the risk-based decision frameworks provided in the Australian and New Zealand WQGs (ANZECC & ARMCANZ, 2000). However, the interpretation protocol for soils and sediments requires modification. It is not at all clear how one is to proceed at the end of step 3. Does it stop there or proceed to subsequent steps? This should be resolved. The criteria for suspension of cloud seeding operations are completely appropriate.

Having said this, it remains unclear to me, why samples of moss are being collected and subsequently analysed for silver and indium. The logic behind collecting and analysing the water, soil and sediment samples is that they can be compared to trigger values. The moss samples can not be used in the same manner – as there are no guidelines to which they can be compared. If the aim is to use these pre-trial results as the baseline to which subsequent values are compared, to determine if the concentrations are rising, then the question is whether sufficient samples were collected and analysed.

In relation to the bioavailability protocols, whether the extractant specified is appropriate for soils, sediments and moss, given the nature of the alpine environment and vegetation

For water the bioavailable fraction is operationally defined as the fraction that remains in water after having been passed through a 0.45 µm filter. It is important that there is no single means of chemically specifying bioavailability as it is species specific. Regardless of this, the definition of bioavailability is consistent with the ANZECC and ARMCANZ WQGs (2000). It is also important to note that it is specified in the report that if the 'bioavailable fraction' exceeds the trigger values that biological testing will be conducted. This overcomes the problem that the above operational definition of bioavailability is not perfect.

For soils, sediments, peat, humus and moss the operational definition of bioavailability is the fraction that remains in water that has passed through a 0.45 µm filter after being mixed with soil, sediment, peat, humus or moss for 48 hours. This is quite an acceptable operational definition given the environmental conditions covered in this report. The only parameter that is reported on the water used for the extraction is that it has a conductivity of 18 M Ohms. Given that the bioavailability of silver is affected by a variety of parameters (as stated in the report, but also including water hardness (ANZECC & ARMCANZ, 2000)) it would be extremely useful if parameters such as DO, DOC, water hardness and pH of the extraction water were measured and reported. Milli-Q water is highly purified and is likely to have much lower concentrations/values of DOC and water hardness that decrease the bioavailability of silver than the natural water at the sites. In addition, the generation of Milli-Q water usually results in water with a pH of between 5.5 and 6. These characteristics of Milli-Q water would suggest that the method used is likely to overestimate the bioavailable concentration compared to that achieved at the sampling sites. Ideally, water representative of that found at each site should be used to undertake the bioavailability determinations – in order to generate site-specific estimates of bioavailability. Such a procedure is recommended in the section of the Australian and NZ water quality guidelines on conducting direct toxicity assessments (ANZECC & ARMCANZ, 2000). Alternatively, the water at a study site in which Ag and In would have the highest bioavailability should be used for all the bioavailability extractions.

The method for soils, sediments and moss only provides an estimate of the fraction of the silver and indium that is available to organisms being exposed via water that has had contact with soil, sediment and moss. It does not address the bioavailability when the soil, sediment or moss is consumed by organisms. If it desired that this type of bioavailability should be addressed, then physiologically-based methods that attempt to mimic the conditions in the stomach and intestines should be used.

The following points are pertinent in determining the suitability of the current bioavailability protocol to determine the bioavailability of Ag to higher plants. In aerobic soils silver is largely immobilized by precipitation to insoluble salts (bromides, chlorides, and iodides) (ATSDR, 1990) and by complexation or adsorption by organic matter, clays, and manganese and iron oxides (Smith & Carson, 1977). Of these, sorption is the dominant process that controls the partitioning and movement of silver in soils (US EPA, 1980; ATSDR, 1990). Silver can leach from soils into groundwater, the more acidic the conditions the greater the loss from soil (ATSDR, 1990). The alpine soils examined in this report typically have high organic matter contents (1 - 40% see Table 8.43 of the report) and are acidic (ie. the vast majority of the measured soil pH values were between 4.1 – 6.6, Table 8.43 of the report). Low pH values such as this would tend to increase the bioavailability of metals compared to neutral or basic soils. The cation exchange capacity of the soils are also quite high with values varying from 4 to 50 milliequivalents/100g with the majority lying between 10 and 20 milliequivalents/100g. Such CEC values will

decrease the bioavailability of In and Ag. Hogstrand and Wood (1998) stated that the toxicity of Ag to fish is correlated with the free ion concentration (Ag+) with other Ag species contributing little to the toxicity despite their bioavailability. The pH of the extraction water (approx 5.5 – 6) covers the pH of many of the soil samples but not all. As such it may underestimate the bioavailability of soils with pH values less than 5.5. In addition, it is well known that some plants release exudates from their roots that increase absorption of nutrients and trace elements. The current method of assessing bioavailability does not consider this. It is therefore extremely difficult to reach a conclusion about the suitability of the current bioavailability method for higher plants.

In general, accumulation of silver by terrestrial plants from soils is low with concentrations of less than 0.1 mg/kg dry weight (US EPA, 1980) being obtained even if the soil is amended with silver-containing sewage sludge or the plants are grown on tailings from silver mines (Ratte, 1999). Silver accumulates mainly in the root systems of higher plants and little is transferred to the above ground portion (Ratte, 1999). Based on the available information accumulation of Ag and In by higher plants is unlikely to be a major issue. Nonetheless if bioavailability to higher plants is to be determined then it is recommended that one of the following options be adopted (1) that site-specific higher plant bioavailability tests be conducted using water with the pH of the soil at that site (2) that the water with a pH equal to that of the lowest soil be used for all the sites or (3) that actual uptake of In and Ag into plants that are present in the area likely to be affected by the cloud seeding, be determined.

In conclusion, I believe the methods used to determine the bioavailable fraction are appropriate to assess the bioavailable fraction in water. The methods are also appropriate to determine the bioavailability via water of In and Ag in soil, sediment, peat, humus or moss but are not appropriate to determine the bioavailability of these media once they have been ingested. It is difficult to reach any conclusion about the suitability of the current method to determine the bioavailability to higher plants. However, if such measurements are considered desirable then site-specific approaches, particularly the direct measurement of In and Ag concentrations in higher plants, would be the most rigorous approach to take.

Whether there is any point in measuring bioavailable silver and indium concentrations, if total concentrations are well below the relevant trigger values

The bioavailable concentration can never exceed the total concentration and is often considerably less than the total. Therefore, measuring the total concentration and comparing that to the TVs is a conservative approach that favours the environment. I would only measure the bioavailable fraction of silver and indium if the total concentration exceeds the TVs. My recommendation is consistent with the approach adopted and recommended in the risk-based decision frameworks in the Australian and NZ water quality guidelines (ANZECC & ARMCANZ, 2000) for water and sediment and the NEPM for soils (NEPC, 1999).

The money saved by only doing the bioavailability analyses when necessary, could be used to permit temporal sampling to be conducted.

Whether there is much point in taking one-off grab samples of water from rivers and lakes

Dr Brien states in his review of the sampling strategy used in the report, that there is little variation in the concentrations measured at sites within a cluster (e.g. Blue Lake). This is reflected in the data presented in the report. However, the above could at least be partly caused by the fact that the sites are close to each other and they are collected at the same time. Given

that the cloud seeding is only done when the appropriate atmospheric conditions occur (ie. those likely to cause snow) there is likely to be temporal variations in the concentrations of indium and silver in snow and in water bodies (both through direct deposition and melting of snow). It might be expected that concentrations would be greatest after a seeding event and once snow melting has begun.

One of the major limitations of grab samples is that they only provide an estimate of the aqueous concentration at the sampled location at the sampled time. For this reason, I would like to see at least one year of temporal data in order to determine if temporal sampling is routinely required and when the maximum concentrations occur. The sampling strategy for consequent years could then be modified to reflect the outcomes of the temporal sampling.

An alternative to the above would be to use a passive sampler that is able to absorb the silver and indium. However, these are not without their own limitations – including that it is difficult (but by no means impossible) to convert the measured concentration in the passive sampler to an aqueous concentration. Further advice, on this matter, could be provided by Dr Ross Hyne (DEC, NSW) and Dr Jochen Mueller (EnvTox, Qld) who have expertise with using passive samplers in environmental monitoring.

In summary, I do not believe that taking a single grab sample at each site adequately reflects the concentration of silver and indium present in the water at a site. I would like to see temporal concentration data for at least one year before resolving the issue of sampling.

I also believe that in subsequent annual reports that the temporal trends for the concentrations of In and Ag in each medium at each site should be presented to determine if the concentrations are increasing over time. This could be extremely useful as it would provide authorities with an early warning that eventually the TVs may be exceeded if current practices continue. Appropriate management decisions could then be made on whether to continue or modify current cloud seeding practices.

Other comments on the document

The correct way of citing the Australian and New Zealand guidelines for fresh and marine waters is ANZECC and ARMCANZ, 2000. It is not ANZECC 2000.

It would greatly facilitate reviewers if the numbers were presented in the normal manner with either a space or coma inserted to denote each third order of magnitude (e.g. 1 000 and 100 000). Without this it is incredibly difficult to read numbers particularly when they are centred in columns of a table.

Given that the methods used to measure bioavailability are not exact measures of this I believe that the report should acknowledge this by stating that the definitions are ‘operational’.

I believe the statement by Associate Prof. Rix that “The monitoring program will answer any concerns regarding the environmental toxicology of the seeding and tracing agents” is not correct. One major issue that the report does not address is the issue of bioaccumulation.

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