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# MID-TERM REVIEW OF THE SNOWY MOUNTAINS CLOUD SEEDING TRIAL

**October 2010**

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## Enquiries

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# 1       Introduction

Since 2004, Snowy Hydro Ltd (Snowy Hydro) has run a trial program in the Snowy Mountains to understand whether cloud seeding can markedly increase snowfall in this area. The trial program is authorised under the *Snowy Mountains Cloud Seeding Trial Act 2004* (the Act), and is subject to strict conditions. It was originally planned to run until 2009. In 2008, the Government extended the trial to 2014[1]. At the same time, the target area for the trial program was increased.

The Natural Resources Commission (NRC) is responsible under the Act for supervising Snowy Hydro's cloud seeding operations and reporting on the environmental impact of those operations. We do this primarily by conducting an independent review of the information in Snowy Hydro's annual reports on the trial program and its environmental monitoring program. In 2005, 2007 and 2009, our reviews found no evidence of adverse environmental impacts. However, we suggested some improvements to the monitoring program, which Snowy Hydro has largely adopted.

This year, we conducted our review based on Snowy Hydro's 2009 Snowy Precipitation Enhancement Research Project (SPERP) Annual Report. This latest annual SPERP report marks the end of the first phase of the trial program (2004 to 2009, known as SPERP 1). It includes Snowy Hydro's analysis of the results of its environmental monitoring program over this phase. It also includes the first available data and analysis of the trial's impact on downwind rainfall and effectiveness in increasing snowfall.

## 1.1      Our approach

In conducting our review, we focused on five key questions:

1.     Is Snowy Hydro conducting the cloud seeding trial in compliance with the Act?

2.     What does the information and analysis presented by Snowy Hydro indicate about the trial's environmental impact over SPERP 1?

3.     What changes (if any) are required to the environmental monitoring program over the second phase of the trial (SPERP 2)?

4.     What does the information and analysis presented by Snowy Hydro indicate about the trial's impact on rainfall in downwind areas to date?

5.     What does the information and analysis presented by Snowy Hydro indicate about the trial's effectiveness in increasing snowfall to date?

As part of our review process, we sought input from relevant NSW agencies[2] and engaged expert scientists to peer review the information and analysis presented in Snowy Hydro's 2009 SPERP report[3]. These experts also met with Snowy Hydro and its scientists to understand the rationale and approach for the trial and environmental monitoring program. We then considered the experts' findings ourselves.

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[1]     The last year of cloud seeding will be 2014. Snowy Hydro will report in 2015.

[2]     The NRC sought input from the Department of Environment, Climate Change and Water; the Department of Planning; the Department of Industry and Investment; and the Southern Rivers, Murrumbidgee and Murray Catchment Management Authorities.

[3]     Attachment 6 sets out the names and areas of expertise of the scientists the NRC used.

## 1.2      Key findings

Overall, the NRC confirms that the trial is being conducted in compliance with the Act, is of a high scientific standard and the evaluation plan is statistically sound.

There is no evidence that cloud seeding operations have had adverse environmental impacts over the first phase of the trial (SPERP 1), based on Snowy Hydro's environmental monitoring results. There is no evidence that the chemicals used as the seeding agent and tracer (silver iodide and indium trioxide) have accumulated in sampled soils, sediments, water or moss in the areas being tested. There is also no evidence of impacts on snow habitats, or of difference in the concentrations of ammonia and nitrogen oxides in seeded and unseeded snow.

The monitoring results have detected no adverse impacts on rainfall in downwind areas during the first phase of the trial.

Snowy Hydro's 2009 SPERP report provides evidence that cloud seeding has increased snowfall in the target area under defined weather and operating conditions. Its primary statistical analysis of the trial data yielded a positive but inconclusive result. However, Snowy Hydro also analysed physical evidence and carried out a number of secondary statistical analyses of the trial data. Together, these indicate that cloud seeding has had a positive effect in increasing snowfall in the overall target area.

## 1.3      Recommendations for the future

The positive results from the first phase of the trial invite the question: are there any outstanding environmental issues which need further investigation in the trial, prior to any decision to make cloud seeding operational?

A key uncertainty identified by the NRC and our specialist peer reviewers is the transport and potential long-term accumulation and impacts of silver iodide and indium (III) trioxide[4]. Although no adverse environmental effects have been detected to date, it is an important matter for future risk analysis to understand the ultimate fate of these seeding chemicals. If the landscape storage of the applied silver iodide and indium trioxide remains unknown, there can be no certainty that environmental impacts will not arise from long-term, repeated cloud seeding.  Given the trial has another 4 years to run, it is important that this uncertainty be resolved in that time. It would not be appropriate to end the trial and make cloud seeding permanent until the monitoring program can detect where the silver iodide and indium trioxide are in fact going.

Therefore, as the trial continues, we recommend Snowy Hydro take a more investigative approach to determine the fate of these chemicals.  It should review its conceptual model of how silver iodide and indium trioxide are transported in the environment and where they are likely to accumulate. Based on this review, Snowy Hydro should direct investigative sampling to detect and quantify any environmental transport and stores.

The purpose of this investigation should be to clearly identify the environmental fate of the seeding chemicals, confirm or evolve the conceptual model and evaluate any implications for its future programs.

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4          Referred to hereafter in this report as indium trioxide.

Depending on the outcomes of the review of the conceptual model, Snowy Hydro may want to reassess and propose modifications to its environmental monitoring program. For instance, some elements of the existing routine monitoring program may no longer be useful and could be wound back, if the model indicates they are unlikely to ever detect increased concentrations of the chemicals. Saved resources should be redirected in the areas where the model indicates the chemicals are most likely to accumulate.

## 1.4     Structure of this report

The remainder of this report discusses our findings and recommendations in more detail:

- Chapter 2 discusses Snowy Hydro's conduct of the trial to date

- Chapter 3 reviews the results of the environmental monitoring program during the first phase of the trial

- Chapter 4 discusses our recommendations on the environmental monitoring for the second phase of the trial

- Chapter 5 reviews the evidence on the trial's impact on rainfall in areas downwind of the trial area

- Chapter 6 reviews the evidence on the trial's effectiveness in increasing snowfall, and makes some suggestions for improving the discussion and presentation of results in future reports, and for future analysis.

# 2        Conduct of the trial to date

As Chapter 1 noted, the *Snowy Mountains Cloud Seeding Trial Act 2004* authorises Snowy Hydro to conduct a trial within a designated area of the Snowy Mountains. The trial is designed to test whether discharging a seeding agent into passing clouds increases precipitation (snowfall) within this area.

The Act sets out conditions related to the conduct of the trial, including what seeding agent can be used, when it can be used, where and how this agent may be discharged, and requirements to monitor and report on the cloud seeding operations and their effects on snowfall and the environment.

Our review found that over the past five years, Snowy Hydro has conducted the trial in compliance with the Act. In particular, it has implemented an environmental management plan that has been approved by the relevant Ministers, and conducted cloud seeding operations in line with the operating criteria in the plan. It has reported operational statistics and results of environmental monitoring and potential impacts from infrastructure in its annual SPERP reports. Internal and external audits have verified the information in the 2009 SPERP report.

We also note that, over this time, Snowy Hydro has broadened its environmental monitoring program in response to recommendations of our previous reviews and to address stakeholder concerns.

# 3    Environmental impact of the trial to date

As part of the trial, Snowy Hydro implements an environmental monitoring program. Over the first phase of the cloud seeding trial, it has monitored the:

▪ concentrations of silver iodide and indium trioxide in soil, lake sediments, potable water storages and moss in the alpine area

▪ impacts on montane riverine ecosystems

▪ impacts on snow habitats

▪ concentrations of ammonia and nitrogen oxides in seeded and unseeded snow samples.

Our review of Snowy Hydro's analysis of data from its environmental monitoring over the first phase of the trial (2004 to 2009) found that it provides no evidence that the trial has had adverse environmental impacts over this period.  The analysis provides no evidence of accumulation of silver iodide or indium trioxide in sampled soils, sediment, potable water or moss in the areas being tested. It also provides no evidence of impacts on montane riverine ecosystems or snow habitats. In addition, it detected no difference between the concentrations of ammonia and nitrogen oxides in seeded and unseeded snow.

## 3.1    Concentrations of silver iodide and indium trioxide in soil, lake sediments, potable water storages and moss

The trial uses silver iodide as the cloud seeding agent and indium trioxide as a tracer agent. There is a risk these chemicals will build up in the environment at generator sites and other locations in the trial's target and control areas, and downwind areas. If they reach sufficient concentrations, they may have adverse environmental impacts. Snowy Hydro monitors these potential impacts in two ways:

▪ first, it measures the levels of silver iodide and indium trioxide in soil samples collected at generator sites and a range of other locations in the target, control and downwind areas; in sediment samples collected from the edges of alpine lakes; in potable water samples collected from water storages; and in moss samples collected from peat bogs

▪ second, it monitors the trends in the average and maximum silver iodide and indium trioxide levels measured in these samples over time.

Snowy Hydro compares both the average and all values from individual samples to the relevant guideline trigger value (GTV), which establishes the level below which the risk of environmental impact is considered low (see Box 3.1 for more information on these GTVs).

The information reported in Snowy Hydro's 2009 SPERP report indicates that the average levels of silver iodide and indium trioxide measured in the soil, sediment and potable water samples have been below the relevant GTV in every year of the trial to date. While a GTV for moss samples has not been identified, concentrations of both chemicals in moss samples have been consistently low over all years of the trial.

The quality control measures applied to the sampling and chemical analyses provide confidence that average levels of these chemicals are below relevant GTVs.

The general indications are that silver iodide and indium trioxide are not accumulating in the areas being sampled.

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**Box 3.1: Guideline trigger values**

Guideline trigger values (GTVs) are used in monitoring environmental impacts to indicate where a risk to the environment may require action to investigate or remove the cause of the impact. GTVs relate to a particular indicator (such as the level of a certain chemical in soil or water), and represent a threshold value for that indicator. Where the indicator is below the threshold value, the risk of environmental impact is considered to be low. Where it is above the threshold value (or outside the desirable range for that value), the risk is considered to be significant enough to trigger action. For example, a finding that an indicator is above the relevant GTV may trigger immediate action to protect environmental values, or further investigation to determine the cause of the finding.

For the cloud seeding trial's environmental monitoring program, Snowy Hydro has derived GTVs for silver iodide and indium trioxide concentrations from the publicly available guidelines where possible. In particular:

- for silver iodide concentrations in potable water, a GTV of 0.1 mg/L was taken directly from the Australian Drinking Water Guidelines based on assessment of risks to human health[5]

- for silver iodide concentration in sediments, the GTV was taken directly from the Australian and New Zealand guidelines for fresh and marine water quality[6]

- for silver iodide concentrations in soil, the GTVs were set in line with those in sediments

- for indium trioxide concentrations, the GTVs were set in line with those for silver iodide concentrations.

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## 3.2    Impacts on montane riverine ecosystems

Snowy Hydro's cloud seeding operations could affect the ecosystems of alpine and montane streams in the Snowy Mountains if the silver iodide or indium trioxide (used as the seeding agent and tracer agent respectively) is toxic to the organisms living in these streams.

Snowy Hydro monitors potential ecological impacts primarily by sampling the number of different types of macroinvertebrates in alpine and montane streams each year, as an indicator of broader ecological health. These samples of macroinvertebrate assemblages are compared to the populations expected to be found in pristine alpine streams based on predictive models developed for the Australian River Assessment System (AUSRIVAS). It also measures the concentration of silver iodide and indium trioxide in alpine stream sediments, as an indicator of potential toxic impacts on macroinvertebrates in streams.

Over 2004 to 2009, Snowy Hydro found that the number and condition of macroinvertebrate fauna in the target area were not significantly different to those in a control area south of the trial. It concluded that there was no evidence of impacts on macroinvertebrate assemblages.

Snowy Hydro also found that concentrations of silver iodide and indium trioxide in stream sediments were not significantly different between the target and control areas. Based on this, it concluded these concentrations were too low to have had any ecotoxic impact on aquatic

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[5]     NHMRC/NRMMC, 2004, *Australian Drinking Water Guidelines: 2004*, available from: http://www.nrmmc.gov.au

[6]     ANZECC/ARMCANZ, 2000, *Australian and New Zealand guidelines for fresh and marine water quality*, available from: http://www.mincos.gov.au

macroinvertebrates, and that there was no evidence of accumulation of either chemical in streams as a result of cloud seeding operations.

Our review found that Snowy Hydro's conclusion that its monitoring provides no evidence that cloud seeding has affected macroinvertebrate assemblages is reasonably confirmed, given the low concentrations of silver iodide and indium trioxide recorded in stream sediments. However, the NRC notes that AUSRIVAS is a coarse measure of environmental impact relative to the low concentrations and toxicity of the potential contaminants in this case.

A remaining element of uncertainty is the transport and deposition of silver iodide and indium trioxide. While no adverse environmental effects have been detected, it is an important matter for future risk analysis to understand the ultimate fate of these seeding chemicals. If the landscape storage of the applied silver iodide and indium trioxide remains unknown, there can be no certainty that environmental impacts will not arise from long-term, repeated cloud seeding.

## 3.3      Impact of cloud seeding on snow habitats

Snowy Hydro monitors the density of seeded and unseeded snow to assess the likely impact of cloud seeding on snow habitats. Snowy Hydro has also reviewed scientific literature on the factors that affect the formation of open spaces below the snow layer (sub-nivean space.) To assess the likely impact on late season snowfall, it monitors snow melt data at four sites within the target area.

Snowy Hydro's analysis of its snow density monitoring results to date found that the density of seeded and unseeded snow was similar. Its literature review also found that snow density is just one of several factors that may affect the formation of sub-nivean space. Other important factors include ground temperature and the presence of natural features such as bushes and boulders. Snowy Hydro concluded that current evidence does not support concerns about the potential impact of cloud seeding on snow density and the formation of sub-nivean space.

Snowy Hydro's analysis of snow melt data from 2004 to 2009 found that, generally, at higher elevations[7], the cloud seeding period ends before complete snow melt; exceptions may be observed in severe drought years when the snow depth is low. At lower elevations, complete snow melt may occur before the end of the cloud seeding period. However, historical data suggests that natural snowfall after a complete snow melt occurs as often as once in every four years[8]. Based on this analysis, Snowy Hydro concluded that the pattern of snowfall due to cloud seeding is likely to be within the range of natural variability.

Our review of Snowy Hydro's analysis found that there is no evidence that cloud seeding affects the habitat available to snow-dwelling fauna. The snow density data collected to date does not indicate a significant difference in the density of seeded and unseeded snow. When compared to other factors, cloud seeding is unlikely to have a significant adverse impact on habitat formation. In addition, the snow melt data suggests that cloud seeding is unlikely to pose a significant threat to snow-dwelling fauna by leading to late-season snowfall.

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[7]      Spencers Creek snow course, at 1,830 m above sea level (ASL), was used as an example.

[8]      Deep Creek (1,620 m ASL) and Three Mile Dam (1,430 m ASL) were used as examples. Whites River (1,709 m ASL) appears to have a similar pattern to Deep Creek.

## 3.4    Concentrations of ammonia and nitrogen oxides in alpine lakes

The Department of Environment, Climate Change and Water (DECCW) has identified elevated concentrations of ammonia and nitrogen oxides in some alpine lakes within the Snowy Mountains but the cause of increased concentrations is unclear.  To assess whether cloud seeding is likely to be responsible, Snowy Hydro engaged the Ecology Lab to undertake a study of ammonia and nitrogen oxide concentrations in seeded and unseeded snow samples, and reported the findings in its 2007 SPERP report. The study did not detect a difference in the ammonia or nitrogen oxide concentrations in the seeded and unseeded samples, and concluded that cloud seeding is not increasing ammonia or nitrogen deposition in alpine lakes.

Our review of Ecology Lab's study[9] found that the methods for sample analysis, statistical analysis and interpretation appear to be appropriate, and supported the findings and conclusion of the study.

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[9]    Peer review undertaken by Professor Gary Jones and Professor Richard Norris of eWaterCRC in 2008.

# 4      Recommendations on environmental monitoring during SPERP 2

Snowy Hydro has implemented a broad environmental monitoring program that has been appropriate for the first phase of the trial. At this midpoint of the trial, and in light of Snowy Hydro's analysis of the results of this monitoring, we have considered what – if any – changes are required to this program during the second phase.

As discussed in the previous chapter, the analysis of results to date has shown no significant accumulation of chemicals at the sites being monitored. However, silver iodide and indium trioxide *are* being added to the landscape each year. The fate of these chemicals remains uncertain and should be verified.

Therefore, as the trial continues, we recommend Snowy Hydro take a more investigative approach to determine the fate of these chemicals.  It should review its conceptual model of how silver iodide and indium trioxide are transported in the environment and where they are likely to accumulate. Based on this review, it should direct investigative sampling to detect and quantify environmental stores. The purpose of this investigation should be to clearly identify the environmental fate of the seeding chemicals, confirm or evolve the conceptual model, and evaluate any resulting implications for its future program.

Depending on the outcomes of the review of the conceptual model, Snowy Hydro may want to reassess and propose modifications to its environmental monitoring program. For instance, some elements of the existing routine monitoring program may no longer be useful and could be wound back, if the model indicates they are unlikely to ever detect increased concentrations of the chemicals. Saved resources should be redirected in the areas where the model indicates the chemicals are most likely to accumulate.

We also suggest Snowy Hydro consider our peer reviewers' comments in light of any changes to the model (see Attachments 1, 2 and 3). Finally, in future reports, we recommend that Snowy Hydro sets out its monitoring and investigation results in the context of this conceptual model.

Given the very high conservation values of the trial location, and that Snowy Hydro may seek to continue cloud seeding beyond SPERP 2, it is reasonable to expect it to continue to investigate whether its operations are posing a significant adverse risk to the sensitive alpine environment of the Snowy Mountains. In particular, as noted in Section 3.2 above, if the landscape storage of the applied silver and indium remains unknown, there can be no certainty that environmental impacts will not arise from long-term repeated cloud seeding.

# 5      Impact of the trial on rainfall in downwind areas

Some stakeholders have expressed concern that if cloud seeding effectively increases snowfall in the target area, it could reduce rain that would otherwise fall in downwind areas. This concern relates primarily to the Monaro region, which lies directly to the east of the trial area, in the rain shadow of the Snowy Mountains. Areas closer to the east coast receive rainfall from easterly weather systems that develop over the Pacific Ocean and are unlikely to be impacted by cloud seeding.

For its 2009 SPERP report, Snowy Hydro compared precipitation during seeded and unseeded events to assess whether cloud seeding may affect rainfall directly downwind of the target area. Visual maps of the spatial patterns of precipitation show increases during seeding events were confined to the target area, and to areas to its west and north. There was no observed impact on precipitation in the downwind area to the east. Based on this analysis, Snowy Hydro concluded that there is no indication of any seeding impacts on rainfall downwind of the trial area.

Snowy Hydro has also reviewed historical weather patterns over the broader Monaro region since the start of the trial, to identify the meteorological conditions that typically occur during winter. The assessment of weather patterns found that, since the start of the trial, rainfall in this region has occurred when southerly or easterly winds bring moist air in from the east coast. Cloud seeding takes place during westerly weather systems, when Monaro is in a natural rain shadow of the Snowy Mountains. This indicates rainfall downwind of the trial generally occurs under different conditions than those favourable for cloud seeding.

Our review of Snowy Hydro's analysis supports its conclusions. The statistical evaluation of precipitation patterns shows there is no change in precipitation directly to the east of the trial area during cloud seeding operations. Our independent peer reviewer has also conducted separate analyses of rainfall records before and after cloud seeding commenced in 2004, which suggests no impact associated with cloud seeding in the broader downwind region as far east as the coast.

# 6      Effectiveness of the trial program in increasing snowfall

As well as monitoring the environmental impacts of its cloud seeding trial, Snowy Hydro is monitoring and evaluating the effectiveness of the trial program in increasing snowfall in the trial area. Its 2009 SPERP report provides the first available information on the results of this evaluation for the first phase of the trial (SPERP 1).

We reviewed Snowy Hydro's trial design and evaluation plan[10], as well as its analysis of the evidence of the trial's effectiveness over SPERP 1. Overall, we found that the trial is of a high scientific standard and its evaluation plan is statistically sound. While Snowy Hydro's primary statistical analysis using all experimental units yielded a positive but inconclusive result, its primary physical analysis and secondary statistical analyses provide evidence that cloud seeding has been effective in increasing snowfall in the overall target area in defined weather and operating conditions.

We expect that as the trial continues to 2014, it will generate additional data to strengthen this evidence, and allow Snowy Hydro to identify opportunities to improve the design and possibly increase the efficiency of its cloud seeding operations. Based on our peer reviewers' comments[11], we also have some recommendations for improving the discussion and presentation of Snowy Hydro's analysis in future reports, and for further analysis during SPERP 2. These findings and suggestions are discussed in more detail below.

## 6.1      Snowy Hydro's trial design and evaluation plan

International cloud seeding trials have found that it is often difficult to conclusively demonstrate that cloud seeding is effective in increasing snowfall. These trials usually use statistical and physical evidence to test a conceptual model of how precipitation processes differ between seeded and unseeded clouds. Scientific confirmation of effectiveness requires robust and accurate statistical analyses of snowfall, ideally supported by physical evidence that the seeding agent is involved in the initiation and development of precipitation in clouds. Good experimental design is required, so the trial can detect small effects against the background of high natural variability in weather conditions that occurs in many regions.

Snowy Hydro's cloud seeding trial has an innovative experimental design and a sophisticated evaluation plan, which seek to overcome these difficulties. The experimental design compares snowfall from seeded clouds to an estimate of natural snowfall within a target area. It uses a tracer agent as well as a seeding agent to demonstrate that clouds have been effectively targeted.

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[10]     Snowy Hydro Ltd (2008), *Snowy Precipitation Enhancement Research Project Annual Report*, Appendix A, p. 95. Evaluation Plan by Professor Michael Manton (note: a version of this evaluation plan was also published as Manton, MJ, Dai, J, and Warren, L (2009) Evaluation Plan for a Snow Enhancement Experiment in Australia, *Journal of Weather Modification*, Vol.  41, pp. 27-42.)

[11]     We engaged an independent climate scientist (Professor Roger Stone) and a statistician (Dr Dennis Sinclair) to each conduct a peer review of Snowy Hydro's evaluation plan, and its analysis of the evidence of effectiveness to date. Our reviewers also met with Snowy Hydro's experts to ensure they understood the design and implementation of the trial. Their findings are contained in Attachments 4 and 5 respectively.

The evaluation plan identifies a primary target area for increasing snowfall, as well as a secondary target area (Figure 6.1). The primary target area is the region in the Snowy Mountains where winter precipitation consistently and predominantly falls as snow. It covers the highest ridge of the region, where site elevations range from 1560 m to 1950 m.  Based on its use of the GUIDE model, Snowy Hydro expected that snow induced by its cloud seeding operations during SPERP 1 would fall in this primary target area[12].

To allow for uncertainty in targeting seeding material, the evaluation plan also identifies a secondary target area. This area is to the east and west of the primary target area, where site elevations range from 1000 m to 1630 m. The primary target area plus the secondary target area constitute the overall target area where increased precipitation due to seeding was expected[13].
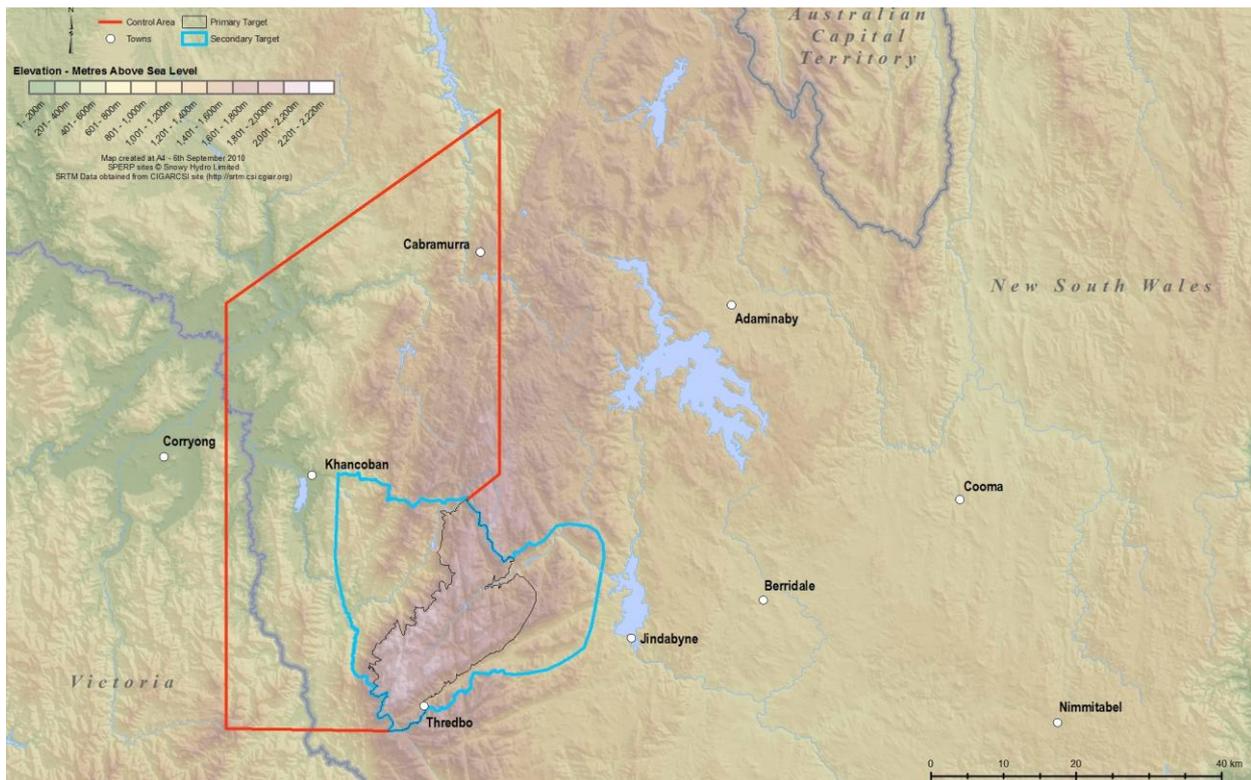


**Source: Snowy Hydro, 2010**

**Figure 6.1        SPERP 1 Primary and secondary target areas (together the overall target area)**

The evaluation plan also specifies that both statistical and physical lines of evidence would be used to assess the effectiveness of cloud seeding in increasing snowfall.

▪   The statistical evidence is derived by comparing measurements of snowfall from seeded clouds to an estimated baseline of natural snowfall within the target area. The analyses rely on correlations between observed natural snowfall in the control area and the target area to predict how much snow would have fallen in the target area if the cloud had not been seeded.

▪   The physical evidence is derived by comparing the concentrations of silver iodide (the seeding agent) and indium trioxide (the tracer agent) in seeded and unseeded snow. If silver iodide is causing enhanced snowfall, its concentration should be higher in seeded snow than unseeded snow. Within seeded snow, concentrations of silver iodide should be higher than indium trioxide, because the silver iodide seeding agent will be captured in ice crystals whereas the indium trioxide tracer agent will not.

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12     See note 9. Snowy Hydro (2008) p. 2, or Manton et al (2009) p.28.
13     *Ibid*.

In addition, the evaluation plan specifies that both primary and secondary analyses will be conducted. It states "*the primary analysis is seen as the key test of whether there has been an impact of seeding on the amount of precipitation in the target area*"[14]. It includes data related to snowfall in the primary target area only, and to all experimental units conducted during SPERP 1. The plan indicates that to yield an unequivocally positive result, the primary analysis must provide:

- statistical evidence of an increase in snowfall with 10 per cent statistical significance across all experimental results and across the primary target area, and

- physical evidence of an increase in the silver iodide concentration in seeded snow with 5 per cent statistical significance.

If the primary analysis does yield such a result, the plan indicates that secondary analyses will be used to confirm the scientific integrity of the result. However, "*if the primary analysis yields a negative or uncertain result, the secondary analyses will be used to clarify where and how the seeding hypothesis broke down*"[15]. These analyses can also be used to support scientific advice on policy decisions about potential future cloud seeding[16].

## 6.2    Snowy Hydro's analysis of effectiveness to date

Snowy Hydro's 2009 SPERP report presents the results of its primary analysis for the effectiveness of cloud seeding during SPERP 1, as well as the results of its secondary analyses.

Table 6.1 summarises the results of the primary analysis. In line with the evaluation plan, this analysis included both statistical and physical components, and used data for the primary target area from the full set of 107 experiments conducted between August 2005 and June 2009.

**Table 6.1       Summary of Snowy Hydro's primary analysis of the effectiveness of cloud seeding during SPERP1**

| Component of analysis | Number of experimental units | Area over which snowfall measured | Experimental result | Statistical significance | |
|---|---|---|---|---|---|
| | | | | Experimental value | Criterion for success |
| Statistical | 107 | Primary target area | 7% increase in snowfall | 24% | 10% or less |
| Physical | 107 | Primary target area | Greater than 300% increase in peak value of silver iodide | 0.0002% | 5% or less |

The statistical component of the primary analysis indicates that cloud seeding achieved a 7 per cent increase in snowfall in the primary target area with 24 per cent statistical significance. This does not meet Snowy Hydro's initial criterion for success, which was to demonstrate an increase in snowfall with a level of statistical significance of 10 per cent or less. However, the physical component of the analysis indicates that the median maximum concentrations of silver iodide in seeded snow were 32 parts per trillion compared to 10 parts per trillion in unseeded snow with statistical significance of 0.0002 per cent. This does meet Snowy Hydro's criterion for success of statistical significance of 5 per cent or less.

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[14]    See note 9. Snowy Hydro (2008) p. 20, or Manton et al (2009) p.35.

[15]    *Ibid.*

[16]    *Ibid.*

Table 6.2 summarises the results of the secondary analyses. These analyses repeated the statistical component of the primary analysis using several different data sets, including:

- the same full set of 107 experimental units used for the primary analysis, but with snowfall measured over the overall target area (ie, primary plus secondary target areas)

- a subset of 84 experimental units, comprising only those experiments where the seeding occurred for 45 hours or longer, [17] with snowfall measured across the primary target area

- the same subset of 84 experimental units, with snowfall measured across the overall target area.

**Table 6.2        Summary of Snowy Hydro's secondary analyses of the effectiveness of cloud seeding during SPERP1**

| Data set | Number of experimental units | Area over which snowfall measured | Estimate of increase in snowfall | Statistical significance of increase (Note 1) |
|----------|------------------------------|-----------------------------------|----------------------------------|-----------------------------------------------|
| All experiments | 107 | Overall target area | 9% | 13% |
| Experiments with greater than 45 hours generator time | 84 | Primary target area | 14% | 8% |
| | | Overall target area | 14% | 3% |

Note 1: The scientific community generally agrees that a statistical significance of less than 5 per cent provides a satisfactory level of confidence in an effect.

The secondary analyses indicate that when snowfall is measured over the overall target area, the effect of cloud seeding in increasing snowfall increased from 7 per cent to 9 per cent, and the statistical significance improved from 24 per cent to 13 per cent (which still does not meet the initial success criterion of 10 per cent or less statistical significance). When experiments that lasted less than 45 hours are excluded, the effect of cloud seeding further increased to 14 per cent for both the primary and overall target areas, and the statistical significance improved to 8 per cent in the primary target area and 3 per cent in the overall target area. Snowy Hydro explains that the stronger statistical significance of analyses based on the overall target area arose "*because the correlation between precipitation in the control and overall target area is greater than in the control and primary target area*".[18]

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[17]     Snowy Hydro found that 25 per cent of experimental units had a combined operation time across all generators of less than 45 hours due to changes in wind direction, freezing levels rising above 1600 m, or operations cut short to meet the safe operating criteria in the trial's environmental management plan. The results of the trial were re-analysed after excluding these experimental units.

[18]     Snowy Hydro Ltd. (2010) , *Snowy Precipitation Enhancement Research Project Annual Report 2009*, Appendix D, p. 46.

## 6.3 NRC's comments and suggestions

As indicated above, based on the information provided on Snowy Hydro's primary and secondary analyses of the effectiveness of the trial to date, we consider that overall there is acceptable evidence that cloud seeding has increased snowfall in the overall target area under defined weather and operating conditions.

Based on our peer reviewers' comments[19], we have some suggestions for improving the presentation and discussion of the analysis when Snowy Hydro next reports on the effectiveness of the trial, and for further analysis that would assist policy decisions about future cloud seeding.

### 6.3.1 Suggestions for improving discussion and presentation of results

As stated previously, the NRC considers Snowy Hydro's trial is of a high scientific standard and its evaluation plan is statistically sound.

To improve stakeholder understanding of and confidence in the results of its analysis of the effectiveness of the trial over its second phase (SPERP2), Snowy Hydro could improve the way it presents and discusses its analysis. For instance, we suggest it:

- explain what hypothesis it is testing through each analysis

- provide a summary table for each set of analysis that indicates the type of analysis, the data set, the target area and the evaluation criteria, as well as the results (similar to our Tables 6.1 and 6.2 above)

- consider providing graphical presentations of the full distribution of each data set, accompanied by a discussion of the influence of outliers.

In addition, we suggest that when its analyses deviate from those set out in the evaluation plan, Snowy Hydro outlines why this is the case.

Finally, we note that Snowy Hydro intends to publish its results in international scientific literature and we agree this is critical to further quality assure the scientific integrity of the trial. Given the ongoing stakeholder interest in the trial, we also recommend that it publicly releases future reports on the trial.

### 6.3.2 Suggestions for further analysis

As Snowy Hydro designs further secondary analyses of the trial's effectiveness, we suggest that it consider the comments of our statistical peer reviewer (see Attachment 5).

Also, given that major changes in the timing and extent of precipitation have already been observed in the Snowy region[20], Snowy Hydro should study the likely impact of climate change on the conditions necessary for cloud seeding to be effective. It is not yet known whether climate change will result, for example, in a reduction each year in weather systems of the type needed for cloud seeding, or only in some years. A concerted study of the likely changes in key parameters required for successful seeding would allow a more realistic assessment of the

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[19] See Attachments 5 and 6.

[20] For example, see Murphy, BF, and Timbal, B (2008), A review of recent climate variability and climate change in southeastern Australia, *Int J Climatol*, **28:** 859-879, and Timbal, B (2007), Compare documented climate changes with those attributable to specific causes, *South-Eastern Australia Climate Initiative, June 2007 End of Project Reports,* Project 1.1.2 (http://www.seaci.org/docs/reports/SEACIProjectReportsJune2007.pdf#page=4)

potential for cloud seeding to effectively increase snowfall to be made at the conclusion of the trial in 2014.

In addition, we note that Snowy Hydro has not yet confirmed whether increases in snowfall provide commensurate increases in run-off water and available water in dams. The evaluation plan suggests some methods for assessing correlations between snowfall and available run-off water and stream flow. At this stage of the trial it is unlikely that sufficient data are available to draw a reliable conclusion on how much extra run-off and stream flow cloud seeding may produce. We expect Snowy Hydro will report on the results of this analysis at the conclusion of the trial in 2014.

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# natural resources commission

# Attachment 1

## Peer review

Dr Graeme Batley
Chief Research Scientist
Centre for Environmental Contaminants Research
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# Review of the Snowy Precipitation Enhancement Research Project 2009 Annual Report

## For the Natural Resources Commission

## Graeme Batley

**Centre for Environmental Contaminants Research, CSIRO Land and Water, Lucas Heights, NSW**

### Overview of Brief and Scope of Work

This review focuses on the results of Snowy Hydro's environmental monitoring program as documented by Snowy Hydro in their 2009 Annual Report for the Snowy Precipitation Enhancement Research Project (SPERP) (Snowy Hydro, 2009). In particular, I was asked to address whether the monitoring was adequate, whether the conclusions Snowy Hydro have drawn are justifiable and whether monitoring should be improved in the future.

The desirable framework for a monitoring and assessment program has been documented in the Australian Guidelines for Water Quality Monitoring and Reporting (ANZECC/ARMCANZ, 2000a). One of the first steps in planning a monitoring exercise is the development of a conceptual model of pollutant transport and dilution pathways, as this helps define the monitoring sites. While this has not appeared in the recent SPERP reports, a model was presented in a report for Snowy Hydro by CSIRO (Kearns, 2004) that presumably was used to inform the development of the monitoring program and sampling site selection. It would have been useful to refine this model based on monitoring to date, as is recommended by the Guidelines.

My interpretation of the processes that might be involved in this model would see silver and indium depositing in snow, on some soil and bog surfaces and to a lesser extent on the smaller surface area of alpine lakes and rivers. The potential for dissolution of silver iodide and indium trioxide is minimal, and what does dissolve is likely to eventually attach to particles. The snow-associated contaminants are not expected to be mobilised until snow melt occurs when they will flow through to soils and then overland to alpine lakes, creeks and rivers. The high snow melt volumes will effectively dilute any silver and indium deposits (which may well be buried by later deposits but presumably stratified). This dilution will mean that riverine concentrations will be very low and the possibility of accumulation of silver and indium in riverine sediments will be minimal as, except in backwater areas, sediments are likely to be swept long distances downstream by the flows, as evidenced by the abraded characteristics of the river beds. Because of this, the effects on macroinvertebrates in the river systems are expected to be negligible, except to the extent that the surface depositions in winter during low flow conditions might have some minor impact. In the alpine lakes, sedimentation of silver and indium may occur, but this is likely to be greatest in the deepest parts and not at the edges.

My analysis of the report has reviewed the data in relation to the proposed conceptual model, to see whether or not the findings are consistent with this. If they are not, then according to the framework, the conceptual model should be revised and the monitoring program may also need to be revised to focus on those areas where contaminant accumulation is most likely (ANZECC/ARMCANZ, 2000a).

## Sampling of Waters, Snow, Soils and Sediments

The sampling of waters for analysis of silver and indium at ultratrace (ng/L) concentrations is a non-trivial exercise. Our laboratory was involved in the sampling and analysis of waters, soils and sediments for Snowy Hydro in 2003 and provided instruction on the necessary sampling and sample handling protocols to minimise losses and contamination that can be a major source of errors in ultratrace analysis. These procedures were subsequently applied by Snowy Hydro in 2004 when CSIRO again undertook the analyses. Since then sampling has been undertaken by Snowy Hydro, and as far as can be assessed, the recommended sampling protocols are being applied. The sampling procedures for waters, soils, peat bogs and sediments appear satisfactory from the information provided.

Sampling of snow requires similar rigour. In particular, the desirability of looking at depth profiles in snow means that special care will be needed in sectioning such core samples, more than would be needed for sectioning of sediment cores. The 'profiler' procedure used appears to be satisfactory, although I would have thought the use of a cylindrical acrylic core sampler that could be chilled and sectioned in the laboratory might have been simpler.

## Analysis of Waters, Snow, Soils and Sediments

Satisfactory analytical methods with adequate detection limits are being applied and there appears to be adequate quality assurance and quality control (QA/QC). As expected at the concentrations being analysed, precision is not high, but acceptable. On a minor issue, I note that the University of Melbourne methods document provided reported analysis of a certified reference material as pg/g, whereas the published reference material analyses are as ng/L. The pg/g number might be appropriate for snow where the sample is presumably weighed, but is inappropriate for total metals analysis on unfiltered water samples.

For standard analyses for silver and indium, water samples were unfiltered, but were acidified (Bilish, 2009). The method for bioavailable metal was to involve only 0.45 µm filtration, presumably of the unacidified sample (filtering an acidified sample is inappropriate). This is hardly a bioavailability measurement, and should not be referred to as such, although better than a total analysis. The hierarchical assessment framework provided in the Australian and New Zealand water quality guidelines (ANZECC/ARMCANZ, 2000b) clearly states that a bioavailable measurement involves speciation of some sort (on an unacidified sample). In the case of silver, the use of a chelating resin or even ultrafiltration might be the best options. It was noted that if the trigger value was exceeded, then extra studies were to be undertaken to assess the contribution of any colloidal fraction.

This framework is what is effectively being followed, but given the low concentrations of silver detected, there is no need to measure bioavailable metals as shown in the framework, in reality such measurements at ng/L concentrations might be problematic. It would be instructive however in the highest samples analysed to have some idea as to what fraction is by definition dissolved as this would help in understanding the ultimate fate and transport.

## Data for Silver and Indium Concentrations in Snow

A discussion of snow chemistry is presented in the initial report on SPREP Phase 1 by Manton (Appendix D of Snowy Hydro (2009)). More detail was included in earlier reports (Manton (2009a,b). His studies were concerned with Ag/In ratios at each experimental unit (EU) site, from a consideration of the microphysical and operational aspects of the cloud seeding.

Analyses were undertaken on 2-cm slices of snow. Down-core profiles indicated that the elevated values were typically distributed over around 3-6 slices, although in most instances the highest values were well below the core surface. The time of sampling of snow for each experimental unit's (EU) operation was stated as 1 hour after the 5-hour operation had ceased, but the results imply there was considerable 'clean' snowfall between cessation of seeding and collection of the samples.

From an environmental perspective, the concentrations of silver in snow, and hence in the diluted melt, is of interest. The snow chemistry data listed in Appendix T of the 2009 SPERP Report show concentrations of total silver in core slices as high as 250 pg/g. Indium was as

high as 33 pg/g.  If for example this 250 pg Ag/g slice (of 2-cm depth ) is diluted by 50 cm of 'clean' snow, then the concentration of silver in runoff from snow melt may or may not be significant depending on the spatial distribution of this elevated concentration.  In general, it is likely that the diluted concentration will be insignificant compared to the background concentration (assumed in Appendix T to be 3 pg Ag/g).

**Environmental Monitoring Data**

Before commenting on these data, I must comment on the misuse of the terms 'ecotoxicological data' and 'ecotoxicity sampling'.  In no instance is ecotoxicology testing being undertaken.  Any conclusions with respect to ecotoxicological effects are assumed based on exceedance or otherwise of the TVs that have been accepted for this study.  More correctly, the section should be entitled 'environmental monitoring', and I have examined the data from this perspective.

The toxicity data used in deriving the guideline trigger value for silver in freshwater do not show a particularly good fit in the species sensitivity distribution used in their derivation, so there is considerable uncertainty in the derived number of 20 ng/L, while there is no guideline for indium.  Furthermore the silver guideline was derived for largely Northern Hemisphere species which may differ considerably in their sensitivities to silver from those that inhabit the Snowy Mountains waterways.  Within the next six months it is likely that the silver guideline will be better defined as part of the current guideline revision exercise being conducted by the Department of the Environment, Heritage and the Arts (DEWHA).

The NRC recommended (NRC, 2005) that there was little value in taking one-off grab samples of surface water once a season to assess potential ecotoxicity. However, there may be a potential concern about ecotoxic effects in water if silver concentrations can be detected in potable water samples at close to half the ecosystem protection trigger value which is itself not terribly robust, coupled with the fact that concentrations in snow have exceeded the trigger value by more than an order of magnitude.

On this basis, an absence of toxicity really cannot be assumed. While a reasonable case might be argued for minimal bioavailability of silver iodide and indium trioxide based on their chemical form and solubility, it would be useful to demonstrate this by testing some selected samples.

*Snowmelt and water data*

No data are presented for snowmelt and surface water with respect to ecosystem protection, although potable water data are reported.  Effectively, the potable water sample data could be evaluated in relation to more stringent ecosystem protection guidelines for freshwater rather than drinking water guidelines.

Data presented in the Cardno Ecology Lab report in Appendix K of the 2009 SPERP Report (Snowy Hydro, 2009) show that silver in potable water in the alpine lakes and Thredbo River was typically below 1-2 ng/L, although on one occasion, a value near 8 ng/L was reported.  It was noted that this was during spring runoff, which raises a concern if concentrations can reach this high.  As discussed above, this would have been a good case for the measurement of dissolved metals as the first step in the hierarchical assessment framework, however, unless split samples were kept where only one was acidified, this may have been impossible.  It would be useful to confirm that silver and indium are mostly present in particulate (or colloidal) forms and largely non-bioavailable.  This is probably best done on selected melted snow core samples where high concentrations are expected.

*Sediment data*

Total silver in sediments from Hedley Tarn, reported in Appendix K, was as high as 45 µg/kg. This is well below the ANZECC/ARMCANZ (2000) trigger value of 1000 µg/kg.  Samples were collected 4 m from the edge of the lake, but this is less likely to be as important a deposition zone as the bottom of the lake.  Although sampling there would be more difficult, at some stage in at least one alpine lake, this should be done to ensure that important evidence is not being missed.

The more important question is whether concentrations are increasing with time.  Data presented in the Cardno Ecology Lab Report in Appendix J of the 2009 SPERP Report (Snowy

Hydro, 2009) indicate an increase in mean silver concentrations in Hedley Tarn sediments from pre 2004 to 2006 but a decrease thereafter to 2009. Blue Lake sediment silver increased from 2004 to 2007 and subsequently decreased. Similar trends were seen for indium. These are interesting findings that on the face of it are reassuring for their environmental consequences. Of greater concern is why concentrations should decrease? This could occur if the higher silver and indium containing sediments were being washed into the deeper parts of the lakes, or if their concentrations were being diluted by inputs of other particulate matter. In this context, down core profiles where these are possible would help to resolve this question, as well as informing the suitability of the near shore sampling sites.

Sediment sampling at the sites in rivers and creeks where macroinvertebrates were sampled showed silver and indium concentrations generally below 60 µg/kg, and in many cases even lower.

The likelihood of any biological effects from silver and indium in sediments will relate to their bioavailability, and, while concentrations are not near the guideline trigger values some consideration of bioavailability might be useful to fully allay concerns. I note that it was intended to apply leach tests (e.g. ASTM D-3987) to sediment (and moss) samples, if necessary, to determine bioavailability. This type of leach test is effectively a water elutriate test that measures water solubility of contaminants, however it ignores the sediment ingestion pathway and the acidic gut pH of many organisms, so would not reflect what was bioavailable to the organism. A cold dilute acid leach is what is recommended for sediments (ANZECC/ARMCANZ, 2000b). Hydrochloric acid is typically used, but given the insolubility of silver chloride, either nitric acid or a pepsin leach might be more appropriate.

As a general comment regarding data reporting, it is inappropriate to report data to five significant figures (e.g. 12,578 ppt Ag) when the precision of the analyses is around 10%. Numbers should be rounded off to no more than three significant figures (e.g. 12,600 ppt Ag).

*Soils data*

A major monitoring focus has been on the accumulation of silver and indium in soils at generator sites and at the intermediate, target and downwind areas and control sites (SPERP1 and 2). No sampling dates are given, so it was unclear whether these soils were collected after snow melt, or indeed whether there was snow cover at the time of potential silver and indium deposition. It was noted in the sampling methodology that meadow soils (as distinct from generator soils) were collected as late as January, after snow melt.

Generator soils had silver concentrations as high as 110 µg/kg, whereas in meadow soils, concentrations were lower and did not exceed 62 µg/kg. The depth of sampling was 2 cm and this seems a reasonable depth at all sites to be permeated by melting snow or for seeing the effects of direct aerial deposition. The measured concentrations are well below the accepted soil quality guideline trigger value of 1000 µg/kg.

The extent to which runoff containing silver (and indium) permeates into soils as distinct from being washed into lakes and rivers is unknown, and based on the sediment monitoring this remains unclear, as there is the opportunity for sediment concentrations to be diluted with sediments from less contaminated areas.

*Moss data*

Historically, mosses have been used as passive samplers of atmospheric contaminants, but in this instance they were used in bogs and fens to measure silver and indium transported by water and sediment. It is not clear from the methods whether sediment was removed before analysis, nevertheless, analyses showed extremely low concentrations (<50 ng/kg), indicating either that they did not represent a major depositional/accumulation zone, or that these metals were not binding effectively to the moss.

*AusRIVAS data*

The Australian River Assessment Scheme is a rather coarse measure of ecosystem health that compares ratios of macroinvertebrate populations in potentially impacted sites vs reference or control sites. At the measured concentrations of silver and indium in sediments from these

sites, effects on populations would be expected to be minimal.  Based on water monitoring upstream of these sites, the effects from silver in water is also likely to be minimal.  As already noted, the receiving surface area of such waterways is small and only in one instance, under snowmelt conditions, was an elevated concentration seen.

A better indicator of ecological effects might be seen in alpine lakes, but here the nature of the biological communities is unknown.

**General Discussion**

Overall, I was quite satisfied with the quality of the sampling, chemical analyses, and other monitoring data collected and their interpretation. The general indications are that silver and indium are not accumulating in the areas being tested, with expected increasing temporal trends not evident, nor are they having measurable effects on macroinvertebrate communities in the creeks and rivers tested.  This is consistent with the model described above, and assumes that the bulk of the silver and indium is transported by creeks and rivers for long distances before accumulating in deposited sediment.  Indeed the dispersion of these deposits may be so large that their detection will continue to be difficult.

Given the total mass of silver and indium being added to the system, it needs to be confirmed that the proposed transport and dilution pathway is the main one.  In the conceptual model of Kearns (2004), alpine lakes are potential primary receptors, yet there are still insufficient data to determine the loads of silver that these lakes are trapping.  It is here that biological receptors might show the first indications of stress and the potential for bioaccumulation.  An absence of any effects here would give greater confidence that effects in other areas would be minimal.

If cloud seeding is to continue for several decades, it will be important that monitoring sites are able to reflect the additional silver and indium inputs, or if not, that we have a reliable and verifiable model of where the added metals are going.  Once trends are able to be verified, then determining the significance of the measured concentrations can follow.  Where measured concentrations of silver and indium begin to increase significantly above background concentrations in waters, sediments or soils further investigation of potential bioavailability is recommended.

Clearly, the intent of Snowy Hydro's environmental monitoring program has been to apply a weight-of-evidence approach that utilises chemistry, toxicity, bioaccumulation and ecology tests. At the moment chemical monitoring indicates concentrations at all of the selected sites below guideline trigger values.  Note that these GTVs have been taken from acceptable nationally accepted tabulations. There is no toxicity testing, but it is probably a reasonable assumption that so far below the trigger values, toxicity will not be detectable.  Nevertheless it would be useful to demonstrate that, at least in melted snow core samples, both silver and indium are present in insoluble and non-bioavailable forms.

There are no measurements of bioaccumulation by aquatic biota, although mosses were an attempt to use a terrestrial organism for this purpose, but it is not clear whether mosses actually bioaccumulate or merely trap silver and indium.  The ecology measurements consider only macroinvertebrates in creeks and rivers as an indicator of river health, and this is probably adequate as a first step, if extended to measures of bioavailability and abundance in alpine lakes.

Using macroinvertebrates as indicators of bioaccumulation might be a possibility, although selection of species, their age and size might be problematic.  It is debatable based on the chemical evidence whether bioaccumulation would be seen here, however, but an absence would be a positive result. Whether there are species higher up the food chain that could be analysed, and what are the priority sites for this needs further discussion.  In general, it would be expected that indium being added as the insoluble trioxide would be of lesser concern in terms of bioaccumulation than silver.

The conclusions drawn to date appear justifiable, however, there might be an opportunity to improve the monitoring program by sampling in alpine lakes to seek a better indication of temporal trends that reflects the known inputs of silver and indium, that is consistent with a model of their expected fate and transport.

## References

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Kearns, A. (2004). Assessment of Snowy alpine ecosystem dynamics in response to cloud seeding. In: Expert Panel Assessment Snowy Precipitation Enhancement Trial, Environ.

Snowy Hydro (2005). Ecotoxicological monitoring program. In: Environmental Management Plan, SPERP.

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July 26, 2010.

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**Centre for Environmental Contaminants Research, CSIRO Land and Water**

Dr Graeme Batley

# natural resources commission

# Attachment 2

# Peer review

Professor Bill Maher
Head, EcoChemistry
Institute of Applied Ecology
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**Review of Snowy Hydro's Annual Report (2009 SPERP report) for the Natural Resources Commission**

**Prof. Bill Maher**
**Institute for Applied Ecology**
**University of Canberra**

**August 2010**

**Preamble**
This peer review specifically addresses Sections 5.1, 5.2, 5.3.1 and 5.3.2 of the 2009 SPERP report as well as Appendix A, I-P and Z and Natural Resources Commission Document No: D05/2226 *Report to the Minister for the Environment and Minister for Planning, Review of Snowy Precipitation Enhancement Research Project Annual Report* (February 2005) and Document No: D08/4086 *Progress report on the Snowy Mountains Cloud Seeding Trial* (April 2009). The review is limited to environmental contamination aspects of Silver (Ag) and Indium (In). Please note that comments in this review are limited to the information in the SPERP 2009 report, which did not contain the detailed justification for choosing sampling locations etc. Please note that the term "Ecotoxicity impacts" is inappropriate as this is a contamination study not an effects study.

**General considerations**
*Methods of data collection and analysis*
As the 2009 SPERP report did not outline the rationale for the choice of sites other than the potentially impacted area, I presume sites have been chosen where potential accumulation of silver and indium would occur. Given that silver iodide is relatively insoluble it will be primarily associated with sediments thus moved by erosion processes. Sampling sites should be chosen with this in mind. Although it should be noted that high concentrations of silver and indium have been measured in water samples (Tables 1 and 2). The study design appears to be a BACI design but how controls were chosen is not obvious. As well, a difficulty already identified is that the pre trial 'before' dataset is extremely limited, being based on a single small survey conducted immediately before the trial commenced (Natural Resources Commission Document No: D05/2226 ) which makes subsequent assessments difficult. ANOVA has been used to test 'pre' and 'post' trial data. Given the low environmental concentrations relative to the trigger values this statistical approach would detect significant increases well before the trigger value is reached as stated by the text (power analysis) on Page 43.

However, it is my opinion that the sampling program used to determine significant increases of environmental silver and indium concentrations needs to be revisited. Has a power analysis been performed on the number of samples required to identify concentrations as high as, say, double the background concentration range? If an objective is to ascertain if an increase of silver and indium is occurring a trend analysis is needed that accounts for some sites increasing while others don't. As well, as previously indicated, adequate replication in time is needed to determine if increases are occurring (Natural Resources Commission Document No: D05/2226).

Another issue that it is unclear to me is how any increases in silver and indium concentrations from cloud seeding would be disentangled from increases from other sources (Appendix P). Note in some of control sites silver and indium has also increased since pre trial data was collected (Tables 1 and 2). Presumably the control site data could be used, if spatial controls are considered adequate, for this but given the variability of results between sediment cores in Marx et al 2010 study this would depend on how atmospheric contaminants are dispersed across this region.

Silver and indium at these concentrations are difficult to measure. As there were no data quality statements in the report, it is not possible to assess the quality of the data. Data quality statements should verify that appropriate sampling procedures (precautions to prevent contamination and preserve samples) were followed and appropriate laboratory Quality Controls used to demonstrate accuracy of the data.

*Veracity of conclusions (as stated on Pages 42-44)*
SPERP1
Mean concentrations of silver and indium in soil, stream sediments, moss, peat and waters are a fraction of GTVs
For SPERP1 this conclusion is obvious and supported by data.

Other conclusions
The other conclusions as to trends and temporal trends in silver and indium concentrations are hard to verify as the summary of data given in Tables 5.4-5.8 is insufficient to draw these conclusions and reference to the specific supporting data is not given . It should be noted though that if Pretrial ranges given in Tables 5.10-5.14 apply for these samples, silver and indium concentrations in potable water and potentially in soils exceed background concentrations.

SPERP 2
Mean concentrations of silver and indium in soil, stream sediments, moss, peat and waters are a fraction of GTVs
For SPERP1 again this conclusion is obvious and supported by data, and, based on trigger values, no management intervention is required. A mass balance of silver and indium applied to the catchment would probably confirm that average silver and indium would never exceed GTVs.

Silver and indium concentrations in stream sediments, moss and waters pre and post seeding operations are within range of background variations
For SPERP2 this conclusion is not supported by data (see Tables 1 and 2 below) where some values are not in background range e.g. Watsons Gorge Creek (Appendix J Figure 6) and Expanded target locations (Appendix K Figure 7).

Table 1 Comparison of pre trial, 2009 and post 2009 season for silver values based on Tables 5.10-5.14. Only exceedances noted.

| Area | Pre trial range (ng/l or mg/kg) | SPERP 2 Post 2009 From Tables 5.10-5.14 Max (ng/l or mg/kg) |
|---|---|---|
| *Potable Water* | | |
| Intermediate | 0.29-0.34 | 3.0 |
| Expanded target | 0.1-1.2 | 5.47 |
| *Other soils* | | |
| Down wind | 0.013-0.176 | 0.418 |
| Expanded target | 0.015-0.070 | 0.256 |
| *Moss* | | |
| Southern control | 0.009-0.060 | 0.064 |

Table 2 Comparison of pre trial, 2009 and Post 2009 season for indium values based on Tables 5.4-5.14. Only exceedances noted. Nd = not detectable.

| Area | Pre trial range (ng/l or mg/kg) | Post 2009 max (ng/l or mg/kg) |
|---|---|---|
| *Potable Water* | | |
| Intermediate | 0.01-0.03 | 0.26 |
| Expanded target | nd-0.29 | 1.09 |
| *Other soils* | | |
| Expanded target | 0.004-0.086 | 0.216 |
| Intermediate | 0.017-0.054 | 0.058 |
| Northern control | 0.04-0.080 | 0.092 |
| *Moss* | | |
| Expanded target | 0.0001-0.005 | 0.007 |
| Southern control | 0.001-0.004 | 0.006 |

<u>There is no evidence of statistically significant increases of silver and indium in the expanded target area</u>
If ANOVA is only used to determine if significant increases in means are occurring then this conclusion is correct. However, there may be/are increases on a site by site basis as indicated in my Table 1 and Table 7.1 in the Natural Resources Commission Document No: D05/2226 and in Figure 3.1 in the Natural Resources Commission Document No: D08/4086.

*Presentation of data, analysis and conclusions*
The presentation and analysis should include more analysis of values that exceed background ranges. As indicated on Page 43 these may be associated with activities at one site but data has not been presented in a way to support this statement. It should be noted that Dr Warne (a previous reviewer) also proposed 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 (Natural Resources Commission Document No: D05/2226).

**Impacts currently monitored**
*Veracity of conclusions*
As stated above using ANOVA to determine if significant increases in means then conclusion that "there is no evidence of statistically significant increases of silver and indium in the expanded target area" is correct but there may be increases on a site by site basis.

*Improvement in monitoring and analysis to resolve uncertainties*
It is my opinion that other options such as trend analyses at individual sites should be explored to determine if environmental concentrations of silver and indium are increasing. If this is an objective of the monitoring program, a power analysis should be performed on the number of samples required to determine the change of interest.

*Significant adverse environmental impacts*
Based on GTVs there is no evidence of silver and indium concentrations causing significant environmental impacts.

*Potential impacts not currently monitored*
Silver iodide and indium trioxide are being used but the fate of silver iodide and indium trioxide has not been measured. I presume a desk analysis has been performed as to silver iodide and indium trioxide's potential ecotoxicology affects. Again a simple mass balance approach could be used to predict a worse case scenario of a concentration increase.

*Potential for bioaccumulation of silver and indium over long term*
A simple mass balance approach could be used to predict the potential for bioaccumulation of silver and indium over the long term. As mentioned above, silver iodide is relatively insoluble and probably associated in sediments thus moved by erosion processes although there is some evidence of enrichment in water samples (Tables 1 and 2). Thus bioaccumulation is likely to occur in organisms in soil, if it occurs at all. The monitoring program as described in the report is not designed to indicate if bioaccumulation in occurring in soil dwelling organisms. The justification of measuring silver and indium concentrations in moss is not clear.

*Can this be monitored?*
Bioaccumulation of silver and indium in soil organisms e.g. worms could be monitored. However, given the lack of solubility of silver iodide and indium trioxide it would probably not occur. A desk top study of the bioavailability of silver and indium in soil would determine the efficacy of undertaking any biomonitoring of this type. I concur with the NRC's view that it should not be necessary to address this issue unless some evidence emerges of elevated total concentrations in the matrices currently being monitored (Natural Resources Commission Document No: D05/2226).

*Appropriate conditions to trigger monitoring of indicators of bioaccumulation*
A desk top study of the bioavailability of silver and indium in soil is needed to answer this question if biomonitoring is deemed to be necessary.

*Other potential environmental impacts and feasibility of monitoring*
No other environmental impacts are obvious.

*Adequacy of environmental monitoring for expanded operations*
The monitoring program as described is adequate to assess if GTVs are being exceeded. As mentioned above the monitoring program may need to be refined to detect environmental increases in silver and indium based on management needs.

*Has the environmental monitoring program been appropriately adjusted to include the expanded trial area*
The monitoring program as described is adequate to assess if GTVs are being exceeded. As mentioned above the monitoring program may need to be refined to detect environmental increases in silver and indium based on management needs.

*Is current environmental monitoring program likely to detect significant impacts?*
As mentioned above the monitoring program as described is not designed to measure impacts only the accumulation of silver and indium in water, soil, sediments, peat and moss. The presence of impacts is inferred if GTVs are exceeded. Sublethal effects are not addressed at all.

# natural resources commission

# Attachment 3

## Peer review

Professor Richard Norris
Director
Institute for Applied Ecology
University of Canberra

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**Review of Snowy precipitation enhancement research project 2009**
**2009 Survey of macro invertebrates**

Prof. Richard H. Norris
eWater CRC and Institute for Applied Ecology
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Canberra 2601

5 August 2010

## 1. Suitability of approach and methods

a. This report compiles the findings of a rigorously conducted study to test the potential effects of cloud seeding with silver iodide and a tracer of indium sesquioxide.

b. The study covers an area recently expanded to 2,150 km² of the Kosciuszko National Park and surrounds.

c. The study includes measurements of silver and indium in aquatic sediments and macro invertebrates at 16 sites, three of which are outside the affected area to the south and used as controls.

d. The number of sites sampled has been reduced from 24 in 2007. 16 sites were sampled in 2008 and again in 2009 and these two years also included edge samples in addition to the riffle samples that were also collected in 2007. Given the levels of natural variability expected in silver and indium and the macro invertebrate assessments, the low number of sites could not be expected to provide a very powerful test of the potential effects of the cloud seeding.

e. Nowhere in the report is there a statement of the effect sizes that are considered important to be detected, or what could be detected with the sample size collected. Also, the power of the tests to detect such effect sizes should be presented. It is expected that the effect size would be quite large and that the power quite low. The PERMANOVA test employed may not allow calculation of traditional effect size and power but it was noted in the methods that the sample sizes were sometimes too small even to allow an appropriate number of permutations for the test. Even on this basis some comment is warranted. 16 sites with just a few per treatment (e.g. by catchment) is certainly very small for multivariate analyses.

f. The previous report on 2008 (2009 report) concluded that …"The conclusions that can be drawn from these comparisons, however, are limited due to the small amount of data available…" The same conclusion was drawn in the current report. This relates to (e.) above and has not been addressed in the 2009 work reported in 2010.

g. There are no statements as to whether criticisms from previous reviews have been addressed in the methods or the results. The 2008 review of 2007 results made several criticisms. It is possible that these were addressed in a review of the 2008 data, if one was done.

## 2. Appropriateness of discussion and conclusions

a. The executive summary for the macro invertebrate section makes no comparison with the previous work and the discussion only limited reference to the previous reports, despite concluding that invertebrate assemblages have become poorer over time and that "…This finding is important, because it provides and indication of the magnitude and direction of change that can occur in aquatic macro invertebrate assemblages that are not influenced by SPERP."…

**b.** The effect sizes and power of the tests should be stated with the statement of hypotheses and/or with the methods. Some discussion is needed on (1.e) and (1.f) above on the appropriateness of the study design relative to the effect sizes that could be detected and with what power, relative to the effect sizes considered ecologically important. There should be some statement of what size ecological effects are considered important. Previous reports have stated that a change in one AUSRIVAS band is small, however, such a change actually represents ~20% change in the number of families, which is not a small change. The AUSRIVAS bands were chosen merely as a convenient way of reporting the data. A change in one AUSRIVAS band is again alluded to as 'small' in the current report, which is inaccurate.

**c.** The conclusion that the cloud seeding has no effect on macro invertebrate assemblages is likely to be accurate, given the low concentrations of silver and indium recorded (assuming the values in the figures to be inaccurate). However, there are so few data that the conclusion needs to be couched in terms of the likelihood of picking up an effect (power) and how big that effect would be. Thus, based on the data it is accurate to say that no effect was found but this is rather meaningless if the data are too few and variable to ever determine and effect of ecological significance.

**d.** The discussion claims to use a Multiple Lines and Levels of Evidence approach but this is incorrect in the epidemiological sense from which it is derived. Several lines of evidence are used (metal concentrations, macro invertebrate assemblages etc.) but not levels. Levels of evidence would normally be included for each line and include temporality (effect only after introduction of the stressor), dose response, consistency of association and these have not been properly tested.

**e.** Some parts of the discussion e.g. para 2 in 4.1.2, but other areas as well, are just descriptive of the results and don't add any interpretation. The interpretation is needed relative to the purpose of the study.

**f.** In several places there are statements that there are 'differences' among the data where it would be simpler and more informative to say what the differences were. Sometimes there are follow up sentences to describe them in which cases the first sentence is redundant.

**3. Tables and Figures**

**a.** It is not clear why Figures 1a and 1b are both included. The only difference appears to be the inclusion of the black line indicating the boundary of the expanded area. This could easily have been included on one figure.

**b.** There appears to be a problem with the units and/or the results in the figures for silver and indium. International units for parts per thousand (ppt) would normally be grams/kilogram (g kg$^{-1}$), or more commonly milligrams/kilogram (mg kg$^{-1}$). The values in the table don't make sense. The text indicates that the values are very low – an order of magnitude less than the Guideline Trigger Values (that are not quoted). However, the figures indicate 10 – 60 grams per kilogram (ppt) for silver and 20-45 for indium. In ecological terms these would be very high indeed. I note in the review of the 2008 report (2007 data) that the highest levels around the generator sites the maximum concentrations were ~1 mg kg$^{-1}$.

natural
resources
commission

# Attachment 4

# Peer review

Professor Roger Stone
Director, Australian Centre for Sustainable Catchments
Professor, Climatology & Water Science
University of Southern Queensland

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# Snowy Precipitation Enhancement Research Project (SPERP) Evaluation Plan

# Review by Prof Roger C Stone

# University of Southern Queensland

Prepared for NSW Natural Resources Commission

August 2010

# Contents

## 1.0 Overview

The Snowy Precipitation Enhancement Research Project Annual Report 2009 and the associated Evaluation Plan and relevant manuscripts provide a remarkably comprehensive set of data, analyses, and conclusions for what could be regarded as quite a difficult study. It is suggested the analyses techniques that have been developed for this Project are of a very high standard indeed.

However, some aspects related to the adequacy of the Control Area in the Project are questioned as are whether aspects associated with already noticeable long-term shifts in precipitation in the region (and relevance to climate change) should have been addressed. The latter seems important if policy measures are to be considered and provided in regards to the future viability of such precipitation enhancement projects in this region. On the other hand, given the noticeable and significant reduction in precipitation in many locations in the region such precipitation enhancement may offer some means of amelioration of and some potential for adaptation to long-term climate/precipitation shifts.

## 2.0 Control region selection and applicability

Results of correlation analysis of EU precipitation with precipitation in the control region have been provided but I am not sure if simple correlation analyses are sufficient for the purpose intended. It is noted the Report also utilises mean and standard deviations but more information on the relationships between the target and control areas would have been useful. I am not quite sure why reference is made to trends in the data over this short period when an inference could then be made that longer term trends are not taking place, when in fact there appear to be such trends taking place (see, for example Murphy and Timbal, 2008 or Timbal, 2007). (A small issue in regards to language and whether 'weak ENSO years' is meant to infer 'weak El Nino' years?)...

## 3.0 Climate change issues

The key issue of whether cloud seeding would still remain to be effective under climate change seems to have been neglected, although this aspect may have been outside of the Terms of Reference or scope of the Annual Report. Nevertheless, it would seem to be important to determine whether the relevance of only testing current effectiveness is valid when, in the longer-term, major shifts in precipitation in the region also appear to be taking place.  It is thus surprising that no mention is made of climate change anywhere in the Report (as far as I can see). In other words, if it is demonstrated that cloud seeding *is* currently effective and is a feasible system in terms of enhancing snowfall over the catchments of the Snowy Mountains Scheme (and it appears that this is the case), will cloud seeding necessarily remain effective in achieving this outcome in the future?

There are already major shifts in precipitation occurring over the medium to longer-term over this general region and this is, perhaps, a sound reason for investing in cloud seeding to help overcome (albeit in a modest way) these likely continued shortfalls in precipitation. However, the question remains as to whether there will, indeed, be sufficient EUs available for seeding

in the not too distant future? IPCC and other climate change scenario outputs are available for the region in question and they indicate a likely reduction in overall winter precipitation for this region.

It is pointed out that the region is strongly dominated by major global climate systems ('climate drivers' such as ENSO, the sub-tropical ridge (which is surprisingly not mentioned in the Evaluation Plan), the southern annular mode, and, perhaps, the Indian Ocean Dipole. B. Timbal and others (eg Timbal, 2007; Murphy and Timbal, 2008) clearly show a major impact already on rainfall in this region from the increasing intensity (and perhaps further southward displacement) of the sub-tropical ridge resulting in decreased precipitation over this general region, especially in autumn, winter, and spring – key periods of relevance to current and future cloud seeding in the study area (see also Appendix 3). It would seem paramount that a concerted study be soon conducted of the likely changes in key parameters relevant to cloud seeding under climate change for this region (ie changes in supercooled liquid water; freezing level, wind direction, potential instability, etc) using methods, for example, as described in Suppiah et al, 2007, so that a more realistic assessment of the likely future efficacy of cloud seeding in this region can be made.

## 4.0 Statistical analyses

The statistical analyses and overall approach (Manton) is remarkably thorough and necessarily conservative and presents a significant contribution to the science of this type of work, especially in attempting to overcome the issue of assessing efficacy when dealing with relatively few years from which sample assessments can be made.

## 4.1 Seeding impacts outside of the target area

The issue of possible seeding impacts outside of the target area – the report provides a very effective and detailed analysis and provides useful description of previous studies, although one would have thought some aspects of Hydro Tasmania work could have been included (unless confidentiality issues pertain there). A wider spatial representation may have been useful for this work (if only to dispel doubts) rather than only considering the direct adjacent rain shadow region immediately to the east of the target area.

As an adjunct to this report, issues related to downwind impacts for this study have been analysed by myself and USQ/ACSC staff and are provided in Appendices 4-6. In particular, aspects related to changes in relationships (ratios) between rainfall in upwind locations (upwind of the seeding region) and in a major region downwind of the seeding area (downwind through to coastal locations) are also addressed to provide an adjunct to the analysis already completed in the Project. Analysis has been completed that investigates possible shifts in ratio rainfall values: between 1996-2003 and 2004-2009; 1998-2003 compared with 2004-2009, and the entire historical rainfall record before 2003 with that following commencement of seeding in 2004. This additional set of analyses suggests no actual or statistically significant change in *rainfall ratio values* between 'west' stations and 'east' (downwind) stations when the analyses were conducted on these two relatively broad regions. It is noted more detailed analysis of more adjacent stations has also been completed

as part of the Evaluation Plan (Manton) and similar overall results obtained. In particular, there was *no instance* in any of the analyses in this adjunct work that suggested the ratio in rainfall relationships depicted larger amounts of rainfall decline in the broader 'downwind' region compared to the broad 'upwind' region (see Appendices 4-6) since 2004. The 'West-East' ratio values, that use both yearly and winter data, actually suggest a decrease in ratio values over this time period, *reflecting a lesser decrease in rainfall in the broad downwind 'east' region compared to the upwind 'west' region. This suggests that (in this adjunct analysis), despite an overall reduction in rainfall across the entire region (western and eastern regions combined) over the long-term historical record and in the subset of years analysed, the reduction in rainfall broadly east and downwind of the seeding region **is relatively less** than the reduction in rainfall west (upwind) of the seeding target region. This analysis also suggests no impact on rainfall downwind **across this broader region** associated with seeding operations.* Subsets of the above analysis to investigate more restricted regions (eg the Cooma township or similar) could also be provided.

## 4.2 Statement of Outcomes

The conservative statement of outcomes is welcomed – "the primary analysis leads to the result of a positive but not statistically significant impact of seeding. It is found that seeding yields an increase of 7% in precipitation across the primary target area but there is substantial statistical uncertainty in that figure: in particular a statistical significance of 10% was required from the evaluation plan but the actual significance was only at the 24% level. On the other hand, the analysis of the targeting of seeding material was unequivocally successful. Further analysis - suggests that the uncertainties in the estimation of the impact of seeding on precipitation in the target area are due primarily to a substantial number of EUs where the seeding material generators operated for a relatively small number of hours. Indeed, 10% of EUs had fewer than half the maximum number of generator hours…eight EUs had to be suspended when the specified suspension criteria were reached where suspension was most often due to the height of the freezing level (0 deg C) being higher than 1600m. It was unfortunate that 6 of the 8 suspended EUs were seeded so they further negatively biased the outcome of the primary analysis.

Therefore, when the analysis of the seeding impact is repeated using only EUs which received more than 45 generator hours, the increase in precipitation in the primary target area is 14% at a statistical significance level of 8% - that is: within the specified level of 10%...when the analysis is applied to the overall target area, the precipitation increase is 14% at the 3% significance level.

Issues related to use of the '10% significance level' are well explained, although one had to utilise the manuscript in preparation to obtain more comprehensive information, including reference to the work of Nicholls (2001) in which the entire issue of significance testing in science is examined and questioned.

## 5.0 Scientific support statement

The Report provides useful scientific support for the results obtained in the primary analysis, in particular, as follows "in particular, in addition to generator hours, it is found that the seeding impact was influenced by the amount of supercooled liquid water (SLW) available at the start of an EU, and that the SLW tended to be consumed in seeded (but not unseeded) EUs". This is important information but could have been elaborated upon further and this section made much more comprehensive as may be possible. This is because scientific support (mechanistic support for the statistical analyses) seems to be needed to remove all doubt as to the scientific validity of the approach taken and the hypothesis developed. Given the prominence made to statistical significance testing and statistical analyses necessary for this Research Project and the potential shortcomings certain statistical analyses always seems to provide in this type of research initiative, it would seem to make sense to increase the size of the Scientific Support Statement to provide as much associated support information as possible. The subsequent 'Lessons learnt' section is well written.

## 6.0 The SPERP Evaluation Plan - comments

In my opinion, the SPERP Evaluation Plan provides a remarkably comprehensive description of the analysis techniques. It is noted that Prof Manton makes the point that the 'current Plan does not consider the expansion of the SPERP target area to take effect from the 2009 winter'. Nevertheless, Prof Manton makes the point that the 'primary analysis must be as robust as possible'. Taking this point, I agree with others that the Plan is statistically rigorous, stating that the 'primary analyses in the Evaluation Plan employ methodologies that are well known – including the very relevant and appropriate non-parametric tests for this type of analysis such as the Wilcoxon and Kolmogorov-Smirnov tests and 'bootstrap' procedures to give confidence levels and confidence limits and avoid assumptions about the statistical distribution of the variables being analysed'.

In detail (with reference to sub-headings contained in the Evaluation Plan):

1.2 Selection of Target and Control Areas. Appropriate information provided in regards to the Target Area but more information on selection of data for the Control Area would have been worthwhile. It is, however, recognized that the Target Region is located in a remarkably unique region of Australia so that identifying a completely appropriate Control Area would be somewhat problematic.

1.3 Issues – very useful discussion on snow observations in a region such as the Snowy Mountains.

2. Climatological Studies. – data analysis appropriate – issues related to Control Area sites are again highlighted in terms of their adequacy for this Project – issue related to the high variability in precipitation in the region and that simulations form a time series longer than five years would be desirable in terms providing final aim of detecting a seeding effect against this background variability.

There is surprising lack of information regarding the influence of the sub-tropical ridge which is an important climate 'driver' for this region and likely to be a contributing cause of the shifts in precipitation in this Target Region and the general region as a whole (see Murphy and Timbal, 2008). This latter aspect could be important in terms of recognition of the longer-term impacts of climate change and associated relationship between climate change, the sub-tropical ridge, and future precipitation in the Snowy Mountains.

2.5 Seasonal variability of EU's – important information is contained in this section in that although there is large variability in the number of EUs in each year, the properties of each EU do not show the same degree of variation from year to year. 'This result gives us some confidence that all EUs can be treated as coming from the same class'.  This aspect may also be worth considering in any study of climate change impacts on EUs as it appears the properties of EU's are little impacted by year to year (seasonal) variation at least and may not be under climate change. (This remains an open research question).

2.7 Spatial variability of EU precipitation.

Very appropriate (k-means) cluster analysis techniques applied. I'm not sure whether the sentence 'thus the cluster analysis implies that the EU precipitation is somewhat coherent across the region of interest' refers mainly to the Target Region or the combined Target and Control Region. Given issues related to the relevance of the Control Area in this Project, this aspect needs to be elucidated.

Very appropriate use of principal component analysis (PCA) (although information as to whether the components were rotated or otherwise and what type of PCA was applied would have been useful).

3.0 Probability of detection of seeding impact.

Notwithstanding the comments made earlier regarding the adequacy of the Control Area (and the difficulties in identifying and delineating such a Control Area in the region concerned) this section is very well provided and argued. However, the author notes 'because the variability in precipitation across the region, the correlations (between precipitation in areas of interest – primary target; overall target; control; extended) are not particularly high'. Also, 'the correlations between the precipitation in the Target and Control Areas are found to be significantly different from zero but, again, not particularly high'. 'This result indicates that the detection of an impact of seeding in the target area is not expected to be straightforward'. In other words, the issue of detection of a seeding impact needs to be very well argued as aspect of the use of the Control Area in this Project remains an important issue. Given this challenge, the author does a remarkable amount of work to provide a useful and comprehensive set of outputs to adequately demonstrate detection of a seeding impact in this region.  This means that the author has recognized the difficulty in such a region as the Snowy Mountains in obtaining a highly relevant Control Area and has developed an adequate process to overcome this obstacle. Nevertheless, continued work on better defining a (more) suitable Control Area in this difficult (orographically challenging) region seems warranted.

4.2 Adjustment of precipitation data.

This section is well argued and presented in terms of adjustments needed to be applied to instrumentation.

4.3 Classification of EUs – issues related to supercooled liquid water (SLW) and the need to include another analysis that considers the sensitivity of the seeding impact to the SLW flux is well made.

4.4 Snow chemistry.

Appropriate.

5 Primary analysis of seeing impact.

This entire section is very well argued and presented, especially in regards to identification of significance levels for the observed values and associated confidence limits. The author makes a special mention of the value – or otherwise – of significance testing. Additionally, the author notes the value of the two tests being applied are physically independent. This is an important point.

6. Secondary analyses.

This entire section is appropriately presented and argued. Use of principal component analysis in this project, especially this section, is well presented and an important inclusion to this Project.

7. Targeting of seeding material.

Appropriate with useful Table provided (Table 6).

8. Downwind effects.

Appropriate analyses applied.

9. Conclusions.

Very appropriate assessment of the methods used to identify the most appropriate analyses.

10. References.

Appropriate.

Appendices:

All appropriate.

## 7.0 References cited in this Review

Lavery, B., Joung, G., and Nicholls, N. (1997) 'An extended high-quality rainfall data set for Australia' *Aust Met Mag* **46**, 27-38.

Murphy, B.F., and Timbal, B. (2008) 'A review of recent climate variability and climate change in southeastern Australia' *Int. J. Climatol.* **28**: 859–879 (2008).

Nicholls, N. (2001) 'The insignificance of significance testing' *Bull Am Met Soc.*, **82**, 981-986.

Suppiah, R., Hennessy, K.J., Whetton, P.H., McInnes, K., Macadam, I., Bathols, J., Ricketts, J., and Page, C.M. (2007) 'Australian climate change projections derived from simulations performed for the IPCC 4th Assessment Report' *Aust. Met. Mag.* **56** (2007) 131-152.

Timbal, B (2007) 'Compare documented climate changes with those attributable to specific causes' *South-Eastern Australia Climate Initiative June 2007 End of Project Reports* 1.1.2. (http://www.seaci.org/docs/reports/SEACIProjectReportsJune2007.pdf#page=4).

## 8.0 Appendices

## 8.1 Appendix 1

To illustrate aspects associated with important long-term shifts in precipitation in the overall region, below are graphical descriptions of interannual and longer-term variability in precipitation at Spencer's Creek and Guthega (Target Region) together with Fall's Creek, Dartmouth Dam, Bogong, and Omeo (other locations are also available). However, while almost all stations analysed display a remarkable downward shift in precipitation over the last 30 years (40 years in the case of Falls Creek) the amount of shift and type of variability differs considerably between a location such as Spencer's Creek in the Target Region and a location such as Falls Creek. For example, note the differences in plots/trends between (a) and (c) suggesting differences in overarching climatic regimes. Also, note the differences in precipitation trends and tendencies between Khancoban (q) and Spencer's Creek (a), also suggesting a differing overall climatic regime. Other locations are provided simply for interest and inter-comparison in terms of climatic shifts occurring in this general region. Appendix 2 provides an analysis of major long-term shifts for south east Australia, possibly associated with climate change.
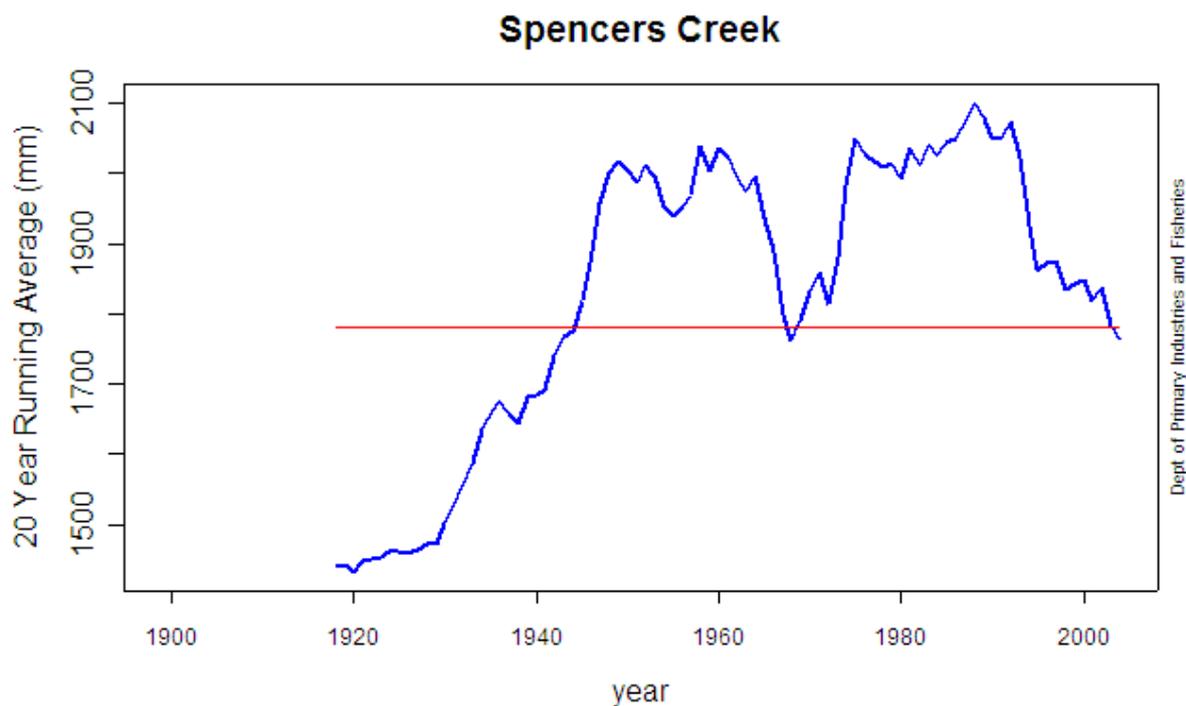


(a) Twenty-year running mean of precipitation at Spencers Creek (Control Region). Note only slight downward trend in precipitation since approx 1990.
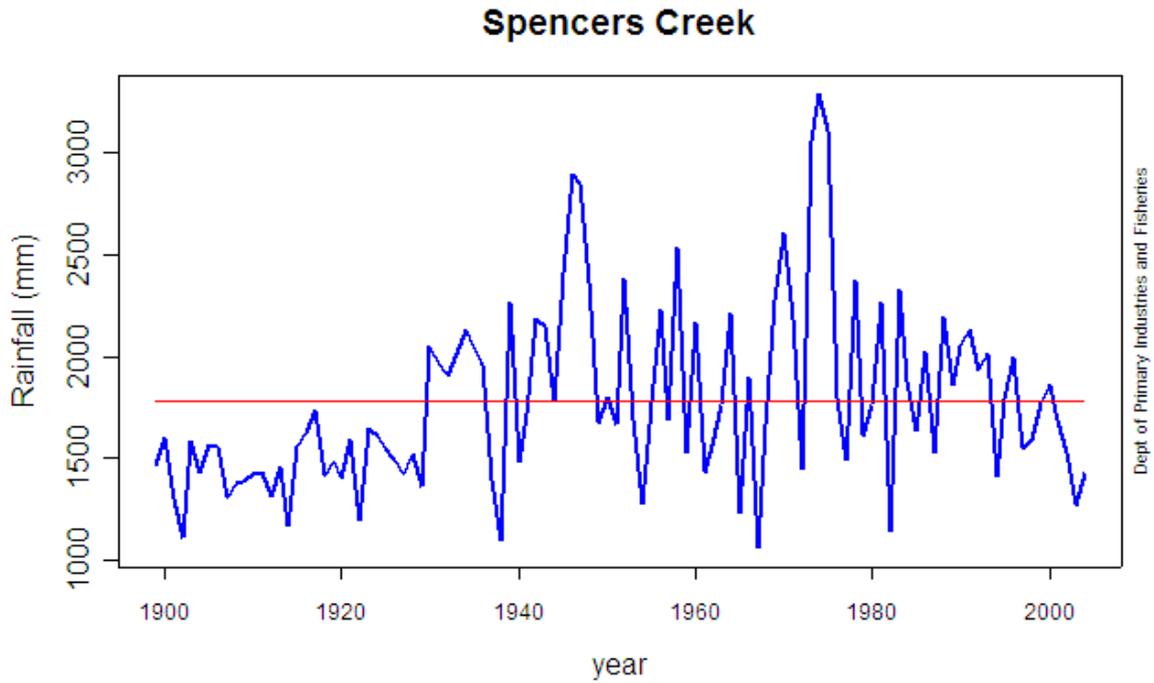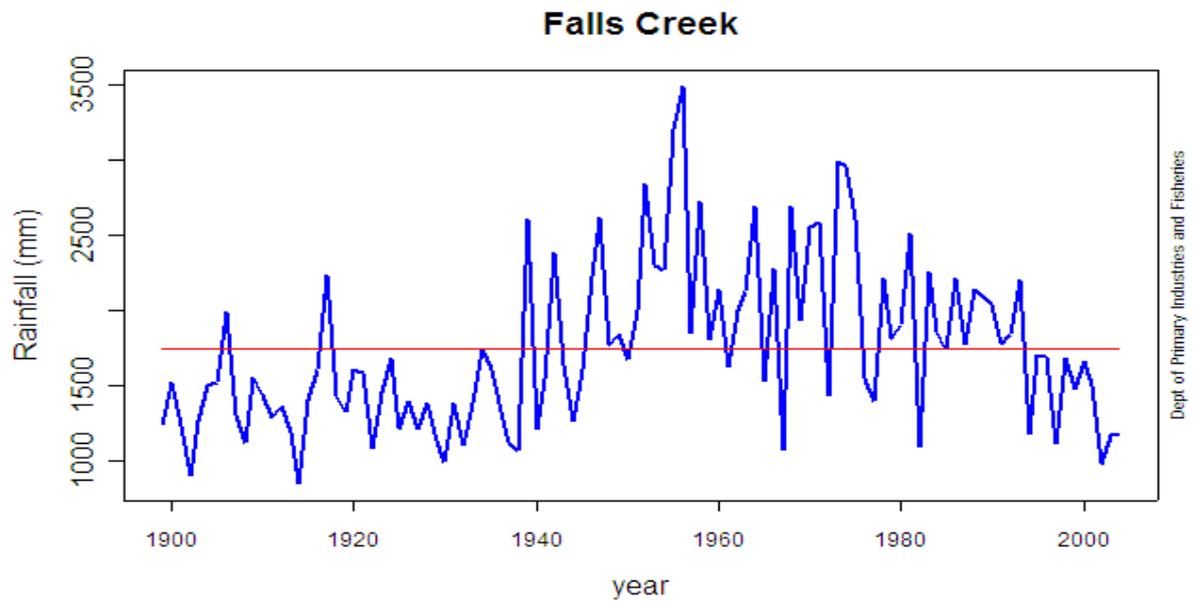
**Spencers Creek**

(b) Interannual variability in precipitation at Spencers Creek – shows large year to year variability.
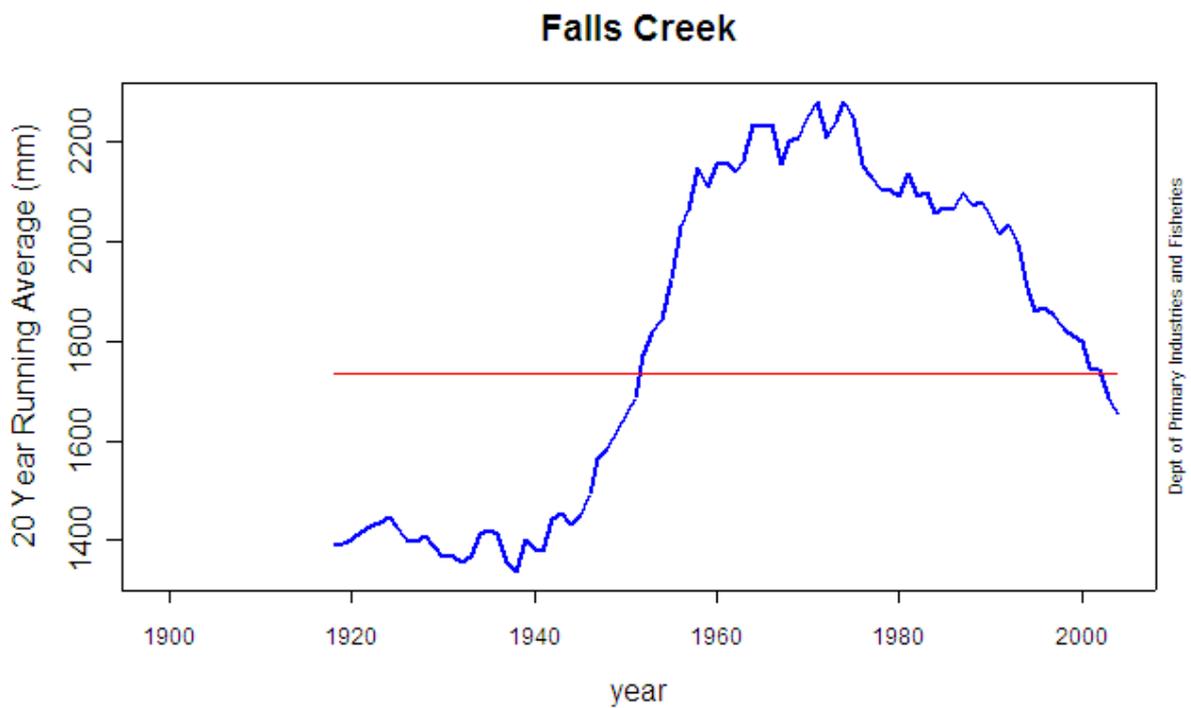


**Falls Creek**

(c) Twenty year running mean of precipitation at Falls Creek. Under this analysis, note the distinctive shift since approx 1976.
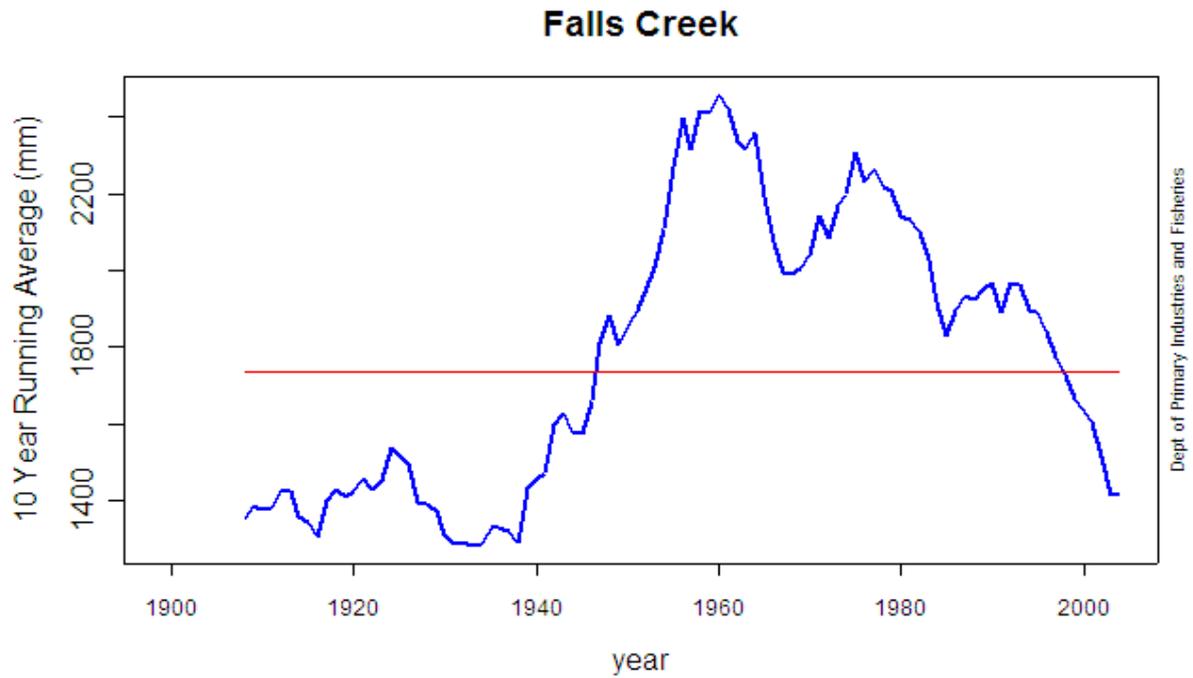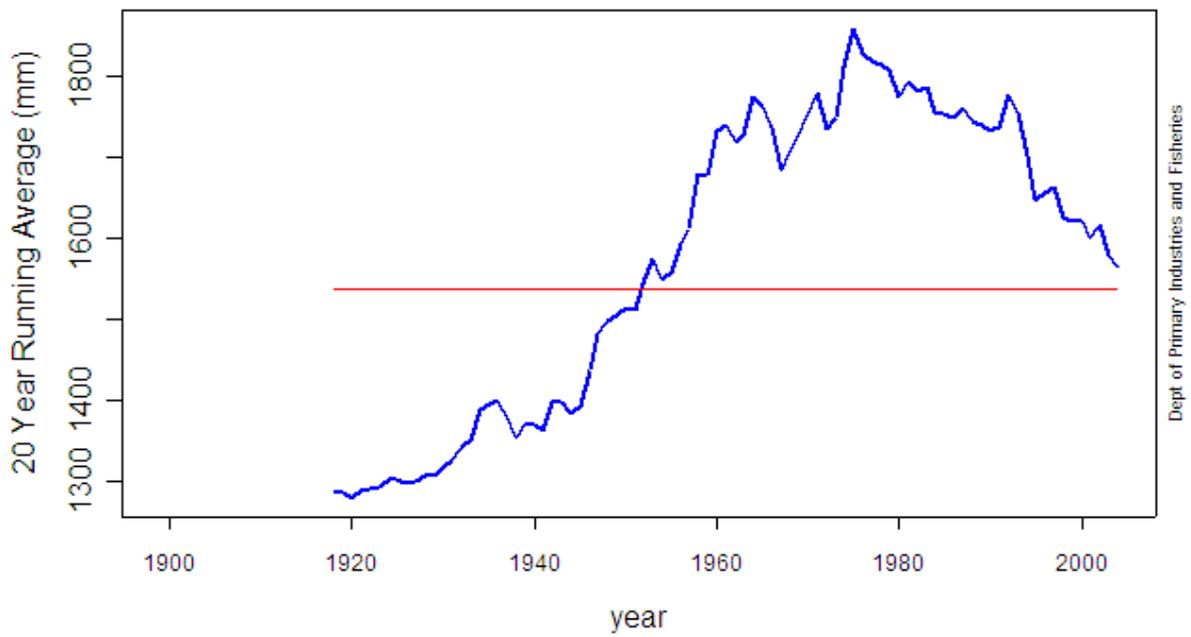
## Falls Creek



(d) Ten year running mean of precipitation at Falls Creek. Under this analysis, note the distinctive shift since 1960 and again in (approx) 1976.
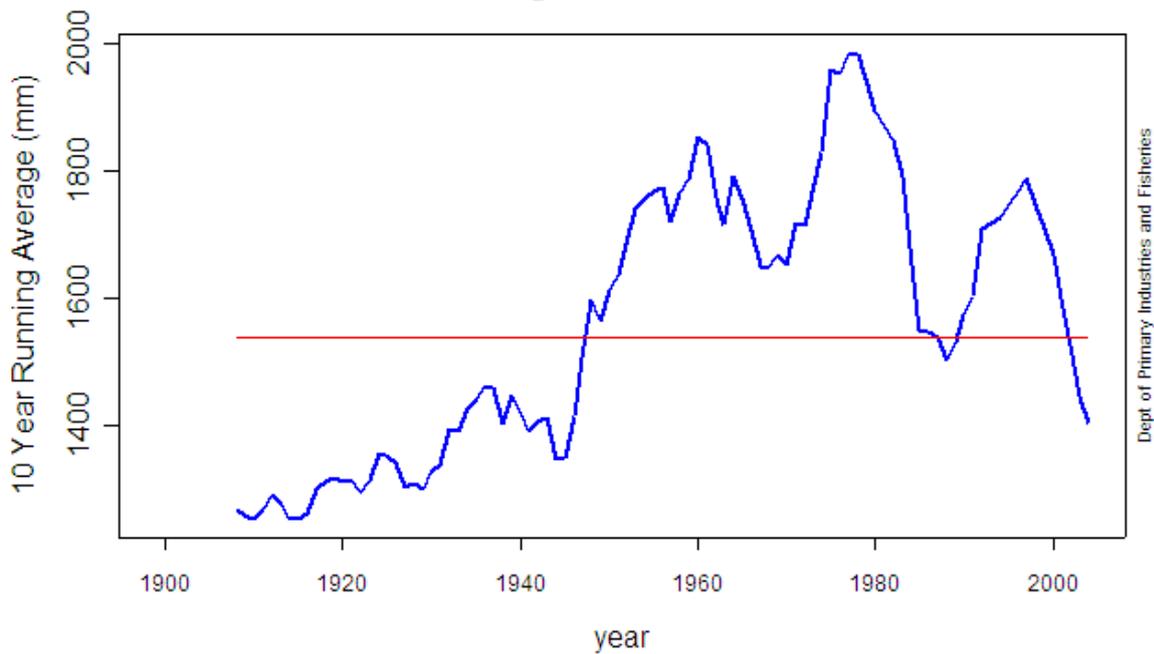
## Falls Creek



(e) Interannual variability in precipitation at Falls Creek.

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**Guthega Power Station**

(f) Twenty-year running mean of precipitation at Guthega – note the shift since late 1970s.



**Guthega Power Station**

(g) Ten year running mean precipitation at Guthega, also suggesting some impact of decadal and interdecadal variability.
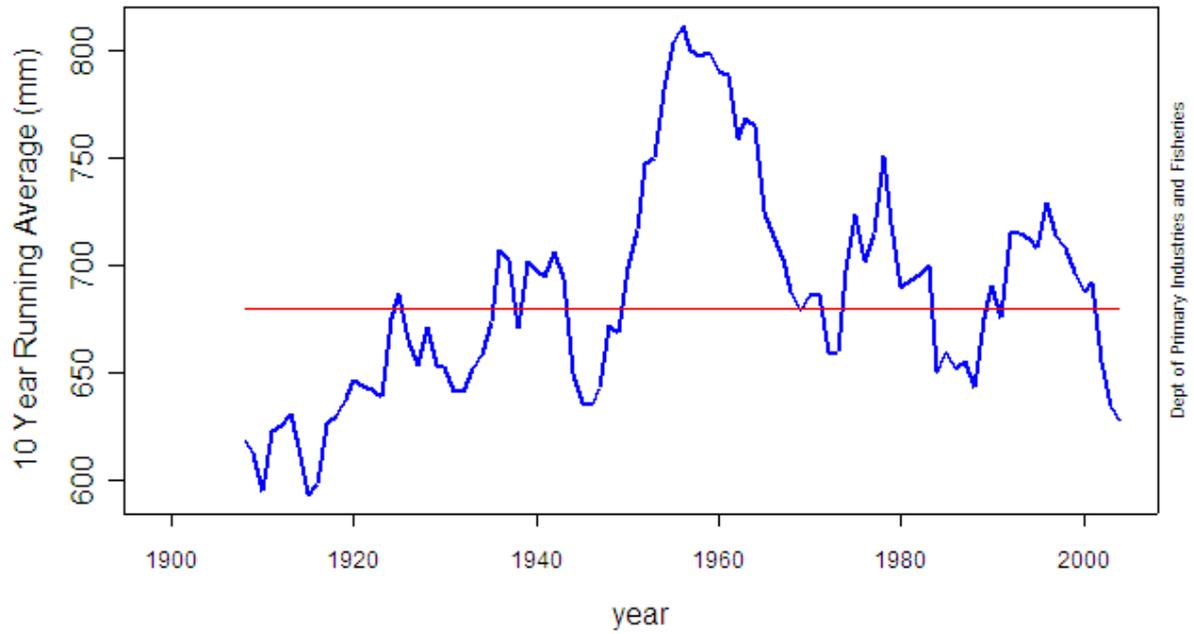
13

**Guthega Power Station**
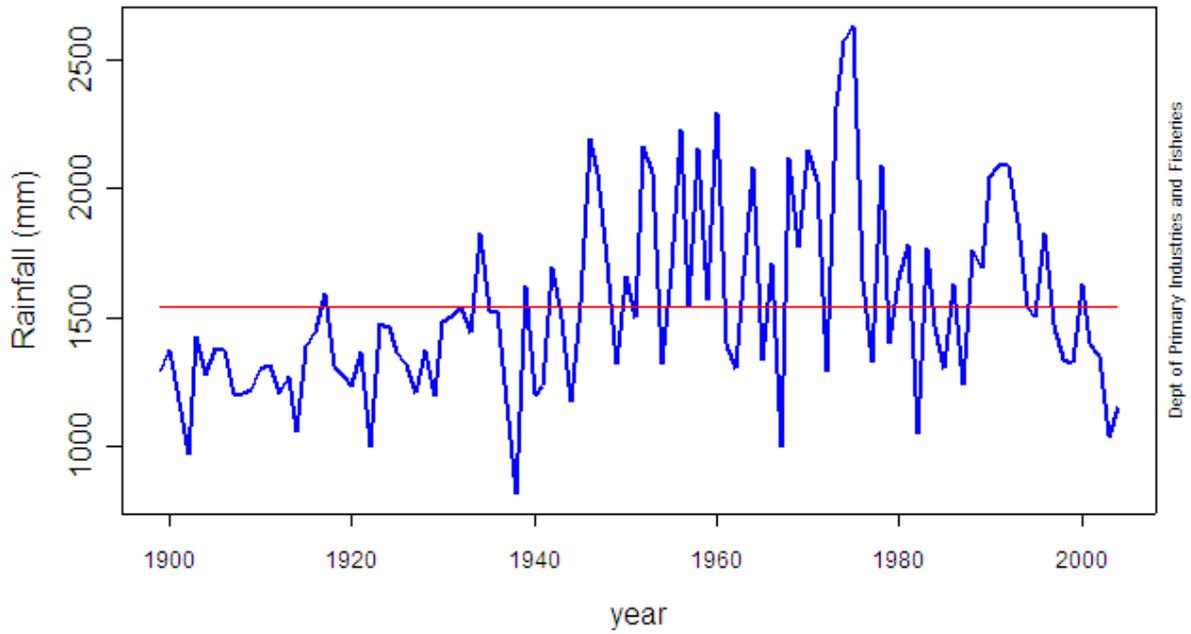
(h) Interannual variabiity in precipitation at Guthega.



**Omeo Comparison**
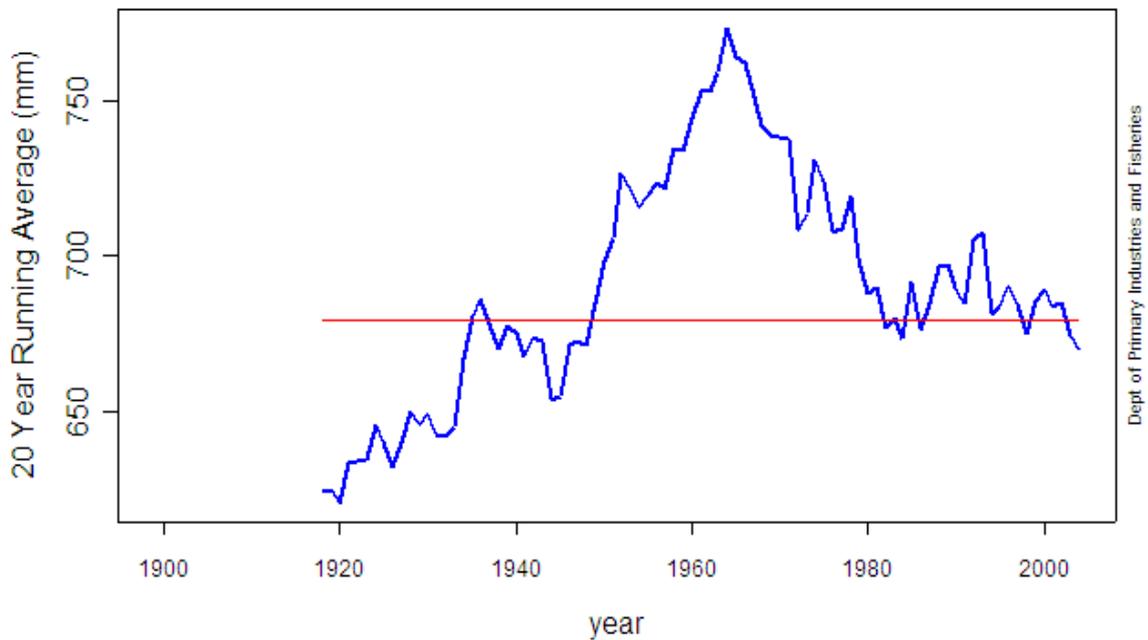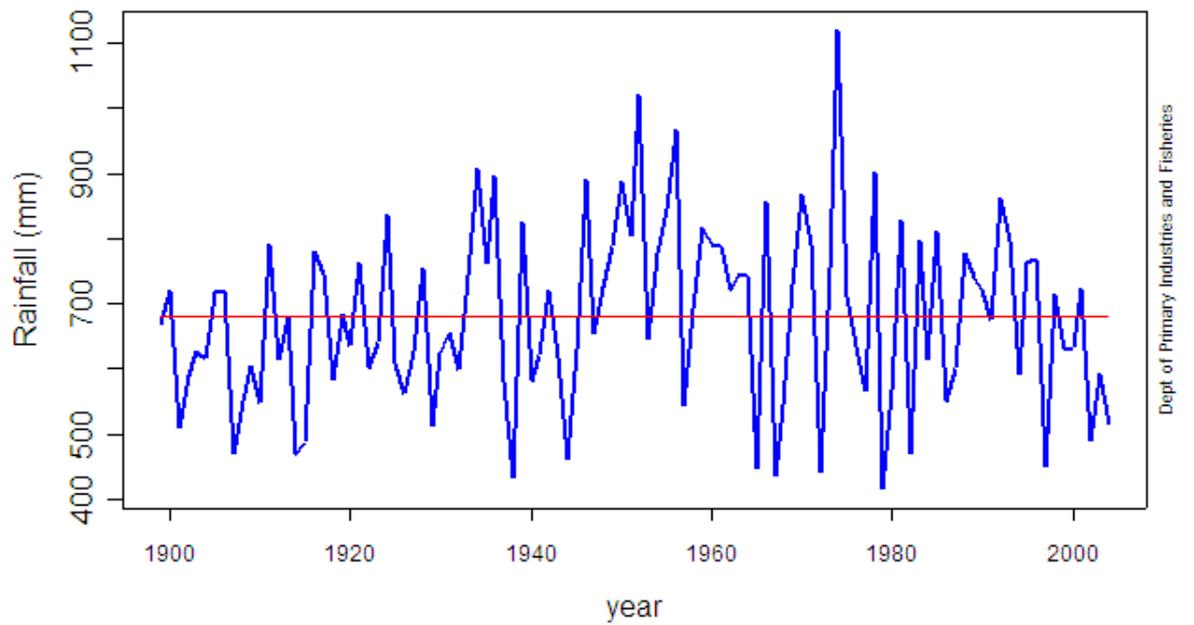
(i) Twenty-year running mean precipitation analysis for Omeo. Note the change in tendency in about 1960 but some 'levelling off' since 1980.

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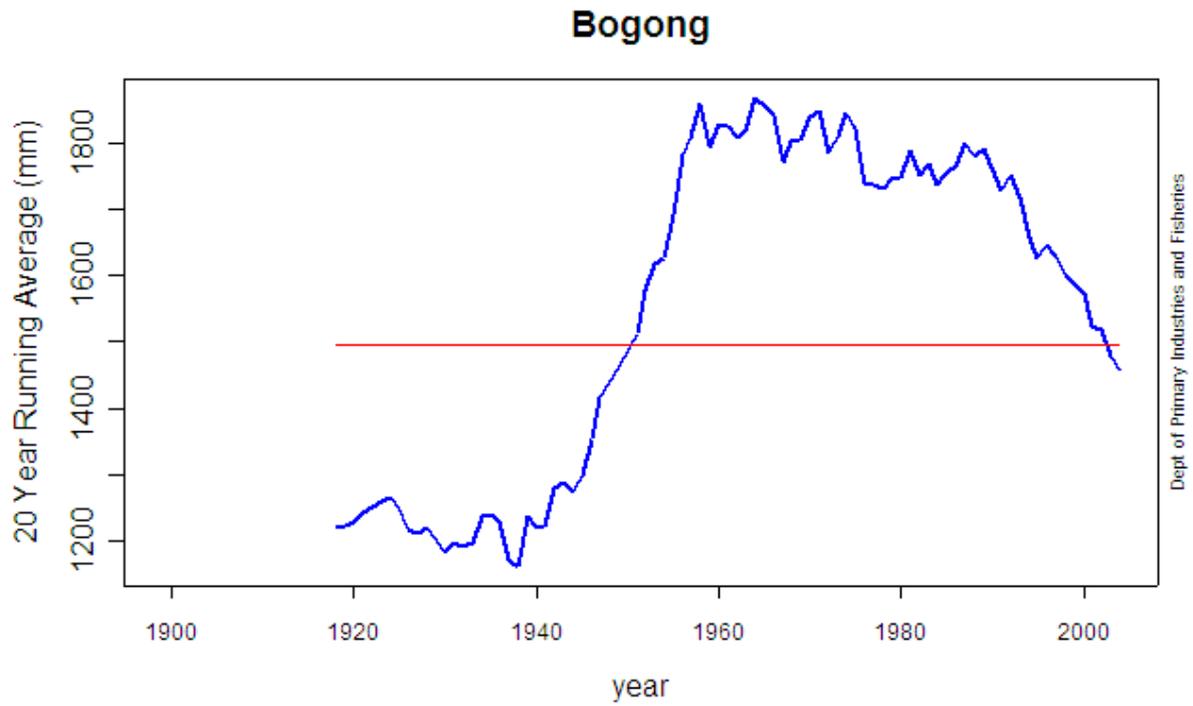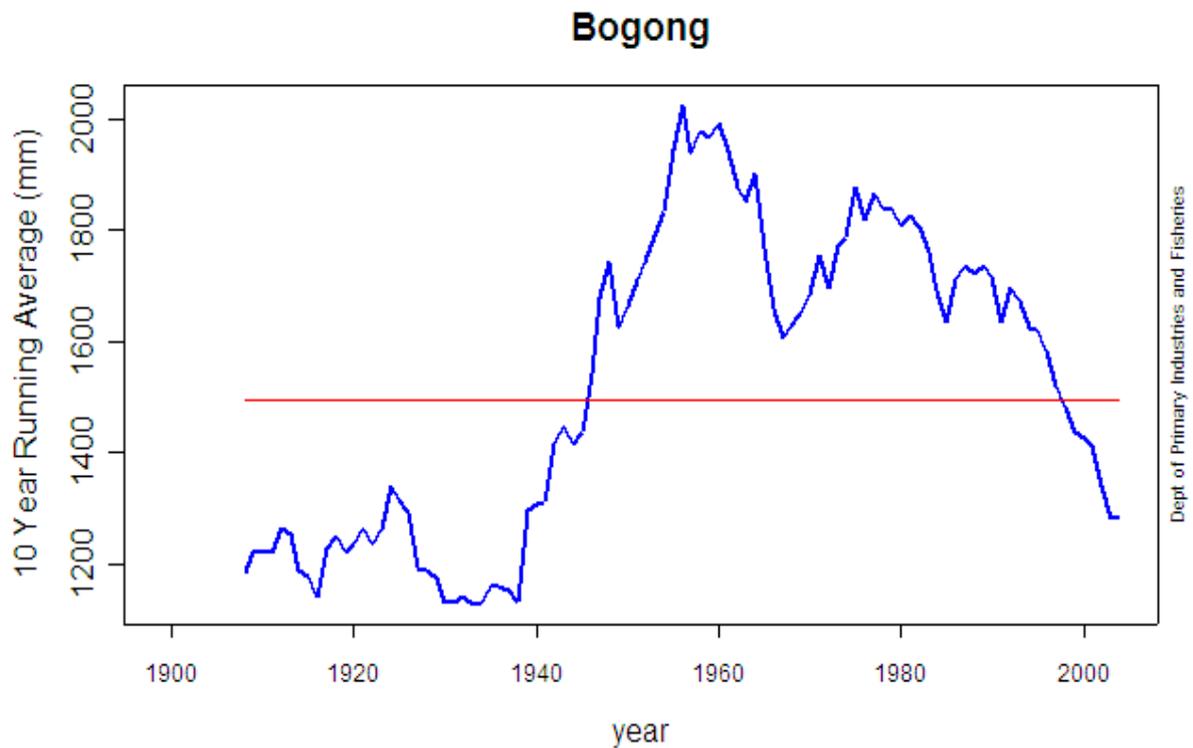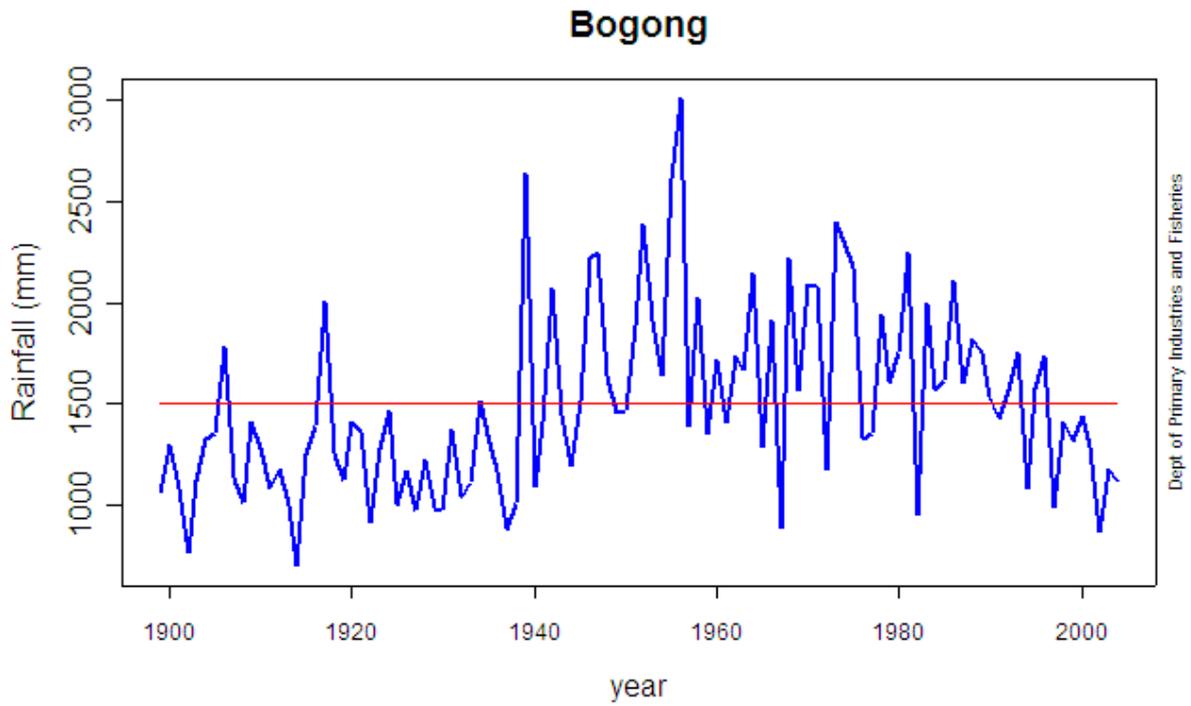(j) Ten year running mean of precipitation data for Omeo.



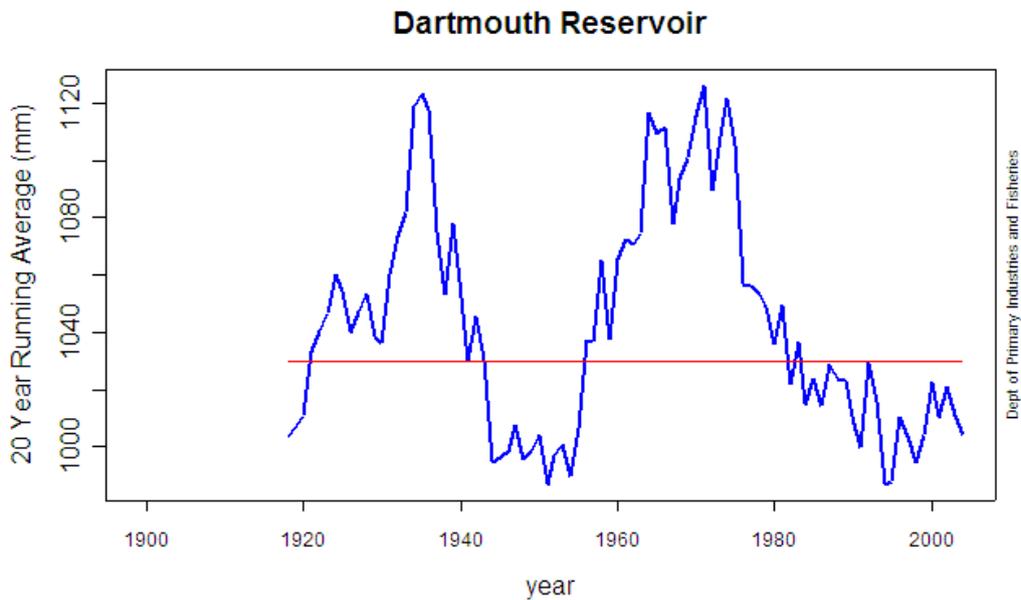(k) Interannual precipitation variability for Omeo.

Bogong

(l) Twenty year running mean precipitation analysis for Bogong indicating a shift in tendency since late 1950s.
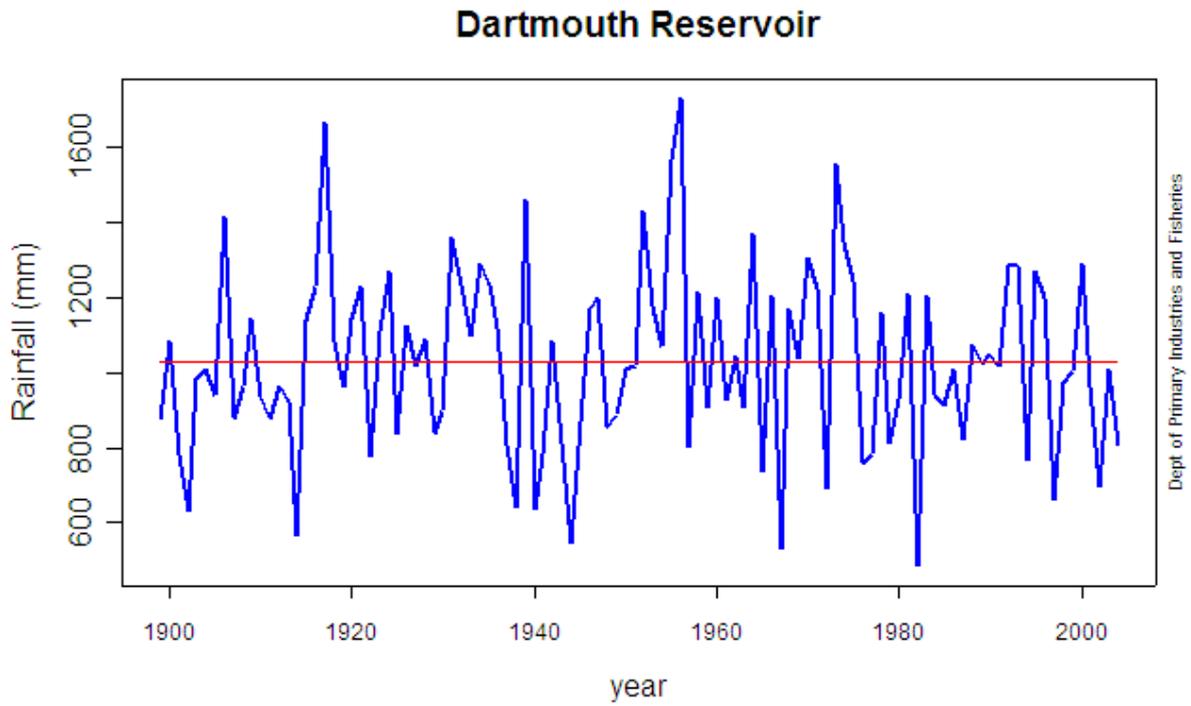


Bogong

(m) Ten year running mean precipitation for Bogong – note the shift in trend in the late 1950s and decadal influence.

(n) Interannual precipitation variability for Bogong.



(o) Twenty year running mean analysis for Dartmouth Reservoir. Note the major difference between this location and those for alpine locations.

(p) Interannual variability in precipitation for Dartmouth Reservoir.
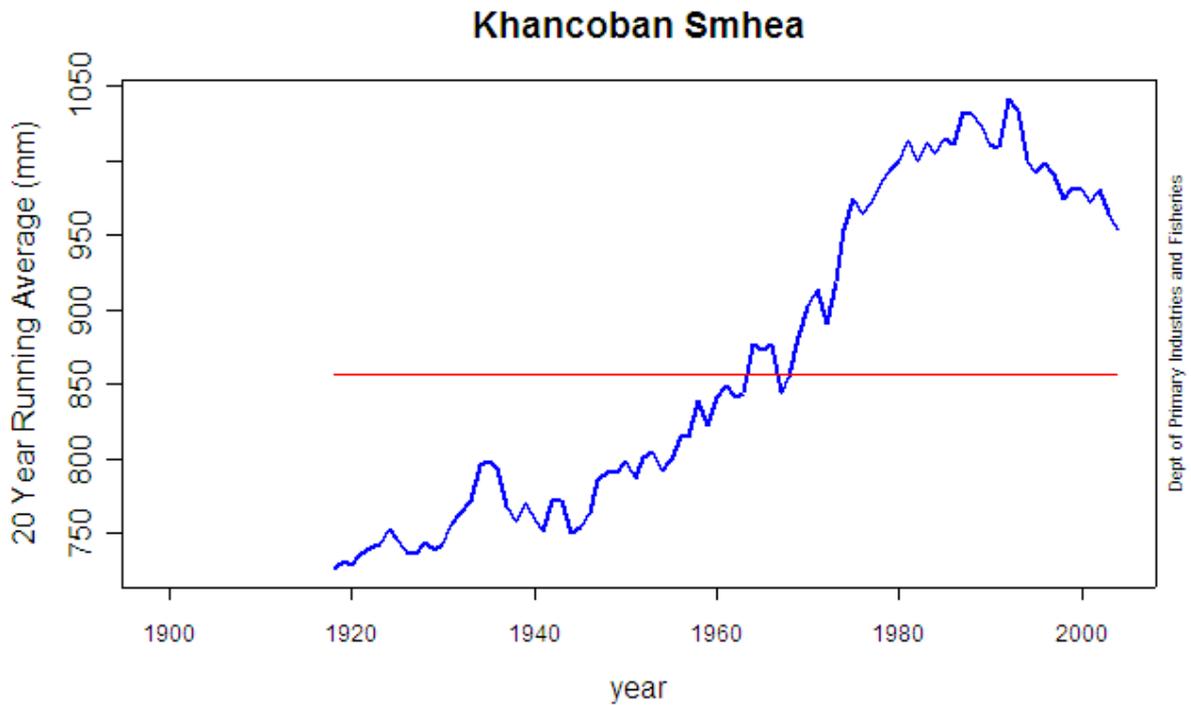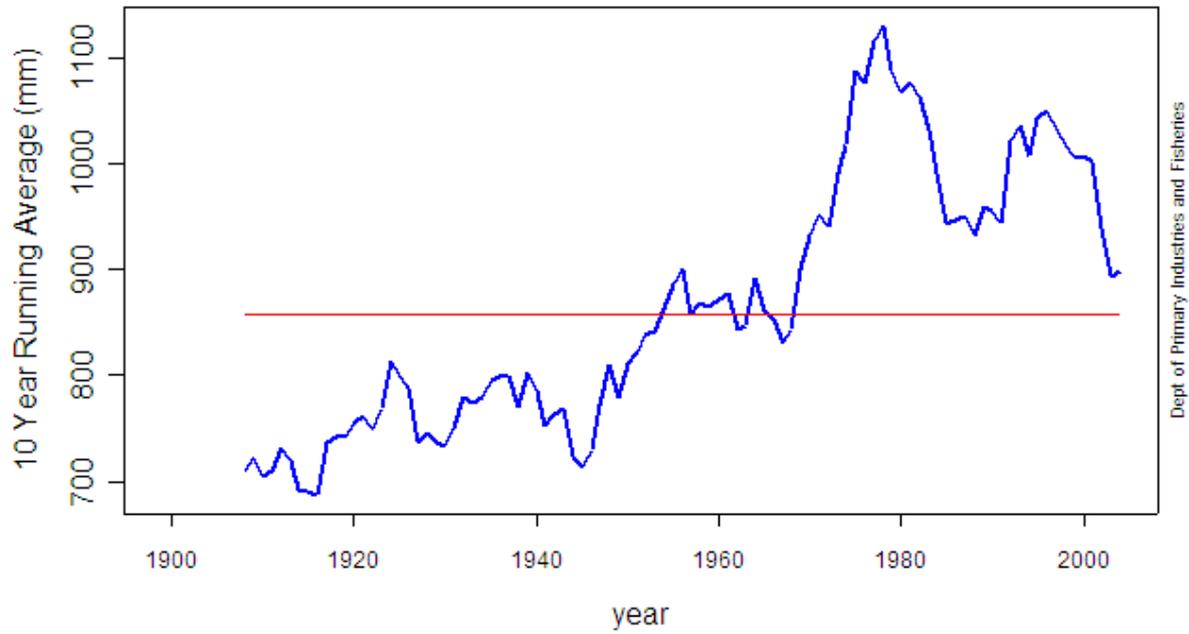


(q) Twenty year running mean of precipitation at Khancoban. Note the mostly increasing trend in precipitation until approx 1990 (in comparison with other stations in the Snowy Mountains Region).

## Khancoban Smhea



(r) Ten year running mean precipitation for Khancoban.

## Khancoban Smhea
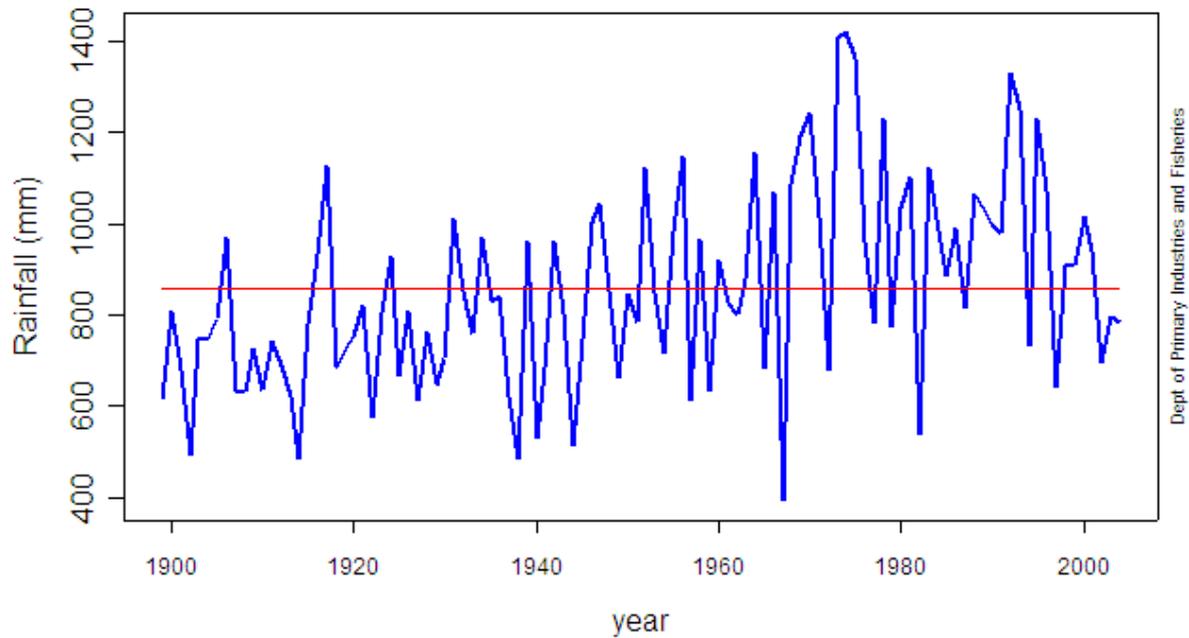


(s) Interannual variability in precipitation for Khancoban.

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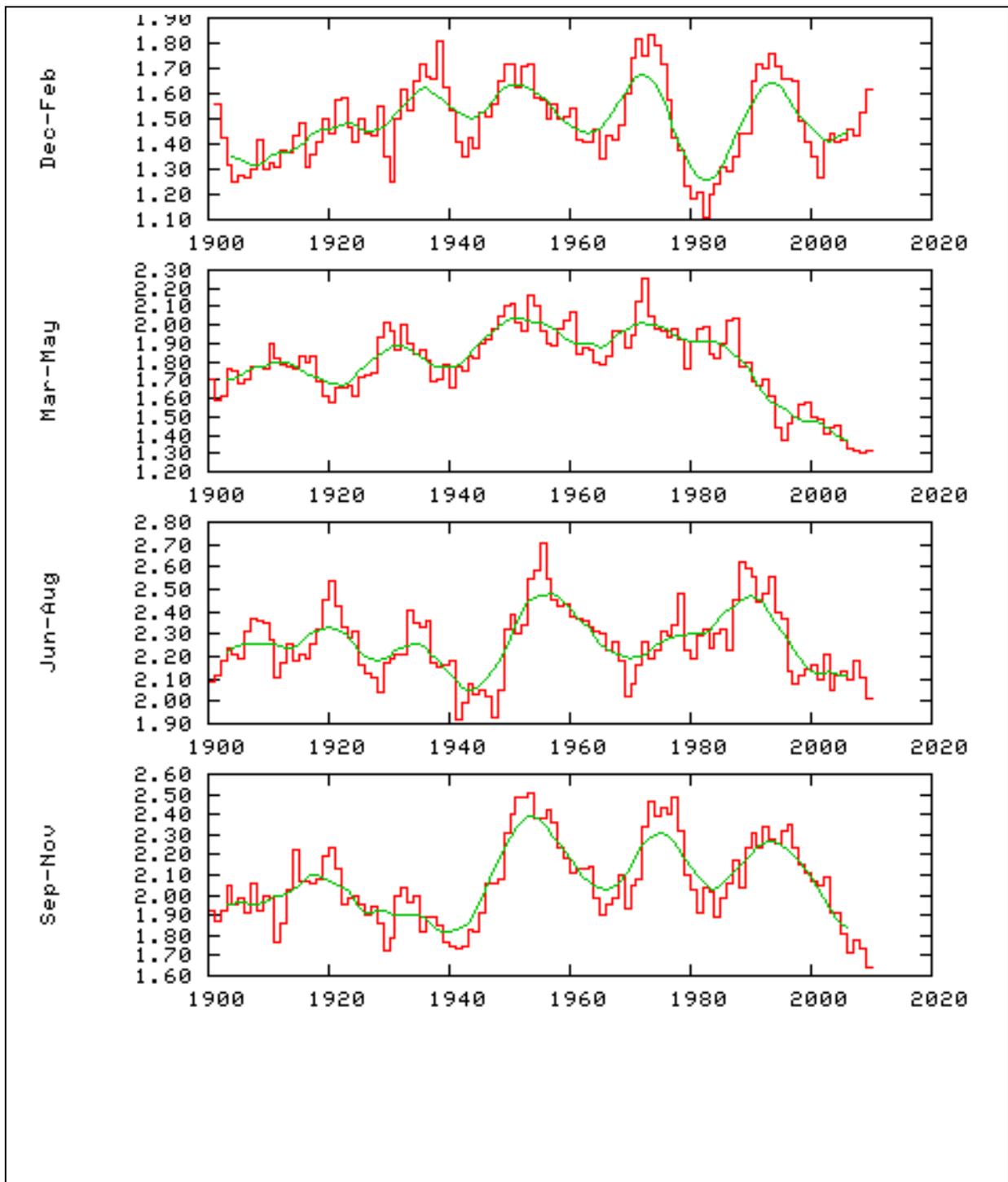
## 8.2 Appendix 2



**Appendix 2.** Time series of rainfall for seasonal periods for south-east Australia indicating a marked decline in March-May rainfall and, more recently, September-November rainfall. Green line indicates 10-year running mean and red line indicates 7 year running mean) (from Timbal, 2009, courtesy, H Hendon, Bureau of Meteorology (Centre for Australian Climate and Weather Research).

## 8.3 Appendix 3
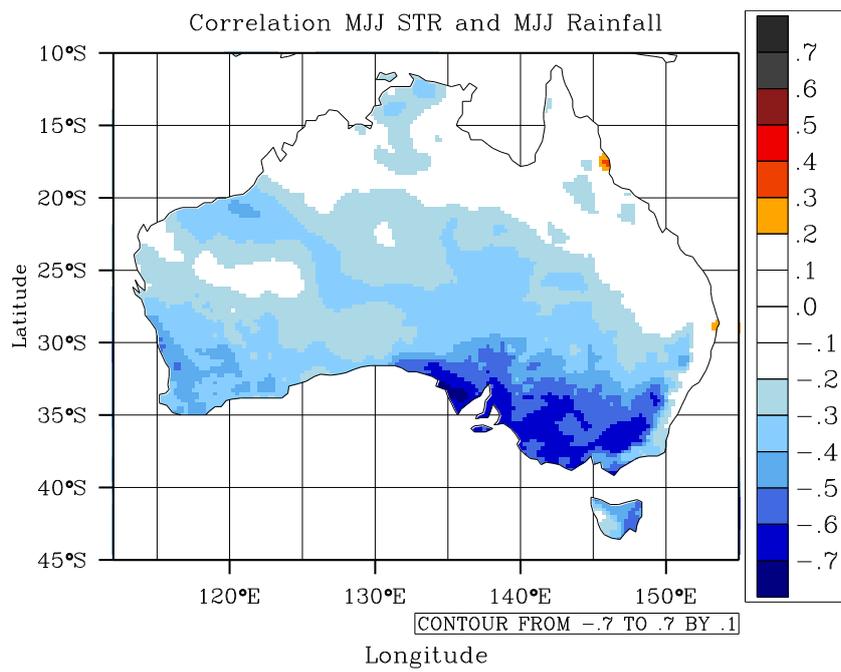


**Appendix 3.** Correlation between the Sub-Tropical Ridge intensity and rainfall across Australia in May-June-July, correlations significant at the 95% level and above are colour shaded (Maps courtesy of Clinton Rakich, BoM NSW regional office).

## 8.4 Appendix 4

| Station | Name (rainfall stations east) | 1996-2003 | 2004-2009 | 1996-2003 | 2004-2009 |
|---|---|---|---|---|---|
| 68229 | BENDALONG STP | 1116 | 1003 | 363 | 340 |
| 69003 | BEMBOKA POST OFFICE | 640 | 605 | 176 | 141 |
| 69010 | BRAIDWOOD (WALLACE STREET) | 660 | 610 | 193 | 162 |
| 69013 | CANDELO POST OFFICE | 632 | 615 | 178 | 162 |
| 69017 | MONTAGUE ISLAND LIGHTHOUSE | 784 | 678 | 249 | 234 |
| 69018 | MORUYA HEADS PILOT STATION | 857 | 778 | 254 | 243 |
| 69022 | NAROOMA RVCP | 932 | 835 | 306 | 251 |
| 69024 | PAMBULA POST OFFICE | 723 | 685 | 225 | 223 |
| 69042 | MORUYA (THE LAGOON) | 859 | 864 | 275 | 228 |
| 69049 | NERRIGA COMPOSITE | 694 | 689 | 231 | 220 |
| 69054 | TUROSS | 683 | 773 | 210 | 203 |
| 69111 | QUAAMA (MERRYDALE) | 783 | 856 | 254 | 244 |
| 69132 | BRAIDWOOD RACECOURSE AWS | 606 | 605 | 188 | 156 |
| 69134 | BATEMANS BAY (CATALINA COUNTRY CLUB) | 869 | 808 | 264 | 242 |
| 69138 | ULLADULLA AWS | 1035 | 1063 | 362 | 359 |
| 69139 | BEGA AWS | 563 | 614 | 178 | 165 |
| 69140 | BROGO DAM | 699 | 738 | 214 | 196 |
| 70000 | AINSLIE TYSON ST | 659 | 560 | 215 | 147 |
| 70005 | BOMBALA (THERRY STREET) | 565 | 576 | 151 | 181 |
| 70014 | CANBERRA AIRPORT | 573 | 526 | 180 | 134 |
| 70016 | CAPTAINS FLAT (FOXLOW ST) | 681 | 659 | 218 | 173 |
| 70072 | QUEANBEYAN BOWLING CLUB | 577 | 549 | 182 | 136 |
| 70083 | THARWA GENERAL STORE | 628 | 588 | 196 | 145 |
| 70165 | ROCK FLAT (OLD POST OFFICE) | 416 | 437 | 113 | 91 |
| 70232 | SUTTON (UBA) | 605 | 557 | 210 | 156 |
| 70237 | NIMMITABEL (COTTESLOE) | 763 | 759 | 328 | 203 |
| 70278 | COOMA VISITORS CENTRE | 443 | 492 | 135 | 99 |
| 70308 | TORRENS (DARKE ST) | 597 | 562 | 210 | 140 |
| 70334 | NERRIGA (TIMBERLIGHT) | 609 | 624 | 190 | 182 |
| 70339 | TUGGERANONG (ISABELLA PLAINS) AWS | 573 | 553 | 178 | 137 |
| | **EAST Average** | **694.1** | **675.4** | **220.9** | **189.8** |

| | | Yearly | | Winter | |
|---|---|---|---|---|---|
| Station | Name (rainfall stations west) | 1996-2003 | 2004-2009 | 1996-2003 | 2004-2009 |
| 70032 | FAIRLIGHT STATION | 739 | 725 | 274 | 205 |
| 70217 | COOMA AIRPORT AWS | 439 | 446 | 116 | 130 |
| 70310 | TIDBINBILLA NATURE RESERVE | 803 | 681 | 295 | 214 |
| 71032 | THREDBO AWS | 1297 | 1171 | 413 | 309 |
| 71041 | THREDBO VILLAGE | 1659 | 1606 | 692 | 561 |

| | | | | | |
|---|---|---|---|---|---|
| 71042 | INGEBYRA (GROSSES PLAINS) | 782 | 736 | 280 | 218 |
| 71072 | PERISHER VALLEY SKI CENTRE | 1788 | 1200 | 793 | 417 |
| 72043 | TUMBARUMBA POST OFFICE | 905 | 834 | 378 | 315 |
| 72044 | TUMUT (WATTLE CRES) | 742 | 732 | 313 | 263 |
| 72056 | BLOWERING DAM | 871 | 802 | 388 | 294 |
| 72098 | LACMALAC (FEDERAL PARK) | 792 | 792 | 362 | 300 |
| 72154 | MOUNT HOREB (MARATHORN) | 717 | 670 | 299 | 245 |
| 72161 | CABRAMURRA SMHEA AWS | 1106 | 1107 | 479 | 427 |
| 72162 | KHANCOBAN AWS | 846 | 828 | 374 | 318 |
| 73141 | GUNDAGAI (WILLIAM ST) | 610 | 562 | 242 | 192 |
| | **WEST ('upwind') rainfall mean** | **939.7** | **859.5** | **379.9** | **293.9** |
| | **EAST ('downwind') rainfall mean** | **694.1** | **675.4** | **220.9** | **189.8** |
| | **Ratio** | **1.354** | **1.273** | **1.720** | **1.549** |

**Appendix 4. Downwind rainfall analysis**. Table depicting mean rainfall for the periods 1996-2003 and 2004-2009 using high quality recording stations identified after Lavery et al., (1997) (Bureau of Meteorology) for those stations broadly west of the seeding target region and those broadly downwind (east) of the target area and extending to NSW coastal locations. Note 'West-East' ratio values that use both yearly and winter data suggest a decrease in ratio values over this time period, *reflecting a lesser decrease in rainfall in downwind 'east' locations and region compared to the 'west' region. This suggests that, despite an overall reduction in rainfall across the entire region (western and eastern stations combined) over the long-term historical record and in the subset of years analysed, the reduction in rainfall broadly east and downwind of the seeding region **is less,** relatively speaking than the reduction in rainfall on and west of the seeding target region. This analysis also suggests no impact on rainfall downwind **across this broader region** analysed associated with seeding operations.* Subsets of the above analysis to investigate more restricted regions (eg the Cooma township or similar) can also be provided as can full analyses using all time periods (analysis courtesy T. Marcussen, USQ/ACSC).

## 8.5 Appendix 5
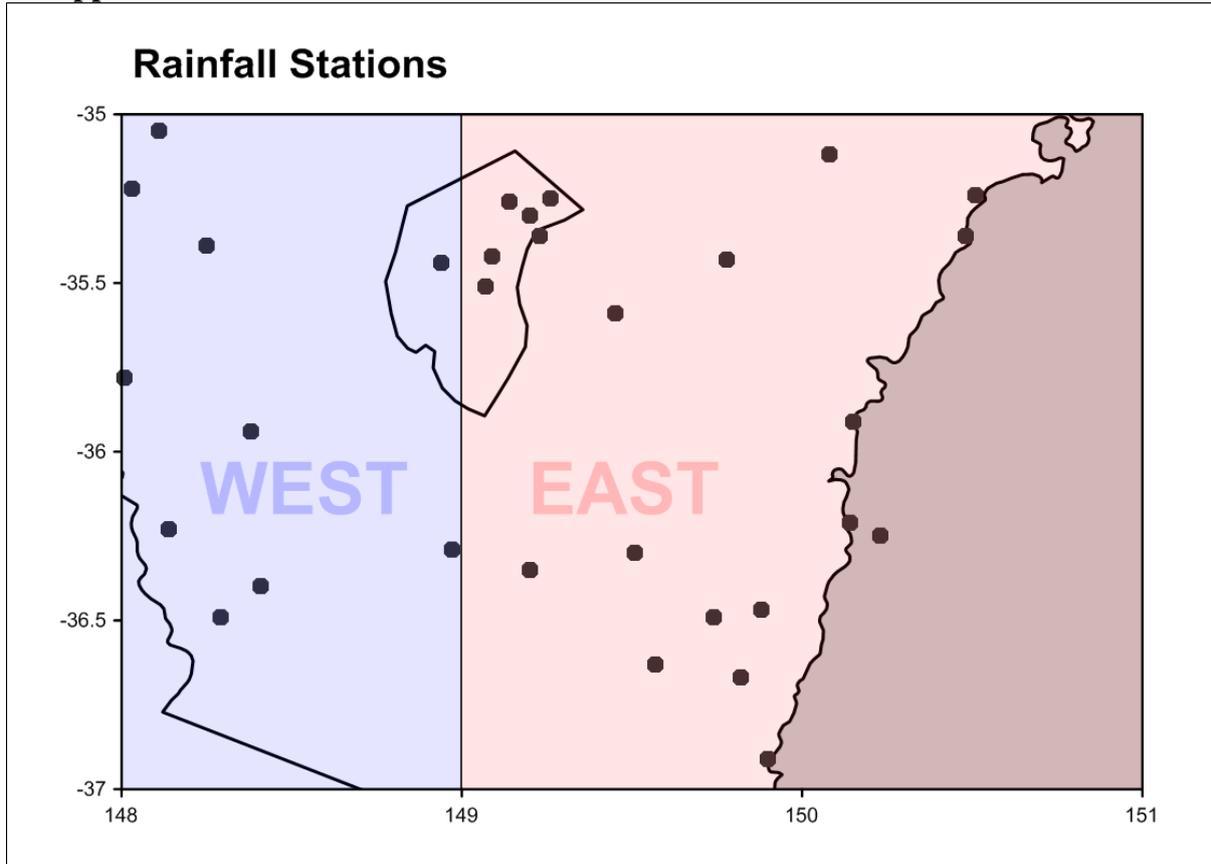


**Appendix 5.** Map of high quality rainfall stations used to provide ratio analysis and associated significance testing related to assessment of downwind rainfall changes before and after 2004 (courtesy T Marcussen, USQ/ACSC).

**8.6 Appendix 6**

# NON-PARAMETRIC TEST:   YEARLY RATIO

## Hypothesis Test Summary

| | Null Hypothesis | Test | Sig. | Decision |
|---|---|---|---|---|
| 1 | The distribution of Ratio is the same across categories of Group. | Independent-Samples Mann-Whitney U Test | .423 | Retain the null hypothesis. |
| 2 | The distribution of Ratio is the same across categories of Group. | Independent-Samples Kolmogorov-Smirnov Test | .441 | Retain the null hypothesis. |
| 3 | The distribution of Ratio is the same across categories of Group. | Independent-Samples Kruskal-Wallis Test | .423 | Retain the null hypothesis. |

Asymptotic significances are displayed.  The significance level is .05.

# Independent-Samples Mann-Whitney U Test

## Group
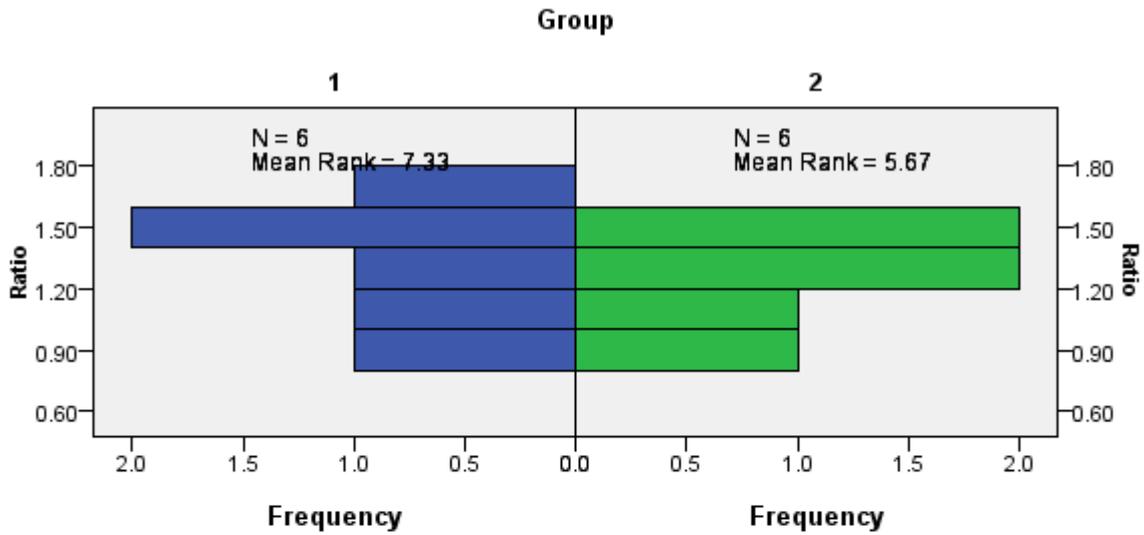


| Total N | 12 |
|---|---|
| **Mann-Whitney U** | 13.000 |
| **Wilcoxon W** | 34.000 |
| **Test Statistic** | 13.000 |
| **Standard Error** | 6.245 |
| **Standardized Test Statistic** | -.801 |
| **Asymptotic Sig. (2-sided test)** | .423 |
| **Exact Sig. (2-sided test)** | .485 |

## Independent-Samples Kolmogorov-Smirnov Test
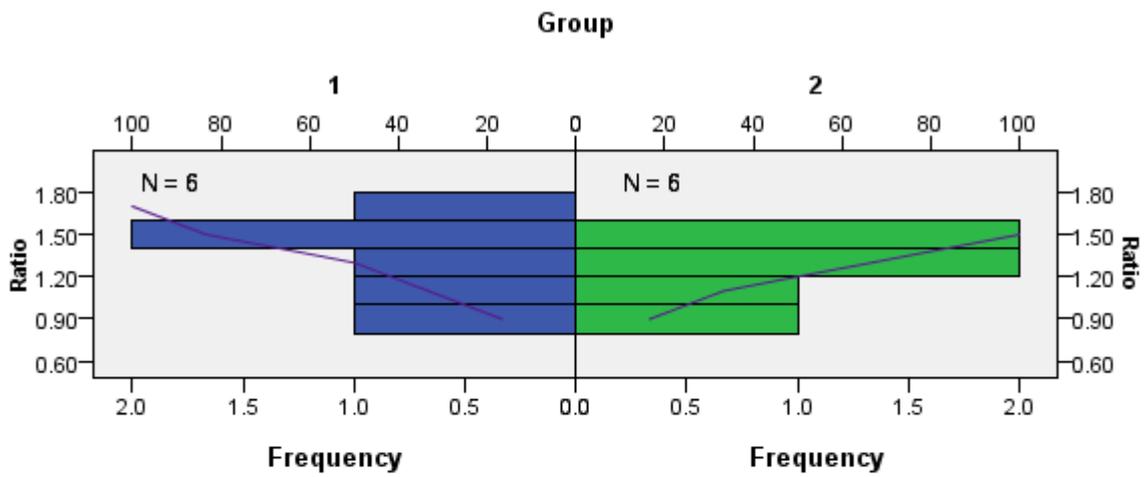


| Total N | | 12 |
|---|---|---|
| Most Extreme Differences | Absolute | .500 |
| | Positive | .167 |
| | Negative | -.500 |
| Test Statistic | | .866 |
| Asymptotic Sig. (2-sided test) | | .441 |

## Independent-Samples Kruskal-Wallis Test
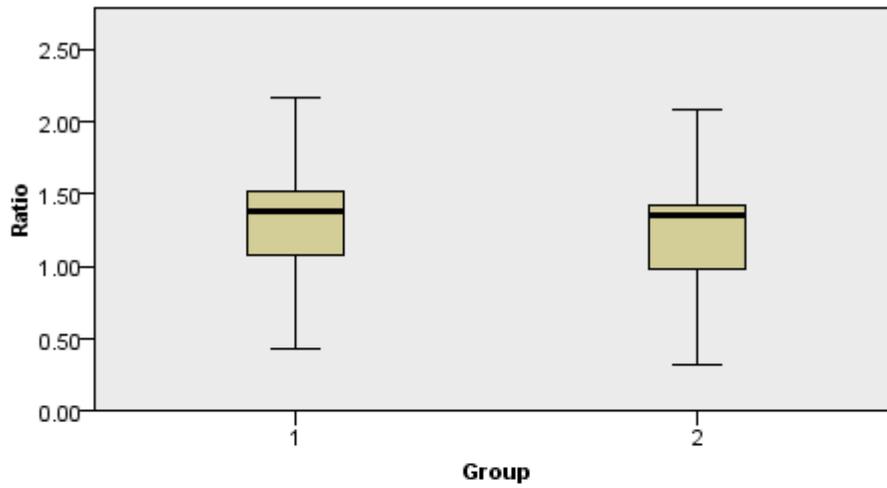


| Total N | 12 |
|---|---|
| Test Statistic | .641 |
| Degrees of Freedom | 1 |
| Asymptotic Sig. (2-sided test) | .423 |

1. The test statistic is adjusted for ties.

# NON-PARAMETRIC TEST:   WINTER RATIO

## Hypothesis Test Summary

| | Null Hypothesis | Test | Sig. | Decision |
|---|---|---|---|---|
| 1 | The distribution of Ratio is the same across categories of Group. | Independent-Samples Mann-Whitney U Test | .631 | Retain the null hypothesis. |
| 2 | The distribution of Ratio is the same across categories of Group. | Independent-Samples Kolmogorov-Smirnov Test | .893 | Retain the null hypothesis. |
| 3 | The distribution of Ratio is the same across categories of Group. | Independent-Samples Kruskal-Wallis Test | .631 | Retain the null hypothesis. |

Asymptotic significances are displayed.  The significance level is .05.

# Independent-Samples Mann-Whitney U Test

## Group
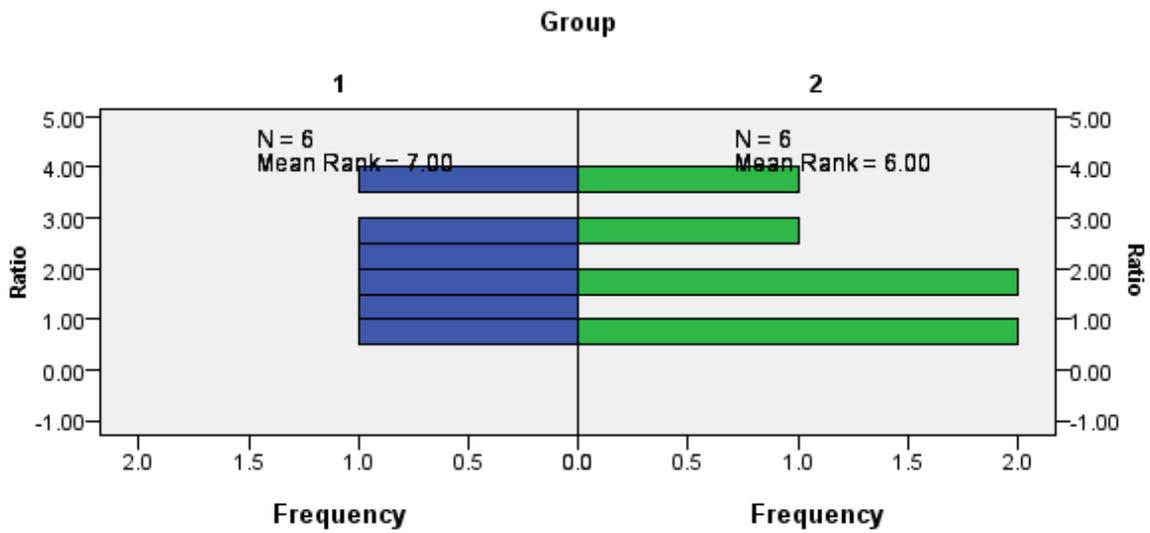


| Total N | 12 |
|---|---|
| **Mann-Whitney U** | 15.000 |
| **Wilcoxon W** | 36.000 |
| **Test Statistic** | 15.000 |
| **Standard Error** | 6.245 |
| **Standardized Test Statistic** | -.480 |
| **Asymptotic Sig. (2-sided test)** | .631 |
| **Exact Sig. (2-sided test)** | .699 |

30

## Independent-Samples Kolmogorov-Smirnov Test

### Group
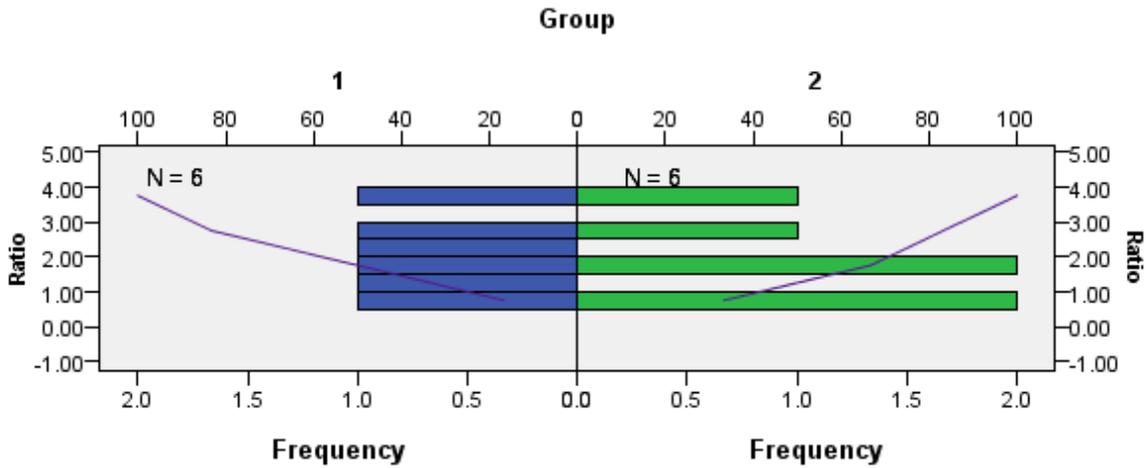


| Total N | | 12 |
|---|---|---|
| **Most Extreme Differences** | Absolute | .333 |
| | Positive | .167 |
| | Negative | -.333 |
| **Test Statistic** | | .577 |
| **Asymptotic Sig. (2-sided test)** | | .893 |

**Appendix 6.** Results of non-parametric tests on both the 'yearly ratio values' and 'winter ratio values' for 'rainfall stations west' and 'rainfall stations east' (extended downwind stations). Note the significance levels for the **Mann-Whitney U Test, Kolmogorov-Smirnov Test, and Kruskal-Wallis Test are all well below that required to accept the research hypothesis that there are significant differences in rainfall relationships before and after commencement of cloud seeding (winter, 2004**). The significance level chosen for acceptance of the research hypothesis was arbitrarily chosen p=.05. Alternatively, p=.10 would also have been acceptable. However, most results in this analysis show significance levels of p=.441 to p=.893 suggesting no significant change in the relationships between the relativity of rainfall values broadly west of the target area and rainfall values broadly east (downwind) of the target area, since winter 2004 when seeding commenced.   (In the diagrams "1" = before winter, 2004; "2" = after winter, 2004) (courtesy, S Mushtaq, USQ/A)

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# Attachment 5

## Peer review

Dr Dennis Sinclair
Managing Director
Sinclair Associates Pty Ltd

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# NRC REPORT


**Snowy Precipitation Enhancement**

**Research Project Annual Report 2009**

**Peer Review**

Prepared by
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## Scope of the Review

I have been asked to provide a peer review of the 2009 SPERP Annual Report with respect to the robustness of the statistical analysis. I was asked to pay particular attention to assessing whether the statistical analysis in the SPERP report supports the conclusions drawn on cloud seeding efficacy and snow density. As a consequence my report will concentrate specifically on Appendices D and E (the SPERP-1 Evaluation Report and Dr Doug Shaw's review of the report), Section 5.3.3 and Appendices R and S (the snow density analysis and accompanying data), and Section 5.3.5 (downwind precipitation).

## Appendix D: Initial Report on the Evaluation of Phase 1 of the Snowy Precipitation Enhancement Research Project (SPERP-1) prepared by Michael J Manton

1.  The overall design and implementation of the project is commendable, and all involved should be congratulated for a well-executed and rigorous study. It is important that the standard of the statistical analysis of the results matches the high quality of the data collected.

2.  The Executive Summary of the SPERP 2009 Annual Report summarises the efficacy results in Dr Manton's report. On page 2 it is stated:

    *"when the primary analysis is repeated using only those experiments where the overall target was effectively covered we find: … the precipitation increase is 14% at the 3% significance level".*

    There is a footnote which refers to the reduced number of EUs in the subset of the data included in this analysis. There should be more explanation qualifying this important finding (specifying that the reduced data set was for EUs with generator hours greater than 45 and applied to the overall target area rather than primary target area).

3.  There are several references back to the 2008 SPERP-1 Evaluation Plan. I believe that the Evaluation Report should be a standalone document, so where an argument, an equation, or formula from the Evaluation Plan is referred to, it should be repeated, at least in summary form, in the Report. Page 4 of the Plan states that suspended EUs should be retained in the primary analysis to maintain *"statistical integrity"*. Also on page 26 of the Plan it is stated that *"the primary analysis must include all EUs"*. There were eight suspended EUs in the total of 107. All of these recorded generator hours in the lowest decile of EUs in terms of generator hours. Importantly, the decision to suspend an EU was made "blind", so whether the EU was seeded or not did not affect the decision to suspend. The Evaluation Report recognises that these low generator events will bias the precipitation results downwards. On page 2 of the Evaluation Report it is stated that *"six of the eight suspended EUs were found to be seeded, further negatively biasing the outcome of the primary analysis"*. Usually in statistical analysis we are after unbiased results, and care is taken to remove known sources of bias in the analysis wherever possible. Therefore it would seem legitimate to analyse the non-suspended EUs only. This rather obvious analysis has not been presented in the Report.

4.  Page 8 of the Report provides the priority rating of the precipitation measuring instruments.  On page 3 of the Evaluation Plan is a discussion of the need for DFIR enclosures to accurately measure the snowfall in exposed high elevation sites.  It is argued that lower priority gauges significantly under-estimate precipitation at such sites.  Appendix 3 of the Evaluation Plan lists the instruments in use across the sites.  It appears that there was a general upgrade of measuring equipment after the 2005 season.  Other gauges were started in subsequent years.  The Report should comment on whether the underestimate of precipitation due to lower priority gauges biases the results in favour or against the effect of seeding.  In particular, some discussion of the gauges used respectively in the target and control high elevation exposed sites would be useful in the Report.  There is mention in the Plan of adjusting for *"snow undercatch"*, but no such adjustment appears to have been attempted in the Evaluation Report.  If snowfall measurement accuracy improved over the course of the five years of the study, this should be incorporated in the data analysis.

5.  Figure 2.3 on page 8 of the Report shows the number of "valid" precipitation measurements in each area per EU.  This begs the question: what is the definition of "valid"?  The only reason for missing readings given is *"occasional outages during the experiment"*.  Is this the only reason precipitation data were omitted?  Were there other quality control checks on incoming data that led to exclusion?  The outcome is that the number of sites within each area group vary over the EUs.  The way to account for this in a statistical analysis is to do a weighted analysis, with more weight being given to means with larger sample sizes.  It would appear that all EUs in the analysis presented in the Report were given equal weight, regardless of the sample sizes.

6.  The table toward the top of page 9 of the Report purports to test *"the sensitivity of the analysis to the representative precipitation in each area"*.  Other than confirming what was already acknowledged, that the higher priority gauges give more accurate (higher) readings, I do not see the practical significance of this analysis.

7.  The correlations with the control precipitation readings shown on page 9 include all EUs.  If there is a seeding effect, then this will increase the target readings relative to the controls.  Mixing seeded and unseeded results would be expected to dilute the correlation.  It would be interesting to see the corresponding correlations for the unseeded EUs only.

8.  On page 16, the Kolmogorov-Smirnov test is used to compare distributions.  The test on page 16 compares the precipitation distribution of precipitation in seeded and unseeded EUs in control sites.  It is always beneficial to show a graph of the two distributions.  Furthermore, if there is a statistical difference between the two distributions, some discussion is required to explain why the difference is noteworthy.  These same comments apply to all other applications of the Kolmogorov-Smirnov test to compare distributions in the Report.

9.  On page 16 it is noted that *"the target precipitation is generally about 1.5 times that in the control area"*.  I am not sure what this is based on (presumably combining seeded and unseeded data), but as can be inferred from Figure 3.2, and from the examples given in the discussion, the variation in ratio from EU to EU is huge, so the word "generally" is not appropriate.  If this is based on the ratio of the means, say, this should be specifically stated.  Essentially the general learning is that precipitation in the target area is typically (or on average) higher than precipitation in the control area.

10. The regression equation for primary target precipitation versus control precipitation for unseeded EUs (the primary analysis) on page 16 should be displayed in Figure 3.2 (the coefficients a and b are revealed, a little too late, in the text on page 17). It is customary to also display the $R^2$ for the regression relationship.

11. Dr Manton favours randomisation tests to determine the significance level of his results. There is a statistical adage: as is the design, so goes the analysis. The design randomly allocated seeded and unseeded EUs in blocks of 6 in the ratio of 2:1. The randomisation tests should do the same. The upgrading of measuring devices over the life of the study alone would suggest that there may be a time effect in the results. Therefore doing the randomisation tests in blocks of 6 will help account for that. It will be interesting to see whether using the more correct restricted randomisation would change the significance levels of the results, and hence the conclusions from the primary analysis.

12. On page 18 the Report states:

> *"The Evaluation Plan for SPERP-1 (Snowy Hydro, 2008) specifies that the snow chemistry variable for the primary analysis is the peak value of silver (Ag) over sites in the primary target area where chemistry observations can be unambiguously aligned with an EU and where the concentration on Indium (In) is larger than 1 ppt."*

As the Evaluation Report should be a standalone document, there should be some justification given here for this choice of metric. The argument in the Evaluation Plan (page 20) that Max Ag be used rather than mean Ag is not clear. When using a maximum value as a metric, outliers can be overly influential. I would like to have seen the analysis repeated for the mean, although I suspect the result would still be highly significant.

13. There seem to be more EUs with missing snow chemistry data in the early years of the trial (page 18). Is there a reason for this? Would it bias the results?

14. The double ratio is introduced on page 19 of the Report, but is not defined. Again, rather than expecting the reader to refer back to the 2008 Evaluation Plan, the double ratio should be defined here. Nevertheless, it was argued convincingly in the Evaluation Plan that the fractional increase approach is more valid than the double ratio, so it is difficult to see the value of including the double ratio analysis at all in this Report.

15. On page 19, the new regression equation using the overall target area should be presented, as well as the $R^2$. The equivalent graph to Figure 3.2 should be presented.

16. From a statistical standpoint I believe the argument on pages 21 and 22 regarding the preferred seeding ratio is very laboured. In the conclusions on page 46 the 1:1 seeding ratio is preferred on the grounds of *"scientific robustness"*. I would suggest that the statistical reason why 1:1 is a better seeding ratio for the study than 2:1 is simply that the resulting tests will have greater power of detecting a difference between seeded and unseeded samples.

17. On page 27, all of the EUs with generator hours less than 35 are displayed. The subsequent discussion and analysis is for all EUs with generator hours greater than 45. Therefore, for completeness, it would be more appropriate to list here all EUs with generator hours less than 45.

18. The Report should be clear that a new regression of precipitation for overall target precipitation on control precipitation for unseeded EUs with generator hours greater than 45 was carried out. The new regression equation should be presented, as well as the accompanying graph (as per Figure 3.2) and the $R^2$. It is useful to interpret the regression equation, and comment on how the coefficients have changed from the previous versions.

19. It has already been well established through sound argument that the chosen primary analysis metric for precipitation effects is fractional increase (FI). I do not see the point in confusing the analysis with the "single ratio", an inferior metric.

20. Eyeballing the scatterplot in Fig 8.3, omitting the suspended EUs (which were identified on p27), the relationship between seeded residuals and Generator Hours appears to be stronger. As mentioned earlier, it will be very interesting to see the analysis of the data with only the suspended EUs omitted.

21. On page 31 it is stated: *"the precipitation residuals (RS) are different in seeded and unseeded EUs at the 6% level"*. Different in what way? Following on from the previous paragraph, this presumably means they have statistically different distributions (the Kolmogorov-Smirnov test?). This should be made clear, and the practical significance of different distributions should be discussed.

22. It is not clear whether Figure 8.3 is based on primary target or overall target data. I have assumed it is primary target.

23. There is a lot of discussion on pages 32 to 34 about the change in supercooled liquid water (SLW) during the period of an EU. I do not understand why the obvious metric of change in SLW from beginning to end of the EU is not also presented. This is particularly noticeable when the concluding remark is *"there is clear evidence of seeding impacts being associated with the consumption of SLW over an EU"*.

24. There is a minor error in the third paragraph on page 38. It should read:
    *where a = -0.148 and b = 0.226.*

25. I agree with the statement on page 38 that *"further analysis of the conditions associated with EU33 is needed to justify the removal of it from the analysis"*. But in the months during which this report was prepared I am surprised that no reasons can be reported. This is a perfect example of how one anomalous data point can dramatically change a regression fit, and also the value of showing the data in graphical form rather than simply calculating correlation coefficients. One would want to be satisfied that this one rogue observation has not affected other conclusions drawn in the Report. For further on the value of plotting data rather than simply calculation correlation coefficients I refer the reader to the famous paper by Frank Anscombe (Anscombe FJ, 1973, "Graphs in Statistical Analysis," The American Statistician, 27, 17-21).

26. The list of potential contributing factors in the table on page 39 warrants an analysis beyond the univariate. (Every analysis in this report has been looking at one variable at a time.) Multiple linear regression or perhaps multivariate analysis could throw much more light on the results. I understand that there will be more secondary analysis to be done, but given the depth of analysis carried out in some areas of this report, I would have expected at least a multiple regression at this stage to investigate the combined impact of the drivers of precipitation.

27. On pages 42 and 43 there is a need to test statistically the claims coming from the contour analyses.

28. From a statistical standpoint let me conclude my review of the Evaluation Report with some summary points:

- The quality and breadth of experimental data allow a major outcome of the study to be not so much a statistical test to confirm that cloud seeding does indeed increase precipitation, but rather a robust model to use to predict the magnitude of the effect of seeding given certain conditions. Hopefully further secondary analyses will head in this direction.

- In some scientific literature, results that are not significant at the 5% level are not even reported (5% being the standard accepted Type 1 error rate). Effects with a significance level greater than 5% are often dismissed as "insignificant". The Report should be careful not to overemphasise the importance of effects that have a significance level greater than 10%.

- More use of simple diagrams such as scatterplots, histograms, box plots, stacked dot plots, time series plots, would help in explaining the analyses as well as identifying anomalous data points worthy of investigation.

- Any data points removed from the analysis should be discussed and the reasons for removal justified.

- The concept that the primary analysis is "warts and all" – ie including incorrect readings or biased data - is not convincing from a statistical point of view. If known sources of bias are at play, it is statistically valid to take account of this in the analysis. Otherwise incorrect conclusions could be drawn, or the power of a statistical test is diminished. It is akin to running a randomised block design and ignoring blocks in the analysis, or not adjusting for a measured covariate such as age or gender in a medical trial.

- In future secondary analyses, include more than one variable at a time in the causal analyses.

- While randomisation tests are advocated when the underlying assumptions of more conventional parametric method may be questionable, it is useful to complement the randomisation tests with the parametric ones. I would have liked to have seen the parametric test results.

- The randomisation tests should have used restricted randomisation to match the study design.

- Dr Manton has carried out a broad-ranging "initial" analysis of the SPERP-1 data. The primary analyses matched those proposed in the Evaluation Plan. The statistical techniques used are, in general, appropriate. The robustness of the conclusions would need to be tested using the restricted randomisation.

- Dr Manton had the difficult choice to decide which secondary analyses he would include in this report. There are more secondary analyses to come. I expect many of my comments above are already in the plan for the further secondary analyses.

**Snow Density (Section 5.3.3 and Appendices R and S)**

Unlike the seeding efficacy results, which apply to SPERP-1, the snow density results apply to the target area for SPERP-2. As the results address separate aspects, this is not a significant issue, but the Annual Report could be a little clearer in differentiating between SPERP-1 and SPERP-2.

My analyses of the data for 2009 confirmed that there was no statistically significant overall difference in mean snow density for seeded versus unseeded samples. The mean for unseeded samples was 0.207 g/cc, while the mean for seeded samples was 0.202 g/cc.

My analyses also confirmed that there were significant differences in mean snow density across sites.

In a site by site comparison, two sites showed a statistically significant difference: Farm Ridge (unseeded mean 0.242 versus seeded mean 0.153) and Jagungal (unseeded mean 0.202 versus seeded mean 0.155). This would seem to be at odds with the statement in the second dot point in Section 5.3.3.1:

- *The difference in mean densities of seeded and unseeded snow samples were not dependent on the key locations considered*

Different conclusions are reached when the data were "pooled":

- *When data from seeded and unseeded snow samples were pooled, statistically significant differences in mean densities of snow samples were found among key locations within the SPERP 2 Target Area*

Rather than citing a computer program (PERMANOVA+), the authors should explain clearly what is meant by the term "pooled" in their analyses.

Despite these minor concerns, in no case was there evidence to support the view that seeded snow is denser than natural snow.

I was also asked to review Cardno EcoLabs' assessment of the 2005 – 2008 snow density data. My findings were:

- My analyses of the data concur with the Ecology Lab report dated March 2008 for the snowfall density data for the years 2005, 2006 and 2007.

- The 2008 results are presented in the Cardno Ecology Lab report dated March 2009. It is noted in the report that in addition to the snow density data from the target area, data were also collected from 10 sites within the control area. The reason for combining the unseeded target samples with the (unseeded) control samples in the subsequent analysis was not provided.

- When all samples are included, the two sample t-test is statistically significant with the unseeded mean being 0.2170 and the seeded mean 0.2262. This represents a 4.3% increase in snow density from unseeded to seeded samples. (The report states: *"This difference, however, is very small (<4%), reflecting the high sensitivity of the t-test due to the large number of samples".*) In statistical parlance, this situation is often referred to as being statistically significant but practically insignificant.

- When the control samples are omitted, my analyses showed a statistically significant difference, with the snow density being 7.6% higher for the seeded samples (unseeded mean 0.2103, seeded mean 0.2263).

- The report goes on to present an analysis of variance comparing snowfall densities between treatments (target seeded, target unseeded, control unseeded) across locations. Many data points were omitted to obtain "balance" to carry out the ANOVA. As data is often difficult to obtain, as a general rule one should avoid deleting data points from an analysis wherever possible. There are legitimate statistical techniques for analysing unbalanced data which do not require the omission of data points.

- The scientific conclusion from a statistically significant result is that the chance that the results were due to natural variability (or random variation) is very small. The difference in snow density between seeded and unseeded samples *was* found to be statistically significant. So the final statement that: *"These results suggest that the differences were small, and within the range of natural variability"* is strictly incorrect. Perhaps the authors meant to say that the difference, while statistically significant, was of little practical significance.

## Section 5.3.5 (Downwind precipitation)

The statistical evaluation of the downwind effects reported in this section of the Annual Report are given in Section 9 of the Evaluation Report. The results are presented in the form of contour maps, which provide an excellent visual summary. The section concludes with:

*"there is no evidence of seeding material being consistently transported downwind of the target area or of any change in the natural precipitation patterns downwind of the target area".*

This reflects what the contour maps are showing. I would like to see the visual analysis supported by objective statistical tests.

## Doug Shaw Review of SPERP 1 Evaluation Report

I have no disagreements with the comments of Dr Shaw.

I agree with the comment that outliers need to be investigated and reported on. The Report highlighted that this could be an important issue as a) there were unexplained outliers left in the data sets, and b) other data points had been deleted with minimal explanation.

Dr Shaw commented:

*"Dr Manton's secondary analyses are largely based on correlation coefficients and the significance levels associates with them. … the text might be read to imply that some of the relationships had more predictive power than was justified."*

This is very much in line with some of my specific comments above on the Evaluation Report. The footnote referred to above is not sufficient. More needs to be done in the secondary analyses to determine causal relationships, using, for example, multiple regression or multivariate techniques.

# Attachment 6   Scientific advisors

| Role | Name | Position | Relevant expertise |
|---|---|---|---|
| NRC Project Mentor | Professor Gary Jones | Chief Executive eWater Cooperative Research Centre (CRC) eWater Limited | ▪ Freshwater ecology<br>▪ Environmental flow management in working rivers<br>▪ Toxicology and management of cyanobacteria (blue-green algae)<br>▪ Aspects of urban water management |
| Peer Reviewer | Dr Graeme Batley | Chief Research Scientist<br><br>Centre for Environmental Contaminants Research<br><br>CSIRO Land and Water | ▪ Analytical and environmental chemistry of trace contaminants in natural water systems<br>▪ Particular emphasis on heavy metals and their chemical forms, fate, transport, bioavailability and ecotoxicology in waters and sediments<br>▪ Weight of evidence approaches, risk assessment and the development of regulatory guidelines for contaminants |
| Peer Reviewer | Professor Bill Maher | Head EcoChemistry Laboratory Institute of Applied Ecology University of Canberra | ▪ Biogeochemical cycling of metalloids, nutrients, trace metals and hydrocarbons in marine and freshwater ecosystems<br>▪ Catchment water quality, including water quality guidelines and the design of sampling programs<br>▪ Microanalytical chemistry |
| Peer Reviewer | Professor Richard Norris | Director Institute of Applied Ecology University of Canberra | ▪ Freshwater ecology and water management<br>▪ Biological assessment of rivers, including metal and coal mine effluents, heated water, agricultural effects, sewage effluents, siltation, environmental flows and predictive modelling |
| Peer Reviewer | Dr Dennis Sinclair | Managing Director Sinclair Associates Pty Ltd | ▪ Accredited statistician |
| Peer Reviewer | Professor Roger Stone | Director (Australian Centre for Sustainable Catchments) and Professor (Climatology & Water Science) University of Southern Queensland | ▪ Climatologist<br>▪ Aviation meteorology<br>▪ Advisor on the efficacy of cloud seeding research (to the Queensland Government)<br>▪ Integrated climate-agricultural-financial-water resource modelling |

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